



# A New Robot Sound Vocabulary | Sonic Interaction Design for Dairy Farm-Based Robots

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**Master thesis**  
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Sonic Interaction Design for Dairy Farm-Based Robots  
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**“MOOOO.”**  
**- Bertha 32**





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## Executive summary

On the modern-day dairy farm, automated machinery has become an increasingly integral part of daily operations. To ensure smooth operations and the safety of the individuals present in the barn, the machinery uses notification sounds to alert the farmer in case of emergencies or to inform them of the actions being performed. While the use of sound is intended to enhance safety and user experience, the current notification sounds are often perceived as confusing and unpleasant by farmers. This has led some farmers to remove the audio system altogether, putting the safety of those in the barn at risk. This project aims to develop a sound design framework and a concise set of sounds that take the safety and well-being of both humans and cattle into account.

The focus of this project is the creation of consistent sound-based user feedback for dairy farm robots developed by Lely. Lely is an innovative company in the agricultural sector, with a portfolio that includes a wide range of autonomous and stationary robots performing various tasks around the dairy farm.

The concept of sound was explored through literature research, examining its perception from both a human and cow perspective. Relevant sonic interaction methods were explored to serve as the groundwork for the development of the notification sounds. To gain an understanding of the current context, interviews were conducted with Lely's product development, and safety & compliance teams. The current notification sounds were mapped out, and the safety guidelines the sounds must adhere to were identified. Based on the literature research and interviews, technical sound design guidelines were developed.

Through interviews with dairy farmers and regular farm visits, six core problem areas were identified: the unclear meaning of the notification sounds, the inability to identify the robots by their sound, the perceived unpleasantness, the disturbance to neighbours, the inaudibility, and the lack of guidelines for the use and creation of notification sounds. To address these issues, sonification techniques were utilised to develop new sounds, which were then tested and adapted based on user feedback.

For the final design, a concise set of sounds was created, along with a sound design framework that includes guidelines for the development of new notification sounds for future Lely robots. Each robot has been given a distinct voice to allow the user to differentiate the robots based on their sound. The sounds are designed to be intuitive, pleasant, and clearly audible over the ambient noise in the barn, while ensuring they are not too overwhelming or disruptive to the neighbours. To minimise the noise inside the barn, several solutions were proposed to safely reduce the frequency and loudness of the notification sounds.

This project addressed a sound design issue that impacts the daily operations and well-being of farmers and their cattle, which has so far been overlooked. The final design performed well in meeting the set criteria. However, further research is required to evaluate the notification sounds after long-term exposure.

# Table of content

Acknowledgements	04
Executive summary	05
Glossary	08
<b>Introduction</b>	<b>10</b>
1.1 General Introduction	11
1.2 Project scope	12
1.3 Project approach	13
<b>Literature review</b>	<b>16</b>
2.1 Psychoacoustics	17
2.2 Auditory display and sonification	20
2.3 Sonification in Human Robot Interaction	22
2.4 The perception of sound from a dairy cow perspective	23
2.5 Key takeaways	25
<b>The dairy farm</b>	<b>26</b>
3.1 The purpose of the Lely robots & systems on the farm	27
3.2 The shared acoustic environment	30
3.3 Ambient noise levels	31
<b>The current situation</b>	<b>34</b>
4.1 The creation and regulation of the notification sounds	35
4.2 The ISO guidelines	36
4.3 Identified robot actions and sounds	37
4.4 Identifying the needs of the listeners	42
<b>Design vision &amp; brief</b>	<b>46</b>
5.1 Design brief	47
5.2 Preliminary design vision	49
<b>Conceptualisation</b>	<b>52</b>
6.1 Defining the sound categories	53
6.2 Solution finding for the core problems	57
<b>Embodiment</b>	<b>62</b>
7.1 Robot differentiation	63
7.2 Sound categories	66
7.3 Interim evaluation moment	70
7.4 User test	71
7.5 User preferences	80
7.6 Iterations	86

<b>Final design</b>	<b>90</b>
8.1 The sound design framework	91
8.2 Developed set of sounds	96
8.3 Implementation	102

<b>Evaluation</b>	<b>104</b>
9.1 Design criteria	105
9.2 Validation	107
9.3 Recommendations	108
9.4 Reflection	110

<b>References</b>	<b>112</b>
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<b>Appendix</b>	<b>118</b>
Appendix A: The use of sound in the automotive industry	119
Appendix B: Ambient noise level measurements	120
Appendix C: Project brief	122
Appendix D: User test	126
Appendix E: Farmer questionnaire	143
Appendix F: The robot voices	146
Appendix G: Buzzer guidelines	156

## Glossary

### Acoustic biotope

A shared sound environment where sound-induced actions take place in a specific space.

### Ambient noise level

The total sound pressure level (dB) of all the sounds present in the environment.

### Attack time

The amount of time it takes for a sound to reach its full intensity or loudness after it starts.

### Auditory icon

A sound that represents a real-world object, action, or event. It consists of a familiar, everyday sound used to convey information or meaning to the listener.

### Auditory masking

Occurs when the perception of a target sound gets affected by the presence of another sound (the masker), in some cases making the target sound inaudible.

### A-weighting - dB(A)

A frequency weighting applied to decibel measurements to reflect the sensitivity of the human ear.

### Barks

A scale that is used to describe critical bands.

### Critical bands

A range of frequency bands, with each band representing a certain range of frequencies that the ear processes together.

### Earcon

A short abstract sound that represents a piece of information or an event.

### Frequency

The number of times per second a sound pressure wave repeats itself, often measured in hertz (Hz).

### Harmonics

The sound waves that are related to the fundamental frequency (strongest harmonic) as an integer multiple.

### Intensity

The physical quantity of a sound, which can be measured in decibels (dB).

### Loudness

The subjective perception of a sound's intensity by the human ear, influenced by the frequency of the sound.

### LUFS

Loudness Units Full Scale, it measures the perceived loudness by combining the human perception of sound and the electric signal intensity to create a consistent listening experience across different tracks.

### Pitch

The perceived frequency of a sound, typically measured in Hertz (Hz). It determines how high or low the sound is perceived.

### Psychoacoustics

The human perception of sound from a psychological and physiological standpoint.

### Register

A specific range of pitch, volume, or timbre that a sound can have.

### Rhythm

The combination of timing, duration, and organization of sounds.

### Sonification

The process of translating information into sound.

### Timbre

The distinctive quality or "character" of a sound that enables listeners to differentiate between sounds, even when they have the same pitch and loudness.

### True Peak

An estimate of the peak level the analog waveform will reach after A/D conversion.

### Abbreviations

#### SID

Sonic Interaction Design

#### HRI

Human Robot Interaction



This chapter explains the importance of using auditory feedback for farm-based automated machinery, and why a sound design framework focused on the farm environment and its listeners is necessary. In addition this chapter will cover the project scope and the approach.

- 1.1 General introduction
- 1.2 Project scope
- 1.3 Project approach



## 1.1 General Introduction

Automated machinery has become an essential tool in optimising the milk production, reducing the farmer's workload, and improving the cattle's wellbeing (Jacobs & Siegford, 2012). To ensure smooth operation and a safe environment, the machinery needs to be able to notify the listeners present in the barn in case of emergencies or potential issues before they escalate. Given the dynamic nature of a dairy farm where multiple processes and systems are running simultaneously, farmers are often performing multiple tasks in and around the farm at once. Auditory feedback is a crucial element in drawing attention to potential issues that would otherwise go unnoticed with visual notifications.

With the use of auditory notifications in a farm environment comes the risk of negatively impacting the listeners present in the barn. The modern day dairy farm is a space where cows, humans, and automated machinery interact with each other in a shared acoustic environment. It is important for both the dairy farmers and the cows to keep the ambient noise level to a minimum.

The presence of noise on the farm is one of the most common stress triggers for dairy cows and negatively impacts their milk production (Ciborowska et al., 2021).

The presence of excessive auditory notifications can lead to alarm fatigue, where the farmer and possible other listeners present in the barn become desensitised to the auditory feedback, potentially leading to critical safety and technical alarms to be missed (Sendelbach & Funk, 2013). Moreover, the constant presence of noise caused by overlapping auditory notifications causes listener fatigue, reducing the overall productivity of the farmer (Colorado Ear Care, 2022).

Despite the importance of having minimal noise present on the farm, there are no guidelines available for the sound design of farm based machinery that take both the perception of sound from a human and cow perspective into account.

This project focuses on developing consistent sound-based user feedback for the Lely robots. Lely is an innovative company active in the agricultural sector. Their goal is to "make the life of farmers worldwide easier and work together on creating a sustainable, feasible and pleasant future in this field" (Lely, n.d.-a). Lely tries to achieve this goal by creating innovative solutions that help farmers run their farms more efficiently. Lely's product portfolio consists of a wide range of robots performing various tasks around the farm, see figure 1.1.

The robots operate around the cattle on a daily basis. To notify the listeners present in the barn about the actions the robots are performing, and to alarm them in case of dangerous situations or technical errors, the robots produce a buzzer sound. However, rather than ensuring a safe farm environment and supporting the daily operations around the farm, the buzzer causes annoyance and confusion for the farmer. Leading to farmers removing the buzzer from the robots entirely, jeopardising the safety of the people and cows present in the barn. By creating notification sounds based on a sound design framework that is focused on the context of a farm environment and the wellbeing of the listeners present in the barn these issues can be resolved.



Figure 1.1: The Lely robots.

## 1.2 Project scope

### 1.2.1 Project aim

The aim of this project is to develop a sound design framework and a concise set of sounds that can be implemented across all robots in Lely's product portfolio.

To achieve this goal the following objectives will be explored:

- Explore the current sound environment of the dairy farm, focusing on the experience of the dairy farmers and identifying the problem areas.
- Explore the perception of sound from a cow and human perspective.
- Develop a sound design framework that can be utilised to develop sounds for Lely's current product portfolio and future products.

### Relevance

This project addresses a sound design issue that directly influences the daily operations in and around the dairy farm, and the safety and well-being of the users interacting with the Lely robots. Although the issue has a significant impact, it has so far been overlooked.

### 1.2.2 Boundaries

- Lely's product portfolio consists of robots that are part of a bigger system. This project solely focuses on the robots that operate within/around the barn. This scope helps to ensure that notification sounds are used only where necessary.
- Although Lely's products are sold on an international scale, the scope of this project is limited to dairy farms based in the Netherlands. Expanding the scope to international markets would introduce a range of variables that need to be considered, such as different cultural interpretations of sound and varying farm conditions, making it more complex to develop a concise set of sounds with the given resources and time frame.
- The Lely farmers receive auditory notifications via the Lely robots and their mobile phone. Only the auditory feedback provided by the Lely robots will be considered during this project.
- Human speech as a form of auditory feedback will not be considered during this project. This boundary was set by Lely.

### 1.2.3 Stakeholders

The primary stakeholders in this project include Lely, the dairy farmers, and the dairy cows.

#### Lely

Lely will implement the set of sounds in their products and use the sound design framework as a guideline for future products.

#### Dairy farmers & Lely service technicians

The dairy farmers with one or more Lely products and the Lely service technicians rely on the auditory feedback to interact with the Lely robots/systems.

#### Dairy cows

The dairy cows interact with the Lely robots/systems on a daily basis. The outcome of the developed set of sounds directly influences their well-being.

## 1.3 Project approach

### 1.3.1 The approach

The structure of this project is based on a User-Centric Design (UCD) approach. This is an iterative process where the designer focuses on the user and their needs during every phase of the design process.

The project consists of the following five phases: 1. Explore, 2. Empathise, 3. Define, 4. Design, and 5. Evaluate.

#### Explore

The Explore phase is divided into two stages. The first stage focuses on gaining a deeper understanding of the concept of sound by conducting literature and desk research. First, relevant sonic interaction methods are reviewed, focusing on how sound and sonic interaction methods can support human-robot interaction. Second, the perception of sound from both a human and cow perspective is explored.

Sound does not exist in isolation, it interacts with the environment, the users, and the Lely robots and systems it supports. During the second stage, the context of the dairy farm environment is explored through desk and field research. The role of the Lely robots on the farm is described, the listeners and their sound-induced actions are identified based on the framework of acoustic biotopes, and the ambient noise levels are measured.

#### Empathise

The Empathise phase focuses on understanding the listeners exposed to the notification sounds, including their needs, wants, and the challenges they face. Through interviews with dairy farmers and regular farm visits to observe the context, key problem areas are identified and analysed.

Additionally, this phase explores the reasoning behind the current use of buzzer sounds from Lely's perspective. Through interviews with the product development and safety & compliance teams, the robot actions that may require auditory feedback are identified, along with potential limitations and shortcomings of the current sound design.

#### Define

In the Define phase, the information gathered during the Analyse and Empathise phases is reviewed to re-evaluate the initial design brief and define the core problems. Based on the new design brief, a set of user-centered wishes and requirements is formulated, along with preliminary sound design guidelines, to serve as a foundation for the upcoming design phase.

#### Design

The Design phase is split into two stages: the conceptualisation stage and the embodiment stage. The conceptualisation stage serves as a preparatory phase before moving into the embodiment stage. During this stage, possible solutions for the identified problems are generated, and a sound design framework is developed.

The embodiment stage focuses on creating the sounds. During this stage, a set of sounds is created using the sound design framework developed in the conceptualisation phase. Throughout this stage, the sounds are continuously refined and adjusted based on feedback from both Lely and the users.

#### Evaluate

The final phase is the Evaluate phase. In this phase, the sound design framework and the developed set of sounds are assessed through user testing to determine whether the specified requirements and user needs are met. Based on user feedback, areas of improvement are identified, and design adjustments are made accordingly.

### 1.3.2 The methods

This project utilises a combination of sonic interaction design (SID) methods and the framework of acoustic biotopes. SID explores how sound can be used to convey information, emotions, meaning, or aesthetic attributes in an interactive context (Serafin et al., 2011).

Acoustic biotopes are shared sound environments where sound-induced actions take place in a specific space, in this case the barn (Özcan et al., 2022).

#### Acoustic biotopes

To identify the listeners and their role within the shared acoustic environment, the framework of acoustic biotopes is utilised. This framework categorises different listening types to help identify their role and the degree to which they engage in sound-induced actions. By identifying the different types of listeners, strategic design choices can be made to fulfill the specific needs of each listener.

#### Sonic interaction design (SID)

Sonic interaction design methods form the basis for developing the set of notification sounds. The characteristics of the robots are transformed into sound through sonification, during this process robot data is mapped to sound parameters such as pitch and timbre.

To communicate the actions of the robots, auditory icons and earcons are utilised. Auditory icons are sounds inspired by real-world sounds, while earcons are abstract sounds used to represent an action or state.



This chapter presents the literature review. The literature review aims to explore studies related to the topic and similar contexts to use as a foundation during the research phase. The first paragraph covers psychoacoustics, the study of how humans perceive sound from a psychological and physiological standpoint. The second paragraph will examine the field of auditory displays and sonification. Paragraph 3 explores the use of sonification in human robot interaction. Lastly, in paragraph 4 the perception of sound from a dairy cow perspective will be presented. For additional information about the use of sound in (autonomous) vehicles, see Appendix A.

- 2.1 Psychoacoustics
- 2.2 Auditory display and sonification
- 2.3 Sonification in Human Robot Interaction
- 2.4 The perception of sound from a dairy cow perspective
- 2.5 Key takeaways



## 2.1 Psychoacoustics

Psychoacoustics focuses on the human perception of sound from a psychological and physiological standpoint. By analysing the barn environment through a psychoacoustic lens, a more realistic understanding of the soundscape and its listeners can be obtained. This section will cover the human perception of sound and important factors that influence our perception of sound.

### 2.1.1 Frequency range and loudness

Humans can hear frequencies between 20 Hz to 20.000 Hz, the upper limit of this range will vary depending on age. Human infants are able to perceive sounds slightly above 20 kHz, while the upper limit for the average adult is between 15 to 17 kHz (Purves et al., 2001).

The human ear does not transmit all the frequencies within the 20 to 20 kHz range equally. Humans are most sensitive to frequencies between 2000 to 5000 Hz. This difference in sensitivity affects the perceived loudness of a sound. The loudness level is a frequency-compensated decibel scale, measured in phons (TU Darmstadt, n.d.). The scale is based on equal loudness contours where 0 phons at 1000 Hz is equal to 0 dB (World Soundscape Project et al., 1975). Figure 2.1 shows the Fletcher-Munson curve, this curve indicates how the perceived sound pressure level (dB) changes depending on the frequency level of a sound (Yule, n.d.). To illustrate, a sound of 300 Hz needs to be played at 18.05 dB and a sound of 3000 Hz at 3.04 dB in order to be perceived as equally loud, in this case 10 phons (10 decibels at 1000 Hz).

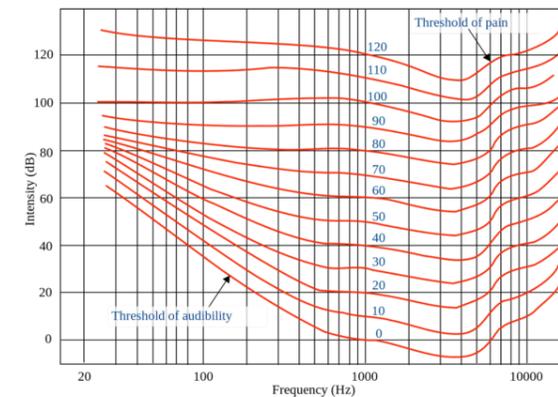


Figure 2.1: Fletcher-Munson Curve (McAllister, 2023).

### 2.1.2 Auditory masking

Auditory masking occurs when the perception of a target sound gets affected by the presence of another sound, in some cases making the target sound inaudible (complete masking) (Siemens Digital Industries Software, 2019). There are two types of masking, spectral masking and temporal masking.

#### Spectral masking

Spectral masking occurs when a target sound becomes inaudible due to the presence of a masker with a different frequency. The perception of the masker's frequency blocks the perception of the target sound's frequency. The loudness and frequency of the masker determine the extent of the masking effect. A stronger masking effect occurs when the masker and the target sound are close in frequency. A low-frequency masker is more effective at masking high frequencies than vice versa (Ansys, 2023). The louder the masker, the greater the masking effect and the wider the frequency range it covers.

To determine if a sound will be masked, the masking curves can be used, as shown in figure 2.2 (Siemens Digital Industries Software, 2019). The curves illustrate the loudness of the masker. The y-axis represents the loudness of the test tone in decibels, i.e. the target sound. The x-axis shows the difference in frequency between the test tone and masker in barks (critical bands), where  $Z_M$  is the masker and  $Z_T$  the test tone. Figure 2.3 on the next page shows the critical band values (bark) plotted against the frequency to determine the critical band value for a given frequency. The bark value can also be calculated with the following formula:

$$\text{Bark}(z) = 13 \arctan(0,00076 * f) + 3,5 \arctan\left(\left(\frac{f}{7500}\right)^2\right)$$

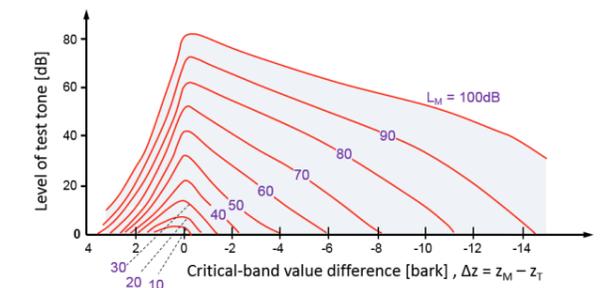


Figure 2.2: Masking curves (Siemens Digital Industries Software, 2019).



## 2.2 Auditory display and sonification

Auditory displays are systems that use audio to communicate information to the user. They encompass all aspects of the human-machine interaction system, including both the technical components and the interaction with the display system. Sonification is a component of an auditory display, it focuses on the technique of generating sound based on data or interactions. This section highlights the relevant aspects of auditory displays and introduces several sonification techniques.

### 2.2.1 Auditory displays

Sonification is a subtype of auditory displays that uses non-speech audio to communicate information (Hermann et al., 2011).

In the context of farm-based machinery, auditory displays can be utilised for alerting functions (alarms, alerts and warnings), and status and progress indicating functions (status, process and monitoring messages).

Alerts and notifications indicate something is about to occur, has occurred, or notify the listener to immediately attend to something in the environment. The information these sounds convey is limited resulting in simple and straightforward sounds. For instance, the sound of a microwave consists of one or more single-tone beeps that tell the user the timer duration has elapsed. It does not tell the user if the food is actually fully warmed up.

Alarms and warnings are alert or notification sounds that require immediate action or attention. Alarms and warnings should carry more information than alerts and notifications. In other words, the user should know based on the alarm there is an adverse event that requires immediate action. However, the specificity of the information is limited. An example, a fire alarm indicates an adverse event (fire) that requires immediate action (evacuation), the alarm does not indicate the location of the fire or its severity.

Progress indicating functions can either perform a basic alerting function about the status or progress of an action, or offer more detail about the action presented through the sound. Progress indicating functions are mainly intended to inform the user and don't necessarily require the user to attend to anything (Hermann et al., 2011).

### 2.2.2 Sonification

Sonification is the process of translating information into sound. It enables users to interpret complex data, or enhance communication through sound (Hermann, n.d.). There are several types of sonification techniques that are designed based on different types of data, desired outcomes, and contexts. The sonification techniques that are relevant in the domain of farm-based robots are parameter mapping, auditory icons, and earcons (Hermann et al., 2011).

#### Parameter mapping

Parameter mapping sonification (PMSon) is the translation of multivariate data or specific parameters into sound. The process of parameter mapping sonification consists of assigning each parameter from the chosen data/ information to an auditory characteristic, such as pitch, timbre or rhythm. This sonification technique offers a wide range of mapping options and lends itself appropriate for particular circumstances. However, this wide range of options also comes with challenges in terms of consistency and comprehensibility. When mapping a piece of information it is important to take into account what information gets lost. Mapping information on a universally understood sound might lead to it losing its intuitive nature when changing certain sound parameters (Hermann et al., 2011).

#### Auditory icons

Auditory icons are brief sounds that directly mimic everyday non-speech sounds that people might be familiar with from previous experience, hence why the meaning often does not need to be learned. Auditory icons are frequently used in digital systems to make the actions more intuitive. An example, when taking a picture on your phone you might hear the sound of a camera shutter to indicate that the picture is taken (Gould, 2016).

When trying to communicate multiple pieces of information parametric auditory icons can be used. Parameterisation can be achieved by altering the loudness, playback rate, or using filters. These alterations only work in a narrow range as the identifiability of the sound might get lost. Another approach is using different recordings of the action. This could be pouring a liquid into a container at different speeds to convey information about the speed of the action (Hermann et al., 2011).

#### Earcons

Earcons can be utilised when there are no real-world sounds that correspond with the given action. They are short abstract sounds that represent a piece of information or an event. Different from auditory icons, earcons are synthesised tones or sounds that have no direct relationship to the event. Rather, they are only used as a representation of the event and need to be learned. To create an earcon the parameters rhythm, pitch, timbre, register and dynamics can be varied. For instance, an earcon for deleting a file could be a three-note pattern with decreasing loudness and pitch. The diminishing loudness and pitch represent the process of deleting (Dingler et al., 2008). There are four types of earcons: one-element earcons, compound earcons, transformational earcons, and hierarchical earcons. One-element earcons are used to convey a single parameter of information.

Compound earcons are formed by linking one-element earcons to create a more meaningful message. The compound earcon can be seen as the sentence and the one-element earcons as the words in the sentence.

Transformational earcons are constructed based on a set of rules, where specific values of data parameters are mapped to specific values of the assigned auditory attribute. These rules make it easier for the user to understand the meaning of the earcon, the user only needs to learn the rules (which auditory parameters are mapped to which data attributes), instead of each sound individually.

Similar to transformational earcons, hierarchical earcons are based on a set of rules. The set of rules follow the same structure as a typical hierarchy where the earcons inherit the properties of the earcons above (Hermann et al., 2011).

In order to optimise the recognition of earcons the sounds need to abide by a set of guidelines (Hermann et al., 2011; Dingler et al., 2008):

- **Timbre:** musical timbres are more effective than simple tones. Using multiple harmonics aids in the perception of the sound and avoids masking. Different data values should be mapped with timbres that are easily distinguishable.
- **Pitch:** pitch should never be used as a single indicator to differentiate earcons. It should always be used along with another sound parameter as it is difficult for the listener to distinguish two earcons solely on their pitch. Pitch ranges should not go above 5kHz or below 125-150 Hz to avoid masking.
- **Register:** similar to pitch, register should also not be used alone to differentiate earcons. It should be combined with another sound parameter. In case the register does get used on its own, the least important data should be assigned to it. The register should also have a large difference of two or three octaves.
- **Rhythm:** similar rhythms are likely to get confused by the user. Hence, why the rhythm of different earcons should be as different as possible. The combination of rhythm and pitch proved highly effective to differentiate different earcons.
- **Intensity:** listeners should always be in control of the sound level of the auditory display as the perception of loudness differs from person to person. Intensity should not be used on its own to differentiate earcons, it is best to keep earcons close in intensity range in order to ensure no sounds get lost when the user changes the system's volume.
- **Timing:** between each earcon there should be a small gap of at least 0.1 seconds to ensure the user knows one earcon ends and another begins. If multiple earcons start at once there should be at least a 300ms gap between each start.

## 2.3 Sonification in Human Robot Interaction

Human robot interaction (HRI) is a multidisciplinary field that focuses on understanding, designing, and evaluating interactions between humans and robotic systems (Kanda, 2012). This section focuses on how sonification can be utilised in HRI to facilitate both functional and expressive communication.

### 2.3.1 The sonification of robot features

Humans react to robotic voices in a similar manner as they do to human voices. Based on the robot's speaking style humans draw conclusions about the robot's character, competence and intelligence (Nass & Brave, 2005). This offers the opportunity to convey certain robot features via sound in order to differentiate the robots. A publication from Fischer and Niebuhr (2023) investigated the relationship between the acoustic properties of a robot's voice and its size. The findings suggested that the size of the robot can be communicated through sound. Robot voices with higher pitch levels were significantly more often associated with smaller robots. Robot voices with a lower fundamental frequency were associated with larger robots.

A study by Orthmann et al. (2023) confirms this finding. This study focused on developing a layered-based sonification framework that allows robot features to be mapped to audio parameters combined in one single audio stream. By designing sounds using this framework listeners are able to intuitively understand the robot's characteristics, actions and intentions.

The study focused on how the size, speed, interactivity, urgency, and directionality of a robot could be communicated.

To communicate the size, the study concluded that pitch can be used as an indicator. Big robots were given a lower pitch and small robots a higher pitch. The assigned pitch was based on the natural relationship between the size of an object, and its pitch and loudness. For example, animals and humans with bigger vocal tracts tend to have lower-pitched voices compared to animals and humans with smaller vocal tracts. Consequently, people will associate larger objects with a broader, heavier and lower-pitched sound, and smaller objects with a thinner, lighter, and airy sound.

To convey the feeling of speed the study proposed the adaptation of the sound parameters pitch and tempo. The study displayed slow speed by gradually increasing and decreasing amplitude slopes, resulting in a gentle ocean-like wave motion and a constant audio signal as a base. Fast speed was shown through quick amplitude changes, resulting in a choppy sound of helicopter blades cutting through air.

For interactivity the assumption was made that non-interactive robots would be the default, and robots that could be interacted with would be indicated. To make the robot more approachable the study proposed adapting the parameters timbre and pitch by adding brightness and positive tonality to create a "happy" sound. This modification was made based on emotion theories, which suggest that people are more approachable when they show positive emotions, such as happiness.

To convey urgency the study concluded that the use of frequencies that stand out in the human hearing system (2000 - 5000 Hz) and the creation of rhythms, where fast patterns signal higher urgency work best. The use of fast patterns to convey urgency has also been proven to work by other studies. A study from Langlois et al. (2008) concluded that a fast tempo and a short attack time (the time it takes for the amplitude of a sound to go from zero to 100%) increases urgency perception.

For directionality the study utilised pitch and spatialisation. Two options were proposed to create spatialisation, i.e. distributing the signal between two stereo channels or using spatial audio (simulating a 3D audio environment). In some cases the use of a stereo speaker setup is not feasible. As an alternative for spatialisation, directionality through the modulation of pitch was proposed. In this concept the pitch is mapped on the horizontal axis, where the lower pitch tones are placed on the left side and the higher tones on the right side, similar to the distribution of tones on a piano.

## 2.4 The perception of sound from a dairy cow perspective

The dairy cows are the primary listener group that will be exposed to the robot sounds. To ensure that the new robot vocabulary does not negatively affect the welfare of the cattle, it is essential to have a proper understanding of their perception of sound and its impact on their behaviour. This section explores the auditory perception of cows and the effects of sound on their wellbeing.

### 2.4.1 Auditory perception of cows

Dairy cows have a different auditory perception compared to humans, as shown in figure 2.5, which provides an overview of the differences in sound perception between dairy cows and (adult) humans. Dairy cows perceive a wider frequency range, with a hearing ranging from 23 Hz to 35 kHz, and an upper limit of 37 kHz for high frequencies. The hearing range of dairy cows for high frequencies covers the ultrasonic range of 17 to 37 kHz of an adult human (Dimov et al., 2023; Purves et al., 2001). The auditory system of dairy cows is the most sensitive to frequencies around 8 kHz, whereas humans are most sensitive to frequencies ranging between 2000 to 5000 Hz (Lumen Learning, n.d.).

Despite having a wider hearing range, cows have more difficulty locating the origin of a sound than humans. In order to locate the source of a sound, cows will use their hearing as well as their sight (Purebred Dexter Cattle Association of North America, 2021).

### 2.4.2 The effect of noise on cattle

One of the most common stress triggers for cattle is the presence of noise on the farm (Ciborowska et al., 2021). Noise is classified as an unpleasant or unwanted sound and can be chronic or periodic (Britannica Dictionary, n.d.). The impact of noise on cattle is dependent on the intensity (dB), frequency (Hz), pattern, and the duration of the noise exposure. The response to noise will also differ per cow depending on their age, psychological state, breed, and earlier experiences with noise (Dimov et al., 2023).

According to Dimov et al. (2023), farms with noise levels consistently exceeding 70 dB have a harmful impact on the wellbeing of the cattle and can cause excessive anxiety, an increased heart rate, and a decrease in milk yield. If the noise levels exceed 70 dB it should only be for a short period of time. This finding is also supported by a study from Ciborowska et al. (2021) which reported that there is a correlation between the sound pressure level of the noise and the severity of its effects. As stated in the paper, the effects of noise range from an increased heart rate and a reduction in feed intake at an 80 dB noise exposure, to morphological and biochemical changes in blood at noise exposure exceeding 100 dB (Ciborowska et al., 2021).

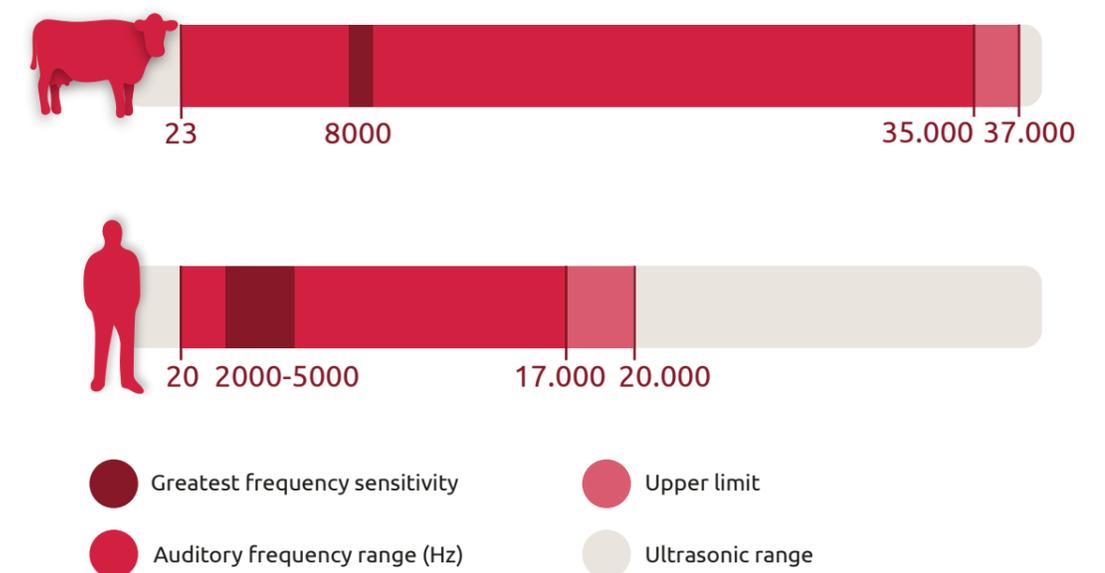


Figure 2.5: Hearing range of dairy cows and humans in hertz (Hz).

### 2.4.3 Positive impact of sound on cows

Previous research has shown that exposing cows to music promotes the feeling of relaxation, leading to improved health and increased milk production. (Ciborowska et al., 2021). Not all types of music have the same relaxing effect on cattle. While some music tracks promote relaxation, other tracks have the exact opposite effect. The amount of relaxation the music promotes is dependent on the genre, sound pressure level and tempo of the music. A study by Kemp (2020) showed that cows displayed the most relaxed behaviour and highest milk yield when exposed to lullabies. Still, the highest milk yield was produced by the control group where no music was played. The results of a study by Crouch et al. (2019) concluded that music alternated by periods of no auditory stimulation improved relaxation and increased the milk yield. The findings from Erasmus et al. (2022) contradict these findings by stating that constant exposure to slow classical music, i.e. 52 to 122 beats per minute (bpm) with an average of 85 bpm, increases the milk yield and lowers the activity level of Holstein cows. The authors argue that providing periods of no auditory stimuli increases the activity level of the cows, which is associated with a stressed cow (Erasmus et al., 2022).

## 2.5 Key takeaways

### Psychoacoustics

- An average human adult can hear frequencies between 15 Hz to 17 kHz.
- Humans are most sensitive to frequencies between 2000 to 5000 Hz.
- The perceived sound pressure level (dB) changes depending on the frequency level of a sound. When designing sounds, the intensity of some of the frequencies needs to be boosted to ensure the frequencies are perceived as equally loud.
- The notification sounds might become inaudible as a result of spectral masking and/or temporal masking.
- Spectral masking: the masker and notification sounds are not allowed to be close in frequency to limit the masking effect.
- Temporal masking: the shorter the duration of the notification sound, the quieter the sound will be perceived.
- The greater the distance, the greater the damping of higher frequencies. For notification sounds that have to travel a longer distance to reach the farmer's ear it is best to include lower frequencies.

### Sonification and Human robot interaction

- Parameter mapping: to communicate information about the actions the Lely robots perform and to communicate the robot model, each piece of information can be mapped to a sound parameter.
- Auditory icons: to make the Lely notification sounds intuitive in nature, everyday sounds that people might be familiar with can be used, i.e. auditory icons.
- Earcons: for robot actions that do not have a corresponding real-world sound earcons can be used. To ensure recognition of the earcons, the guidelines for earcons need to be used.
- The sound parameter pitch in combination with another parameter can be used to communicate the robot's size.
- The sound parameter rhythm can be adapted to convey urgency. A sound with a fast pattern and short attack time is perceived as urgent.

### The perception of sound from a dairy cow perspective

- Dairy cows perceive a frequency range from 23 Hz to 35 kHz, with an upper limit of 37 kHz for high frequencies. The hearing range covers the ultrasonic range of 17 to 37 kHz of an adult human.
- Dairy cows are the most sensitive to frequencies around 8 kHz.
- Farms with noise levels exceeding 70 dB have a harmful impact on the wellbeing of the cattle. Noise levels above 70dB should only be present for a short period of time.

This chapter gives an overview of the dairy farm environment. It covers the layout of an average Dutch dairy farm, the role of the Lely robots within the environment, the shared acoustic environment, and the ambient noise level. This information is necessary to understand the context in which the robots operate.

- 3.1 The purpose of the Lely robots & systems on the farm
- 3.2 The shared acoustic environment
- 3.3 Ambient noise levels

# 03

## 3.1 The purpose of the Lely robots & systems on the farm

In order to understand the current scenario, this section provides background information about the seven Lely robots/ systems that are considered during this project.

Each Lely robot/system has its own task within the domain of milking, cleaning or feeding. Figure 3.1 shows a map of where each robot/system is located on the farm. The purpose of each individual Lely product is explained on the next page.



### Astronaut A5

The Astronaut A5 is a fully automated milking robot that operates on a 24/7 basis, allowing the dairy cows to choose themselves when they want to be milked. The milking robot is a stationary robot located in the cowpen to enable the cows to go up to the robot whenever they please (Lely, n.d.-d). Typically, farmers own multiple Astronauts.

### Discovery Collector

The Discovery Collector is an autonomous manure robot developed to clean solid barn floors on a 24/7 basis. The robot cleans the barn floor using scrapers, brushes and a vacuum technique. The vacuum technique is used to collect the manure and transport it to a central collection area. The robot mainly drives inside the cowpens, moving between the dairy cows (Lely, n.d.-b).

### Discovery 90SW

Similar to the Collector, the Discovery 90SW is an autonomous manure robot that cleans the barn floor on a 24/7 basis. The robot mainly drives inside the cowpens, moving between the dairy cows. Unlike the Collector, the 90SW is developed to clean slatted floors (floors with long narrow holes) by scraping the manure from the floor to stop it from building up and blocking the slats. Farmers usually own either the 90SW or Collector depending on the type of floor they have (Lely, n.d.-j).

### Sphere

The Lely Sphere is a circular manure-handling system that separates the manure and urine, and converts the nitrogen emissions into fertilisers. The Sphere is a stationary system that is located next to the barn. Farmers typically own multiple Spheres depending on the size of their barn (Lely, n.d.-h). Although the Sphere is technically a system instead of a robot, it will be referred to as a robot in this report to avoid any confusion.

### Juno

The Juno is an autonomous feed pushing robot that operates on a 24/7 basis. The Juno ensures the feed stays within reaching distance of the dairy cows by pushing the feed back towards the feeding fences (Lely, n.d.-k). The robot drives six to eight times a day through the alleys of the barn to push the feed (Lely, n.d.-c).

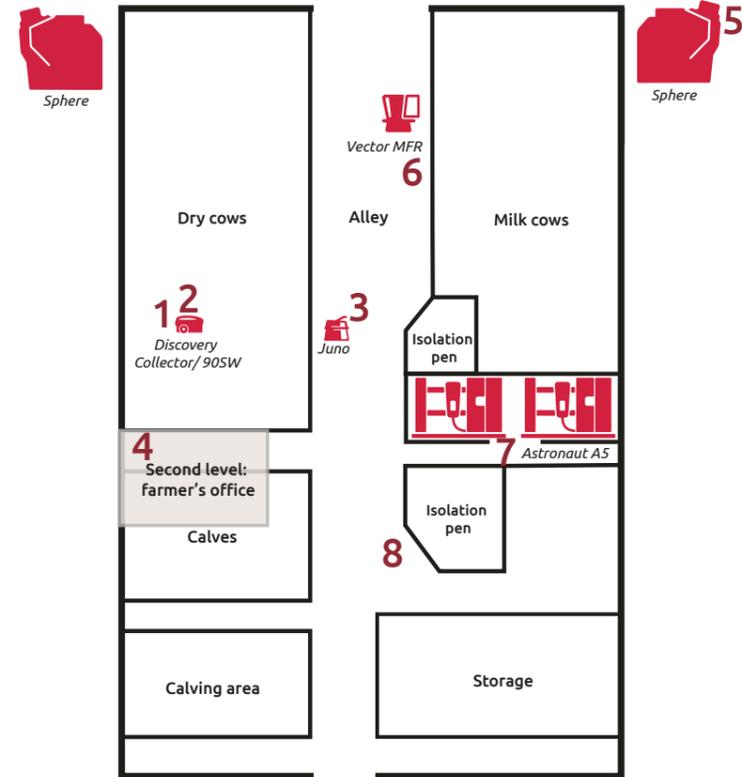
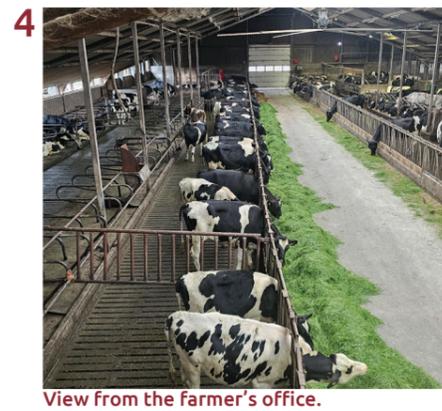


Figure 3.1: Map of a dairy farm with the Lely robots.

### Vector MFR

The Vector MFR is a mixing and feeding robot that is part of the Vector feeding system. For this project only the Vector MFR will be considered. The MFR compiles mixed ration and transports it to designated herd in the barn on a 24/7 basis. The robot drives inside the barn, and to and from the feed kitchen where the food is stored and loaded into the Vector (Lely, n.d.-i).

### Exos

The Exos is an autonomous robot that mows, transports, and fertilises grass on a 24/7 basis. The robot drives on land and inside the barn to harvest the grass and feed it to the cows (Lely, n.d.-e).

## 3.2 The shared acoustic environment

This section provides an overview of the shared acoustic environment of the barn. The overview is based on the framework of acoustic biotopes, i.e. shared sound environments where sound-induced actions take place in a specific space (Özcan et al., 2022).

The farmers and the Lely technicians are the primary users of the notification sounds. However, there are more listeners who will be affected by the sounds the robots produce. Figure 3.2 shows all the listeners in the shared acoustic environment of the barn that will be taken into account during this project. In total five listener groups are identified, listed below:

### The farmer - active listener

The farmer actively listens for any sounds indicating that the robots are malfunctioning or need attention. If a technical issue arises that the farmer cannot fix, they will contact a service technician.

### The dairy cows - (in)active listener

The cows are both inactive and active listeners depending on the robot the cow is interacting with. They are the main listener group that will be exposed to the sounds. Hence, why it is important to ensure the robots do not produce sounds the cows experience as disturbing. Any disturbing sounds will have a negative impact on the cows' behaviour and performance (Dimov et al., 2023).

### The Lely service technician - Sound user

Technicians rely on the sounds produced by the robots when performing maintenance and resolving technical issues. The sounds allow the service technician to identify the criticality of the issue at hand.

### The family - Passive listener

The family of the farmer typically lives close to the farm and helps out from time to time. They will not react to the majority of the sounds the robots produce, unless it is an alarm sound.

### The neighbours - inactive listener

The neighbours are exposed to the sounds when the robots are driving outside the barn. This group has no control over the sounds and does not perform any sound induced actions.

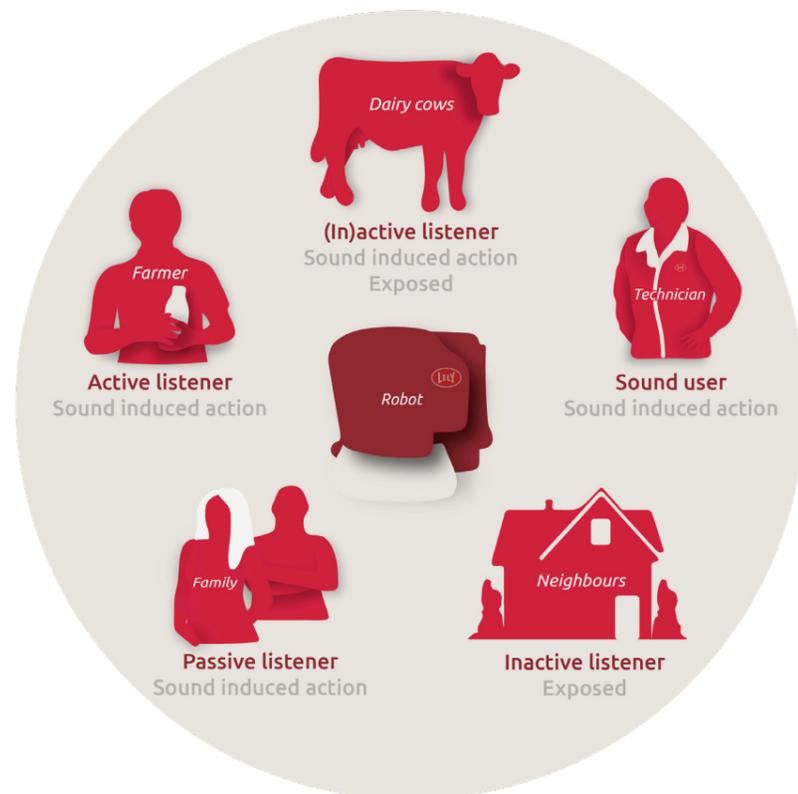


Figure 3.2: Identified listener groups.

## 3.3 Ambient noise levels

To determine the sound pressure level of the notification sounds, the ambient noise levels of the dairy farm must be measured. This section outlines the measurement protocol and presents the measurement results.

### 3.3.1 Measurement protocol

In order to create consistent results the following parameters need to be considered:

#### Time of day

The sound pressure levels will vary depending on the time of day. The ambient noise will be measured during the day between 09:00 and 17:00. This measurement is based on the time period the farmer will most likely be present in the barn (Department of Environment, Parks, Heritage and the Arts, 2008).

#### Weather conditions

To minimise the parameters that will affect the noise measurements, the ambient noise will be measured when there is no rain or high wind (more than 5 km/h) present.

Rain may disrupt the ambient noise measurements by acting as a dominant noise source. The humidity and temperature will affect the measurements as well. However, this is only relevant for long distance measurements. For source-to-measurement distances below 25 m the influence of temperature and humidity will be negligible.

The effect of wind will also be primarily negligible. Wind affects the noise measurements over a long distance by increasing or decreasing the speed of sound. The stronger the wind the greater the effect will be. The speed increases in the case of downwind, where the wind blows the sound source towards the noise measurement location. This causes the expected noise levels to increase. During upwind conditions, the wind blows in the opposite direction of the sound source. This decreases the speed of sound and the expected noise level. A strong persistent wind can create a shadow zone, a zone where the sound waves can't transmit (Paré, 2023).

All the measurements that will be taken have a source-to-measurement distance below 25 metres. Meaning that the weather conditions do not have to be measured and the influence of temperature, humidity, and down- or upwind conditions do not need to be considered (Turner et al., 2015). The only weather conditions that will be taken into account are the presence of a turbulent wind and rain. These two factors could act as dominant noise sources, potentially overshadowing the targeted sound.

#### Frequency weighting

The decibel values inside the barn will be measured using the frequency weighting A. A-weighting is an adjustment applied to the measured decibels to reflect the sensitivity of the human ear (Redon, 2022). The weighting is dependent on the frequency of the sound, the decibel amount will be higher for frequencies humans are more sensitive to and lower for frequencies humans are less sensitive to. This weighting is commonly used to assess noise pollution or to test the noise levels of equipment. During the noise level assessment the A-weighting will be applied by changing the settings on the sound level meter (SML) to A-weighting.

#### Measurement location

The measurements will be done using a handheld sound level meter mounted on a tripod.

To obtain accurate data, each measurement will follow the same protocol: the sound level meter will be mounted on the tripod pointed towards the noise source at the standard ear height of an average person, i.e. 1.5 m above the ground (National Park Service et al., 2011). All the measurements will be taken at a 50 cm and 1.5 m distance from the sound source. The only measurements that do not abide by this guideline are the general barn measurements, see table central barn measurements Appendix B.

The sound level meter will be placed at an 1.5 m distance from any windows and 1 m distance from the walls and any other major sound reflective surfaces (Department of Environment, Parks, Heritage and the Arts, 2008). In case these distance conditions cannot be met, it will be noted in the measurement results. The observer will stand at a minimum distance of 50 cm from the sound level meter to avoid reflecting the sounds via their body.

### Measurement duration

The noise will be measured over a time span of 10 consecutive minutes to guarantee the measurement adequately represents the sound pressure level of the noise source (Department of Environment and Science, 2020).

### 3.3.2 Method

#### Equipment

- Handheld Sound level meter (SLM)
- Microphone windshield
- Tripod
- Measurement form (Appendix B)
- Measuring tape
- Pen
- Camera

#### Procedure

In total eight measurement sets will be measured consisting of seven measurement sets focused on each of the seven Lely robots and one set focused on the central barn points. The following protocol will be followed:

1. Check if the windshield is on the microphone of the SLM.
2. Set the SLM to A-weighting, dB(A).
3. Adjust the height of the tripod to 1.5m above the ground.
4. Locate the SLM at the indicated distance on the measurement form. Make sure the SLM is pointed towards the noise source.
5. Check if the distance between the SLM and any reflective surfaces is at least 1 m. For windows the distance should be at least 1.5 m. In case the minimum distance cannot be met, indicate this on the measurement form.
6. Stand at a minimum distance of 50 cm from the SLM.
7. Measure the sound for a duration of 10 minutes.
8. Write down the average measured sound pressure level on the measurement form.
9. Take photos of both the background and the measurement location.



Figure 3.3: Measurement setup.

### 3.3.3 Ambient noise level measurements

The map of the farm environment shows the decibel measurements in dB(A), figure 3.4.

The measurements were taken between 13:30 and 16:15 on 12-12-2024. There was no rain or high wind present during this time. The Juno, Discovery 90SW, and Exos were absent.

#### Central barn point

The central barn measurement shows a range of 57 to 69 dB(A). The 69 dB(A) peak is caused by the dairy cows putting their head through the metal feeding fences which causes a clunking sound. Another action that caused decibel peaks were the vocalisations of the dairy cows. The clunking sound of the feeding fences and the cow vocalisations happened sporadically, the base level decibel amount was 57dB(A). The measurements were taken at a 150 cm distance from the metal feeding fences.

#### Entrance barn

The decibel measurements at the entrance of the barn show a range of 53 to 63 dB(A). Similar to the central barn point measurements, the decibel peaks were caused by the metal feeding fences and the vocalisations of the dairy cows. The decibel measurements were taken inside the barn at a 150 cm distance from the main entrance.

#### Outside of the barn

A decibel range of 47 to 57 dB(A) was measured outside of the barn. The measurements were taken in front of the barn at a 150 cm distance from the entrance.



Figure 3.4: Map of the measured ambient noise level in dB(A).

#### Astronaut A5

The decibel values of the Astronaut A5 are dependent on the actions the Astronaut is performing. During cleaning a decibel range of 80 to 86 dB(A) at a 50 cm distance, and a decibel range of 70 to 81 dB(A) at a 150 cm were measured. The decibel peaks (86 dB(A) and 81 dB(A)) were caused by the sprayer that cleans the milking cups. This was a short spray lasting 3 seconds.

During milking a decibel range of 74 to 78 dB(A) at a 50 cm distance, and a range of 69 to 76 dB(A) at a 150 cm distance were measured. The decibel peaks were caused by the constant sound of the milk pumping through the tubes.

Measurement remarks: the measurements with a 150 cm distance were taken at a 30 cm distance of a semi wall (about 1,0 m in height) although the sound level meter was located above the wall (1,50m above the ground) the wall could have negatively impacted the decibel measurements by reflecting the sound.

#### Discovery Collector

The motor of the Discovery Collector produces a humming sound when driving, causing a decibel range of 61 to 68 dB(A) at a 50 cm distance and 58 to 66 dB(A) at a 150 cm distance.

Measurement remarks: other sounds present in the barn could have influenced the decibel measurements. The other sounds were included in the decibel measurements as this is an accurate representation of the real-life scenario.

#### Sphere

The Sphere produces a constant low humming sound causing a constant decibel amount of 61 dB(A) at a 50 cm distance, and 59 dB(A) at a 150 cm distance to be measured.

#### Vector MFR

The Vector MFR produces a constant humming sound when driving. A decibel range of 66 to 68 dB(A) at a 50 cm distance, and 63 to 65 dB(A) at a 150 cm distance were measured.

Measurement remarks: The measurements were taken while the Vector was driving in the barn. Other sounds present in the barn could have influenced the decibel measurements. The other sounds were included in the decibel measurements as this is an accurate representation of the real-life scenario.

This chapter focuses on understanding how the current notification sounds were created and identifies the criteria they must meet. It presents key robot actions and their corresponding notification sounds. Additionally, this chapter highlights the current issues from a user perspective. The information provided in this chapter is derived from interviews with the Lely product development teams, the Lely safety and compliance manager, and dairy farmers.

- 4.1 The creation and regulation of the current notification sounds
- 4.2 The ISO guidelines
- 4.3 Identified robot actions and sounds
- 4.4 Identifying the needs of the listeners

# 04

## 4.1 The creation and regulation of the notification sounds

This section presents the interviews that were conducted with the product development teams, and the safety & compliance manager in order to understand how the current notification sounds were created, and to identify the requirements the notification sounds need to abide by from a safety perspective.

A total of five Lely product owners and one manager from the safety & compliance team were interviewed regarding the current notification sounds. Each product owner is responsible for managing the product backlog of one or more Lely robots.

### 4.1.1 Product development

The product development teams are responsible for implementing the guidelines composed by the safety & compliance team, these guidelines are leading to ensure the user's safety. The implementation of auditory alarms initially started from a safety perspective. However, as time progressed non safety alarms were added to the set of alarms the robots produce. These alarms are identified as "informative sounds". They provide the farmer with information regarding the actions the robots perform. There are no specific guidelines for the informative sounds, and there seems to be a lack of communication between the product development teams regarding the notification sounds. Most product owners were unaware of the sound design of the other robots apart from their own. Furthermore, to save on costs the same buzzer is used for multiple robots. As a result, there is an overlap in the sounds the robots produce with no consistency in when a certain sound is used. It is also important to note that none of the product development teams asked for user feedback from the farmers or service technicians.

### 4.1.2 Safety & Compliance

Lely's safety & compliance team is responsible for conducting the risk analysis of the robots. Based on the analysis, guidelines for the implementation of sound from a safety and regulation perspective are created. These guidelines only concern warning signals. The feedback sounds for non-warning signals are developed by the product development teams. Lely strives to abide by the ISO standards in order to get the robots ISO certified. ISO standards are global standards to ensure the quality and safety of a product. Companies are not legally required to implement ISO standards unless it is mandated by law or by other regulations. Because of Lely's innovative nature and the specific scope of the robots, the majority of the Lely robots do not fit the scope of the currently available ISO standards. Only the Vector and the Exos fit within the scope of an ISO standard, i.e. ISO 3991 Agricultural machinery — Robotic feed systems — Safety. This document states the audible alarm of the robots shall meet the requirements of ISO 7731:2008 Danger signals for public and work areas - Auditory danger signals. The next section presents the ISO guidelines.

## 4.2 The ISO guidelines

This section covers the ISO guidelines the notification alarms need to comply with.

The guidelines stated in ISO 7731 serve as a basis for the development of the critical auditory alarms of the Lely robots. ISO 7731 makes a distinction between three different types of auditory alarms shown in figure 4.1. To abide by the ISO standard, the auditory alarm should be clearly audible, unambiguous, and convey urgency. The parameters of the alarm should be designed to stand out from the other sounds present on the farm and other auditory feedback the robots provide. The alarm of a moving robot should be recognisable regardless of the speed and direction of the robot.

### Auditory emergency evacuation signal

- Leave the danger zone immediately.
- Signal indicating the beginning or the actual occurrence of an emergency involving the possibility of injury and instructing the person(s) to immediately leave the danger zone in the recognised manner.

### Auditory emergency signal

- Take urgent action for rescue or protection
- Signal marking the start and, if necessary, the duration and the end of a dangerous situation.

### Auditory warning signal

- Take preventative or preparatory action
- Signal indicating the possibility or actual occurrence of a dangerous situation requiring appropriate measures for the elimination or control of the danger.

Figure 4.1: Types of auditory alarms.

The following design criteria, derived from ISO 7731, need to be met in order to meet the described characteristics of a critical alarm (ISO, 2003).

### Sound-pressure level

The effective masked threshold needs to be noticeably exceeded. The effective masked threshold is the sound-pressure level of the auditory alarm that is required to make the alarm audible in the presence of a masker (another noise), taking the ambient noise and the listening deficiencies (e.g. hearing loss and hearing protection) into account. The sound-pressure level of the alarm is not allowed to be lower than 65 dB or exceed 118 dB at any position in the signal reception area (the area in which a person is required to recognise and respond to an alarm). The alarm should exceed the sound-pressure level of the ambient noise by 15 dB or more. In case there is a clear difference in frequency and/or temporal distribution (the pattern of a sound over time) between the ambient noise and the alarm the 15 dB difference is not required. A sound-pressure level difference starting at 10 dB will suffice depending on the type of octave-band. An octave is the interval between two notes with a frequency difference of a factor  $\sqrt{2}$ , in this case a difference starting at 10dB will be sufficient. In the case of an  $\frac{1}{3}$  octave the frequency difference is a factor of  $\sqrt[3]{2}$ , for this octave-band a difference starting at 13 dB will be sufficient.

### Frequency content

The alarm should include frequency components in the 500 to 2500 Hz frequency range. In general, it is recommended to include two dominant components from 500 to 1500 Hz.

### Temporal pattern

It is advised to use pulsating auditory alarms rather than alarms that are constant in time. The alarm cannot have a similar pulse duration and pulse repetition frequency (number of pulses per specific time unit) as the ambient noise present in the signal perception area.

## 4.3 Identified robot actions and sounds

This section presents the identified robot actions and the current notification sounds.

### 4.3.1 The buzzer sounds

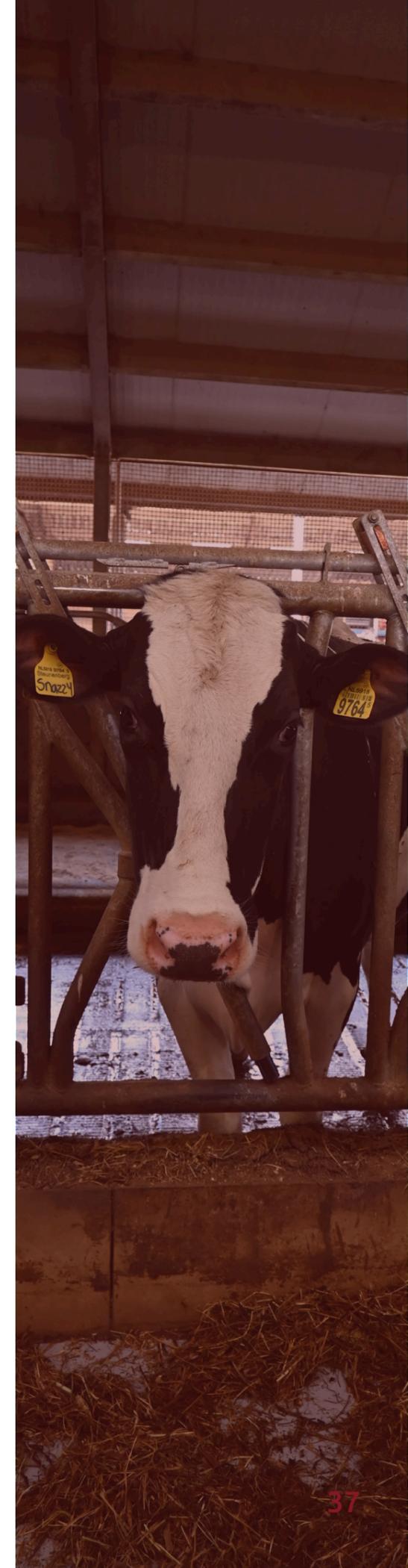
The Lely robots provide the farmers with auditory feedback through a buzzer.

All the buzzers are able to produce a continuous or pulse sound. The frequencies of the buzzers cannot be adapted.

The Vector MFR, Juno, Discovery Collector and Discovery 90SW all use an Auer panel mount buzzer of 3500 Hz, see figure 4.2. The Astronaut A5 uses an Auer panel mount buzzer with a frequency of 7000 Hz. The Exos uses a buzzer with a 2800 Hz frequency. The Sphere is the only robot that does not have a buzzer or any other form of auditory feedback.



Figure 4.2: Auer panel mount buzzer (Conrad, n.d.).



### 4.3.2 Identified actions and sounds per robot

This section presents the identified robot actions and the current notification sounds. Figures 4.3 to 4.9 show an overview of the current sounds and important actions per robot obtained from the interviews with the product development teams and the user manuals from the robots. The names presented in figures 4.3 to 4.9 are those used by the product development teams. The name for the same type of notification sound may vary depending on the robot. The term “No sound” indicates that there is currently no notification sound for that action. However, the robot action is identified as possibly needing a sound.

All the audio files presented in this report were recorded by hand and used as a starting point during the design phase.

#### Astronaut A5

The Astronaut has two alarm categories: continuous alarms and pulse alarms. Both alarm categories are communicated to the farmer through an auditory alarm, LED alarm and a phone call. Continuous alarms generate a phone call after a certain time to inform the farmer of a technical issue. The pulse alarm directly generates a phone call to inform the farmer about a cow in the robot that needs help. Both alarm categories must be acknowledged by the user and the cause of the alarm must be removed for the alarm to stop. An additional third category is identified for alarms that do not require the farmer’s immediate attention, the non-critical alarm/ warning. This alarm notifies the farmer about preparatory action or maintenance that needs to be performed or else the robot might not be able to operate after a certain amount of time.



Figure 4.3: Identified actions of the Astronaut A5.

#### Discovery Collector

The Discovery Collector has 121 different alarms that are categorised into three different categories: “no alarm”, “non-critical alarm” and “critical alarm”. The “no alarm” consists of sounds that provide information about the current task the robot is performing. The “starting a route”, “driving a route”, “driving backwards”, and “driving to and from the charging station” fall under this category. The non-critical alarms are warning alarms regarding issues that require the farmer to check the robot or perform maintenance. According to the user manual the robot produces an auditory alarm for non-critical alarms. However, both the product owner and the test engineer stated the robot does not produce an auditory alarm for non-critical alarms. Instead, the farmer receives a notification on their phone and the LED located inside the pause button will blink. The critical alarm generates a blinking LED, a notification on the farmer’s phone, and an auditory alarm that continues until the problem is acknowledged.

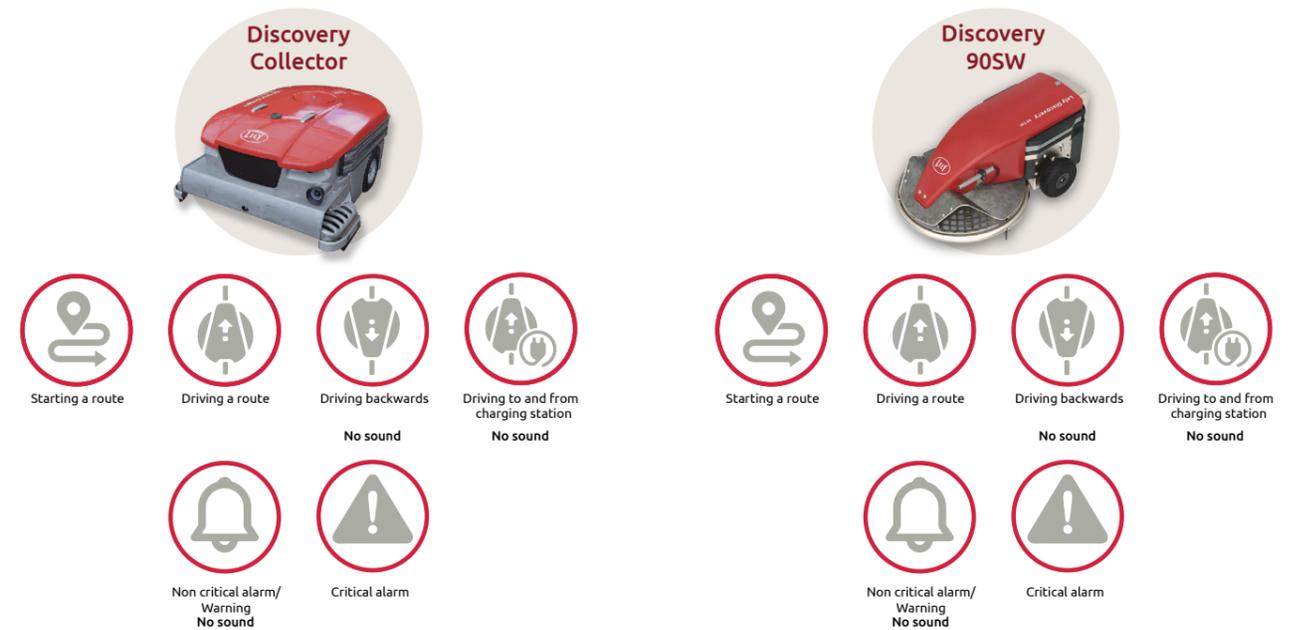


Figure 4.4: Identified actions of the Discovery Collector.

Figure 4.5: Identified actions of the Discovery 90SW.

### Sphere

The Sphere produces a low humming sound when it is in operation. The farmer uses this sound as an indicator to know if the robot is on. The Sphere does not produce any other sound other than the mechanical humming sound. Six important actions are identified, two of those actions, i.e. the non-critical alarm and the critical alarm/ emergency stop, are identified as actions that require a sound. The usage of sound for the remaining four actions will not be necessary with the implementation of a feedback light and the presence of the humming sound.

### Juno

The sounds of the Juno fall under two different sound categories: normal operation and the occurrence of an alarm. The normal operation category notifies the user the robot will start moving or is moving. The actions “starting a route”, “driving a route”, and “driving to and from the charging station” fall under the normal operation category. The Juno has one sound for critical and non-critical alarms. During a critical alarm the Juno stops operating. The farmer receives a notification on their phone about the critical alarm with extra information about the alarm. The Juno will resume its route after the critical alarm is resolved. In case of a non-critical alarm, the farmer receives a notification and the alarm is added to the alarm list. The Juno will try to resume its route.

### Vector MFR

The Vector MFR currently has eight actions that instigate a sound. These actions are paired with a coloured LED to provide the farmer with both visual and auditory feedback. The action “waiting in front of narrow alley” is activated when the Vector approaches an alley with less than 0.5 metres on one or both sides of the robot. The Vector will wait for a time period and activate an auditory and LED alarm to notify the listeners present in the barn the robot is approaching. There is one alarm sound that is used for both technical errors and emergency safety situations. In case the robot bumps into an object the robot will wait a few seconds before trying to continue its route. After a few attempts of trying to continue its route the robot will generate an alarm message.

### Exos

The Exos is currently in the development phase, meaning that the list of identified actions might be subjected to change at a later stage. In total six actions are identified, four of those actions instigate a sound. The actions “caution zone” and the “driving to and from the charging station” are identified as actions that will require a sound to avoid dangerous situations when the robot starts driving or when the listener is present in an area where they are at risk. The implementation of the “caution zone” action will also be mandatory to meet ISO guidelines.



Figure 4.6: Identified actions of the Sphere.



Figure 4.7: Identified actions of the Juno.



Figure 4.8: Identified actions of the Vector MFR.



Figure 4.9: Identified actions of the Exos.

## 4.4 Identifying the needs of the listeners

This section focuses on identifying the current pain points of the notification sounds from a listener's perspective. Two Lely test farms were visited to gain an understanding of the context space in which the robots operate. To identify the user's needs and wishes, on-site semi-structured interviews were conducted with the farmers and a Lely service technician. In total two farmers (farmer A and farmer B) and one Lely service technician were interviewed. During the interviews the farmers were asked how they experienced the current robot sounds.

Three main themes were identified based on the interviews: confusion, safety, and customisation.

### Confusion

When asked about whether they deemed the current sounds to be useful/ informative the farmers expressed that they found the sounds to be confusing. Both farmers stated that the use of the same buzzer model for multiple different robots, and the unknown events that trigger the buzzer to go off, was the main cause of the confusion. The use of the same buzzer causes the alarms of different robots to overlap. Farmer A when talking about the overlap in sound:

**"I think there is only one type of buzzer in Lely's warehouse at the moment."**

The overlap in sound makes it hard for the farmers to identify where the sound is coming from. Both farmers stated that they often need to check multiple robots in order to find the source of the sound.

Farmer B stated that the current sounds are

**"So unclear that it's of no use."**

When talking about the Astronaut A5, farmer B and the service technician stated they did not know what specific robot action triggered the auditory alarm.

### Safety

The main concern of the farmers and the service technician is the absence of a distinction between critical and non-critical alarms. Currently, the farmers are unaware of the severity of the alarms because the same auditory alarm is used for both critical and non-critical alarms. One alarm sound could either indicate a minor warning that requires a check-up, or a critical alarm that requires immediate attention or else the robot is unable to operate.

The Lely technician also stated that some farmers ask for the buzzer to be removed because they find the sound of the buzzer to be annoying. This prevents the robots from notifying the farmer when a dangerous situation occurs.

### Customisation

The farmers expressed a need for customisation in regard to the loudness of the alarms, when an auditory alarm is produced, and for what specific robot action.

Both farmers stated that the alarm of the Astronaut A5 is too soft. Farmer A explained he made a system out of a paper cup and extra wiring to make the sound audible. Farmer B experienced the same issue with the Juno when the robot drives through the barn. Farmer B expressed he sometimes gets surprised by the robot when he is focused on another task.

The farmers receive a constant stream of alarms consisting of buzzer sounds and/or push notifications on their phone. The push notifications serve as an extra way to notify the farmer when they are out of the auditory or visual range, and provide information about the type of alarm. Currently, the robots produce sounds regardless of the time of day and whether the farmer is present in the barn. The farmers also receive push notifications on their day off. The Lely service technician stated that Lely is most likely unable to make the distinction regarding when a robot should produce a sound as each farmer has their own unique way of managing their farm. A sound that one farmer might perceive as important might not be deemed important by another farmer. The customisation regarding the time of day and the type of action that triggers a sound should be done in consultation with the farmer.

Figure 4.10 shows an overview of the identified problems based on the interviews. In total five main problems were identified.



### Unable to locate the sound



The farmer is busy with a task.



The robots driving through the barn all produce a sound via a buzzer. The Juno produces an alarm sound that requires the farmer's attention.



The farmer hears the alarm sound.



There is no clear distinction between the two robot sounds. As a result, the farmer is unable to identify from which robot the sound is coming from.

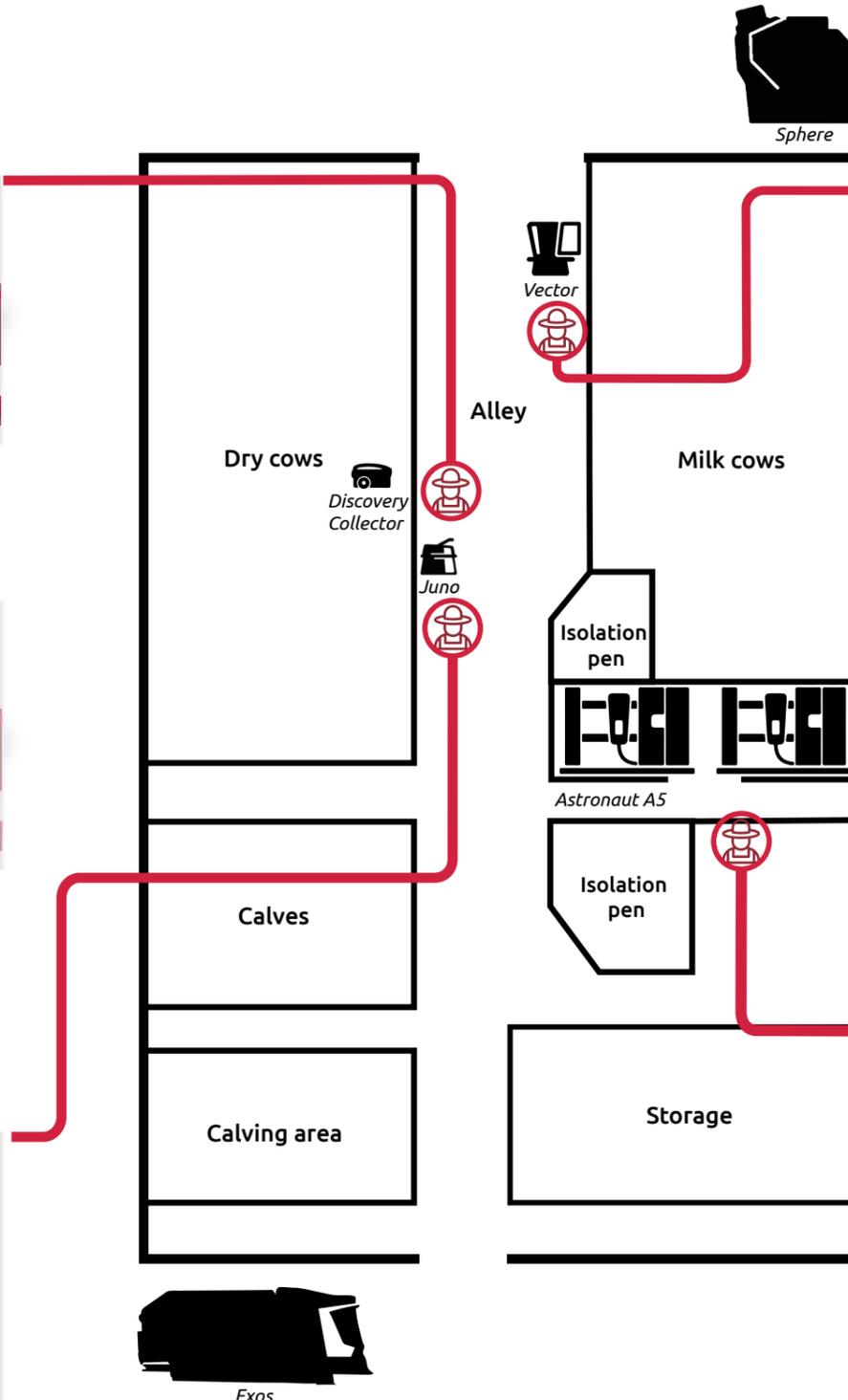
### Unknown meaning



The Juno makes a sound to notify the farmer.



The farmer does not know what the sound means.



### Perceived as annoying



The farmer is irritated by the sounds the robots produce.

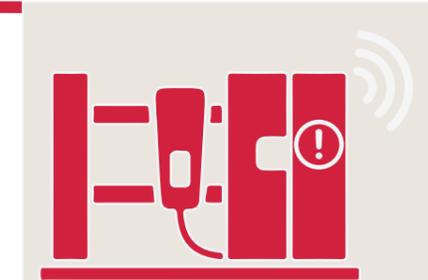


The farmer decides to remove the buzzer from the robots.



The robots no longer produce sound. The farmer will not be warned in case of a dangerous situation or critical technical error.

### Inaudible



The Astronaut produces an alarm sound.



The farmer is busy with another task and cannot hear the alarm.



When walking past the Astronaut the farmer can hear a barely audible sound.

### Disturbing the neighbours



The neighbours are exposed to the sounds when the robots drive outside of the barn.

Figure 4.10: Identified problems from the listener perspective.

This chapter presents the identified core problems and the revised design brief based on the insights gathered during the research phase. Additionally, a preliminary design vision will be presented to serve as a starting point during the design phase.

5.1 Design brief  
5.2 Design vision

## 5.1 Design brief

This section presents the identified core problems and reevaluates the initial design brief (Appendix C) composed at the start of the project. Further, a list of wishes and requirements from the user's perspective will be formulated.

### 5.1.1 The core problems

Based on the research presented in the previous chapters the following core problems are identified:

**1. The robot actions that trigger a notification sound are unclear.**

The user is unable to understand the meaning of every notification sound and cannot intuitively determine the corresponding robot action just by hearing the sound.

**2. The user is unable to locate the sounds.**

The same buzzer model is used across multiple robot models, resulting in overlapping sounds. This makes it challenging for the user to identify which robot is producing a particular sound.

**3. The buzzer sounds are perceived as unpleasant.**

The buzzer sounds are experienced as shrill and unpleasant. This causes the user to remove the buzzer from the robot entirely. The absence of auditory feedback may result in dangerous situations or cause operations to be put on hold due to unresolved technical issues.

**4. The notification sounds disturb the neighbours.**

The users receive noise complaints from their neighbours when the Lely robots are driving outside of the barn.

**5. The buzzer sounds are inaudible.**

Certain notification sounds are masked by the sounds the robots produce during operation, making the notification sounds inaudible.

**6. There are no sound design guidelines for creating notification sounds.**

Apart from the safety guidelines composed by the safety & compliance team, there are no specific guidelines for creating notification sounds. As a result, the feedback of the notification sounds is inconsistent and overwhelming for the user. This inconsistency is evident, as each Lely robot produces a different sound despite performing the same action.

### 5.1.2 Design goal

At the start of the project the following design goal was defined: "Develop a consistent set of sounds for the Lely robots encapsulated in the "Robot code of conduct handbook" with requirements for Lely's product development team to improve the sound-based user feedback for the farmers and technicians."

This overarching goal will remain the same continuing this project. With the additional specification that this project will deliver two deliverables. The first deliverable is a sound design framework consisting of both technical and practical requirements that describe the sound parameters of the sounds and how the sounds should be implemented.

The second deliverable is a concise set of sounds developed for each of the seven Lely robots. The set of sounds and sound design framework will be focused on using a speaker instead of a buzzer.

### 5.1.3 Wishes and requirements

Based on the presented findings a set of wishes and requirements is formulated. The wishes and requirements are focused on the wishes and needs from a user perspective, i.e. it does not include any technical requirements for the development of the sounds. The technical requirements are described in the next section: 5.2 Preliminary design vision.

#### Requirements

The requirements are formulated based on the six defined problem areas from the user's perspective, as well as the needs of other listeners in the shared acoustic environment.

- The notification sounds need to have a clear distinction between critical alarms and informative sounds.
- The user must be able to differentiate the robots based on their notification sounds.
- The exposed listeners should not perceive the informative sounds as unpleasant.
- The user should be able to intuitively understand the purpose of the notification sounds.
- The behaviour and productivity of the dairy cows must not be negatively affected by the notification sounds.
- The notification sounds are not allowed to disturb the neighbours surrounding the barn.
- The users must be able to hear the notification sounds over the ambient noise present in the barn.

#### Wishes

The wishes are formulated based on the preferences the users expressed during the interviews and the research findings on cow well-being.

- The informative sounds should not only be non disturbing for the listeners present in the barn, but also experienced as relaxing by the cows.
- The farm must be as quiet as possible.
- The users are able to customise the notification sounds within a predetermined range.

## 5.2 Preliminary design vision

This section presents a preliminary sound design vision based on the information gathered during the research phase. It outlines the technical requirements the set of sounds need to abide by in order to ensure the sounds are safe and meet the needs of the users. Additionally, some proposals for the sound design will be introduced.

The robot sound vocabulary consists of one base set of sounds. Each sound within the base set is designed using a set of predetermined characteristics that fit the intended action the sound is trying to evoke. To illustrate, critical alarms are serious and dominant to trigger immediate action. In order to make the auditory alarms intuitive in nature, the sound of the alarms and informative sounds are based on well-known day-to-day sounds that are typically associated with a similar action to the action the robot performs.

To enable the user to differentiate the critical alarms, non-critical alarms and informative sounds, the parameters frequency, loudness, and rhythm are altered. To differentiate the different types of robots the parameter timbre is altered.

### 5.2.1 Frequency

Frequency refers to the number of times per second a sound pressure wave repeats itself (National Park Service U.S. Department of the Interior, n.d.). The critical alarms should have frequency components in the 500 to 2500 Hz frequency range based on the ISO guidelines (ISO, 2003). Non critical alarms and informative sounds need to have a frequency between 500 and 3000 Hz. In case a sound needs to travel more than 300 metres, frequencies below 1000 Hz need to be used. For robot sounds that need to pass through barriers frequencies below 500 Hz need to be used (Stensland, n.d.).

The robot sounds and the ambient noise are not allowed to be close in frequency to limit the occurrence of a masking effect, and changes in quality and pitch. Furthermore, the robot sounds need to have at least four dominant frequency components within the first 10 harmonics (National Research Council et al., 1997).

Harmonics are the sound waves that are related to a fundamental frequency (strongest harmonic) as an integer multiple (Gowda, 2024). Figure 5.1, shows an example of different harmonics. If we assume the fundamental frequency is 50 Hz the second harmonic would be 100 Hz, the third 150 Hz, and so forth. The implementation of harmonics ensures the robot sounds are still audible when maskers are present in the barn.

Critical alarms should have frequency components in harmonics 6 through 10. To make the critical alarms more distinctive, inharmonic frequencies (non integer multiple of the fundamental frequency) can be added. Non-critical alarms and informative sounds should have frequency components in harmonics 1 through 5 (National Research Council et al., 1997).

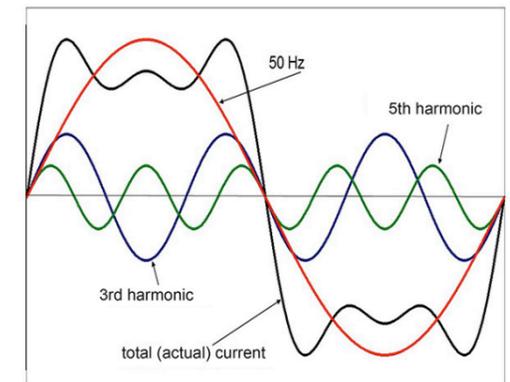


Figure 5.1: Example of harmonics (HyTEPS, n.d.).

### 5.2.2 Loudness and intensity

To indicate the audio level of a sound, the terms loudness and intensity are used. Intensity is the physical quantity of a sound and can be measured in decibel (dB). Loudness is the psychological quantity of a sound that is measured through the perception of the human listener (Hartmann, 2013). Both the intensity and loudness of a sound are taken into account in this design framework as the physical and psychological perception of sound are significantly different depending on the frequency level of the sound. To ensure the perceived sound level is equally loud for all the developed sounds, the Fletcher-Munson curve presented in Chapter 2.1 is used to adjust the amount of decibels where needed.

For the intensity of the sound the ISO guidelines and the perception of sound from a human and cow perspective are taken into account. Sounds become uncomfortable for cows around 70 dB when exposed for a longer period of time, for humans the allowed exposure time drastically drops starting at 85 dB. When surpassing 85 dB the maximum allowed exposure time halves per 3 dB increase (American Speech-Language-Hearing Association, n.d.). To illustrate, for 85 dB the allowed exposure time is 8 hours at a time, with a 3 dB increase the maximum exposure time becomes 4 hours at 88 dB. Figure 5.2 shows the maximum exposure time per intensity level (dB) based on the recommendations of the National Institute for Occupational Safety and Health (NIOSH) (U.S. Centers for Disease Control and Prevention, 2024).

The following guidelines are proposed for the different sound categories. Alarms with higher urgency, i.e. critical safety and technical alarms should have a higher sound pressure level than the informative sounds. The ISO guidelines for danger signals for public and work areas will be followed for the sound pressure level of the critical alarms. The A-weighted sound-pressure level of critical alarms is not allowed to be lower than 65 dB and should be 15 dB above the ambient noise level to avoid the occurrence of auditory masking (ISO, 2003). In case there is a clear difference in frequency and/or temporal distribution between the ambient noise and the alarm a sound-pressure level difference starting at 10 dB will suffice depending on the type of octave-band.

The sound pressure level for non-critical alarms and informative sounds have to be 10 dB above the masked threshold. To avoid disturbing the listeners present in the barn, the sound pressure level of the alarms and sounds should be less than 30 dB above the masked threshold. In case a robot requires a sound level exceeding 115 dB the implementation of a non auditory alarm will be considered (National Research Council et al., 1997).

### 5.2.3 Timbre

Timbre is the perceived sound quality or colour of a sound, note or tone. As it is a perceptual quality this parameter is not measurable. It enables listeners to differentiate different instruments or voices with the same pitch and loudness (Vedantu, n.d.). For example, a listener is able to differentiate the sound of a piano and a flute that are played with the same loudness and pitch. To make a distinction between the different types of robots, each robot is given their own timbre that corresponds with the robot's characteristics.

140+ dBA	0 s
130 dBA	0.9 s
127 dBA	1.8 s
124 dBA	3.6 s
121 dBA	7.2 s
118 dBA	14.4 s
115 dBA	28.8 s
112 dBA	57 s
109 dBA	1.9 min
106 dBA	3.8 min
103 dBA	7.5 min
100 dBA	15 min
97 dBA	30 min
94 dBA	1 hour
91 dBA	2 hours
88 dBA	4 hours
85 dBA	8 hours
82 dBA	16 hours

Figure 5.2: Maximum exposure time per A-weighted decibel level, based on NIOSH recommendations.

### 5.2.4 Rhythm

Rhythm is the combination of timing, duration, and organisation of sounds (M5 Music, n.d.). The critical alarms have a continuous fast pattern to convey urgency. To make the critical alarm intuitive in nature, the patterns of the critical alarms are based on commonly known alarms such as the siren of an ambulance or a police-car. The sound will be played until the desired action is performed by the targeted listener.

The non-critical alarm will have the same pattern as the critical alarm but with more time in between each tone to create a slower pattern.

The informative sounds have a slow pattern to communicate to the listener that no action needs to be performed. The robot will play the sound once to inform the listener about the action it is about to perform, the informative sounds "driving" and "driving backwards" are excluded from this guideline. To avoid overloading the auditory channel, the patterns and the duration of the informative sounds are kept to a minimum. Most of the informative sounds consist of less than two tones that are organised in a steady and even pattern.

### 5.2.5 Lely's brand identity

The notification sounds of the Lely robots will be used to interact with the user. The communication style Lely uses to communicate with the user needs to be reflected in the set of sounds. This section describes the communication style the sounds need to adhere to.

The tone of voice Lely uses towards the user is bright, optimistic, creative and supportive.

To create sounds that are perceived as "bright" harmonically rich sounds need to be created. A rich harmonic spectrum typically causes a sound to be perceived as fuller or brighter, while sounds with fewer harmonics are perceived as hollow or dull (Kiive Audio, 2024).

To create an optimistic, creative and supportive tone of voice the notification sounds will be focused on communicating a pleasant experience for the user with a positive undertone. The only exceptions are the critical alarms. The need for the user to immediately take action overrules the positive tone of voice.

The conceptualisation stage serves as a preparatory phase before moving into the embodiment stage. In this chapter, the groundwork for developing the set of notification sounds will be laid. The first paragraph focuses on defining the sound categories based on their urgency level, after which each robot is assigned its own set of notification sounds based on the robot's functions. The second paragraph addresses the identified core problems by proposing possible solutions.

- 6.1 Defining the sound categories
- 6.2 Solution finding for the core problems

## 6.1 Defining the sound categories

During the research phase a list of robot actions was identified, see Chapter 4.3. In order to ensure the listeners present in the barn will not be over-stimulated as a result of an excessive number of different sounds present in the barn, the identified robot actions need to be evaluated. This section focuses on refining the list of actions and proposes a new system to categorise the sounds.

### 6.1.1 The identified robot actions

The following actions and sounds were identified during the interviews with the Lely product owners:

- Critical alarm
- Pulse alarm: cow needs help
- Continuous alarm: technical error
- Alarm
- Alarm: bumper is off
- Alarm: caution zone
- Non-critical alarm
- Logging into the app
- Calculating a route
- Starting a route
- Driving a route
- Driving backwards
- Driving to and from the charging station
- Warning: approaching narrow alley
- Feed loading (external dispenser warning activated)
- Feed loading is done
- Reset

In order to narrow down the list the overlapping actions need to be sorted out. By grouping similar actions together possible sound categories can be defined, see figure 6.1. To further narrow down the list similar actions are removed or grouped together under one sound. The actions "starting a route" and "driving to and from the charging station" are grouped together under the name "start driving".

Each sound category, except for the informative sounds, will have a single sound to represent all actions within that category. In total, eight sounds will be created: a critical safety alarm, a critical technical alarm, a non-critical alarm, a confirmation sound, and four informative sounds, i.e. start driving, driving, driving backwards, and warning: approaching narrow alley.



Critical safety alarm



Critical technical alarm



Non-critical alarm



Informative sounds

- Start driving
- Driving
- Driving backwards
- Warning: approaching narrow alley



Confirmation sound

- Reset
- Calculating a route
- Logging into the app
- Feed loading is done

Figure 6.1: Sound categories.

In total five sound categories were identified using the priority based system of Özcan et al. (2015), see figure 6.2.

From highest to lowest urgency level the sound groups are “Critical safety alarm”, “Critical technical alarm”, “Non-critical alarm”, “Informative sounds” and “Confirmation sounds”.

The critical safety alarm indicates the beginning or the actual occurrence of an emergency involving the possibility of injury. The alarm instructs the user to immediately leave the danger zone.

The critical technical alarm indicates immediate action needs to be taken to solve a technical error, otherwise the robot is unable to operate.

The non-critical alarm indicates preventative or preparatory action needs to be taken otherwise the robot will be unable to operate in X amount of time. This alarm does not require immediate action.

The informative sounds provide information about the current task the robot is performing. The user does not have to perform any action.

The confirmation sounds provide the user with feedback about the completion of a task. This sound occurs when the user instructs the robot to perform a specific action.



Sound	Meaning	Action
Critical safety alarm	Occurrence of emergency involving possibility of injury	Leave danger zone immediately
Critical technical alarm	Robot is unable to operate without immediate action	Check robot and call service technician
Non-critical alarm	Robot requires attention or will soon be unable to operate	Take preventative or preparatory action
Informative sound	Provides information about the actions the robot performs	No action required
Confirmation sound	Confirms the completion of a task	No action required

Urgency ↑

Figure 6.2: Sound categories and urgency level.

### 6.1.2 Categorising the sound per robot

Every robot requires a different set of sounds to function. This section focuses on determining what sounds are needed for each of the seven robots and identifying the intended listeners.

Figure 6.3 shows an overview of the seven robots and the sound categories. The dark red blocks indicate mandatory sounds, these sounds ensure smooth operations and the user’s safety.

The Lely red blocks indicate optional sounds, these sounds are not essential but provide extra feedback to support the user. The user can decide whether or not to activate these sounds.

All the Lely robots have a critical safety, critical technical, and non-critical alarm. The specific scenarios or actions that instigate an alarm will be dependent on the robot and their functions. These are described in the technical documents of each robot.

The informative sounds that are focused on driving, i.e. start driving, driving, and driving backwards are all mandatory to ensure the user’s safety. The bigger autonomous robots have an extra warning to notify the listeners present in the barn that they are approaching a narrow alleyway.

The confirmation sounds are all optional. These sounds do not have an impact on the user’s safety and are not essential for the robot’s to function.

	Discovery 90SW	Discovery Collector	Jun6	Vector MFR	Astronaut A5	Exos	Sphere
Critical safety alarm	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory
Critical technical alarm	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory
Non-critical alarm	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory
Warning: approaching narrow alley	Optional	Optional	Optional	Optional	Mandatory	Optional	Optional
Start driving	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory
Driving	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory
Driving backwards	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory
Confirmation sound	Optional	Optional	Optional	Optional	Optional	Optional	Optional

Sounds per robot

Mandatory sound
  Optional sound

Figure 6.3: Sounds per robot.

### 6.1.3 The intended listeners

In Chapter 3.2 the shared acoustic environment of the barn was introduced. Figure 6.4 presents a matrix of the intended listeners per notification sound. The farmer is the primary user of the robot sounds. They are the main listener group that will take action upon hearing any sounds that require attention. The Lely service technician will take action when called by the farmer to resolve a technical issue or to perform maintenance. They will typically only interact with the robot they are resolving an issue for. The farmer's family will occasionally help around the farm and will respond to critical alarms. All the notification sounds intended to ensure the user's safety are targeted at all the listener groups within range of the robot.

Another listener group is the inactive listener, this group includes the dairy cows, the farmer's family, and the neighbours of the farmer. The dairy cows are exposed to all the sounds the robots produce on a 24/7 basis. They will not perform any action upon hearing these sounds. However, there is one exception where the dairy cows will switch roles from an inactive listener to an active listener. The driving sounds of the Discovery 90SW and Discovery Collector are intended for the cows when the robots are driving inside the cowpen. The cows will move aside for the robot upon hearing these sounds.

The neighbours of the farmers will be exposed to the notification sounds when the robots are operating outside the barn. This is the case for the Vector MFR, Exos and Sphere. The neighbours will not perform any sound induced actions.

## 6.2 Solution finding for the core problems

This section presents solutions to the identified core problems from both a sound design and operational perspective. By strategically utilising sonification techniques, possible solutions can be found to improve the recognition, localisation, audibility and perceived pleasantness of the notification sounds. However, not every problem can be addressed through sound design. By exploring practical solutions on an operational level the issues surrounding audibility and neighbour disturbance can be resolved.

### 6.2.1 Sound recognition

One of the identified problems is the recognition of the robot actions based on their sound. It is not always clear for the user what specific actions instigate a sound. This section proposes solutions to improve the sound recognition using the sonification methods introduced in Chapter 2.2.

The defined sound categories are based on their level of urgency. The research presented in Chapter 2.2 concluded that rhythm is an effective sound parameter to convey urgency. Hence, why rhythm is chosen to differentiate the five defined sound categories. The research also found it is best to use a combination of different sound parameters to convey information. To further differentiate the sound categories by urgency, the level of complexity of the sounds will be adapted.

The critical safety and technical alarm will receive a fast rhythm with at least two different tones and a short attack time. The non-critical alarm will have the same pattern as the critical technical alarm but with more time in between each tone to create a slower rhythm. This indicates there is an alarm present that requires action to be taken, but not immediately.

Informative and confirmation sounds will be kept as simple as possible with a slow rhythm and a maximum of two different tones. The simplicity of the sounds is not only used to indicate the urgency level, but also ensures the sounds will not be an overbearing presence in the barn.

Based on the sound categories the listeners present in the barn are able to recognise when an alarm occurs and when a regular notification sound occurs. However, the information the informative sounds and confirmation sounds are trying to communicate is still unclear to the listener. To further improve the recognition of the sounds the sonification methods auditory icons and earcons will be used.

The informative sounds will primarily be developed using auditory icons, i.e. well-known day-to-day sounds that are usually linked to actions similar to those performed by the robot.

For the actions that do not have a corresponding real-world action, earcons will be used.

An earcon will be used for the confirmation sound, the earcon will reflect the happy feeling of completing a task. To create this positive feeling, the confirmation sound has to be perceived as pleasant. This can be achieved by creating a bright sound that goes up in scale, as this is generally associated with a positive action (Gould, 2016).

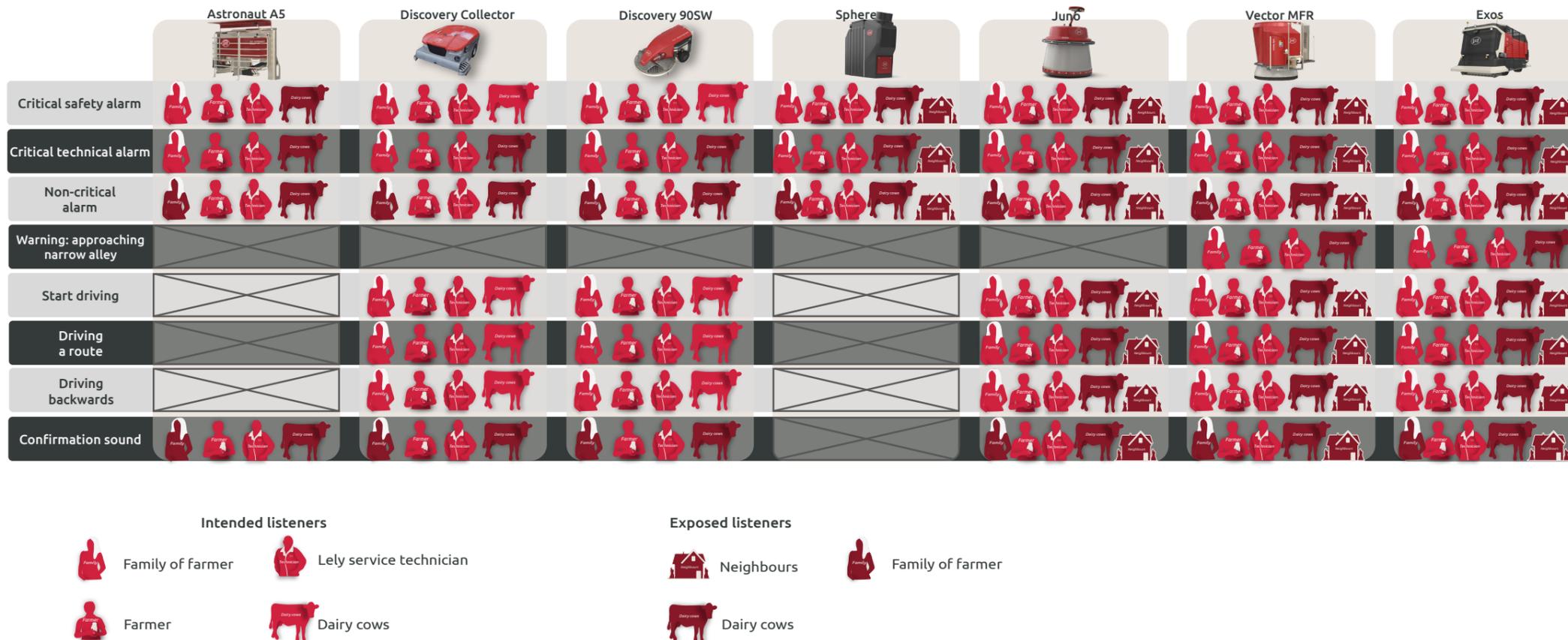


Figure 6.4: Intended listeners.

### 6.2.2 Sound localisation

Another identified problem was the localisation of the sounds. The users have a hard time identifying which robot produces a certain sound. In order to allow the listener to localise the sound, each robot needs to have its own “voice”. The sound parameter timbre will be adapted based on the characteristics of the robots. In order to make the robot voice intuitive in nature, the robot characteristics that will be mapped to the timbre need to be determined. The most promising options are mapping the timbre to the size of the robots, to static versus autonomous robots, to assigned character traits of the robots, or mapping the timbre to the function of the robots. All the options come with their own pros and cons.

#### Mapping to robot size

By mapping the timbre to the robot’s size, listeners in the barn who are unfamiliar with the Lely robots can identify them based on their sound. However, a drawback of this approach is that the sizes of the Lely robots must clearly differ in order to effectively communicate it to the user. The communication could be supported by mapping robot size to both timbre and pitch. Pitch in combination with another sound parameter has been proven to be successful in communicating a robot’s size (Chapter 2.2). This mapping approach is based on people’s natural tendency to associate larger objects with low-pitched sounds and smaller objects with high-pitched sounds.

#### Mapping to static versus autonomous

By mapping the timbre to static versus autonomous robots the user can roughly localise the position of the robot. This mapping option differentiates the two static robots from the five autonomous robots. Autonomous robots can be given an acoustic reverb to create an “airy” sound to indicate a driving robot. For static robots the acoustic reverb needs to be turned off. This approach needs to be combined with another robot characteristic to further differentiate the robots.

#### Mapping to assigned character traits

By mapping the timbre to assigned character traits each robot can have their own personality based on their functions and appearance. This offers the opportunity to create a more personal interaction between the user and the robots. This mapping approach requires a set of traits to be assigned to each robot. Choosing a set of traits is a subjective process that is dependent on a person’s individual association. An example, the Discovery Collector might be considered cute and helpful by one individual, and adventurous and strong by another. By choosing this mapping approach the recognition of the robots will be less intuitive and will most likely be dependent on the user learning the robot voice instead.

#### Mapping to functions of the robots

By mapping the timbre to the functions of each robot distinct sounds can be created that are easy to understand for listeners that are familiar with the robots. The Lely robots can be divided in three categories: feeding, cleaning, and milking. The actions the robots perform within the same category are closely related. When choosing this mapping approach the timbre will be an abstract version of the sound that is typically associated with the robot function.

The mapping of timbre to the robot’s functions and size will be further explored during the embodiment phase. These two mapping options offer the opportunity for the user to intuitively identify the robots based on their sound, and are more reliable than mapping the timbre to autonomous versus static robots or to the assigned character traits. The autonomous versus static mapping option lacks precision, and the character traits mapping option is not based on objective data, making it more difficult to intuitively recognise the robots.

### 6.2.3 Perceived pleasantness

The third identified core problem is the perceived pleasantness of the buzzer sounds. The users experience the sound of the Lely robots to be unpleasant and describe the sounds as shrill. Notably, the Lely robots with the 3500 Hz buzzer were specifically mentioned. This perceived unpleasantness is most likely due to the buzzer’s frequency. Research indicates that sounds perceived as unpleasant typically range between 2000 and 5000 Hz, the frequency range humans are most sensitive to (University College London (UCL), 2012). In the preliminary design vision (Chapter 5.2) frequency components within the 500 to 2500 Hz range for critical alarms were proposed based on the ISO guidelines, and frequency components within the 500 to 3000 Hz frequency range for informative sounds. For the informative sounds the proposed frequency range will be adapted to a frequency range of 500 to 2500 Hz to support the creation of pleasant sounds. The proposed frequency range for critical alarms will remain the same.

To further improve the perceived pleasantness of the set of sounds as a whole, the need for a quiet environment needs to be addressed. The negative perception of the sounds is not only caused by shrill buzzer sounds but also by the amount of buzzer sounds. To avoid creating an overwhelming sound environment the user needs to be able to choose when a sound occurs. In section 6.1.2, the identified sound categories were assigned to each robot, here a distinction is made between the mandatory notification sounds and the optional sounds.

Another opportunity to reduce the amount of noise present in the barn is designing sounds targeted towards cows. The Discovery Collector and Discovery 90SW drive in the cowpens to clean the barn floor. The driving sounds the robots produce are focused on notifying the dairy cows of their presence. However, while these sounds are designed for the cows, they are also audible to human listeners in the barn. By taking advantage of the broad hearing range of dairy cows, which covers the ultrasonic range of 17 to 37 kHz of an adult human, the frequency of the driving sounds could be adapted to only be audible for dairy cows.



### 6.2.4 Neighbour disturbance

The fourth identified core problem is the disturbance of neighbours. To combat this issue, solutions for minimising both the amount and loudness of the alarms will be proposed.

One potential solution is to implement a time-dependent loudness range. Although the robots operate on a 24/7 basis, the intended listener is not always present in the barn to hear the sounds. Additionally, ambient noise levels around the farm vary throughout the day. To minimise disturbances (specifically towards the neighbours), the loudness of the notification sounds could be reduced at night.

Another option is to make the activation of the notification sounds dependent on the user's presence. Through the Lely control app (a robot management application), the user could indicate if they are present on the farm. Based on this input, the informative and confirmation sounds could be activated or deactivated. To prevent dangerous situations or logistical issues caused by user error, the critical safety alarm must remain active at all times. When the critical technical alarm is deactivated, it should trigger a phone call and a push notification to the user's phone instead.

A third option is to adjust the loudness based on the robot's location. This approach relies on the predetermined route the farmer has to define for each autonomous Lely robot. Within this route, the user could set specific sound levels based on the robot's location. For instance, the loudness could be reduced when the robot is driving outside the barn.

### 6.2.5 Audibility

The fifth identified core problem is the audibility of the notification sounds.

To combat this issue the user should be able to adjust the loudness within a predetermined range. By providing a range, both individual variations in loudness perception and the differences in ambient noise levels across different farms would be accounted for. The design choice of offering a loudness range is also supported by the earcon guidelines presented in Chapter 2.2.

The non-critical alarms, and the informative and confirmation sounds should be 10 dB above the masked threshold. Based on the measured ambient noise levels (Chapter 3.3) the sounds should have a loudness range between 65 dB and 70 dB. The critical alarms have to be 10 to 15 dB above the masked threshold. These notification sounds should have a loudness range between 65 and 75 dB.

The central barn measurements showed an ambient noise range of 57 dB(A) to 69 dB(A). The upper limit was caused by sporadic cow vocalisations and the clinging of the metal feeding fences. Figure 6.5 shows a graph of the masked threshold caused by broadband noise. The blue line shows the threshold when no noise is present. The pink dotted line shows the masked thresholds caused by different decibel levels of broadband noise. The dark red line shows the upper limit of the ambient noise levels within the determined frequency range of the notification sounds (500 - 2500 Hz). The red box shows where the notification sounds are located with the determined frequency and decibel range (65-70 dB and 65-75 dB). The maximum measured noise level in the barn was 69 dB(A), the graph shows the determined frequency range for the critical alarms and non-critical sounds are 15 and 10 dB above the limit.

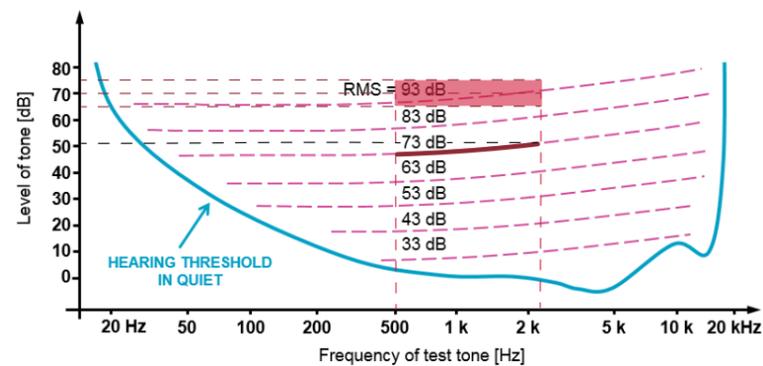


Figure 6.5: Tones masked by broadband noise (Siemens Digital Industries Software, 2019).

Although the notification sounds will not be masked by the ambient noise inside the barn. The notification sounds are at risk to be masked by the sounds the robots produce during operation. To determine if the notification sounds will be masked, the presented graph and formula from Chapter 2.1 will be used. Figure 6.6 shows a graph of the masking curves. The y-axis shows the decibel level of the notification sound, i.e. 65 dB-70dB or 65-75 dB. The x-axis represents the difference in frequency between the notification sound and the masker (the sounds the robot produces during operation). The red curves represent the decibel level of the masker (LM). Figure 6.7 shows the masking curves for the Astronaut 5. The black dotted line shows the cut off decibel level. The non-critical alarm and informative sounds have to be 10dB above the masked threshold, meaning that 55 dB is the cut-off. If the masking curve exceeds this line, the frequency of the notification sound needs to be adapted. The notification sounds of the robots that produce a decibel amount of 70 dB or less will not be masked. The Astronaut A5 is the only robot that produces decibel levels exceeding 70dB. Based on the graph we can conclude that a decibel range of 65-70 dB/65-75 dB will not be sufficient if the masker and notification sound are close in frequency. To avoid a masking effect, the masker and notification sounds should have a critical band value difference outside of the 0.25 to -2 bark range.

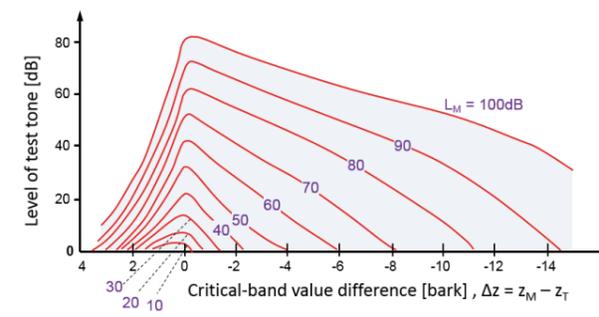


Figure 6.6: Masking curves (Siemens Digital Industries Software, 2019).

To further ensure the notification sounds of the Astronaut are not masked, relocating the speaker should be considered. The Astronaut produces a loudness range of 74 to 86 dB(A) at a distance of 50 cm. Attempting to exceed this loudness range to make the notification sounds audible could be harmful to both humans and cows in the barn. Therefore, relocating the speaker is a more effective solution.

Currently, the buzzer is located inside the Astronaut, this location is in close proximity to the robot's main noise source, and causes the buzzer sounds to be partially absorbed by the door of the Astronaut. Since the Astronaut is a stationary robot located in a separate room, placing the speaker outside the robot would help improve sound audibility. The noise measurements indicate a loudness range of 68 to 81 dB(A) at a distance of 150 cm from the robot. Placing the speaker at a 150 cm distance would reduce the required loudness by approximately 5 dB. Placing the buzzer further away typically is not possible because of the compact size of the milking room. Additionally, the speaker should remain in close proximity to the robot to avoid confusion about which robot the sound belongs to.

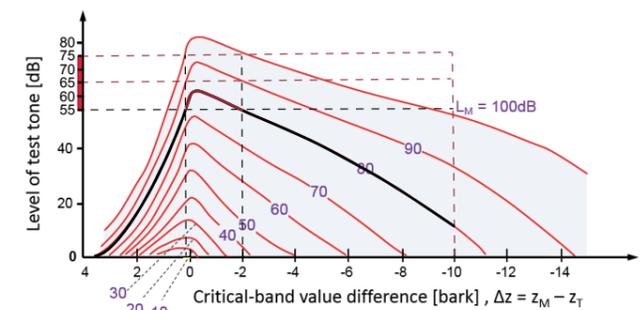


Figure 6.7: Masking curves of Astronaut A5 (Siemens Digital Industries Software, 2019).

This chapter covers the embodiment phase, which focuses on the development of the set of sounds. The first paragraph explores different sound parameter mapping options to create a unique voice for each robot. The second paragraph introduces the first developed set of notification sounds. In paragraph 3, the design choices are evaluated during an interim evaluation with the farmers. Paragraph 4 covers the evaluation of the developed set of sounds through user tests. Paragraph 5 presents the results from the farmer questionnaire to gain insights into the users' preferences. Finally, paragraph 6 outlines the iterations made based on the insights gathered from the user test and farmer questionnaire.

- 7.1 Robot differentiation
- 7.2 Sound categories
- 7.3 Interim evaluation moment
- 7.4 User test
- 7.5 User preferences
- 7.6 Iterations

# 07

## 7.1 Robot differentiation

During the conceptualisation phase it was decided to give each robot its own voice by using the sound parameter timbre. In this section the different mapping options will be explored to create seven different robot voices.

### 7.1.1 Mapping timbre to the functions of the robot

The first mapping option involves mapping the timbre to the functions of the robot. Figure 7.1 shows an overview of each robot and their main functions with possible sound options. One of the main challenges with this approach is finding a balance between creating an abstract sound that is pleasant to listen to and creating a universally understood connection between the sound and the function of the robot. Upon testing this approach, it became clear that the chosen timbres to convey the functions of the robots resulted in unpleasant sounds.



- **Category:** milking
- **Function:** milking the cows
- **Sound:** flowing water, pouring water



- **Category:** cleaning
- **Function:** vacuuming poop off the barn floor
- **Sound:** vacuum, suction sound



- **Category:** cleaning
- **Function:** scraping poop off the barn floor
- **Sound:** bubbles popping, brush



- **Category:** cleaning
- **Function:** separates manure and urine, and converts nitrogen emissions into fertilisers
- **Sound:** wind through trees, soft breeze



- **Category:** feeding
- **Function:** pushes food back to metal feeding fences
- **Sound:** dragging something over the floor, placing crockery on the table



- **Category:** feeding
- **Function:** brings fresh food to metal feeding fences
- **Sound:** shaking a bag of cat food, food sizzling in a pan



- **Category:** feeding
- **Function:** cuts fresh grass and feeds it to the cows
- **Sound:** scissors cutting, wind through a grass field

Figure 7.1: Lely robots with functions and sound options.

### 7.1.2 Mapping the timbre and pitch to the robot's size

The second mapping option is mapping the timbre and the pitch to the robot's size.

The pitch determines the fundamental frequency of a sound wave, in this approach a higher pitch will be mapped to a smaller robot and a lower pitch to a larger robot. Each size category is assigned its own pitch range within the 500 to 2500 Hz frequency range.

Chapter 5.2 covered the importance of harmonics. Harmonics play an important role in the perceived timbre of a sound. The timbre of the robots is chosen based on their harmonic content. For smaller robots a timbre with prominent harmonics in the higher frequencies is chosen. For larger robots a timbre with prominent harmonics in the lower frequencies is chosen.

This approach looks promising but is dependent on a single characteristic of the robot, a characteristic that is very subtle due to the similar size of the robots. To make the distinction more clear, a combination of the robot size and functions could be used. From the first mapping attempt it was found that mapping the specific functions of the robots resulted in unpleasant sounds. This time around, the function categories are mapped to the timbre instead of the specific functions. The seven robots can be divided in three main categories: feeding, cleaning and milking. Within these categories the voices of the robots will be more closely related.

Based on this approach, seven robot voices were created, see figure 7.2. Each voice has been given reverb to create a smooth flow. To produce bright sounds and reduce the occurrence of a masking effect, robot voices that are not naturally rich in harmonics were assigned a square or sawtooth waveform. These two waveforms are rich in harmonics: the square wave contains odd harmonics (frequencies that are odd multiples of the fundamental frequency), while the sawtooth wave contains both odd and even harmonics (Robehmed, 2019).



The timbre of the Astronaut needs to be distinct to communicate the robot belongs to its own function category, i.e. milking. The sound also has to significantly differ from the sounds the robot produces during operation to avoid masking. Based on these requirements a kick bass was chosen for the Astronaut. The timbre has harmonics in the lower and higher frequency range. To make the sound more distinct a synth was added.



The timbre of a kalimba was chosen for the Discovery Collector. This instrument has harmonics that are higher in frequency.



The Discovery 90SW and Collector are similar in size and functions. Farmers usually own either the 90SW or Collector depending on their barn floor. To support these similarities, the 90SW is also given a kalimba timbre with slight adaptations to differentiate the two sounds.



The Sphere has the timbre of a sub bass to reflect its bigger size. The robot's voice has a deep and low-register pitch.



A 70's synth keyboard was chosen for the Juno. The timbre is more breathy and has harmonics both in the lower and higher frequency range. The harmonics are primarily present in the higher frequency range.



The Juno and the Vector share a similar timbre because of their shared function category (feeding). The timbre of the Vector is a synth keyboard with an equal amount of harmonics in the lower and higher frequency range.



The Exos has the timbre of a bass string instrument. The harmonics of the timbre are focused on the lower frequency range.

Figure 7.2: The robot voices.

## 7.2 Sound categories

Each sound category is meant to evoke a different sound induced action. In order to get the desired action the sounds are linked to a characteristic or emotion.

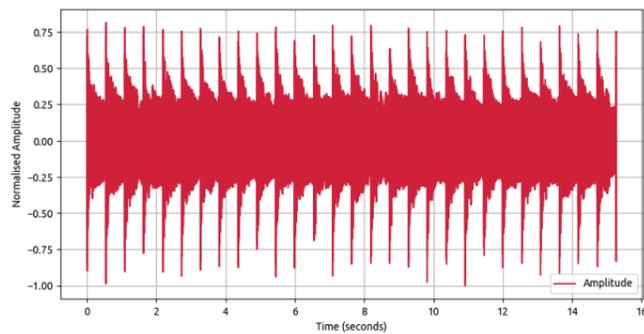


Critical safety alarm

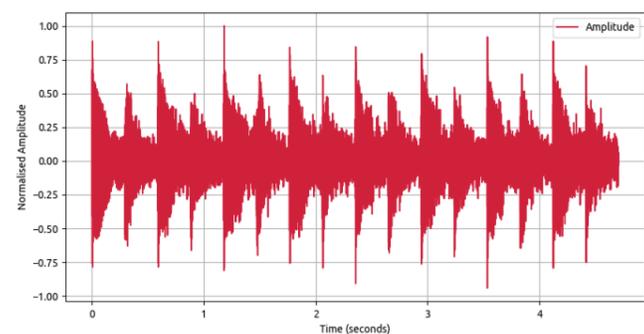
The critical safety alarm is intended to be interpreted as uncomfortable, dominant, serious, and distinct to trigger immediate action.

Two alarm options with different levels of unpleasantness are created.

The first alarm option consists of a single tone repeating itself with a short interval between each tone. Layered over the tone is an auditory icon of an ambulance siren. This sound is used to indicate urgency and to trigger the action of leaving the danger zone. By layering the auditory icon over a basic pattern a more complex sound is created. This complexity makes the sound more dominant and distinct.

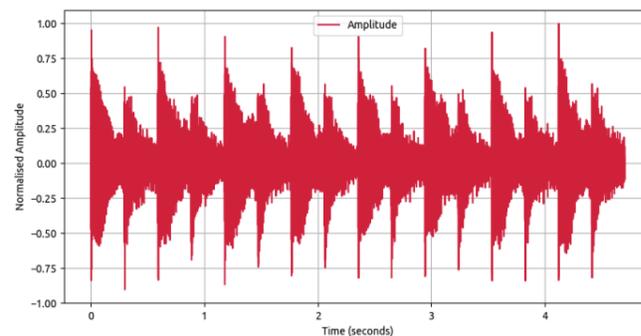


The second alarm option consists of four tones that alternate each other in a fast pattern with no rest in between. The tones are dissonant to create an uncomfortable and serious feeling.



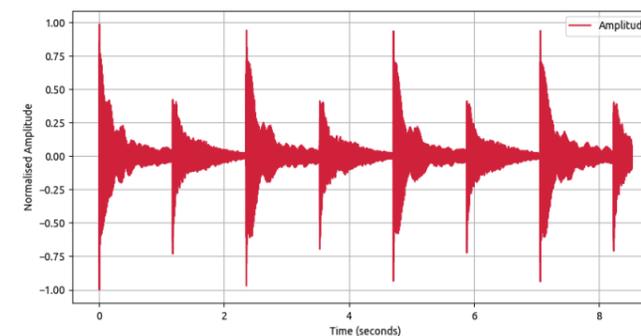
Critical technical alarm

Similar to the critical safety alarm, the critical technical alarm is designed to be dominant, serious, and distinct to trigger immediate action. The rhythm of the critical technical alarm is similar to the critical safety alarm but less complex. The alarm consists of two alternating tones with no rest in between to convey a sense of urgency. This similarity was chosen to ensure the listener intuitively understands both alarms are critical and require immediate action.



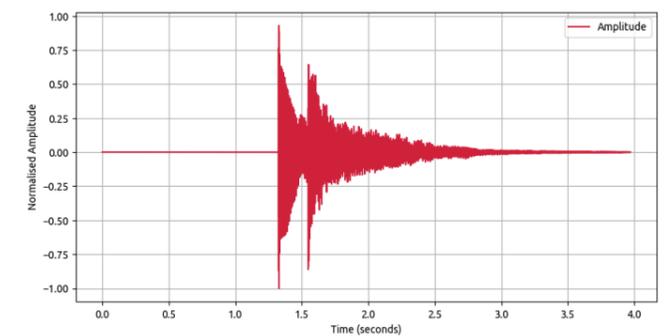
Non-critical alarm

The non-critical alarm is designed to be perceived as attentive and serious. It uses the same two alternating tones as the critical technical alarm to inform the user of a technical issue that requires attention. The alarm has a brief rest between each tone to differentiate the non-critical alarm from the critical technical alarm, and to convey to the user that the issue is less urgent.



Confirmation sound

The confirmation sound is quick, positive and friendly. The sound consists of two short tones that go up in scale to indicate a task is successfully completed.





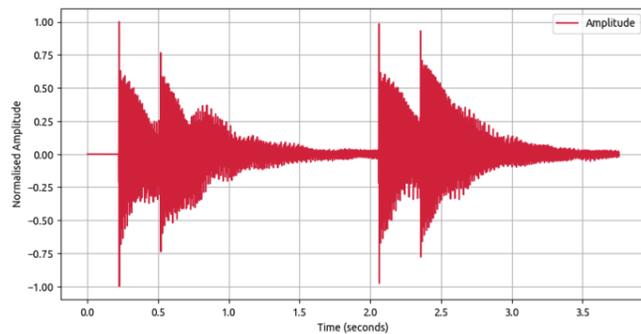
### Informative sounds

The informative and confirmation sounds are based on auditory icons or earcons to make them more intuitive in nature. The sounds are intended to reflect Lely's bright, optimistic, creative, and supportive communication style.



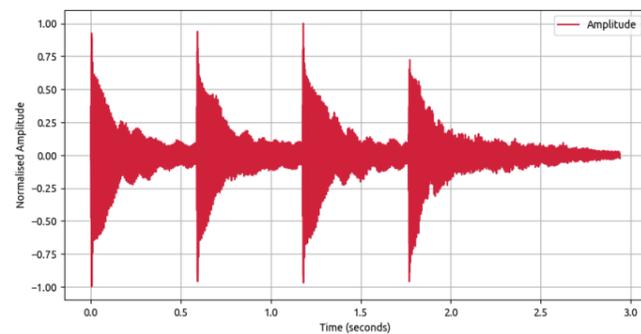
Warning: approaching narrow alley

The "Warning: approaching narrow alley" sound is inspired by knocking on a door, with a slightly urgent and serious undertone. The sound consists of two sets of two "knocks", each made up of a single tone repeated twice. The first tone is slightly shorter in duration, directly followed by a longer second tone. After the first set, the knocks are repeated once more, with a short rest between the two sets.



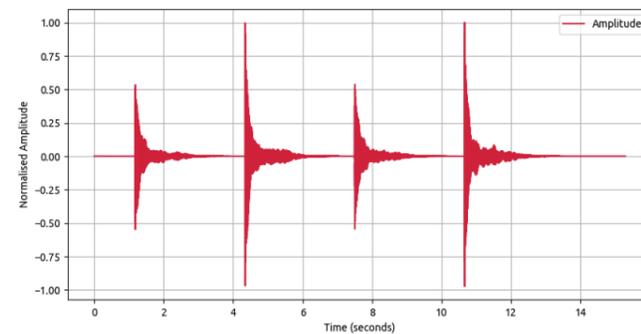
Start driving

The "Start driving" sound is based on the signature "3, 2, 1, GO!" sound of a car race with an active and friendly undertone. The sound has three short tones that represent the "3, 2, 1" and one higher tone to represent the "GO!". The final tone goes up in scale to make the sound more friendly and active. Between each tone there is a short rest to make the sound less urgent.



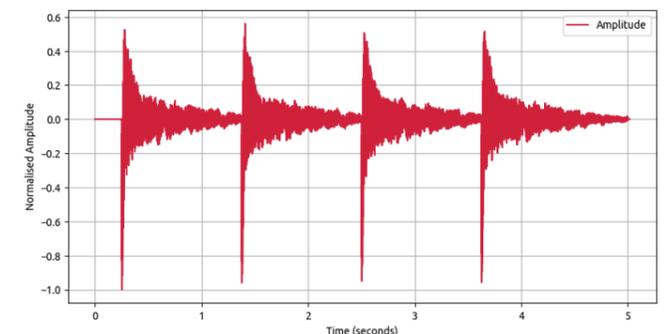
Driving

The "Driving" sound is intended to be gentle and respectful. The sound will play continuously while the robot is driving around the farm. To prevent overstimulating the listeners in the barn, the sound is kept simple, consisting of a single repeating tone with a long rest between each tone.



Driving backwards

The "Driving backwards" sound is intended to be determined and responsible. The sound is based on the beeping sound of a reversing truck, i.e. a single tone that repeats itself with a short rest between each tone. It will continuously play while the robot is driving backwards.



## 7.3 Interim evaluation moment

To determine the intensity of the critical alarms, an interim evaluation moment was held with two Lely test farmers at their farms. During this evaluation moment, the vision behind the sounds was explained, and the complete set of sounds was played to the farmers. The set included the two variants of the critical safety alarm, as described in Chapter 7.2. The first variant of the critical safety alarm consisted of a siren layered over a basic pattern. The second variant was more toned down and consisted of four different tones alternating each other. The farmers were then asked to identify each of the notification sounds using a list of the sound categories.

Both of the farmers recognised the two variants of the critical safety alarm as a critical safety alarm. When asked about their opinions on the sounds, the first farmer stated that he did not want a siren alarm in his barn, describing it as too intense. When asked how often a critical alarm occurs the farmer stated three alarms went off prior to the start of the interview (the interview was held around 10 am).

The second farmer stated he preferred a more intense siren alarm to ensure everyone in the barn is aware of potential danger. He explained:

**“We’re working with several people who are not familiar with the Lely robots, so such a clearly poignant sound works best.”**

The critical safety alarm should ensure the safety of the listener’s present in the barn. This includes avoiding dangerous situations that involve the possibility of injury, and ensuring the notification sound itself does not negatively affect the well-being of the humans and cows present in the barn. Given the frequency of alarms throughout the day, a less intense alarm option is preferred. To ensure the urgency of the alarm is not compromised, the toned down version of the critical safety alarm will be further assessed through user testing.

## 7.4 User test

This section covers the conducted user tests to evaluate the set of sounds.

The goal of the user test was to evaluate the developed set of sounds based on recognition, perceived urgency, and perceived pleasantness. The user test was conducted at the Lely head office with UX designers. This group was chosen based on their knowledge of the Lely robots.

The user test was divided into three stages: Stage 1 involved an introduction and a screening question; Stage 2 focused on testing the recognition of robot models and assessing their perceived pleasantness; Stage 3 tested the recognition of robot actions, as well as their perceived pleasantness and urgency.

### 7.4.1 Method

To test the recognition of the sounds, i.e. recognising the robot model and recognising the robot actions, a forced choice was used. To test the perceived urgency and perceived pleasantness a five-point Likert scale (1-5) was used.

### Participants

In total 5 participants (5 UX designers from Lely) voluntarily participated. All the participants had good hearing and no prior knowledge of the set of sounds.

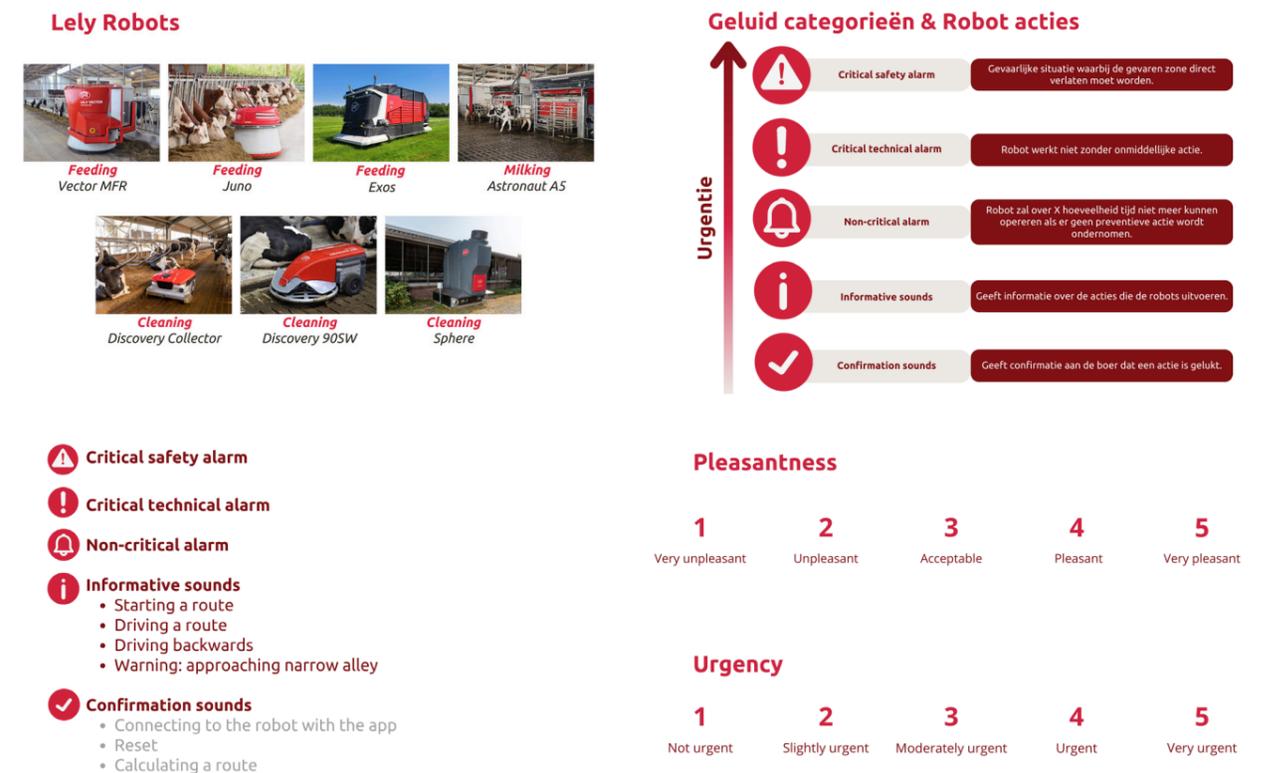


Figure 7.3: User test stimuli.

### Procedure

The user tests took place in a one-on-one private setting. Each session took 45-60 minutes in total. Prior to the start of the user tests the participants received a short introduction, this included information about the project and an explanation of the entire procedure, see Appendix D3 for the interview script. After the introduction the participants were asked to sign an informed consent form (Appendix D1). The researcher informed the participants that there are no right or wrong answers.

To assess how well the participants know the Lely robots and their functions, the researcher asked a screening question to determine their knowledge level.

Afterwards, the researcher moved on to the second stage of the user test.

During the second stage the participants received an overview of the seven Lely robots and information about the logic behind the different sounds. To ensure the participants have a reference point the researcher played all the sounds prior to asking any questions. The researcher then played each sound individually, per sound the researcher asked the following questions:

- Which of the seven robots do you think this sound belongs to, and why?
- On a scale of 1 to 5, how do you rate this sound in terms of pleasantness? (1 = Not pleasant, 5 = Very pleasant)

During the second phase the participants received an overview of all the sound categories and robot actions. The researcher explained the logic behind the sounds and played all the sounds back to back prior to asking any questions. The researcher then played each sound individually, per sound the researcher asked the following questions:

- What action do you think this sound belongs to? Choose one action from the list of actions.
- On a scale of 1 to 5, how do you rate this sound in terms of pleasantness? (1 = Not pleasant, 5 = Very pleasant)
- On a scale from 1 to 5, how urgent or pressing does this sound feel? (1 = Not urgent, 5 = Very urgent)

### Pilot

To evaluate the user test, a pilot was conducted with an UX intern to identify any potential issues regarding the questions or the structure of the test. Based on the pilot, the visuals were adapted for better clarity, and the sound clips were adjusted to prevent audio cut-offs caused by the speaker's playtime delay.

### Data processing & analysis

During the interview qualitative and quantitative data was gathered in the form of typed notes and audio recordings (Appendix D4). The audio recordings were compared to the notes to verify the accuracy of the notes and to identify key themes that might have been missed during the session. The qualitative collected data was analysed by highlighting relevant information and quotes of each user test. The gathered information was then compared to identify themes. The quantitative data was analysed and graphed to create a clear overview.

## 7.4.2 Results

### Robot differentiation

Figure 7.4 shows the amount of times each robot was selected based on its "voice." The results indicate that the robots' voices were not intuitively recognised.

Qualitative data reveals that participants attempted to find patterns in the robot voices but sometimes struggled to choose between one or more robots. Two out of five participants associated the robot voices with the robot's size:

**"Somewhat larger and heavier because of the lower tone."**

**"Pitch again, higher pitch, little robot."**

One out of five participants linked the robot voices to their functions (feeding, milking, and cleaning) and tried to group similar sounds together. This participant also attempted to find a connection between the new robot voices and existing buzzer sounds.

Two out of five participants connected the robot voices to the importance of the robot's functions. One participant, in particular, associated lower tones with robots that posed a lower safety risk:

**"I associate lower tones with robots that have no contact with the cow and have a lower risk of safety issues."**

In addition to looking for patterns across the voices, participants also chose certain robots based on their personal associations. One participant explained their choice of the Juno:

**"The sound reminds me of Wall-E. The Juno looks like Wall-E. It gives me a futuristic feeling."**

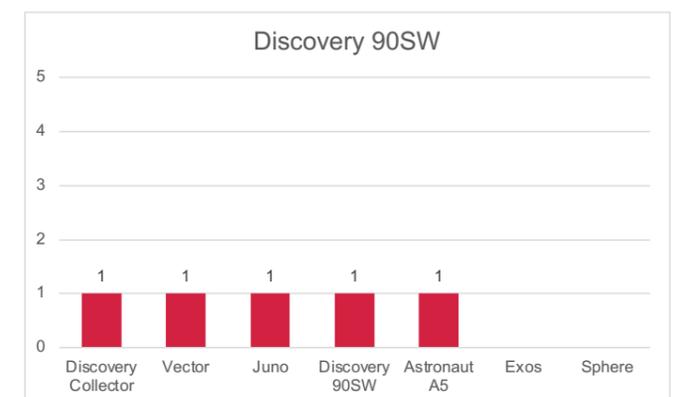
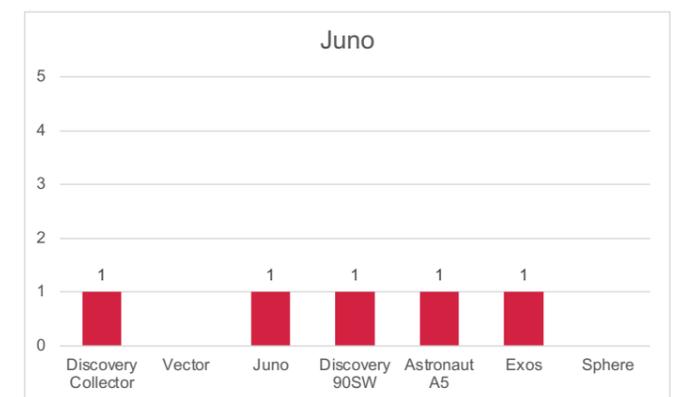
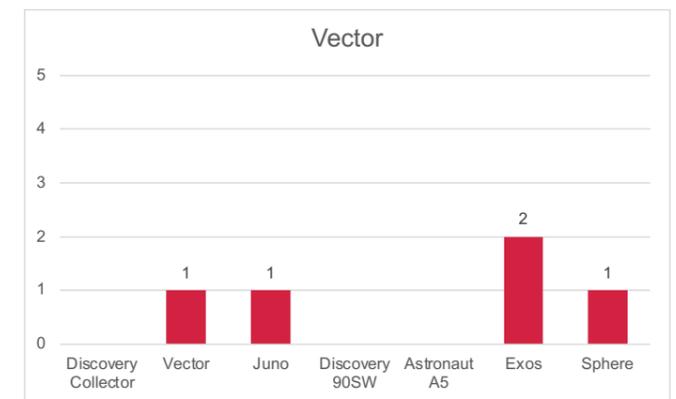
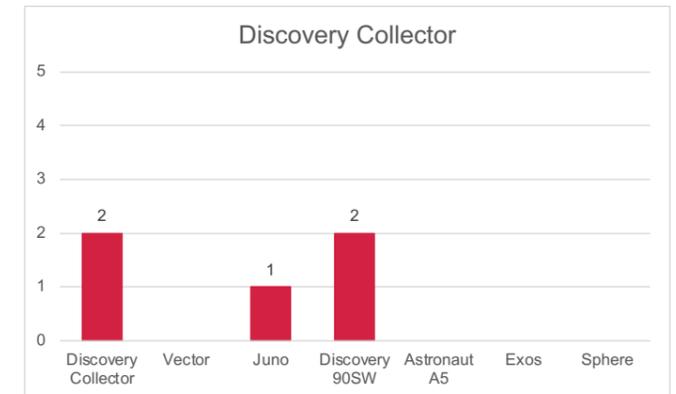


Figure 7.4: Chosen robots per robot voice.

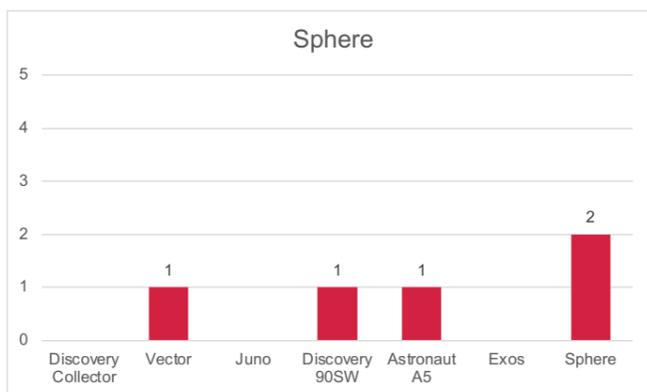
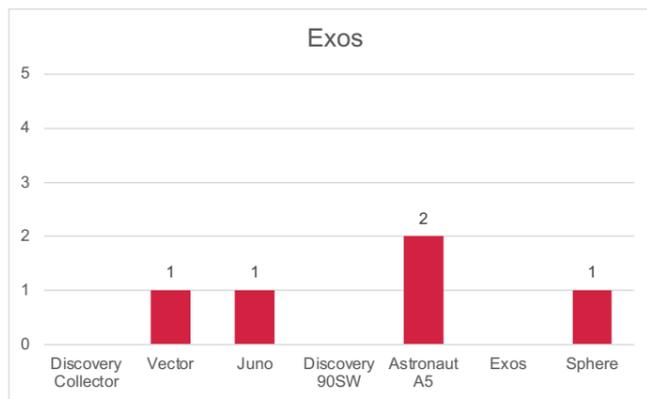
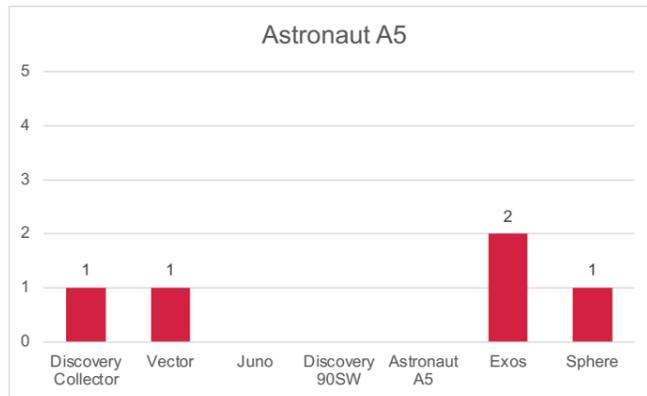


Figure 7.4: Chosen robots per robot voice.

#### Perceived pleasantness of the robot voices

Figure 7.5 shows the perceived pleasantness of each robot's voice. The voices of the Exos and Astronaut A5, which received the highest ratings, were described as subtle and easy to listen to. One participant commented about the Exos:

**"I would listen to this in my earphones."**

Participants also expressed a preference for the low pitch of the Exos voice, with one remarking:

**"It has something satisfying. It doesn't have sharp notes and is also a bit lower in pitch."**

On the other hand, the robots that relatively scored lower on the pleasantness scale, such as the Discovery Collector and Sphere, received mixed reactions. Those who rated the Collector as less pleasant described its voice as "too sharp" compared to the other sounds, with one participant saying:

**"A bit too sharp. Other sounds were more flowy/dreamy."**

However, participants who rated the Collector higher found the sound "chill" and non-disturbing despite the higher pitch:

**"I am not annoyed by the tone, even though it's high-pitched. The change between the two tones is very gradual."**

Participants who gave the Sphere a lower pleasantness rating felt it was less pleasant than the other sounds. On the contrary, those who rated it highly noted that the sound blended nicely into the background and was perceived as "chill," with one participant stating:

**"Just a chill sound with no weird high frequencies. Just good."**

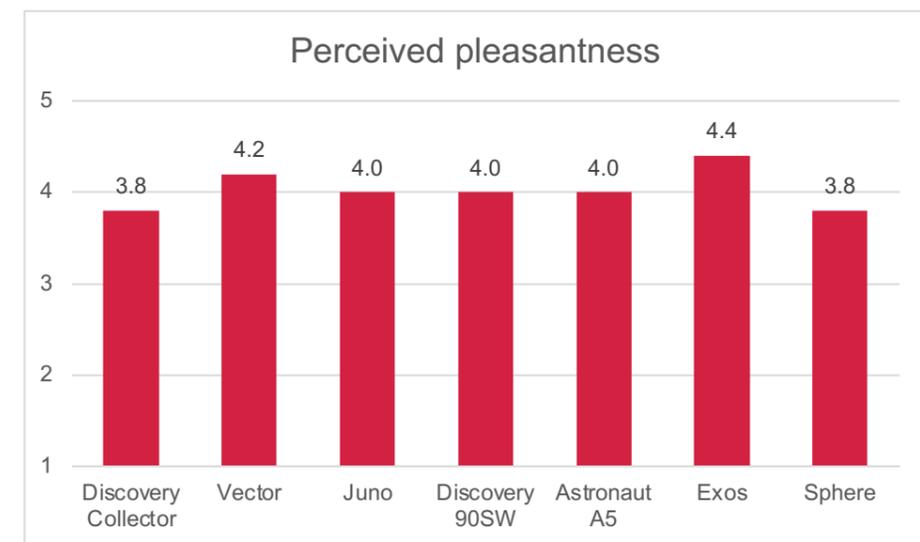


Figure 7.5: The perceived pleasantness of the robot voices.

### Recognition of the robot actions

Figure 7.6 shows the results of the chosen actions. The number inside each bar indicates how many times each of the intended robot actions was selected.

The data shows that 3 out of 5 participants successfully identified the critical safety alarm. These participants rated the alarm with the highest level of urgency, as they found this sound the most unpleasant. One participant experienced difficulty choosing between the critical safety alarm and the critical technical alarm, ultimately choosing the critical technical alarm. Another participant selected the “warning: approaching narrow alley” sound, associating the sound with JAWS.

The critical technical alarm was identified by 4 out of 5 participants, who explained that the repetition and fast pattern of the sound made it feel like a critical alarm.

The non-critical alarm was recognised by 3 out of 5 participants. They noted that the sound was more subtle compared to the critical alarms, with one participant recognising the similarity in patterns between the critical technical and non-critical alarm. 1 out of 5 participants chose the driving sound, describing it as more intense to ensure user safety while the robot is driving. The bar of the chart reaches a count of 4, as one participant could not assign an action to the sound, stating they couldn’t decide between the non-critical alarm, the “warning: approaching narrow alley”, and “driving backwards” sound.

The “warning: approaching narrow alley” sound was successfully identified by 4 out of 5 participants. One participant selected the non-critical alarm, perceiving it as having a higher urgency.

The “start driving” sound was recognised by 3 out of 5 participants, all of whom stated the sound reminded them of the start of a car race:

**“It sounds like a starting gun, like a race.”**

One participant chose the confirmation sound, explaining that the tones going up in scale reminded them of connecting to a Bluetooth device. They also mentioned having difficulty choosing between the informative and confirmation sounds. Another participant selected the non-critical alarm due to the sound’s fast tempo.

The driving sound was identified by 3 out of 5 participants. One participant described it as:

**“Very steady, slow and mostly informative. There is little urgency.”**

While the other two participants chose other driving-related sounds, such as “start driving” and “driving backwards”.

The driving backwards sound was recognised by 4 out of 5 participants, with all of them associating it with the auditory icon of a reversing truck. One participant did not recognise this icon and instead selected the critical safety alarm, stating the fast tempo and high pitch of the sound as the reason.

Finally, 4 out of 5 participants recognised the confirmation sound. They explained that the tones going up in scale reminded them of completing a task. One participant selected the driving sound, though they stated the sound felt like receiving a confirmation:

**“I do get the feeling that I have to enter something myself and get a confirmation in return.”**

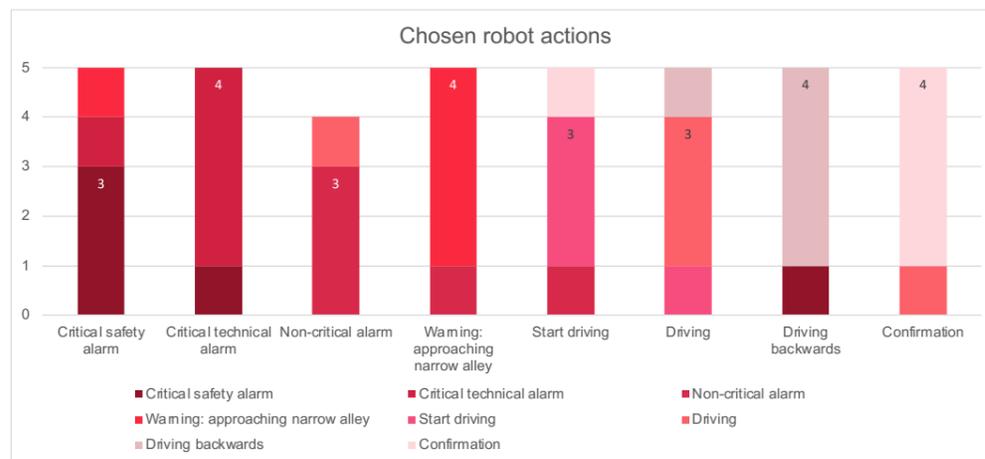


Figure 7.6: The chosen robot actions.

### Perceived pleasantness of the action sounds

Figure 7.7 presents the mean pleasantness ratings for the notification sounds. The chart shows that both the critical and non-critical alarms received relatively low pleasantness scores compared to the informative and confirmation sounds, which was expected.

Participants who rated the alarms 3 or lower expressed that the sounds were unpleasant and induced a sense of urgency, prompting them to take action in order to stop the alarm:

**“The sound itself feels very unpleasant. It gives me an unpleasant feeling, which makes me feel like I have to do something to make it stop.”**

**“Because it doesn’t feel pleasant, I get the idea that it’s urgent. I don’t want this, I want it to go away.”**

Participants who rated the alarms 4 or higher compared them to other alarms, noting that these alarms were relatively more pleasant than other critical alarms:

**“Even though it is an alarm sound, I don’t find it annoying. What you sometimes get with alarm sounds is that they’re high-pitched and shrill, but this one isn’t like that.”**

The informative and confirmation sounds received high ratings on the pleasantness scale. Participants described these sounds as “smooth” and “chill.” They particularly enjoyed the ascending tones in the “start driving” and confirmation sounds, which contributed to a positive feeling. Additionally, the lower pitch and slow tempo of the informative and confirmation sounds were mentioned as factors that made the sounds feel pleasant.

**“The low pitch and slow tempo makes the sound flow and very calm. That feels nice.”**

The “driving backwards” sound was the only informative sound that scored relatively low on the pleasantness scale. The 3 out of 4 participants who recognised the auditory icon of a truck reversing, rated the sound a 4 on the pleasantness scale, while 1 participant was neutral about it. Notably, the participant who did not recognise the auditory icon rated the sound a 2.

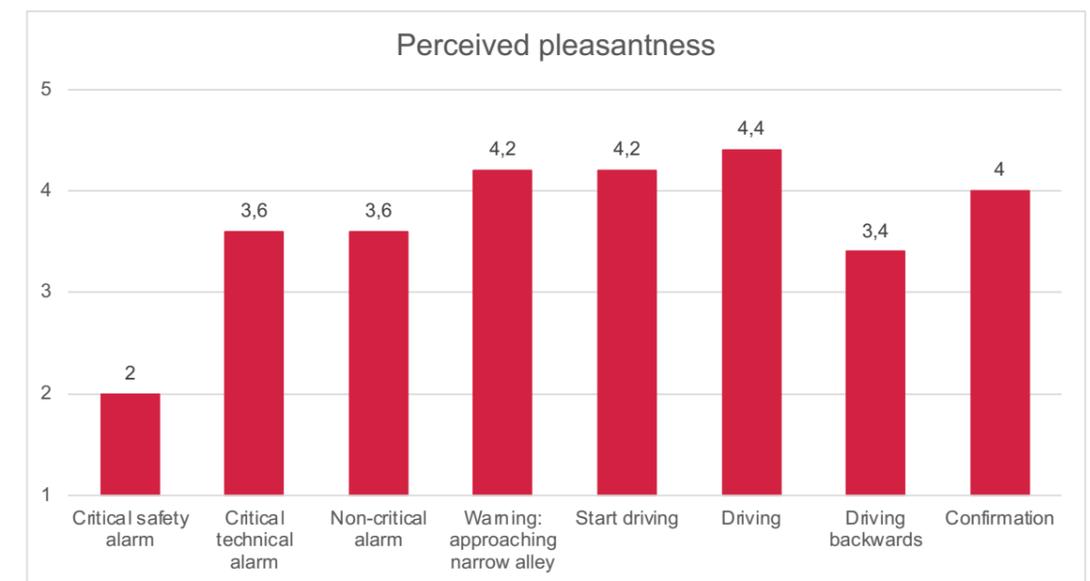


Figure 7.7: The perceived pleasantness of the action sounds.

### Perceived urgency

Figure 7.8 illustrates the mean perceived urgency of the notification sounds. The chart shows that the alarm sounds were perceived as having a higher level of urgency. The participants related the level of urgency to the tempo and the perceived pleasantness of the sound. Sounds with a faster tempo that were perceived as unpleasant were given higher urgency ratings.

One participant, when rating the critical technical alarm as a 3 on the urgency scale, stated:

**“That’s because it doesn’t bother me. It’s quite subtle. I understand that there is urgency, but nothing extremely dangerous.”**

The perceived urgency of the informative sounds shows that the “warning: approaching a narrow alley”, the “start driving” sound, and the “driving backwards” sound were rated around 2 (slightly urgent) on the urgency scale. Participants who rated the “start driving” and “driving” sounds a 2 or higher noted that the short pauses between each tone increased the urgency of the sounds. They also mentioned that the final tone in the “start driving” sound, which ascended in pitch, reduced its perceived urgency. One participant described the “start driving” sound as follows:

**“I think something is going to happen because of the speed of the beep, but I am not in full stress mode.”**

The warning for approaching a narrow alley was intended to convey a slightly urgent tone. Participants stated that the repetition of the sound and the short intervals between tones heightened its sense of urgency.

**“It sounds like it wants something from you. Something is going on, but at the same time, there isn’t. That’s why the warning is informative. You have to pay attention.”**

**“The pattern consists of doing something twice and then nothing repeated twice. The repetition creates a little more urgency.”**

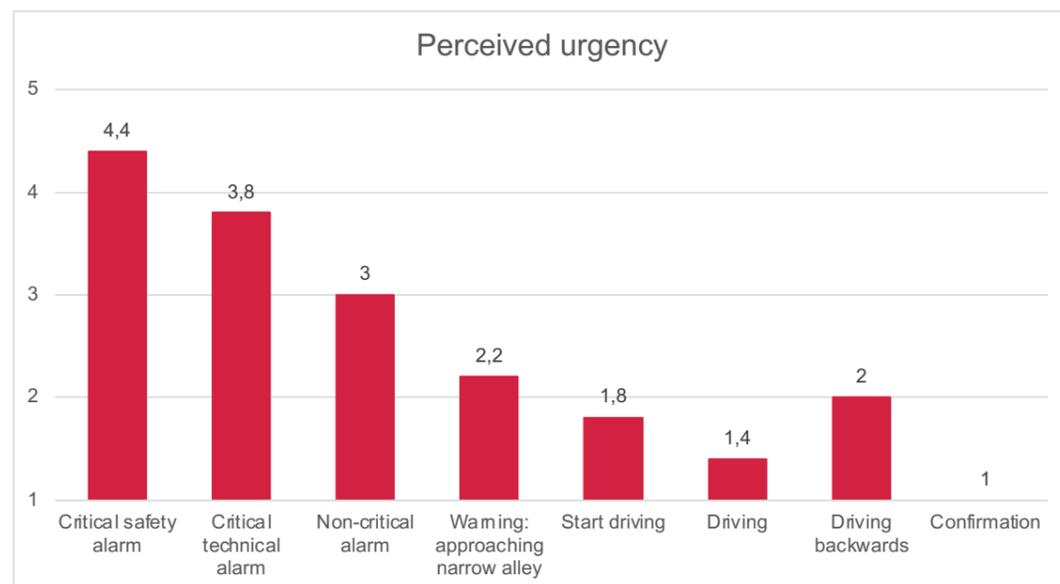


Figure 7.8: The perceived level of urgency.

### 7.4.3 Discussion

The user test aimed to assess the perceived pleasantness and urgency of the developed set of notification sounds, as well as evaluate the sounds based on the recognition of the robots and their actions.

The results show the notification sounds did not score well in terms of robot recognition. While most participants understood the logic behind the sounds, they struggled to associate the sounds with the correct robot. This suggests a need for a more systematic approach in mapping pitch to robot size and timbre to the function category.

When it came to recognising the robot actions the sounds performed well. The majority of the participants recognised the auditory icons and were able to identify the robot actions. The participants who struggled with recognising the actions were often confused by the tempo of certain sounds. Specifically, the fast tempo of the “start driving” and “driving” sounds led to misinterpretations.

The robot voices were generally rated positively in terms of pleasantness. Participants noted that robot voices with more reverb and a lower pitch were perceived as more pleasant. Similarly, the robot actions were also rated positively for pleasantness, with the exception of the alarms. Alarms were intentionally designed to be less pleasant in order to prompt users to take immediate action to stop them. Informative and confirmation sounds, on the other hand, received higher pleasantness ratings, generally ranging from “pleasant” (4) to “very pleasant” (5). The “driving backwards” sound was the only informative sound that received a lower pleasantness rating, the qualitative results suggest that the auditory icon is perceived as less pleasant when the user does not recognise the auditory icon.

In terms of urgency, the robot actions were perceived as intended, with alarms being seen as more urgent, and informative and confirmation sounds as less urgent.

### Limitations

The results are based on the responses of five participants interviewed in a quiet office environment. Conducting the test in a real farm setting, with sounds played from the actual locations of the Lely robots, might have given different results. Additionally, the focus of the test was on the intuitive recognition of the robots, i.e. identifying their voices upon hearing them for the first time. However, sound recognition, like identifying a person’s voice, often improves with experience. The robot voices might have been more easily recognised if the participants had the chance to study the sounds beforehand.

### 7.4.4 Conclusion

This user test investigated the perception and recognition of the Lely robots and their actions based on a set of notification sounds. The results indicate that the sounds effectively communicated the robots’ actions and their urgency levels, although minor adjustments to the tempo of the informative sounds are needed to further enhance the design. The recognition of the robots based on their assigned voices revealed the need for a more structured approach to effectively convey the type of robot to the user.

The robot voices and actions were generally rated well for perceived pleasantness, with alarms scoring lower on the pleasantness scale, and informative and confirmation sounds receiving higher ratings.

Overall, these findings suggest that while certain notification sounds effectively conveyed their intended meanings, improvements are necessary in both the differentiation of robot voices and the recognition of auditory icons.

## 7.5 User preferences

In Chapter 6.2, possible solutions for the identified core problems were proposed. To evaluate the preferences of the farmers, a questionnaire was sent out. This section presents the results of the questionnaire.

### 7.5.1 Method

The initial questionnaire included agree/disagree statements about the user's perception of the current situation and sound preferences, along with sound-focused questions regarding the recognition of the robot voices and actions. The sound-focused questions will not be covered in this report, as the results were insufficient.

#### Participants

A total of 15 Dutch farmers completed the questionnaire, all of whom were familiar with the Lely robots.

#### Questionnaire design

At the start of the questionnaire the participants received a general introduction regarding the questionnaire (see Appendix E for a full overview of the questionnaire). This included the goal of the questionnaire and the estimated duration:

#### Why

*Lely is currently developing new robot sounds. We would like to know how you experience the new sounds. It is important for this survey that you have a speaker or headphones available as some questions contain sound. There are no right or wrong answers.*

#### Duration

*Approximately 4 minutes.*

The next stage consisted of two sets of two statements. The participants were asked to indicate their level of agreement using a 5-point scale (1 = strongly disagree, 5 = strongly agree).



Figure 7.9: Context photo (Melkveebedrijf, 2023).

#### First set of statements

Prior to the two statements, participants were shown a context photo and given a brief explanation of the statements (see figure 7.9):

*As you may know, cows are able to perceive a broader range of sounds than humans. To reduce the number of sounds on the farm for the farmer, we are developing sounds that only cows can hear.*

*This specifically concerns sounds that let cows know that a robot is nearby, such as the driving sound of the Discovery Collector. We call these types of sounds in the questions below: "informative sounds".*

The first statement focused on the perceived disturbance caused by the current buzzer sounds to assess the need for implementing solutions to reduce the amount and frequency of notification sounds. Participants were asked to indicate their level of agreement with the following statement: "The amount of informative sounds produced by the robots bothers me."

The second statement focused on evaluating the user's interest in using sounds that only cows can perceive. Participants were asked to indicate their level of agreement with the following statement: "I want the informative sounds of the robots driving inside the cowpen to be audible only to the cows."

After the two statements, the participants were given the opportunity to explain their answers using a fill in field.

#### Second set of statements

The second set of statements focused on the different robot voices. Prior to this set, the participants received an explanation regarding the two statements:

*Every robot currently makes the same sound. To make it easier for farmers to distinguish the robots based on sound, we want to give each robot a different distinctive sound, a "voice" of its own.*

The first statement focused on differentiating the Lely robots on an individual level by giving each individual robot a different "voice". Participants were asked to indicate their level of agreement with the following statement: Suppose you have two robots of the same model; for example, two Astronaut robots. Indicate to what extent you agree or disagree with the statement below: "I want my two Astronaut robots to have a different distinctive sound."

The second statement focused on differentiating the Lely robots on a model level by giving each robot model its own distinctive sound. Participants were asked to indicate their level of agreement with the following statement: "Suppose you have two different robot models, such as one Discovery Collector (manure robot) and one Juno (feed pusher robot). To what extent do you agree or disagree with the statement: 'I want my Collector and Juno to have different distinctive sounds.'"

After the two statements, the participants were given the opportunity to explain their answers using a fill in field.

### 7.5.2 Results

**Perceived Disturbance of the Notification Sounds**  
Figure 7.10 shows the absolute number of times participants agreed or disagreed with the first statement. The results indicate that the majority of participants either agreed or were neutral toward the statement. Six out of 15 participants agreed that the amount of notification sounds was bothersome, while six other participants expressed neutrality toward the number of sounds. Participants noted that the buzzer sounds were overwhelming at times and expressed concerns about disturbing the neighbours:

**"There are so many beeps sometimes that I have to filter where they are coming from."**

**"The sounds could be perceived as noise pollution by the neighbours if they can be heard outside the barn."**

Additionally, participants expressed a preference for only having sounds for critical alarms and for being able to customise the occurrence of non-critical alarms:

**"I only want sounds for critical alarms and to be able to set alarms myself based on which ones I consider critical."**

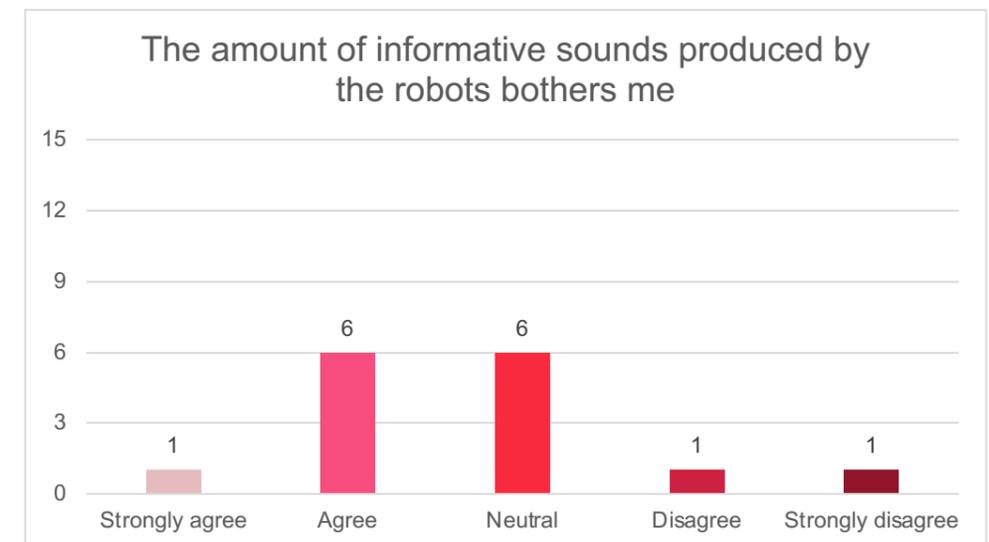


Figure 7.10: Results of the first statement.

### Sounds for cows

Figure 7.11 shows the absolute number of times participants agreed or disagreed with the second statement, i.e., sounds only audible to cows. The results indicate that 7 out of 15 participants agreed with the statement. The desire for fewer notification sounds was again expressed. Six out of 15 participants were neutral toward the statement, while one participant disagreed with the statement.

### A different distinctive sound for each individual robot

Figure 7.12 shows the absolute number of times participants agreed or disagreed with the third statement. The results reveal that 7 out of 15 participants strongly disagreed with the idea of implementing a different, distinctive sound for each individual robot.

### A different distinctive sound for different robot models

Figure 7.13 shows the absolute number of times participants agreed or disagreed with the fourth statement. The results reveal that 4 out of 15 participants strongly agreed, and another 4 out of 15 participants agreed with the idea of implementing a different, distinctive sound for different robot models. Participants explained that having distinct sounds would help differentiate the robots:

**“If there are multiple robots driving inside the barn, it makes it easy to identify which sounds belong to which robot.”**

**“Currently, you don’t know which vehicle you’re hearing. They all have the same sound, which is confusing.”**

However, 4 out of 15 participants disagreed with the statement, expressing a preference for no sound at all or only for alarms:

**“Preferably no sound.”**

**“Not necessary for me. If they don’t drive, just use an alarm.”**

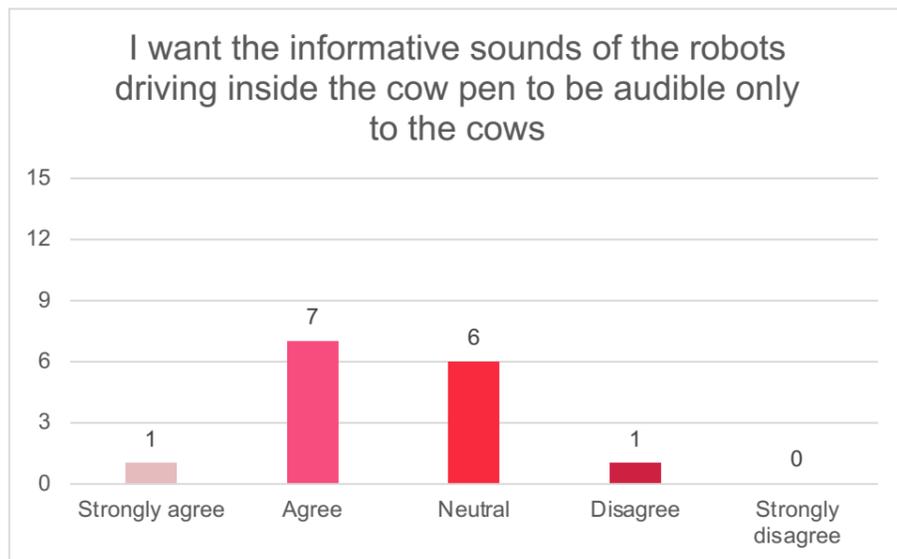


Figure 7.11: Results of the second statement.

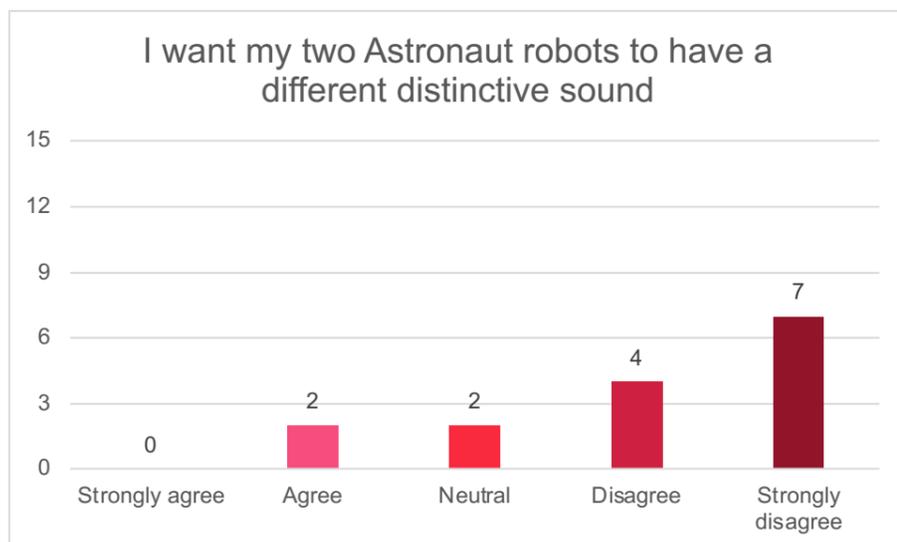


Figure 7.12: Results of the third statement.

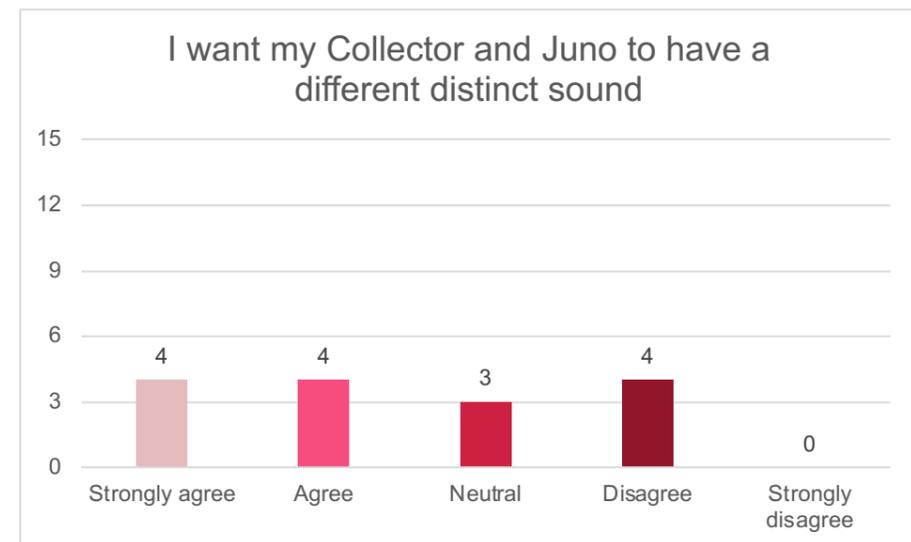


Figure 7.13: Results of the fourth statement.

### 7.5.3 Discussion

The questionnaire aimed to identify the users' needs and preferences in order to make informed design decisions.

The results show that the majority of participants are either neutral toward the buzzer sounds or perceive them as bothersome and confusing. The qualitative data reveals that most participants prefer having sounds only for critical alarms and expressed a desire to choose when non-critical alarms or informative sounds occur.

The findings also indicate that farmers are interested in informative sounds that are only audible to cows. This interest stems from their desire to reduce the overall number of sounds in the barn.

Rather than having the same buzzer sound for multiple robots or a distinct voice for each individual robot, participants preferred having a distinct voice for each robot model. Meaning, an Astronaut A5 and a Juno, would have different distinctive sounds.

### 7.5.4 Conclusion

Based on the findings of the questionnaire, it can be concluded that users prefer having as few notification sounds as possible. This result explains their interest in having notification sounds that are only audible to cows. Additionally, it can be concluded that users prefer a distinct voice for each robot model.



## 7.6 Iterations

This section presents the iterations made based on the gathered results from the user test and farmer questionnaire.

### 7.6.1 Robot differentiation

The user test revealed that it is difficult to recognise the robots by their voice. The robots' voices will be revisited to improve their recognition.

The robots are differentiated by mapping the pitch to the size of the robot and the timbre to both the function category (milking, feeding, and cleaning) and the robot's size. This mapping system will remain the same moving forward.

To map the pitch to the robot's size the frequency range needs to be defined based on the height of the robot. Figure 7.14 shows an overview of the seven Lely robots categorised based on their size. Small robots are defined as robots with a height below 1.8 m, medium sized robots are defined as robots with a height between 1.8 and 2.8 m, large robots are defined as robots with a height above 2.8 m. The fundamental frequency for robots with a height of 1.8 m or less should fall between 1800 and 2500 Hz. For robots with a height between 1.8 and 2.8 m, the fundamental frequency range should be between 1000 and 1800 Hz. Robots with a height greater than 2.8 m should have a fundamental frequency range between 500 and 1000 Hz.

To map timbre to the size of the robot, each robot could be assigned an instrument that naturally has a lower or higher frequency content. Instruments can be grouped into low, low-mid, mid, and high ranges based on their frequency range.

The Discovery 90SW and Discovery Collector are roughly the same size; they are assigned to high frequency range instruments such as the kalimba, flute, or xylophone.

The Juno can be assigned to an instrument with a slightly lower frequency range, such as the violin or mandolin.

The Vector MFR is a medium-sized robot and can be assigned to mid-range instruments like the conga, French horn, or clarinet.

The Astronaut A5 is considered a larger robot within the medium-sized category. The robot can be assigned to mid-low frequency range instruments such as the cello, saxophone, string bass, or tom drums.

The Sphere and Exos are the largest robots. These robots can be assigned to low-frequency range instruments like the double bass, didgeridoo, bass guitar, or bass drum.

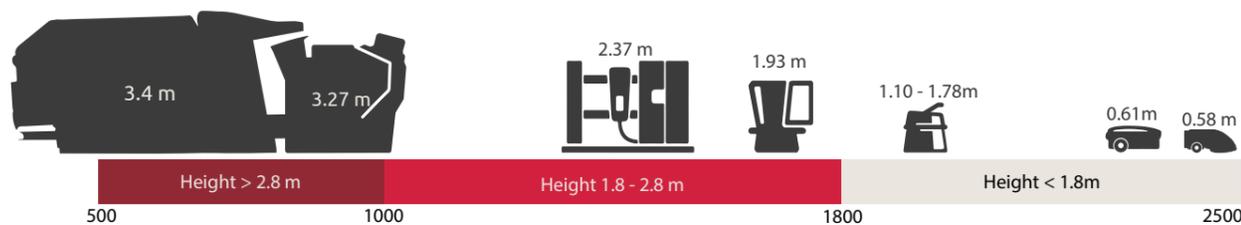


Figure 7.14: Assigned frequency range based on robot height.

To communicate the function categories, inspiration can be drawn from an orchestra. In an orchestra, the instruments are divided into four families: woodwind, brass, percussion, and strings (Bailey, 2023).

Woodwind instruments are played by blowing into their mouthpiece. Examples of woodwind instruments include the flute, clarinet, saxophone, and oboe.

Brass instruments are typically made of brass or metal, with a few exceptions, such as the saxophone. Like woodwind instruments, brass instruments are played by blowing air into their mouthpiece. One key difference between the two families is that brass instruments usually use valves to direct air. Examples of brass instruments include the trumpet, French horn, and tuba.

Percussion instruments are played by striking (hitting) them. This category includes both pitched (instruments with chords) and unpitched instruments. Examples of pitched instruments are the triangle, xylophone, and marimba. Examples of unpitched instruments are the bass drum, gong, and tom drums. While the piano is often considered its own category, it can also be classified as a percussion instrument.

String instruments produce sound through the vibration of strings. Examples of string instruments include the violin, guitar, and cello.

The instrument families of an orchestra are easy to understand for someone with a musical background. However, in the context of farm-based machinery, these categories are not intuitive for the user. To make it more intuitive, the instrument families are rearranged into four groups: wind instruments (which includes both woodwind and brass instruments), percussion, keyboard, and string instruments. The woodwind and brass instruments are grouped together to avoid confusion about the nuanced differences between the two sound families. The keyboard is treated as a separate instrument family, as these instruments are often considered their own group.

The instrument families are divided across the three function categories as follows:

- Feeding: keyboard
- Milking: string instruments
- Cleaning: percussion

Each robot within the same functional category is assigned an instrument from the same instrument family that corresponds to its size. Figure 7.15 shows the selected instruments for each robot.

The wind instrument family will remain unused for now but can be utilised for a possible new robot category in the future.

	Function category	Instrument
Astronaut A5	Milking	String bass
Discovery Collector	Cleaning	Kalimba
Discovery 90SW	Cleaning	Kalimba morph
Sphere	Cleaning	Boomwhacker
Juno	Feeding	70s synth arp
Vector	Feeding	Keyboard
Exos	Feeding	Synth bass

Figure 7.15: Assigned instruments.

### 7.6.2 Sound categories

The findings of the user test indicated that the tempo of the informative sounds needs to be adjusted to improve the recognition of the robot actions. The results also showed that the frequency of the notification sounds needs to be adapted according to their level of urgency.

The user test showed that the tempo of the “start driving” and “driving” sounds made them seem more urgent. To reduce the perceived urgency, a longer pause has been implemented between each tone.

The user test showed that lower frequencies are perceived as more pleasant. To further distinguish the alarms from the informative and confirmation sounds, the alarms will focus on the higher frequency range within each robot’s assigned frequency range, while the informative sounds will focus on the lower range.

### 7.6.3 Loudness

To create a consistent listening experience across all notification sounds, the loudness of the notification sounds needs to be adjusted to -14 dB LUFS during mastering. LUFS (Loudness Units Full Scale) measures the perceived loudness by combining the human perception of sound and the electric signal intensity (Medeiros, 2021). To avoid distortion during the process of encoding and decoding the notification sounds, a maximum True Peak (an estimate of the peak level the analog waveform will reach after A/D conversion) of -1 dB should be used.

### 7.6.4 Audibility

In Chapter 6.2, the audibility of the notification sounds was addressed. The Astronaut A5 was identified as a problem area that required a critical band difference greater than 0.25 or below -2 bark.

The developed notification sounds for the Astronaut A5 have dominant frequency components of 850, 1000, 1050, 1400, 1500, and 1600 Hz (7.5 to 11.5 bark). The ambient noise has dominant frequency components in the 150 to 400 Hz (1.0 - 4.0 bark) and 3800 to 4600 Hz (16.97 - 18.06 bark) range. To determine whether the critical band difference lies outside the 0.25 to -2 range, the critical band difference between the critical band values closest to each other is calculated, specifically 400 Hz (4.0 bark) and 850 Hz (7.5 bark).

$$\Delta z = z_M - z_T$$

$$\Delta z = 4.0 - 7.5 = -3.5 \text{ bark}$$

The critical band difference between the two closest frequencies is -3.5 bark, meaning the notification sounds are not at risk of being masked by the ambient noise.



This chapter presents the final design, including the sound design framework with technical guidelines that the notification sounds must adhere to, the final set of developed notification sounds, and the necessary changes required for their implementation.

- 8.1 The sound design framework
- 8.2 Developed set of sounds
- 8.3 Implementation



## 8.1 The sound design framework

This section presents the final sound design framework of the notification sounds. The framework includes all the technical guidelines the robot voices and notification sounds need to abide by.

### 8.1.1 The robot voices

To allow the user to differentiate the Lely robots based on their sound, each robot model requires a distinct voice. The robot voices should reflect Lely's brand identity and be intuitive in nature. The sound parameters pitch and timbre, must be adapted based on the robot's function category (milking, feeding, or cleaning) and the robot's size.

#### Frequency

Every notification sound should have a pitch within the 500 to 2500 Hz frequency range, as per the ISO guidelines. The pitch is mapped to the robot's size within this frequency range to reflect the natural relation between the size of an object and its pitch. Smaller robots should be assigned to a higher frequency range, and larger robots to a lower frequency range.

Figure 8.1 shows an overview of the seven Lely robots, categorised by size. Small robots are defined as those with a height below 1.8 m, medium-sized robots as those with a height between 1.8 and 2.8 m, and large robots as those with a height above 2.8 m. The fundamental frequency for robots with a height of 1.8 m or less should fall between 1800 and 2500 Hz. For robots with a height between 1.8 and 2.8 m, the fundamental frequency range should be between 1000 and 1800 Hz. Robots with a height greater than 2.8 m should have a fundamental frequency range between 500 and 1000 Hz.

The notification sounds and the ambient noise are not allowed to be close in frequency to minimise the occurrence of the masking effect, i.e. the phenomenon where the notification sounds are affected by the presence of other sounds in the barn. Furthermore, the robot voices need to have at least four dominant frequency components within the first 10 harmonics.

If the notification sounds need to travel more than 300 meters, it is recommended to use frequency components below 1000 Hz. For notification sounds that need to pass through barriers, frequency components below 500 Hz are advised. Harmonically rich waveshapes or timbres need to be chosen to achieve this.

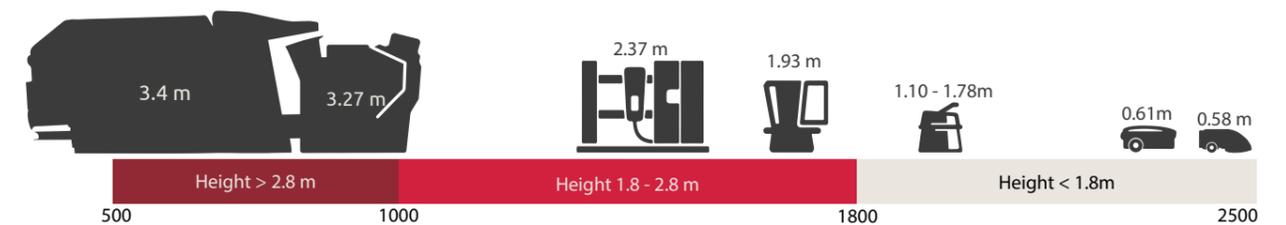


Figure 8.1: Assigned frequency range based on robot height.

### Timbre

The timbre of the robot voice is mapped to both the function category and the robot's size. Each function category is linked to an instrument family, as shown below:

- **Feeding:** keyboard
- **Milking:** string instruments
- **Cleaning:** percussion
- **Future function category:** wind instruments

Based on the size of the robot, each robot is assigned to an instrument that produces frequencies in the low, mid, or high frequency range. Smaller robots should be assigned to instruments that have prominent harmonics in the higher frequency range. For larger robots, a timbre with prominent harmonics in the lower frequency range should be chosen. Figure 8.2 shows the assigned instruments for each robot. The wind instrument family should be used for any additional future function categories.

### Lely's Brand Identity

To adhere to Lely's brand identity, the robot voices must be perceived as bright, optimistic, creative, and supportive to reflect Lely's tone of voice towards the user. To create sounds that are perceived as bright and creative, harmonically rich sounds must be produced. A rich harmonic spectrum typically causes a sound to be perceived as fuller or brighter, while sounds with fewer harmonics are perceived as hollow or dull. Harmonically rich voices can be created by choosing instruments that are naturally rich in harmonics or by adapting the wave shape of a robot voice to a square or saw wave. Figure 8.2 shows an overview of the wave shapes for each robot voice.

To give the voices an optimistic and supportive undertone, reverb should be added to all the voices. This creates a smooth flow and a more pleasant sound. The critical alarms should be designed to be less pleasant to prompt the user to take immediate action to stop the alarm.

	Function category	Instrument	Wave shape
 Astronaut A5	Milking	String bass	Sine
 Discovery Collector	Cleaning	Kalimba	Sine Arp
 Discovery 90SW	Cleaning	Kalimba morph	Sine
 Sphere	Cleaning	Boomwhacker	Square and saw
 Juno	Feeding	70s synth arp	Saw arp
 Vector	Feeding	Keyboard	Saw
 Exos	Feeding	Synth bass	Square and saw

Figure 8.2: Assigned instruments and wave shapes per robot.

### 8.1.2 The notification sounds

The notification sounds are based on five defined sound categories, varying in their level of urgency. Figure 8.3 shows the five sound categories, their meanings, and the intended user actions. Each sound category, except for the informative sounds, has a single sound to represent all actions within that category. In total, eight sounds are created (see figure 8.4): a critical safety alarm, a critical technical alarm, a non-critical alarm, a confirmation sound, and four informative sounds, i.e. start driving, driving, driving backwards, and warning: approaching narrow alley. Each sound varies in rhythm, duration, and pitch depending on their urgency level.

#### Rhythm

Rhythm is the combination of timing, duration, and organisation of sounds. The rhythm of the sounds must reflect their urgency level. A fast rhythm indicates a high urgency level, while a slow rhythm indicates a low urgency level.

The critical alarms should have a fast, pulsating pattern to convey urgency. The non-critical alarm should have the same pattern as the critical technical alarm, but with more time between each tone to reduce the perceived urgency. The informative and confirmation sounds should have a slow pattern to communicate to the listener that no action needs to be performed. To avoid overloading the auditory channel, the number of tones and the duration of the informative and confirmation sounds should be kept to a minimum. The informative and confirmation sounds should consist of one to two different tones, while the alarms should include at least two different tones.

#### Duration

The duration of the critical alarms must be 20 seconds and should repeat with a 5 second interval until the user acknowledges the alarm. If the alarm is not acknowledged after 5 minutes, the robot will stop operating. The non-critical alarm must last for 15 seconds and repeat every minute until the user indicates to be aware of the technical issue via the Lely app or resolves it. If the non-critical alarm remains unresolved to the extent that it negatively impacts the operation of the robot, it will transform into a critical technical alarm.

The informative sounds should play once to inform the user of the action the robot is performing. The informative sounds "driving" and "driving backwards" are excluded from this guideline, as these sounds are required to play for the entire duration the robot is driving through the barn.

At night, the deactivation of the notification sounds should be considered to minimise the amount of sound present in the barn. To ensure the user's safety, the critical safety alarms should remain active at all times. All critical alarms should instigate a phone call and push notification at night.

	Sound	Meaning	Action	
	Critical safety alarm	Occurrence of emergency involving possibility of injury	Leave danger zone immediately	Urgency
	Critical technical alarm	Robot is unable to operate without immediate action	Check robot and call service technician	
	Non-critical alarm	Robot requires attention or will soon be unable to operate	Take preventative or preparatory action	
	Informative sound	Provides information about the actions the robot performs	No action required	
	Confirmation sound	Confirms the completion of a task	No action required	

Figure 8.3: Sound categories.

### Pitch

The pitch of the alarms should focus on the higher frequencies within the assigned frequency range of each robot to reflect their higher urgency level. The informative and confirmation sounds should focus on the lower frequencies.

### Sound pressure level

The user must be able to adjust the loudness of each Lely robot within a predetermined loudness range based on the ISO guidelines for danger signals in public and work areas. All notification sounds must have a minimum A-weighted sound pressure level of 65 dB. The sound pressure level of the critical alarms must exceed the ambient noise level by 15 dB. If there is a clear difference in frequency and/or temporal distribution between the ambient noise and the alarm, a sound pressure level starting at 10 dB above the ambient noise level will also be sufficient, depending on the type of octave-band. An octave is the interval between two notes with a frequency difference of a factor  $\sqrt{2}$ . In this case a difference starting at 10dB will be sufficient. For a  $\frac{1}{3}$  octave band, the frequency difference is a factor of  $\sqrt[3]{2}$ . In this octave band, a minimum difference of 13 dB is sufficient.

The user must be able to adjust the loudness of the critical alarms within a predetermined range of 65 to 75 dB to ensure the alarm is clearly audible. The user must also receive a warning to limit the use of alarms exceeding 70 dB for robots in close proximity to cattle, in order to prevent potential stress or behavioural changes. If the A-weighted sound pressure level of the alarm does not exceed the ambient noise by 10 to 15 dB, a relocation of the speaker should be considered.

The A-weighted sound pressure level of the non-critical alarm, as well as the informative and confirmation sounds, must exceed the ambient noise level by 10 dB. The user shall be able to adjust the loudness within a predetermined range of 65 to 70 dB.

To avoid sound distortion and ensure a consistent listening experience, the notification sounds should be set to -14 dB LUFS with a maximum True Peak of -1 dB during mastering.

### Auditory icons and earcons

To make the notification sounds intuitive and easy to understand, the informative and confirmation sounds should be developed using auditory icons, i.e. well-known everyday sounds typically associated with actions similar to those performed by the robot. For actions that do not have a corresponding real-world sound, earcons should be used. Earcons are short, abstract sounds that represent a piece of information or an event, in this case, a robot action.

### Perceived pleasantness

The notification sounds should be designed to be perceived as pleasant. The alarms are the only notification sounds that do not have to adhere to this rule. The alarms should be perceived as acceptable to create a balance between their perceived urgency level and to prevent farmers from removing the speaker from the robot.

### Assigned notification sounds per robot

Figure 8.5 shows the assigned notification sounds for each robot. All autonomous robots are required to have a critical technical alarm, a critical safety alarm, and a non-critical alarm. The robots must produce a sound if they come into contact with any listeners present in the barn while driving their route.

Stationary robots are required to have a critical technical alarm and a non-critical alarm. The occurrence of a critical safety alarm depends on the functions of the stationary robot. The product development teams are responsible for defining the specific scenarios in which these alarms occur.

The confirmation sounds are all optional. These sounds do not have an impact on the user's safety and are not essential for the robot's to function.



Figure 8.4: The notification sounds.

	Discovery 90SW	Discovery Collector	Jun6	Vector MFR	Astronaut A5	Exos	Sphere
Critical safety alarm	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory
Critical technical alarm	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory
Non-critical alarm	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory
Warning: approaching narrow alley	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory
Start driving	Mandatory	Mandatory	Mandatory	Mandatory	Optional	Mandatory	Optional
Driving	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory
Driving backwards	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory
Confirmation sound	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Optional

Sounds per robot

Mandatory sound
  Optional sound

Figure 8.5: Assigned notification sounds for each robot.

## 8.2 Developed set of sounds

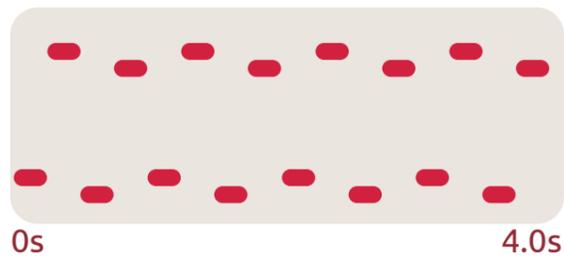
### 8.2.1 The notification sounds

This section presents the developed notification sounds. The perceived duration of the notification sounds may vary due to the added reverb to each robot voice.



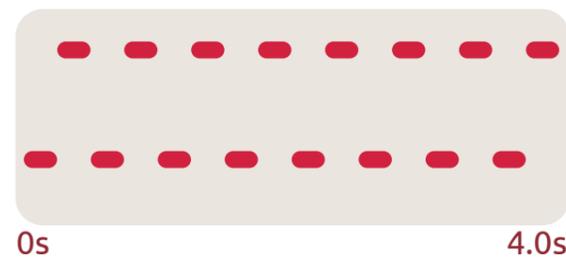
Critical safety alarm

The critical safety alarm consists of four 0.25-second tones that alternate in a fast pattern with no rest in between. The tones are dissonant, creating an uncomfortable and urgent feeling to prompt immediate action. The alarm lasts for 20 seconds and repeats with a 5-second pause in between until the user leaves the danger zone. If no action is taken within 5 minutes, the robot will cease operation.



Critical technical alarm

The critical technical alarm consists of two 0.25-second tones alternating in a fast pattern with no rest in between. This alarm is less complex than the critical safety alarm to reduce the perceived urgency. The two alarms share a similar rhythm to convey that both are critical and require immediate action. The alarm lasts for 20 seconds and repeats with a 5-second pause in between until the user acknowledges the alarm.



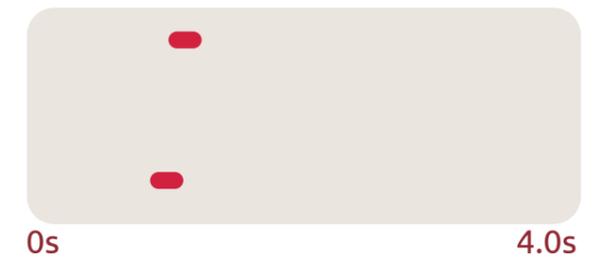
Non-critical alarm

The non-critical alarm consists of the same two alternating tones as the critical technical alarm to inform the user of a technical issue that requires attention. To reduce the perceived urgency, a 0.75-second rest is added between each tone. The alarm lasts for 15 seconds and repeats every 60 seconds until the user acknowledges it. If the issue remains unresolved, the alarm will eventually transform into a critical technical alarm.



Confirmation sound

The confirmation sound is quick, positive and friendly. The sound consists of two short tones (0.25s and 0.20s) that go up in scale to indicate a task is successfully completed.





Informative sounds



Warning: approaching narrow alley

The "Warning: approaching narrow alley" sound is inspired by knocking on a door, with a slightly urgent and serious undertone. It consists of two sets of two "knocks", each made up of a single tone repeated twice. The first tone is slightly shorter in duration (0.19 seconds), followed by a longer second tone (0.5 seconds). After the first set, the knocks are repeated once more, with a long rest (1.3 seconds) between the two sets.



Start driving

The "Start driving" sound is based on the signature "3, 2, 1, GO!" countdown from a car race, with an active and friendly undertone. The sound consists of three short 0.25-second tones representing "3, 2, 1", followed by one higher 0.25-second tone representing "GO!". The final tone goes up in scale to make the sound more friendly and energetic. Between each tone there is a 0.5-second rest to make the sound less urgent.



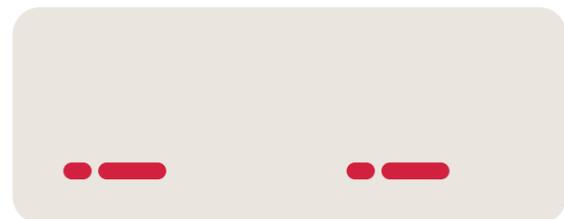
Driving

The "Driving" sound is designed to be gentle and respectful. It plays continuously while the robot is driving around the farm. To avoid overstimulating listeners in the barn, the sound is kept simple, consisting of a single repeating 0.25-second tone with a long rest (3.75 seconds) between each tone.



Driving backwards

The "Driving backwards" sound is intended to be perceived as determined and responsible. It is based on the beeping sound of a reversing truck, consisting of a single repeating tone with a short rest between each tone. The duration of the tone is shorter than the original reversing truck sound to account for the reverb added to each of the robot voices. The sound consists of a 0.13-second tone with a 0.5-second rest in between. It will play continuously while the robot is driving backwards.



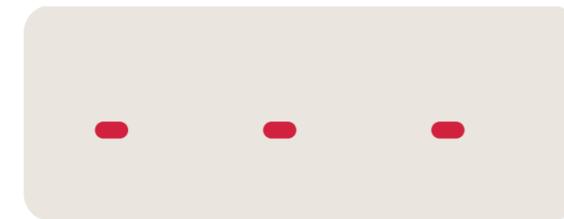
0s 4.0s



0s 4.0s



0s 4.25s



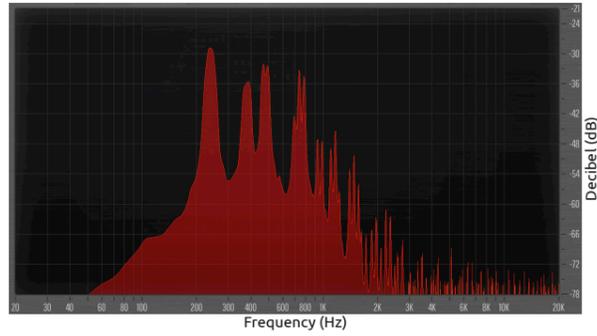
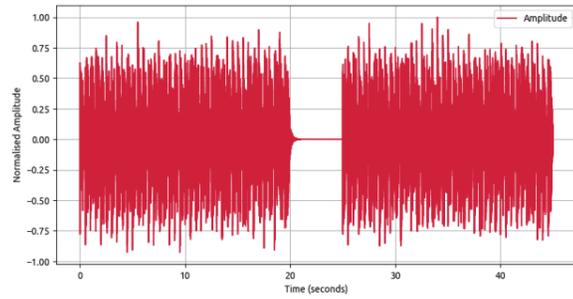
0s 4.0s

### 8.2.2 The robot voices

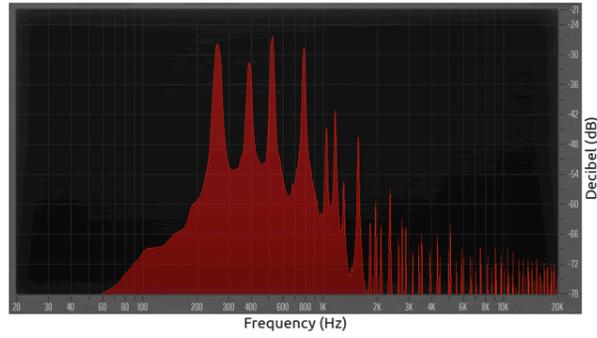
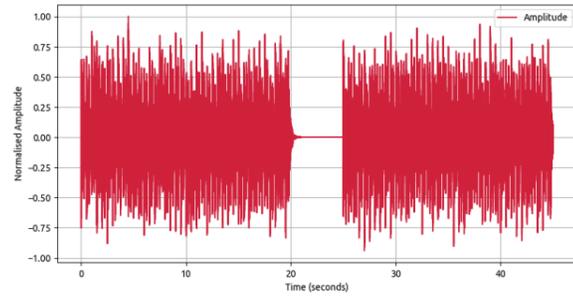
This section presents a visual representation of the Exos' voice. For a full overview of all the robot voices, see Appendix F.

#### Exos

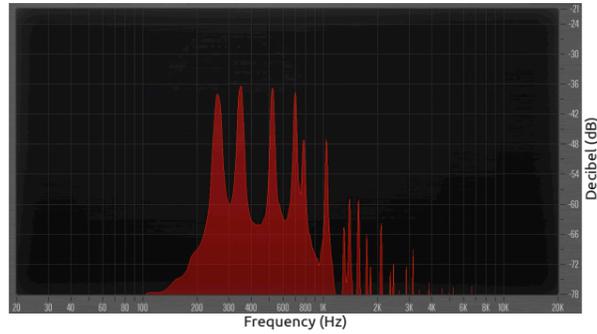
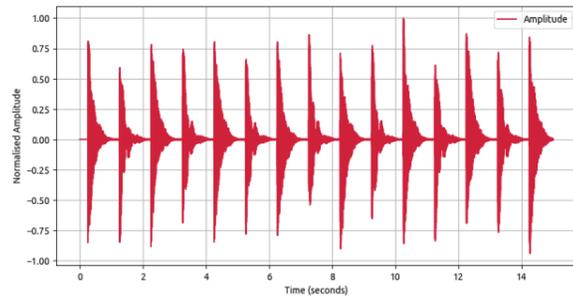
##### Critical safety alarm



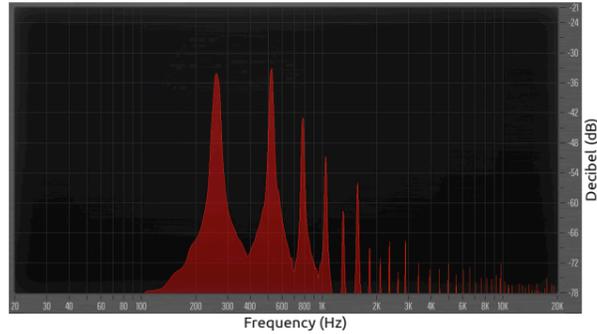
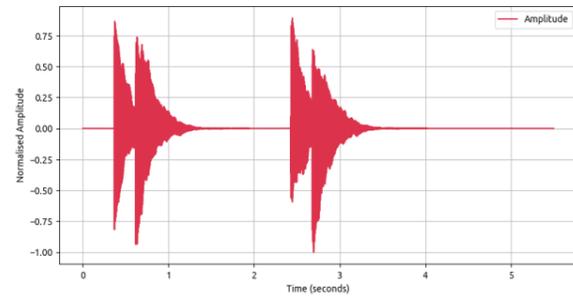
##### Critical technical alarm



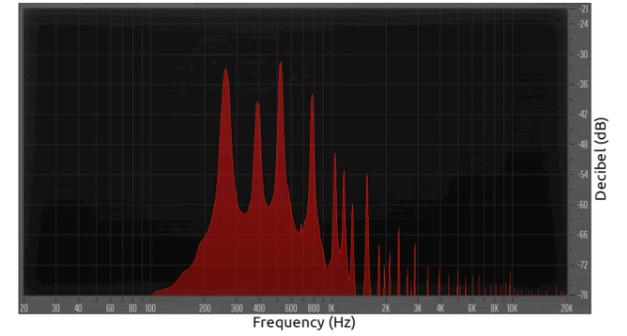
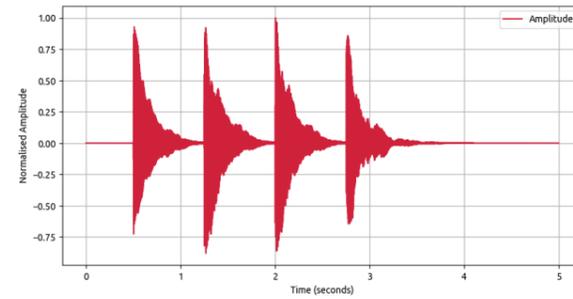
##### Non-critical alarm



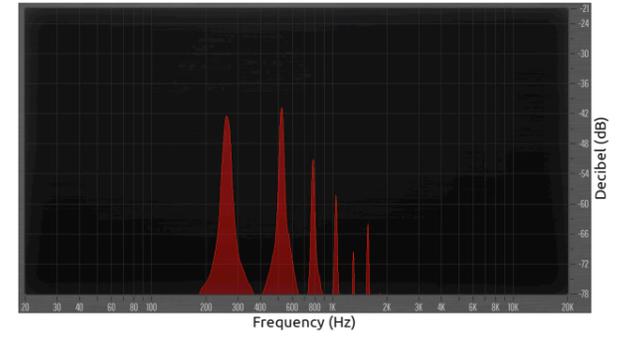
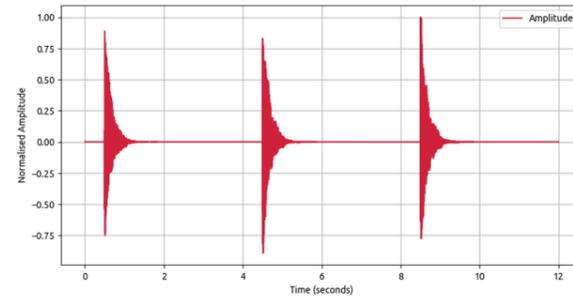
##### Warning: approaching narrow alley



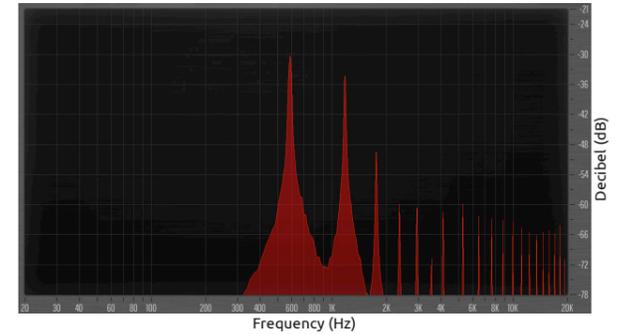
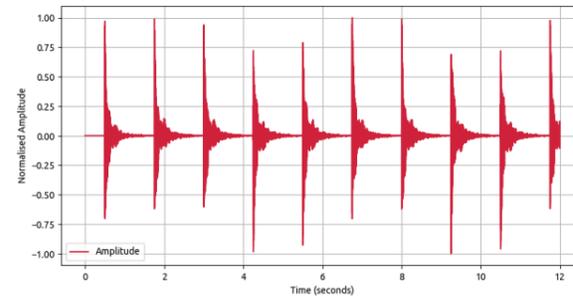
##### Start driving



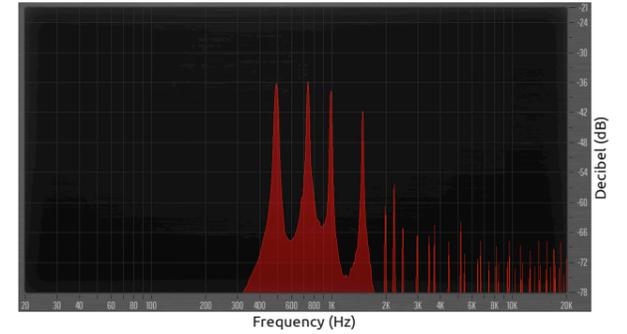
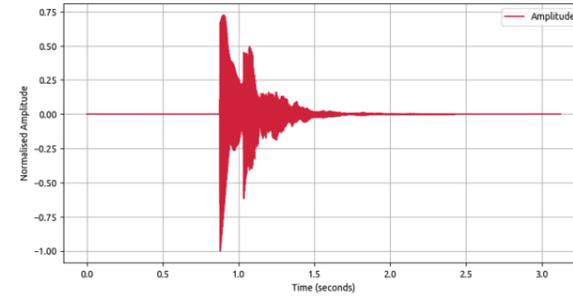
##### Driving



##### Driving backwards



##### Confirmation



## 8.3 Implementation

This section covers the required hardware changes and the practical considerations that need to be taken into account to implement the new set of notification sounds.

### 8.3.1 Hardware

The developed set of sounds requires a speaker instead of a buzzer. The speaker must meet the following criteria:

- To ensure the speaker can withstand the farm environment, it must have a minimum Ingress Protection (IP) rating of 64. This IP value indicates that the speaker is dust-tight and protected against water splashes from all directions.
- The speaker should be capable of producing a frequency range from 100 to 10.000 Hz to cover the pitch of the notification sounds and their harmonic spectrum.
- The speaker should produce a sound pressure level between 65 and 75 dB.
- Most robots have limited space available, the speaker must have maximum dimensions of 6.0 x 6.0 x 8 cm.

- The cost of the speaker should be comparable to that of the current buzzer and should not exceed 60 euros.

Due to the size and durability requirements the speaker must meet, it is best to implement a high-power exciter instead of a traditional speaker. Exciters vibrate the surface they are mounted to, rather than relying on a cone or frame. While speakers require grills or openings, the exciter is fully enclosed, making it more durable and capable of withstanding water and dust (Dayton Audio, n.d.). Exciters have a compact size making them ideal to implement in robots where there is limited space available. One downside of the exciter is that the surface it is mounted to can affect the sound it produces. Therefore, proper placement and testing are required when implementing an exciter.

Figures 8.6 and 8.7 show two exciters that fit the criteria.



Figure 8.6: Exciter DAEX25W-8 (SoundImports B.V., n.d.).



Figure 8.7: Exciter Monacor AR-30 (SoundImports, n.d.).

<b>Exciter model</b>	Dayton Audio DAEX25W-8
<b>IP factor</b>	IP67 (dust tight and able to withstand complete immersion in water for 30 min.).
<b>Frequency range</b>	70 - 20.000 Hz (full range)
<b>Decibel range</b>	0 - 97 dB (depending on mounting surface).
<b>Dimensions</b>	Ø 51.4 mm Height: 20.5 mm
<b>Price</b>	€ 33,95

<b>Exciter model</b>	Monacor AR-30
<b>IP factor</b>	IP68 (dust tight and able to withstand complete immersion in water for longer period of time).
<b>Frequency range</b>	70 - 20.000 Hz (full range)
<b>Decibel range</b>	0 - 100 dB (depending on mounting surface).
<b>Dimensions</b>	Ø 80 mm Height: 40 mm
<b>Price</b>	€ 39,95

### 8.3.2 Setting up the sounds

Part of the identified issues was the unknown meaning of the notification sounds. This issue was addressed by making the notification sounds more intuitive in nature. However, the issue also stems from a lack of information the farmer can access regarding the sounds. One central document explaining the sound categories and the logic behind the robot voices needs to be provided which the user can access via the Lely website.

Furthermore, during the setup of the new notification sounds the Lely service technician needs to walk through the sound categories with the farmer to ensure they are well informed. During the setup, the Lely service technician will also assist the farmer in setting the appropriate sound pressure level (dB) for each robot.

### 8.3.3 Buzzer sounds

The new set of notification sounds will be used for future Lely robots that have transitioned from buzzers to speakers/exciters. The farmers will most likely still own one or multiple Lely robots with a buzzer over the next 10 years. This will result in a farm environment where both buzzer and speaker sounds are present. It will also take a year, if not longer, to implement a speaker/exciter-based system in all the robots.

To provide a solution that can be directly implemented, the urgency-based sound categories and the developed patterns can be applied to the buzzers. This will address the issue of the buzzer's inconsistent feedback and help ease the farmer into the new set of speaker sounds once the speaker/exciter system is ready to be released. It also avoids creating an even more confusing sound environment when both buzzer and speaker sounds are present in the barn. Appendix G shows the guidelines for programming the buzzers according to the urgency-based sound categories.

This chapter focuses on evaluating the design outcomes. The first paragraph evaluates the final design based on the established design criteria. In the second paragraph, the design is assessed in terms of its desirability, viability, and feasibility. Paragraph 3 proposes recommendations for further research. Finally, paragraph 4 provides a reflection on the entire design process.

- 9.1 Design criteria
- 9.2 Validation
- 9.3 Recommendations
- 9.4 Reflection



## 9.1 Design criteria

This section evaluates whether the final design meets the set requirements and wishes.

### 9.1.1 Requirements

#### Distinction

A clear distinction between the critical alarms and the non-urgent sound categories needed to be made to ensure the user takes immediate action when required. Based on the results of the user test, it can be concluded that the user is able to differentiate the critical alarms from the non-urgent sounds.

#### Differentiating robot models

The user must be able to differentiate the robot models based on their notification sounds. The new design enables the user to distinguish the robots through their distinct voices. However, creating robot voices that are intuitively recognised proved to be more difficult due to the overlapping robot features and individuals' personal associations with the sounds. Identifying which voice corresponds to which robot will rely more on the user learning the robot voices than on intuition.

#### Intuitive understanding

The meaning of the notification sounds must be intuitively understood by the user to enhance the listening experience and ensure the safety of the listeners present in the barn. The notification sounds were found to be intuitively understood by the users. The use of auditory icons and the approach of mapping the urgency level to the rhythm of the sound proved effective in achieving this intuitive understanding.

#### Pleasantness

To prevent the user from removing the speaker/exciter from the robot, the sounds must be perceived as pleasant. Alarms are excluded from this requirement to ensure the user takes (immediate) action. Instead, alarms should be perceived as "acceptable" to prevent the removal of the audio system while maintaining their perceived urgency. The results from the user test show that the notification sounds perform as intended, with the non-urgent notification sounds scoring highly on perceived pleasantness and the alarms scoring lower on the pleasantness scale. That said, these results may differ after long-term exposure.

#### Audibility

The users must be able to hear the notification sounds over the ambient noise present in the barn. All the notification sounds are clearly audible above the ambient noise. In problem areas, such as the Astronaut A5, the frequency difference between the notification sounds and the ambient noise has been considered to improve audibility. Additionally, practical solutions are proposed to further enhance the audibility without increasing the loudness of the notification sounds.

#### Neighbour disturbance

The surrounding neighbours of the farmer should not be disturbed by the notification sounds. This report proposes several solutions to safely minimise both the frequency and loudness of the notification sounds without compromising their reliability. As the main focus of this project was the development of a sound design framework and a concise set of sounds, these solutions are merely proposals that require further exploration.

#### Cow well-being

The behaviour and productivity of the dairy cows must not be negatively impacted by the notification sounds. The sound design framework and notification sounds have been developed with the well-being of the dairy cows in mind. The impact of sound on the well-being of the cattle primarily depends on the intensity (dB), frequency (Hz), pattern, and duration of the sound. The allowed decibel range for the notification sounds is kept within a comfortable range for dairy cows: 65 to 70 dB for non-urgent sounds and 65 to 75 dB for critical alarms with a warning for alarms exceeding 70 dB. The dominant frequency components of the notification sounds are focused on a frequency range to which cows are less sensitive, i.e. outside of the 8000 Hz range. The pattern and duration of the non-urgent notification sounds are simple, slow, and short, designed to inform listeners in the barn without negatively affecting the cattle. The patterns and duration of the urgent notification sounds are more complex and faster, but with a maximum repetition duration of 5 minutes to avoid prolonged exposure to alarms.

#### Lely's brand identity

The notification sounds and robot voices are designed to be bright, positive, and pleasant to reflect Lely's optimistic, creative, and supportive communication style towards the user.

### 9.1.2 Wishes

Three nice-to-have objectives were formulated prior to the design phase. The first objective was to create sounds that dairy cows would find relaxing. While the sounds were designed to avoid disturbing the cows, this project did not assess whether they were perceived as relaxing. The behaviour of the cows following prolonged exposure to notification sounds should be studied to validate this objective.

The second objective aimed to develop a farm environment that was as quiet as possible. This project focused on balancing user safety and operational efficiency while keeping the notification sounds to a minimum. This balance was achieved by giving users more control over the occurrence and loudness of notification sounds.

The final objective was to enable users to customise the loudness within a predetermined range. This project defined two loudness ranges based on the ISO guidelines and the auditory perception of dairy cows, one for critical alarms (65 dB - 75 dB) and another for non-critical sounds (65 - 70 dB).

## 9.2 Validation

This section evaluates the final design using the DVF framework. This framework focuses on evaluating a product based on three key aspects: desirability, viability and feasibility.

### 9.2.1 Desirability

Desirability refers to how much the user needs or wants the new set of notification sounds. During the Empathise phase, the users' needs, wants, and pain points were identified. The need for new notification sounds was clearly communicated by the users. Through interviews with the farmers and farm visits, six main problem areas were identified, along with the users' desire to have more control over the occurrence of the sounds. These findings were used to formulate the requirements and wishes for the notification sounds. Throughout the design process, the design choices and sound prototypes were validated based on user feedback. The final design was evaluated against the requirements and wishes to ensure the needs of the users were met (see Chapter 9.1). While the new notification sounds seem to address the needs and wants of the users, further research is required to evaluate how the users experience the notification sounds after long-term exposure in a real-life environment.

### 9.2.2 Viability

Viability focuses on whether the sound design framework and notification sounds generate value for Lely in both the short and long term.

Lely strives to create innovative products that make the day-to-day lives of farmers easier and improve the well-being of their cattle. Part of this goal is ensuring that farmers and their cattle have positive interactions with their products. Providing clear and positive user feedback plays an important role in fostering these positive interactions.

The final design offers both short- and long-term solutions to the current issues. To directly address the inconsistent feedback and the unclear meaning of the notification sounds, structured guidelines are proposed for the buzzer sounds. These guidelines are based on the sound design framework developed for the speaker/exciter-based system to address the transition period where both robots with a buzzer and robots with an exciter/speaker-based system are present on the farm.

To ensure the new notification sounds will stand the test of time, a sound design framework is developed with concise guidelines for the creation of notification sounds for future Lely robots.

The implementation of the new notification sounds and exciter/speaker-based system does not require any significant additional hardware costs. The main cost involved in implementing this new system will be the man hours required to adapt the current system on an operational level.

### 9.2.3 Feasibility

Feasibility focuses on the technical and operational possibilities to implement the new notification sounds.

The implementation of the new notification sounds requires an exciter/speaker-based system to be integrated into the robots' hardware. There are exciters available on the market that meet the requirements and that can easily be implemented, thanks to the expertise of Lely's mechanical engineers.

With the new notification sounds, farmers are given more control over the loudness and occurrence of the notification sounds. This requires a few changes to be made at an operational level. The Lely service technicians will need to be trained to help farmers set the appropriate loudness of the notification sounds for the first time and to explain the rationale behind the notification sounds. The Lely apps that control the robots must be adapted to allow farmers to adjust the loudness themselves after receiving instructions, as well as to enable them to (de)activate the optional notification sounds. Lastly, a system to deactivate the notification sounds at night must be implemented. Similar systems have already been integrated into the Lely robots. The main challenge in this specific scenario is ensuring proper communication between Lely's product development teams to maintain consistency across all robots.

## 9.3 Recommendations

This section provides recommendations for the implementation of the new notification sounds. It addresses the limitations of this project and highlights the aspects that require further exploration in order to successfully integrate the new notification sounds into the Lely robots.

### 9.3.1 Long-term testing

The developed set of sounds has been evaluated through user tests in a one-on-one private setting. To assess how the user interacts with the sounds in a real-life scenario and whether they are still perceived as pleasant after a longer period of exposure, a test running over a longer period of time needs to be conducted. During the test, the behaviour of the dairy cows must also be studied, as the implementation of the notification sounds can have a significant impact on their well-being and productivity.

### 9.3.2 Minimising the amount of sounds

This project focused on the development of a sound design framework and a concise set of sounds. The results of the farmer questionnaire showed there is an interest in reducing the amount and frequency of the notification sounds.

To reduce the frequency and loudness of the notification sounds, the following solutions were proposed:

- Informative sounds only cows can perceive.
- A time-dependent loudness range.
- The (de)activation of notification sounds based on the user's presence.
- A location-based loudness range.

These solutions vary in their level of complexity and require further exploration before implementation.

### Sounds for cows

Developing sounds only cows are able to perceive is the most complex solution to implement. This solution takes advantage of the broad frequency range dairy cows are able to perceive, which covers the ultrasonic range of 17 to 37 kHz of an adult human. The frequency of the informative sounds aimed at cows could be adjusted to only be audible to dairy cows.

However, the effect of this solution is relatively small compared to its complexity. It would only minimise the occurrence of the "start driving", "driving backwards", and "driving" sounds of the Discovery Collector and the Discovery 90SW, two cleaning robots that are typically not present on the same dairy farm.

To implement these high-frequency sounds, a long-term observational study would need to be conducted to assess how the cows react to the sounds. Not only should it be evaluated whether the cows perform the intended actions upon hearing the notification sounds, but also how the cows perceive the sound in terms of pleasantness, to ensure the well-being of the cows is not negatively affected. The masking effect should also be considered, as determining if the sounds will be masked by other noises in the barn will require a different setup. This is because most sound pressure level meters and microphones cannot capture sounds above 20 kHz.

Another drawback of this concept is the hardware limitation. Most full-range audio systems have a frequency limit of 20 kHz, meaning they are unable to produce the ultrasonic cow sounds unless the frequencies remain within the 17 to 20 kHz range. There are audio systems available that cover the ultrasonic range. However, these systems either do not meet the size and IP-factor requirements or cannot produce frequencies below 20 kHz.

Lastly, the "start driving", "driving backwards", and "driving" sounds need to be audible to humans when the robot is driving outside the cowpen. This would require an additional feature to be added to the route calculation of the robots, consisting of indicating when the robot is inside or outside the cowpen to ensure the safety of other listeners present in the barn.

Ultimately, the effort involved in this concept exceeds its potential benefits. Therefore, it is not recommended to move forward with this concept.

### A time-dependent loudness range and the (de)activation of notification sounds

To minimise the disturbance of neighbours a time dependent loudness range was proposed. This solution adjusts the loudness of the notification sounds depending on the time of day. To enhance its effectiveness, this could be combined with the (de)activation of the notification sounds based on the user's presence. By combining these two solutions, the frequency and loudness of the notifications can be minimised. Through the Lely control app, the user could set the loudness for different times of the day and specify when notification sounds should be activated or deactivated.

This solution carries the risk of user error. To prevent dangerous situations or operational incidents, critical alarms must remain active during the day. To assess how users respond to this new feature and whether it addresses their needs, a long-term test needs to be conducted. Additionally, due to the risk of user error, a risk analysis should be carried out to evaluate the potential repercussions of such errors.

### A location-based loudness range

Another solution to minimise neighbour disturbance is adapting the loudness of the robots based on their location. This option can be achieved by using sensors to communicate to the robot when the loudness needs to be adjusted. This approach would require the installation of a new sensor system inside the barn. An easier alternative is to use the predetermined route of the Lely robots. When setting up a route for the robots, the user could be given an additional feature that allows the loudness of the notification sounds to be adjusted based on the robot's location. For instance, the loudness of the robot could be lowered when it is driving outside the barn. Adjusting the loudness within a route may be a tedious task for the user. Further research is needed to determine if the user is willing to use this feature.

### 9.3.3 Expanding the scope

The scope of this project focused on the development of notification sounds for the Dutch market. This choice was made because the perception of sound is largely influenced by an individual's cultural background. However, Lely's products are sold on an international scale. To improve the user experience of the Lely robots globally, the notification sounds need to be evaluated by people from different cultural backgrounds who are not familiar with Dutch culture. Based on these insights, potentially new sets of sounds will need to be created to suit the cultural context of other countries.

## 9.4 Reflection

This section provides a personal reflection on the entire project.

### 9.4.1 The project brief

The project aimed to develop a sound design framework and a concise set of sounds that could be implemented across all robots in Lely's product portfolio. Throughout the project, the need for sound-based user feedback that considers the needs and wants of the user became increasingly apparent. These needs and wants formed the basis of the final design. It also became clear that not every problem could be solved through new notification sounds. To address the identified core problems, changes needed to be made at an operational level, such as giving the farmer more control over the occurrence of notification sounds and their loudness.

### 9.4.2 The process

This report presents the project as a linear process. However, the design of the sounds and the creation of the sound design framework involved a continuous back-and-forth of making small iterations to improve the design. The project was divided into five phases: 1. Explore, 2. Empathise, 3. Define, 4. Design, and 5. Evaluate.

#### Explore

The Explore phase served as an introduction to the field of sound design, its opportunities, and its limitations. During the first part of the Explore phase, I conducted a literature review to gain a better understanding of the concept of sound and how it is perceived by the individuals present in the barn. Throughout this project, I focused on ensuring that the well-being of the dairy cows was not overlooked. Since the cows cannot speak for themselves, it was challenging to evaluate whether their needs were actually met. The concept of sonic interaction design was also explored during this phase to identify techniques I could use to design the notification sounds.

The second part of the Explore phase focused on understanding the current context and the shared acoustic environment in which the Lely robots operate. This part involved both desk and field research. The desk research was primarily centred on acquiring knowledge on how to measure ambient noise levels and learning more about the concept of acoustic biotopes.

#### Empathise

During the Empathise phase, I focused on understanding the users and the context in which they operate. I was fortunate to work with a user group that was very clear about their needs and wishes. All the farmers I spoke with expressed the same issues and desires, which made defining the main problem areas relatively easy. Through interviews with Lely's product owners and the safety & compliance manager, I gained insight into how the current situation came about, with the main cause being a lack of communication between the teams and never asking the users how they experienced the sounds.

#### Define

After identifying the problem areas, it became clear that not every issue could be solved by implementing a new set of notification sounds. Almost all the farmers expressed a need to minimise the amount of sound on their farms. I aimed to make the set of sounds as concise as possible. However, the majority of the sounds had to be included from a safety standpoint. To address this, I proposed several solutions to safely reduce the number and loudness of the notification sounds. The main focus of this project was the development of a sound design framework and a set of sounds. Due to time constraints, it was not possible to explore these solutions further. Instead, recommendations were provided for further research.

#### Design

Before starting the development of the sounds, I first needed to define which sounds should be created. There were several iterations before arriving at the final five sound categories. In the end, eight notification sounds needed to be created. Using the insights gathered from researching sonic interaction design techniques, I decided to use sound parameter mapping, auditory icons, and earcons. These techniques allowed the sounds to be intuitive and easy to understand.

For the creation of the sounds, I used Logic Pro, a professional audio editing software. Apart from experimenting with audio software in the past, I had no prior knowledge of sound production. I learned to use Logic Pro while developing the set of sounds. It did take some time to figure things out, but with the help from YouTube and music mastering blogs, I came a long way.

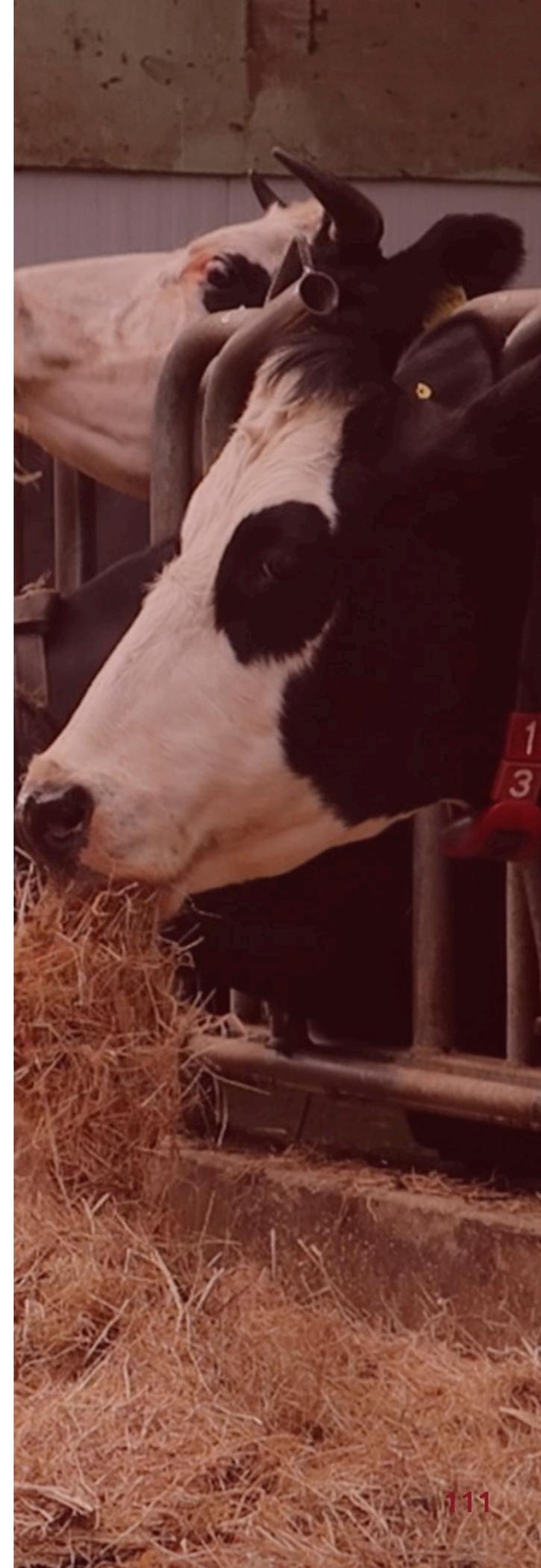
#### Evaluate

The final phase of this project is the Evaluate phase. During this phase, I assessed the set of sounds through user testing and a questionnaire. Initially, I used a questionnaire to gather as much feedback as possible, but this approach proved to be ineffective. The perception of sound is largely dependent on an individual's prior experience with certain sounds. Understanding why someone perceives a sound as (un)pleasant or associates a specific sound with a robot or action provides valuable insights into what could be adapted in the design. However, the questionnaire lacked these aspects, resulting in a collection of quantitative data without any real reasoning behind it. I then conducted physical user tests instead to evaluate the sounds, which provided insightful feedback for improving the design. Although the unsuccessful questionnaire attempt was a setback in terms of time and effort, some of the results were still valuable for making informed design decisions.

### 9.4.3 Personal Development

Before starting the project, I was a complete novice in the field of sound design. I never learned how to play an instrument, and I still cannot read musical notation. That said, I wanted to challenge myself by exploring a new area of design that piqued my interest. I enjoyed delving deeper into the topic of sound and directly applying the new knowledge I gained to the project. Although exploring a new field was stressful at times and required extra time to figure things out, it gave me newfound confidence, knowing that a good amount of motivation can go a long way. Throughout the project, it was easy to get lost in the details. I also found it difficult to present my thought process while all the ideas were still floating around in my head. Starting to write the report helped me organise my thoughts and allowed me to zoom out and see the bigger picture.

All things considered, I am satisfied with the final result I achieved within the given timeframe.



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- Appendix A: The use of sound in the automotive industry
- Appendix B: Ambient noise level measurements
- Appendix C: Project brief
- Appendix D: User test
- Appendix E: Farmer questionnaire
- Appendix F: The robot voices
- Appendix G: Buzzer guidelines

## Appendix A: The use of sound in the automotive industry

This appendix provides information about the use of sound in the automotive industry.

The implementation of audio and the improvement of the mechanical sounds of a car has been an integral part of the automotive industry. Car manufacturers use sound design to improve the driving experience and enhance the (perceived) safety of the vehicle. This section focuses on identifying the sound design techniques from an industry where sound design is well established, in order to find out how sound design can effectively be implemented to enhance the interaction between the listeners present in the barn and the Lely robots.

### Psychoacoustics

The sound design of cars is based on psychoacoustics principles. Psychoacoustics focuses on the cognition of sound and the psychology of how people perceive sounds (Murphy & King, 2022). A prime example of psychoacoustics in the automotive industry is the use of the masking effect, where a sound (a masker) is used to cancel out unwanted noise. Sounds from the outside world are filtered out by ambient noise to avoid driver's fatigue caused by constant noise exposure while driving.

The programming of the sounds inside the car also vary per region as carmakers are aware of the different interpretations of sound based on the cultural background of the user (Warren, 2022).

### Sound design for safety

Car manufacturers not only focus on the sound design on the inside of the car but also on the outside. With the rise of electric and hybrid vehicles the use of audio has become an important factor to comply with safety regulations. The vehicles are too quiet for their surroundings, especially for pedestrians. To combat these safety issues, it has become required by law for electric and hybrid vehicles to produce a constant sound when driving at a speed of 20km/h or less. The volume of the constant sound needs to range between 56 dB and 75 dB when measured at a 2 metre distance (ANWB, n.d.). Luxury car manufacturers use the mandated audio feedback as an opportunity to reinforce the car brand's image and differentiate themselves from competitors. The car brand Volvo for example created a set of alert and warning sounds that reflected luxury, safety, and their Scandinavian image (Sonic Minds ApS, n.d.).

## Appendix B: Ambient noise level measurements

This appendix shows the filled in measurement sheet of the ambient noise level measurements.

Date	Time started	Time finished	Weather
12-12-2024	13:30	16:15	Misty and humid

### Central barn measurements

Measurement	Distance (cm)	Height (cm)	Decibels measured
Central point barn	150 from gates	150	56.7 - 69.2 dB(A)
Entry barn	150 cm from entrance	150	53.3 - 63.3 dB(A)
Outside of the barn (infront)	150 cm from entrance	150	47 - 57 dB(A)

### Astronaut A5

Measurement	Distance (cm)	Height (cm)	Decibels measured
Operating Astronaut Milking	50	150	74 - 77.5 dB(A)
Walking past Astronaut Milking	150	150	69.4 - 76 dB(A)
Operating Astronaut Cleaning	50	150	80 - 85.8 dB(A)
Walking past Astronaut Cleaning	150	150	70 - 80.9 dB(A)

### Sphere

Measurement	Distance (cm)	Height (cm)	Decibels measured
Operating Sphere	50	150	61 dB(A)
Walking past Sphere	150	150	58.7 dB(A)

### Discovery Collector

Measurement	Distance (cm)	Height (cm)	Decibels measured
Operating Collector	50	150	61 - 68 dB(A)
Walking past Collector	150	150	57.5 - 65.5 dB(A)

### Discovery 90sw

Measurement	Distance (cm)	Height (cm)	Decibels measured
Operating 90SW	50	150	-
Walking past Discovery	150	150	-

### Juno

Measurement	Distance (cm)	Height (cm)	Decibels measured
Operating Juno	50	150	-
Walking past Juno	150	150	-

### Exos

Measurement	Distance (cm)	Height (cm)	Decibels measured
Operating Exos	50	150	-
Walking past Exos	150	150	-

### Vector

Measurement	Distance (cm)	Height (cm)	Decibel measured
Operating Vector	50	150	66 - 68 dB(A)
Walking past Vector	150	150	63 - 65 dB(A)

# Appendix C: Project brief

This appendix shows the original project brief composed prior to the start of the project.




## Personal Project Brief – IDE Master Graduation Project

Name student Kyara de Jong

Student number 5083451

**PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT**  
Complete all fields, keep information clear, specific and concise

**Project title** A new robot sound vocabulary: Sonic interaction design for farm-based robots, dairy farmers, and Lely technicians.

*Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.*

### Introduction

*Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)*

On modern dairy farms, automated machinery has become an essential tool in optimising milk production, reducing the farmer's workload, and improving the cattle's well-being. To ensure smooth operation and a safe environment, the machinery needs to be able to notify the farmer in case of emergencies or potential issues before they escalate. Each piece of machinery has its own set of sounds for this purpose. However, in order to create concise sound-based feedback, further research is needed to understand the farm environment from an acoustic biotope perspective. A lack of understanding in this area could result in poorly implemented feedback sounds, which may harm the well-being of the cows, reduce milk production, and cause frustration for the farmer (Dimov et al., 2023).

This project focuses on developing consistent sound-based user feedback for the Lely robots. Lely is an innovative company active in the agricultural sector. Their goal is to "make the life of farmers worldwide easier and work together on creating a sustainable, feasible and pleasant future in this field" (Lely, n.d.). Lely tries to achieve this goal by creating innovative solutions that help farmers run their farms more efficiently. Lely's product portfolio consists of a wide range of robots performing various tasks around the farm, see figure 1. The robots operate around the cattle on a daily basis. In order to not disturb the herd, the robots produce a limited set of sounds using a buzzer to notify the farmer.

The primary stakeholders in this project include Lely, Lely will be implementing the new set of sounds in their product portfolio. The farmers with one or more Lely robots and Lely's service technicians, this group will be relying on the new robot language to interact with the robots. The dairy cows, the cows interact with the robots on a daily basis. The sounds that the robots produce directly influence their wellbeing.

- Dimov, D., Penev, T., & Marinov, I. (2023). Importance of noise Hygiene in Dairy Cattle Farming—A Review. *Acoustics*, 5(4), 1036–1045. <https://doi.org/10.3390/acoustics5040059>
- Lely. (n.d.). Solutions for the agricultural sector. Retrieved August 8, 2024, from <https://www.lely.com/us/about-lely/>



Figure 1: Lely's product portfolio

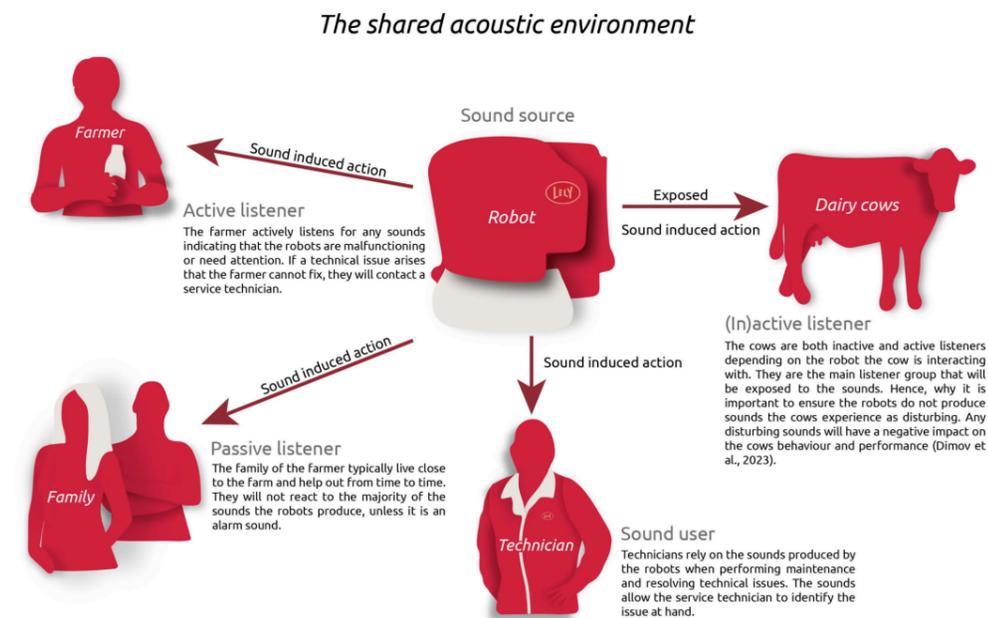


Figure 2: The shared acoustic environment inside the barn (Özcan et al., 2022)

## Personal Project Brief – IDE Master Graduation Project

### Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice. (max 200 words)

The primary issue Lely currently faces with the sound-based user feedback is the inconsistency in the robots' sound output, along with the use of sounds that are experienced as annoying by both farmers and technicians. This leads to farmers who are unable to identify which sounds belong to which robot, and frustration for both farmers and Lely technicians.

The farmers and the Lely technicians are the primary users of the robots' sound output. However, there are more listeners who will be affected by the sounds the robots produce. Figure 2 shows all the listeners in the shared acoustic environment of the barn that will be taken into account during this project. Depending on the type of robot the dairy cows will be active or inactive listeners. It is important to note that the cows will be exposed to sounds on a 24/7 basis. To ensure the well-being of the cows, their daily routine and their perception of sound will be taken into account during this project.

The challenge of this project is to evaluate which robot actions require sound-based user feedback, and to develop a concise set of sounds that can be implemented across all robots in Lely's product portfolio. The sounds must allow farmers to easily differentiate from which robot each sound is coming from. Additionally, the impact on the cows is an important factor to take into account, as a stressful environment negatively affects their milk production. This project provides an opportunity to implement sounds that are not only non-disturbing but also calming for the cows. This implementation is not only beneficial from an animal welfare perspective but also from a business perspective for the farmer, as a stress free cow is more productive (Lely, 2018).

- Lely. (2018, August 10). Maximum cow comfort for happy cows - Lely. Retrieved August 8, 2024, from <https://www.lely.com/us/news/2018/08/10/maximum-cow-comfort-happy-cows/>

### Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Develop a consistent set of sounds for the Lely robots encapsulated in the "Robot code of conduct handbook" with requirements for Lely's product development team to improve the sound-based user feedback for the farmers and technicians.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

The approach of this project is based on both sonic interaction design (SID) and the framework of acoustic biotopes. SID explores how sound can be used to convey information, emotions, meaning, or aesthetic attributes in an interactive context (Serafin et al., 2011). Acoustic biotopes are shared sound environments where sound-induced actions take place in a specific space, in this case the barn (Özcan et al., 2022). This framework will be used to analyse the shared acoustic environment and identify all the listener groups. During the first phase of the project, the following research questions will be explored to gain a better understanding of the current situation, identify user needs, and learn from the use of sounds in other contexts:

- What are the most important actions of the Lely robots?
- What sounds do the Lely robots currently make?
- How are the sounds interpreted and learned by the farmers and service technicians?
- What is the acoustic impact of the sounds on the listeners present in the barn?
- How do certain sounds affect the wellbeing of cows?
- What is the daily routine of the dairy cows?
- How are sounds utilised in other contexts, such as the automotive industry?

These research questions will be the foundation for answering the main research question: *How can variations in audio parameters be utilised to implement one base set of sounds across all robots in Lely's product portfolio?*

Based on these insights a list of requirements will be made to use as a guide during the design phase. The design phase will consist of an iterative approach, i.e. the cyclic process of prototyping, testing, and adapting. This ensures all the needs of the different listener groups are met in the final concept. The development of the sounds will be based on the research presented in previous bodies of work regarding the sonification of human robot interaction. Finally, during the evaluation phase the concept will be evaluated against the requirements.

- Özcan, E., Broekmeulen, C. L. H., Luck, Z. A., Van Velzen, M., Stappers, P. J., & Edworthy, J. R. (2022). Acoustic Biotopes, Listeners and Sound-Induced Action: A case study of Operating rooms. *International Journal of Environmental Research and Public Health*, 19(24), 16674. <https://doi.org/10.3390/ijerph192416674>
- Serafin, S., Franinovic, K., Hermann, T., Lemaire, G., Rinott, M., and Rocchesso, D. (2011). Sonic interaction design. In Hermann, T., Hunt, A., Neuhoff, J. G., editors, *The Sonification Handbook*, chapter 5, pages 87–110. Logos Publishing House, Berlin, Germany.

### Project planning and key moments

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting, mid-term evaluation meeting, green light meeting and graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).

Make sure to attach the full plan to this project brief. The four key moment dates must be filled in below

Kick off meeting	12 September 2024
Mid-term evaluation	04 November 2024
Green light meeting	21 December 2024
Graduation ceremony	03 February 2025

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	<input type="checkbox"/>
For how many project weeks	<input type="text"/>
Number of project days per week	<input type="text"/>

Comments:

### Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five. (200 words max)

With this project I hope to show the analytical thinking skills that I have developed over the course of my master. Specifically, the ability to justify my design choices through the lens of desirability, feasibility, and viability. Throughout the Integrated Product Design master the importance of sustainability was at the heart of the design process. During this project sustainability, in this case animal welfare, will play a crucial role in my design process.

Apart from the above-described learning objectives I will be focusing on the following personal learning ambitions as well:

- Being able to lead my own design project in a professional environment.
- Stakeholder management, this includes successfully communicating with the stakeholders to ensure everyone has a shared understanding of the project, making sure everyone is properly informed about the latest project progress, and managing the stakeholders' expectations.
- Explore a new field of design, i.e. human-robot interaction and sonic interaction design. A recurring theme during my studies is the exploration of different subdomains within the field of design. During my graduation project I want to challenge myself with a new subdomain and apply the skills that I learned during my studies on a project surrounding interaction design.

# Appendix D: User test

This appendix includes the informed consent form, the stimuli, the user script, and the test results.

## D1: Informed consent form

Participant ID: .....

### User test Lely sound design

This research is conducted as part of the MSc study Industrial Design Engineering at TU Delft.

Student: Kyara de Jong  
Contact person: Kyara de Jong

### Informed consent participant

I participate in this research voluntarily.

I acknowledge that I received sufficient information and explanation about the research and that all my questions have been answered satisfactorily. I was given sufficient time to consent my participation. I can ask questions for further clarification at any moment during the research.

I am aware that this research consists of the following activities:

1. Listening to a new developed set of sounds.
2. Answering questions regarding the set of sounds.

I am aware that data will be collected during the research, such as notes and audio recordings. I give permission for collecting this data. Data will be processed and analysed anonymously (without your name or other identifiable information). The data will only be accessible to the research team and their TU Delft supervisors.

The audio recordings will be used to support analysis of the collected data.

I give permission to store the data for a maximum of 5 years after completion of this research and using it for educational and research purposes.

I acknowledge that no financial compensation will be provided for my participation in this research.

With my signature I acknowledge that I have read the provided information about the research and understand the nature of my participation. I understand that I am free to withdraw and stop participation in the research at any given time. I understand that I am not obliged to answer questions which I prefer not to answer and I can indicate this to the research team.

I will receive a copy of this consent form.

\_\_\_\_\_  
Last name

\_\_\_\_\_  
First name

\_\_\_ / \_\_\_ / 2025  
Date (dd/mm/yyyy)

\_\_\_\_\_  
Signature

## D2: Stimuli

### Lely Robots



**Feeding**  
Vector MFR

**Feeding**  
Juno

**Feeding**  
Exos

**Milking**  
Astronaut A5



**Cleaning**  
Discovery Collector

**Cleaning**  
Discovery 90SW

**Cleaning**  
Sphere

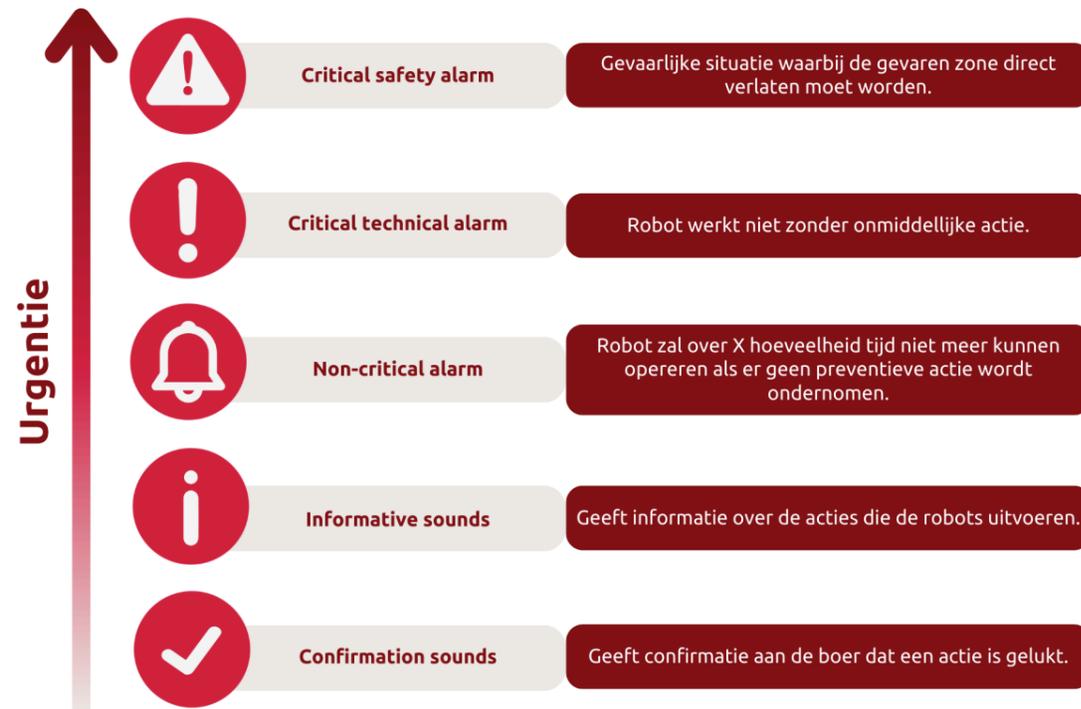
### Pleasantness

- |                 |            |            |          |               |
|-----------------|------------|------------|----------|---------------|
| <b>1</b>        | <b>2</b>   | <b>3</b>   | <b>4</b> | <b>5</b>      |
| Very unpleasant | Unpleasant | Acceptable | Pleasant | Very pleasant |

### Urgency

- |            |                 |                   |          |             |
|------------|-----------------|-------------------|----------|-------------|
| <b>1</b>   | <b>2</b>        | <b>3</b>          | <b>4</b> | <b>5</b>    |
| Not urgent | Slightly urgent | Moderately urgent | Urgent   | Very urgent |

## Geluid categorieën & Robot acties



### Critical safety alarm

### Critical technical alarm

### Non-critical alarm

### Informative sounds

- Starting a route
- Driving a route
- Driving backwards
- Warning: approaching narrow alley

### Confirmation sounds

- Connecting to the robot with the app
- Reset
- Calculating a route

## D3: Interview script

### First stage - Introduction

Thank you for participating in this user test. Today, we'll be discussing your experience with the new set of sounds that have been developed for the Lely robots. The goal is to evaluate how easily you can recognize the robots and robot actions based on these sounds, how urgent they feel, and how pleasant or unpleasant they are to listen to. There are no right or wrong answers, your response will help improve the current set of sounds.

During this session I will be playing two sets of sounds focused on recognising the robots and recognising the robot actions. After hearing the sounds, you will be asked a few questions regarding your recognition of the sound, how urgent the sound feels and how pleasant you find it.

There will be data collected in the form of audio recordings and notes. There will be no identifiable information gathered during this user test. Before starting, I would like you to sign this informed consent form after reading it thoroughly.

**Action:** give two informed consent forms. Give one informed consent form to the participant and keep one for yourself.

- Question: Do you have any questions before we begin?

#### Screening question

- Question: Are you familiar with these seven Lely robots?

**Action:** give the participant the overview of the seven Lely robots.

### Second stage - Identifying the robots based on sound

#### Introduction

In order to recognise the robots based on their sound each robot has their own distinct "voice". I will be playing all the sounds back to back first. After that, I will be playing each of the sounds separately. I want to ask you to choose one out of the seven robots you think best matches the sound and how you rate the sound in terms of pleasantness.

**Action:** play all the sounds back to back

**Action:** play one notification sound

- Question: Which of the seven robots do you think this sound belongs to, and why?

**Action:** play the sound again and give the participant the pleasantness rating scale.

- Question: On a scale of 1 to 5, how do you rate this sound in terms of pleasantness? (1 = Not pleasant, 5 = Very pleasant)
- What made the sound \*insert pleasant rating?

\*Repeat this process for each sound in the set.

#### Order of sounds:

Sound 1 = Discovery Collector

Sound 2 = Vector

Sound 3 = Juno

Sound 4 = Discovery 90SW

Sound 5 = Astronaut

Sound 6 = Exos

Sound 7 = Sphere

### Third stage - Identify the robot action based on sound

#### Introduction

Now we will be focusing on the different robot actions.

Action: Give the participant an overview of the five sound categories, a list of the type of robot actions and the rating scales for urgency and pleasantness.

The robot actions are divided in five different categories: critical safety alarm, critical technical alarm, non-critical alarm, informative sounds, and confirmation sounds.

Critical alarms indicate the occurrence of emergency involving possibility of injury. The listener needs to leave the danger zone immediately.

Critical technical alarms indicate the robot is unable to operate without immediate action. The robot needs to be immediately checked and a Lely service technician needs to be called.

Non-critical alarms indicate the robot will be unable to function in X amount of time and requires preventative or preparatory action.

The informative sounds provide information about the action the robot is performing. No action is required. Examples: start driving, driving, driving backwards.

Confirmation sounds provide information about the completion of a task the user asked the robot to perform. This sound will only occur when the user is operating the robot. Examples: resetting the robot, connecting to the robot with the app. The confirmation sounds all share one sound.

- Question: Do you have any questions regarding the sound categories?

I will now be playing all the notification sounds back to back. Afterwards, I will be playing each of the sounds separately. I want to ask you to choose one action you think best matches the sound and how you rate the sound in terms of pleasantness and urgency.

Action: play the sounds back to back

Action: play the robot action sound

- Question: What action do you think this sound belongs to? Choose one action from the list of actions.

Action: play the sound again

- Question: On a scale of 1 to 5, how do you rate this sound in terms of pleasantness? (1 = Not pleasant, 5 = Very pleasant)
- Question: What made the sound \*insert pleasant rating?
- Question: On a scale from 1 to 5, how urgent or pressing does this sound feel? (1 = Not urgent, 5 = Very urgent)
- Question: What made the sound \*insert urgency rating?

\*Repeat this process for each sound in the set.

Order of sounds:

- sound 1 = critical technical alarm
- sound 2 = start driving
- sound 3 = critical safety alarm
- sound 4 = driving
- sound 5 = narrow alley
- sound 6 = non critical alarm
- sound 7 = confirmation
- sound 8 = driving backwards

### Outro

Thank the participant for their time. Let the participant know that in the case of questions or concerns they are able to contact the researcher using the contact details on their copy of the informed consent form.

### D4: Interview data

#### Participant 1

##### Second stage - Identifying the robots based on sound

Sound 1 - Discovery Collector:

- Discovery 90SW
- De positie van de robot zit tussen de koeien. Hogere frequentie dus hoor je sneller. Je hebt hogere frequenties nodig om hem te vinden. Iets hogere toon dan Collector vanwege formaat.
- 3 pleasantness, het geluid is vervelend maar het is goed om te weten waar het is.

Sound 2 - Vector:

- Twijfel tussen Juno of Vector. Ik denk Juno.
- Het geluid is iets hoger dan het andere geluid dat ik heb gehoord. Formaat is belangrijk. Het geluid is iets doffer.
- 4 pleasantness, minder penetrerend. Verdwijnt lekker op de achtergrond.

Sound 3 - Juno:

- Discovery Collector, toonhoogte weer. Hogere toon kleine robot.
- 4 pleasantness, het hoge piepje voelt alsof die weg fade waardoor die minder hard is. Vind ik wel chill.

Sound 4 - Discovery 90SW:

- Astronaut, het is een stationaire robot en het is belangrijk om te horen dat hij het doet. Het zit tussen alle geluiden in. Valt niet gelijk op maar wel nog goed hoorbaar.
- 3 pleasantness, voor de melkrobot is het te high pitched. Geluid op zichzelf een 4 maar in Context van melkrobot een 3.

Sound 5 - Astronaut A5:

- Exos, omdat dat ding er raar uit ziet, dus dan heeft het ook een raar geluidje. Het voelt alien futuristisch. Ik denk ook aan de locatie. Hij is op het veld dus dan hoeft je ook geen hele hoge pitch geluiden te hebben. Ik denk dat je niet hele hoge bass of frequentie wilt hebben, de burens worden dan helemaal lijp.
- 5 Pleasantness, klinkt net wat anders dan de andere geluiden. Het geluid zelf zegt meer voor mij. Bij de andere was het meer de pitch. Omdat deze in het veld rijdt werkt dit aparte geluid. Anders heb je te veel aparte geluiden in de stal. Apart werkt bij een buitenrijdende robot.

Sound 6 - Exos:

- Vector MFR, ja gewoon, het is dof genoeg om niet irritant te zijn maar het geeft wel aan dat het een groot ding is. Je ziet hem al in de stal rijden, het geeft aan dat hij het doet en rijdt.
- 5 pleasantness, ik zal hier gewoon naar luisteren in mijn oortjes. Ik denk dat deze makkelijk op de achtergrond wegvalt als ik bezig ben.

Sound 7 - Sphere:

- Sphere maar ik vind hem te hoog voor de Sphere. De Sphere is groot en log. Fuck it misschien zou het voor de context voor de sphere wel kunnen de hoge toon. Dan hoor je hem beter vanuit de stal of vanuit de tracker.
- 4 pleasantness, gewoon chill geluidje, geen rare hoge frequenties. Gewoon goed.

### Third stage - Identifying the robot action based on sound

#### Sound 1 - Critical technical alarm

- Critical technical alarm, het patroontje heeft een soort politie sirene. Ik verwacht zo'n soort alarm ook bij een safety alarm maar die moet irriterender zijn.
- 4 pleasantness, chill geluid maar valt wel op
- 4 urgent, het geluid zelf is niet urgent maar het patroon maakt het urgenter.

#### Sound 2 - Start driving

- Start driving, het klinkt als een startschot zoals bij een race.
- 5 pleasantness, het geluid is mellow smooth
- 2 slightly urgent, snelheid van de piepjes denk ik wel, er gaat iets gebeuren maar ik ben niet vol stress mode.

#### Sound 3 - Critical safety alarm

- Warning: approaching narrow alley, omdat ik hier moet denken aan JAWS. Je moet wel echt weg uit de alley of iets doen dat die stopt anders ben je de sjaak.
- 1 pleasantness, het geluid zelf voelt heel erg naar. Ik krijg er een naar gevoel van waardoor ik het gevoel heb dat ik iets moet doen om het te laten stoppen.
- 4 urgency

#### Sound 4 - Driving

- Driving backwards, normaal bij een auto die achteruit rijdt heb je ook een piep. Maar omdat onze robots langzamer rijden is zo'n intense piep niet zo nodig. Als een langzame auto op je afkomt hoef je ook niet constant piepppeip piep piep.
- 5 pleasantness, gewoon fijn geluidje.
- 2 urgency, het is wel weer een ander patroon dan die ik net gehoord heb dus dan denk ik wel hup opletten.

#### Sound 5 - Narrow alley

- Non-critical alarm, ik denk dat we willen met non-critical dat het geen kritisch alarm gaat worden maar je wilt mensen wel de push geven om het nu al te doen. Het doet me denken aan een batterij die bijna op gaat.
- 4 Pleasantness, chill geluid.
- 3 urgency, hij was opdringeriger. Dus voelt dan ook wat meer urgent. "Het voelt als een leidinggevende die in je nek zit te hijgen."

#### Sound 6 - Non-critical alarm

- Driving a route, hetzelfde als driving backwards maar deze is wat feller. In verband met snelheid denk ik dat het belangrijk is als die feller is dan achteruit.
- 4 pleasant, gewoon prima.
- 3 urgent, hij wat feller dus het voelt alsof ik meer moet opletten.

#### Sound 7 - Confirmation

- Confirmation sound, gewoon de tum tum (laag hoog) klinkt als een bluetooth device connectie. Het voelt alsof je je muis verbindt aan je Windows laptop. Het zegt: Ik heb het ontvangen.
- 5 pleasantness.
- 1 urgent, totaal niet urgent. Life goes on, shit is gedaan, ik ga naar huis.

#### Sound 8 - Driving backwards

- Critical safety alarm, ik vind hem daar wel passen. Moet alleen nog wat luider.
- 2 pleasantness, is te hoog en is net iets te snel om fijn te vinden. Wat goed werkt want je wil dat mensen weg gaan en niet dat mensen daar met hun marshmallow gaan staan terwijl dat ding in de fik staat.
- 5 urgent, urgentie komt doordat die irritant is en een hoog tempo.

### Participant 2

#### Second stage - Identifying the robots based on sound

#### Sound 1 - Discovery Collector:

- Discovery 90SW, ik denk dat het een kleine robot is.
- 3 pleasantness, het heeft iets hards. Ik kan me voorstellen dat als je in de stal loopt, dat het wat urgenter is. Het is iets te scherp. Andere geluiden waren meer flowy/ dromerig.

#### Sound 2 - Vector:

- Exos, wat groter en zwaarder vanwege lagere toon.
- 4 pleasantness, er zit een soort dissonantie in waardoor je denkt: "er is iets niet goed" maar dat ligt aan de boodschap.

#### Sound 3 - Juno:

- Astronaut maar later switch naar Juno, Astronaut: ik denk omdat ik het misschien ergens anders heb gehoord. Het voelt een beetje gemiddeld tussen alle andere geluiden.
- Juno: deze heeft een wat hogere frequentie (toonhoogte) en de Juno is een wat minder grote robot. Ik associeer de hogere toonhoogtes met een kleine robot.
- 4 pleasantness, ik vind hem wel wat hard, als in volume.

#### Sound 4 - Discovery 90SW:

- Discovery Collector, kleiner apparaat.
- 4 pleasantness, hier zitten misschien dubbele tonen in. Het voelt in harmonie.

#### Sound 5 - Astronaut A5:

- Vector MFR, het is een wat lager geluid in toonhoogte en de MFR is een wat groter apparaat. Deze heeft ook iets spacey achtigs.
- 4 pleasantness, ik vind een wat lagere toonhoogte aangenamer omdat die wat minder scherp is.

#### Sound 6 - Exos:

- Sphere, het lijkt bijna op een soort strijkinstrument. Een snaar van een cello en dat associeer ik met iets rustigs kalms. De Sphere staat daar gewoon rustig zijn werk te doen.
- 5 pleasantness, het heeft iets van tevredenheid, geen scherpe tonen en ook wat lager in toonhoogte.

#### Sound 7 - Sphere:

- Astronaut (was eerst Juno), Het is geen vol geluid dus dan denk ik iets kleiner of stationairs. Het lijkt op een ziekenhuisbed dus dan associeer ik het gelijk met iets wat stilstaat.
- 5 pleasantness, hij voelt wat gedempt waardoor die op de achtergrond zit.

### Third stage - Identifying the robot action based on sound

#### Sound 1 - Critical technical alarm

- Critical technical alarm, meer in vergelijking dat er nog eentje was die kritischer was. Deze is best wel snel. De snelheid zorgde ervoor dat ik hem vervelend vond, dus toen dacht ik dat hij kritisch was, een soort van stress.
- 2 pleasantness, onaangenaam omdat het zo snel gaat en daarmee ook de urgentie. "Er moet nu iets gebeuren. Het gaat niet goed!"
- 4 urgent, het heeft iets ongeduldigs.

#### Sound 2 - Start driving

- Start driving, het doet me denken aan Mario Kart. Hij gaat omhoog dus dan denk ik er iets goed gegaan.
- 4 pleasantness, voornamelijk door de laatste toon die omhoog gaat. Dat associeer ik met goed, er is iets gelukt.
- 2 urgent, Bij de eerste tonen kreeg ik wel het idee dat ik moest opletten maar door de laatste hoge toon nam de urgentie af.

#### Sound 3 - Critical safety alarm

- Critical safety alarm, valse tonen (geen harmonie) en snel.
- 1 Pleasantness, de valsheid van de tonen door elkaar voelt gewoon niet in harmonie dus niet pleasant.
- 5 Urgent, juist omdat het niet prettig voelt door de dingen die ik zei krijg ik het idee dat het urgent is. Ik wil dit niet, ik wil dat het nu weg gaat.

#### Sound 4 - Driving

- Driving, het is heel steady, langzaam en vooral informatief. Er zit weinig urgentie in.
- 5 pleasantness, omdat het niet zoveel is met de lange pauze ertussen. De lage toon maakt het ook dat het wat warmer aanvoelt.
- 1 urgent, door de langzaamheid en lage toonhoogte.

#### Sound 5 - Narrow alley

- Narrow alley, het snelle achter elkaar geeft wel aan mmm er is iets maar het is niet heel erg.
- 5 Pleasantness, de lage toonhoogte en het langzame tempo waardoor die heel kalm vloeit. Dat voelt fijn.
- 2 urgent, de dubbele snelle toon zorgt voor urgentie. De lange pauze zorgt dat de urgentie wordt afgevlakt.

#### Sound 6 - Non-critical alarm

- Non-critical alarm, dat komt ook door de vorige test. Ik dacht ook dat dit op achteruit rijden lijkt.
- 3 pleasantness, er zit een soort valse toon in waardoor het niet in harmonie is. Vind ik niet fijn.
- 3 urgent, Het is wat langzamer waardoor het minder kritisch is.

#### Sound 7 - Confirmation

- Confirmation, het is herkenbaar. Toen ik het geluid voor het eerst hoorde zag ik ook een vinkje voor me. Je gaat eerst naar beneden en dan omhoog.
- 3 Pleasantness, ik vind het niet zo chill want er zitten twee tonen in die ik niet helemaal bij elkaar vind passen. Er zit een te grote stap tussen de toonhoogte.
- 1 Urgent, het voelt wel licht en die toon omhoog dat het goed is.

#### Sound 8 - Driving backwards

- Driving backwards, ik denk binnen de range die je hebt laten horen dat deze het meest herkenbaar is. Het is een chill ritme niet te snel.
- 4 pleasantness, het ritme is fijn: niet te snel en niet te langzaam.
- 1 Urgent, door de luidheid komt het minder hard aan. Het zweeft een beetje. Het voelt in harmonie.

### Participant 3

#### Second stage - Identifying the robots based on sound

#### Sound 1 - Discovery Collector:

- Ik twijfel tussen de Juno en de Discovery Collector. Maar omdat die zo hoog is, denk ik dat het de Discovery Collector is. Omdat de Discovery Collector belangrijker is en de toon hoog is denk ik de Discovery Collector.
- 4 pleasantness. Ik erger me niet aan de toon ondanks het feit dat het een hoge toon is. De afwisseling is heel geleidelijk.

#### Sound 2 - Vector:

- Ik ga richting de feedingkant op. Ik twijfel tussen de Vector en de Juno. Omdat het een lage toon heeft is de urgentie nog niet zo hoog dus daarom de Juno. Ik ga toch voor de Vector FMR omdat ik denk dat bij de Juno de toon iets lager zal zijn omdat deze minder belangrijk is. Hoe lager de toon, hoe minder belangrijk.
- Switch naar Exos, dit duintje doet me denken alsof een elektrische auto een deuntje krijgt. De Exos lijkt ook meer op een elektrische auto dan de Vector FMR.
- 4 pleasantness, ik vind dit een subtiel alarm. Het ergert me ook niet.

#### Sound 3 - Juno:

- Ik vind deze kwa toon hoog. De afwisseling tussen de tonen vind ik iets korter. Dan krijg ik al het gevoel dat het urgenter is omdat het iets sneller is dan de rest. Daarom denk ik aan de Astronaut A5.
- 4 pleasantness, ik twijfelde tussen de 3 en 4 omdat het een hogere toon is dan de rest en de overgang van de een na de andere toon iets korter is. Het kan iets korter naar mijn mening omdat de milking robot iets gevaarlijker is. Omdat deze robot direct contact heeft met de koe verwacht ik een urgenter geluid.

#### Sound 4 - Discovery 90SW:

- Ik ga voor de Exos want de Exos zelf is een grote robot. Als hij ergens tegenaan komt, kan het kapot gaan. Ik denk dat de boer dat wel snel moet horen, daarom de hoge toon.
- Switch naar Vector FMR, het voer kan bijvoorbeeld op zijn dus dat is urgent. De Vector heeft meer dingen die je snel moet weten.
- 4 Pleasantness voor de Exos, het doet me denken aan een speelauto die vast zit. Het doet me denken aan een vrachtwagen die achteruit rijdt. Ik vind de korte tussen momenten goed.

#### Sound 5 - Astronaut A5:

- Waarom moest ik gelijk denken aan Star Wars. Aan Wall-E, zo heet hij toch? De Juno lijkt op Wall-E. Ik krijg er een futuristisch gevoel van. Ik vind het totaal niet passen bij de Astronaut. Ik twijfel tussen de Juno en de Sphere. Maar de Sphere is altijd buiten een stal dus als de toon wat lager is, is het dan ook moeilijker om te horen? Ik ga nu voor de Sphere omdat het afwijkt van de andere geluiden die ik heb gehoord. De Sphere staat buiten dus het geluid moet ook anders zijn dan de robots in de stal. Stel er is een probleem met de Sphere, dan zal het ook niet zo urgent zijn als bij de andere robots. Ik associeer lagere tonen met robots die geen contact hebben met de koe en die minder risico hebben op veiligheidsproblemen.
- 3 Pleasantness, omdat de afwisseling nog te kort is, dat mag van mij nog wel iets geleidelijker.

#### Sound 6 - Exos:

- Juno, omdat die ten eerste een beetje op Wall-E lijkt. Het geeft me weer een beetje zo'n futuristisch gevoel. Dit geluid associeer ik weer met de Juno die dan ergens tegenaan rijdt. De Juno komt niet echt in contact met de koe dus de urgentie hoeft niet zo hoog te zijn.
- 4 pleasantness, Ik vind het gewoon een heel aangenaam geluid.

#### Sound 7 - Sphere:

- Discovery 90SW, deze vond ik het subtielst. Ik zit wel te twijfelen tussen de Sphere en de Discovery 90SW omdat ik de urgentie niet echt voel. Ik hoor het verschil met de rest maar het laat me ook gelijk twijfelen met de andere geluiden omdat het een beetje lijkt op iets anders wat ik heb gehoord.
- 3 pleasantness, in vergelijking met de rest vind ik het minder aangenaam. Ik kan het nog niet echt een plekje in mijn hoofd geven. Ik associeer heel snel een geluid met een bepaald beeld wat ik heb en met dit geluid heb ik dat wat minder. De Discovery 90SW is ook het kleinst dus dan komt die misschien sneller vast te zitten.

### Third stage - Identifying the robot action based on sound

#### Sound 1 - Critical technical alarm

- Het is een deuntje dat best wel snel gaat. Omdat het snel gaat ligt de urgentie denk ik ook hoger. Daarom denk ik critical technical alarm.
- 4 Pleasantness, Het is niet een storend deuntje.
- 3 Urgentie, dat komt omdat het mij niet ergert. Het is best wel subtiel. Ik snap dat er urgentie is maar niet dat het uiterst gevaarlijk is.

#### Sound 2 - Start driving

- Ik zit hier heel erg te twifelen tussen de informatieve geluiden en de confirmatie geluiden. Het doet me denken aan een bluetooth geluid of dat er iets wordt berekend.
- Uiteindelijke keuze: confirmation sounds.
- 4 Pleasantness, ik vind het echt gewoon een helder geluid.
- 1 urgentie, geen enkel gevoel van urgentie, het is meer een bevestiging.

#### Sound 3 - Critical safety alarm

- Dit is echt kritisch. Dit geeft gevaar aan. Dit doet me denken aan films waar gevaar nadert. Ik kies critical safety alarm. Ik zou wel de zone verlaten als ik dit hoor.
- 2 Pleasantness, Ik associeer het met een nare ervaring.
- 4 Urgentie, geen vijf want als iets echt urgent is heb ik een sirene in mijn hoofd.

#### Sound 4 - Driving

- Informative sounds, dit is echt een kort moment om aan te geven iets gaat van start. Starting a route of driving backwards. Maar mijn gevoel gaat toch meer uit naar starting a route.
- 4 Pleasantness, aangenaam deuntje en het is gewoon duidelijk.
- 1 Urgentie, ik voel geen enkele vorm van urgentie.

#### Sound 5 - Narrow alley

- Ik twijfel tussen driving backwards en warning narrow alley. Het lijkt een beetje op zo'n stop geluid. Ik ga eerder voor een warning: approaching narrow alley omdat ik vind dat er korte tussentijd in zit waardoor het meer waarschuwt.
- 4 Pleasantness, ik weet dat het een waarschuwing is maar ik vind het niet storend.
- 2 Urgentie, Het komt over als een melding/ waarschuwing. Van hey, pas op.

#### Sound 6 - Non-critical alarm

- Ik twijfel tussen critical technical alarm en non-critical alarm. Na het nog een keer horen van geluid 2 duidelijk non-critical alarm. Ten opzichte van geluid 2 is deze wat subtieler. Ik weet wel dat er actie van mij wordt verwacht maar omdat het geleidelijk is doet het deuntje me denken alsof iets straks gaat uitvallen zoals lege batterijen. Ik moet iets doen op het gebied van de robot zelf maar niet urgent.
- 3 Pleasantness.
- 3 Urgentie, Ik sta er heel neutraal in bij dit geluid.

#### Sound 7 - Confirmation

- Hier krijg ik het gevoel dat er iets van start gaat: start driving. Ik krijg wel het gevoel dat ik zelf iets invoer en dat ik dan een bevestiging krijg. Switch naar driving a route.
- 3 Pleasantness, ik vind het een aangenaam geluid maar iets te lang voor driving denk ik. Als boer wil ik iets kort en snels.
- 1 Urgentie, het geeft in geen enkele vorm een gevoel van "er iets aan de hand". Het geeft meer een bevestiging dat hij weer gaat rijden.

#### Sound 8 - Driving backwards

- Driving backwards, hier heb ik echt het gevoel van: ja, er gaat iets achteruit. Het lijkt op het geluid van auto's die achteruit rijden.
- 3 pleasantness, het is niet echt een geluid dat opvalt. Het is gewoon een acceptabel geluid
- 1 urgentie, het is een middelmatige toon en valt niet echt op.

### Participant 4

#### Second stage - Identifying the robots based on sound

##### Sound 1 - Discovery Collector:

- Discovery Collector, Het was een vrij licht geluid vergeleken met de andere geluiden. Het was een iets meer vrolijke klank. De latere geluiden klonken wat serieuzer omdat ze dieper waren en er minder pling in zat.
- 5 Pleasantness, Ik vind het wel een chill geluid. Er zit een bepaalde vibratie in het geluid. Het klinkt meer als een natuurlijk geluid door een bepaalde vibratie wat erin zat. Er waren twee tonen: de lage toon zat op een aangename frequentie, ik denk dat de hoge toon meer is om je aandacht te pakken. Maar ondanks dat die wat hoger was, is die niet storend. Ik zou hier voor een langere tijd naar kunnen luisteren. Ik denk dat de twee tonen goed werken. Het is simpel.

##### Sound 2 - Vector:

- Vector, Het was een iets dieper geluid. Maar het klonk niet super serieus. De functies van de Vector vind ik belangrijker dan de Discovery Collector.
- Tweede keer horen: ik twijfel of dit nu wel de Vector is. Ik twijfel of het nu ook de Exos zou kunnen zijn. Maar ik blijf bij de Vector. Bij de Exos dacht ik net een iets meer futuristisch geluid te horen. De Vector is meer traditioneel dus dan ook een meer traditioneel geluid
- 5 pleasantness, Ik denk dat het een geluid is waar je wel voor een langere tijd naar kan luisteren.

##### Sound 3 - Juno:

- Discovery 90SW, ik baseer het op: hoe hoog klinkt het geluid en hoe serieus klinkt het geluid. Minder serieuze geluiden horen bij kleinere robots en de functie.
- Tweede keer luisteren: het zou ook nog de Juno kunnen zijn. Het is in ieder geval een kleinere robot.
- 4 pleasantness, ik vind de andere geluiden denk ik meer pleasant. Ik weet niet welke key dit is maar het lijkt op een soort C. De lage toon leek harder in volume dan de hoge toon. Dit geluid klinkt iets meer alsof je een film aan het kijken bent en iemand sneakt ergens naar toe. Vandaag de 4 ipv de 5. Ik word er suspicious van.

##### Sound 4 - Discovery 90SW:

- Juno, Die klinkt iets meer natuurlijk dan het vorige geluid. Want er zit een soort van stok die ergens op slaat. De "toenk" klinkt als een soort xylofoon met een houten ding. Hij klonk wel vrij hetzelfde qua formaat als het vorige geluid. Daarom denk ik de Juno.
- 5 pleasantness, ik vond hem opzich wel very pleasant. Het klinkt minder suspicious dan het vorige geluid.

##### Sound 5 - Astronaut A5:

- Exos, ik blijf bij de Exos omdat het veel meer futuristisch klinkt. Ondanks dat er hoge tonen in zitten klinkt het wel zwaarder. Het klinkt futuristisch omdat het meer als een laserachtig synth geluid klinkt. Het past bij de Exos omdat het product zelf ook meer futuristisch is (nieuw product). Het concept op zichzelf is ook vernieuwend. Iets wat futuristisch klinkt heeft meer synth, iets wat traditioneel is klinkt meer organisch. Het klonk als een laser, de hoge tonen maar de lage tonen waren wel zo laag dat ik het associeer met een grote robot.
- 4 pleasant, ik vind deze iets minder pleasant omdat het minder organisch klinkt. Ik vind het wel goed bij de Exos passen.

##### Sound 6 - Exos:

- Sphere, Dit geluid klinkt serieus. Als de Sphere een probleem heeft is het waarschijnlijk erger dan de Discovery Collector. Dit geluid klinkt serieuzer dus vandaar de Sphere.
- Tweede keer luisteren: het klinkt als een zwaarder geluid, dus een groter iets. Het klinkt ook alsof er een echo of reverb op zit waardoor het geluid groter klinkt. Het voelt alsof je in de mestput zelf zit. Een geluid wat minder reverb geeft klinkt kwa ruimte kleiner. Als je meer reverb op een geluid zet klinkt het groter doordat het geluid verder reikt.
- 4 Pleasantness, ik zou hem eigenlijk middenin 4 en 5 zetten. Maar als dat niet mag, ga ik voor 4. Hij klinkt iets meer als een soort van suspicious geluid dan de andere geluiden die ik hoorde. Er is iets sneakies aan dit geluid. Ik kan het niet helemaal plaatsen. Het klinkt alsof het om de hoek zit. Het is mysterieus. Je hoort maar je kan niks zien, daarom minder fijn dan 5 pleasantness.
- Verandering: Astronaut A5, het kan ook zijn dat het zo klinkt omdat het rechtstreeks naast de koeien staat. Dus dan wil je niet al te hoge tonen gebruiken dus dan iets meer reverb.

#### Sound 7 - Sphere:

- Astronaut A5, formaat robot en taak.
- Tweede keer horen: ik denk dat ik wat moet gaan omdraaien. Dit klinkt iets meer als een hartmonitor. Dus je zou zeggen dat het iets meer te maken heeft met iets wat leeft, dus iets met de koe. Tegelijkertijd klinkt het best wel serieus. Dus ik twijfel. Kwa formaat kan ik hem moeilijk plaatsen. Het kan zijn dat ik de laatste twee dan toch omdraai. Nee. Ik vind de laatste twee heel lastig.
- Toch switch naar Sphere.
- 3 Pleasantness, het klinkt als een hoog geluid maar ook ja.. Het klinkt iets meer gevaarlijk. Ik vond hem wel moeilijk te plaatsen.

#### Third stage - Identifying the robot action based on sound

##### Sound 1 - Critical technical alarm

- Critical technical alarm, dat klonk vrij serieus.
- 4 Pleasantness, omdat het geen hard en scherp geluid is. De toon zelf is pleasant maar omdat die zich vaak herhaald en het een snel patroon is wordt het urgent.
- 4 Urgentie.

##### Sound 2 - Start driving

- Non-critical alarm, omdat het eindigt met een positieve toon waardoor ik denk dat het een minder urgent alarm is. Het is best wel een lang geluid dus dan denk ik niet confirmation of information sound. Ik verwacht een korter geluid bij een confirmation of information sound.
- 4 pleasantness, het is een natuurlijk geluid. Het geluid op zichzelf is aangenaam om naar te luisteren en het eindigt op een hoge positieve toon.
- 3 urgentie, het klinkt minder urgent dan het vorige geluid omdat het zich niet herhaald.

##### Sound 3 - Critical safety alarm

- Critical safety alarm, Oh my goodness. Dit klinkt een beetje alsof ik in een horror film zit. Bij dit geluid denk ik wel "oh volgens mij moet ik nu wel iets gaan doen anders gaat er iets fout".
- 2 Pleasantness, het is unpleasant maar ik snap waarom het unpleasant is.
- 5 Urgentie, ik kan me geluiden voorstellen die nog meer urgent zijn maar ik snap dat dat misschien niet handig is in de context van boerderij.

##### Sound 4 - Driving

- Driving a route of non-critical alarm, Hmmm lastig. Voor Driving a route vind ik het iets te intens om het zo snel achter elkaar te horen. Omdat het zich herhaalt kan het geen confirmatie geluid zijn. Als er meer tijd tussen de tonen zat zou ik driving a route zeggen.
- Keuze: driving
- 4 Pleasantness, omdat de toon op zichzelf pleasant is om naar te luisteren. Het geluid op zichzelf is een aangenaam geluid.
- 1 of 2 urgentie, Ik denk dat er toch een bepaalde urgentie in zit omdat hij toch wel vaak herhaalt. Als die minder snel achter elkaar zou klinken zou ik 1 kiezen.

##### Sound 5 - Narrow alley

- Eerste keer luisteren: Nog geen idee.
- Tweede keer: ik vind het lastig. Informatief zou kunnen. Warning: approaching narrow alley. Hij klinkt alsof hij iets van je wil. Er is iets aan de hand maar tegelijkertijd ook weer niet. Daarom warning informatief geluid. Je moet wel opletten.
- 4 Pleasantness, natuurlijk geluid is aangenaam.
- 2 Urgentie, vanwege het patroon. Er is twee keer iets en dan weer niks en het herhalende zorgt voor iets meer urgentie.

#### Sound 6 - Non-critical alarm

- Non-critical alarm of driving backwards, I don't knowww. Dit wordt heel moeilijk. Er zitten te veel dingen bij die een non-critical alarm zouden kunnen zijn. Het klinkt alsof er iets gaande is maar tegelijkertijd niet kritisch. Het geluid herhaalt zich vaak genoeg waardoor je actief aan het luisteren bent. Er is iets gaande maar het is niet kritisch.
- 4 Pleasantness, de algemene ervaring van het geluid is aangenaam.
- 3 Urgent, hij is herhalend. Hij heeft twee verschillende tonen. De snelheid van het herhalen van de tonen maakt het toch wel semi urgent.
- Note: participant kwam hier echt niet uit. Hij zat erg te twijfelen tussen driving backwards, non-critical alarm of warning: narrow alley way.

#### Sound 7 - Confirmation

- Start driving, dat klinkt als een startgeluid. Ook omdat die korter is. Bij een langer geluid denk ik aan een meer kritisch geluid.
- Tweede keer luisteren: starting a route of confirmation. Het klinkt positief door de lage toon gevolgd door de hoge toon.
- Uiteindelijke keuze: confirmation
- 5 pleasantness, fijn geluid.
- 1 Urgentie, omdat het een kort geluid is en eindigt op een positieve toon.

#### Sound 8 - Driving backwards

- Driving backwards, omdat ik het associeer met een vrachtwagen die achteruit rijdt.
- 4 Pleasantness,
- 2 Urgent, als een robot achteruit rijdt is het misschien niet urgent maar je houdt wel je aandacht erbij door de hoge toon die zich herhaalt.

## Participant 5

### Second stage - Identifying the robots based on sound

#### Sound 1 - Discovery Collector:

- Juno, door de high pitch. Het is een soort van kort maar duidelijk.
- 4 Pleasantness, het is niet dat ik zeg: het is geweldig maar het is goed. Het geluid is niet te schel. Het is duidelijk en helder.

#### Sound 2 - Vector:

- Eerst Exos bij gezet maar ik denk misschien toch Sphere. Dit geluid is anders dan de rest daarom de Sphere. Er zijn twee geluiden die meer galm hebben en wat dieper zijn dus dan denk ik dat die zijn om statische robots aan te geven. Deze is wat dieper dus Sphere.
- 4 pleasantness, het klinkt gewoon goed. Geen vervelende hoge pitches. Het is comfortabel voor het oor.

#### Sound 3 - Juno:

- Exos, Ik denk dat de Juno, Exos en Vector een soortgelijk geluid moeten hebben omdat ze bij dezelfde familie horen: feeding. Deze klinkt als geluid 1.
- 4 Pleasantness, aangenaam voor het oor. Het is duidelijk om te horen. Ik vind het ook niet te hoog.

#### Sound 4 - Discovery 90SW:

- Discovery 90SW, omdat dit geluid overeenkomt met geluid nummer 5 en ik denk dat dat Discovery Collector is. Deze twee robots zijn familie van elkaar dus dan lijken de geluiden ook op elkaar.
- 4 Pleasantness, bij ieder geluidje is het gewoon goed. Niet vervelend.

#### Sound 5 - Astronaut A5:

- Discovery Collector, voor mijn gevoel lijkt het op wat de Collector nu ook voor geluid heeft.
- 4 Pleasantness, gewoon goed. Ze zitten allemaal op hetzelfde niveau.

#### Sound 6 - Exos:

- Astronaut A5, Ik heb het idee dat dit het minst storende geluid is en dat vind ik wel bij de Astronaut passen. Het is de robot die de meeste acties uitvoert en als je dan een geluidje hebt dat vanuit de Astronaut moet communiceren verwacht ik ook een minder storend geluidje omdat die dat geluidje ook vaker maakt. De rijdende robots verwacht ik een iets storender geluid omdat je die moet kunnen horen als ze rijden.
- 4 Pleasantness, dezelfde reden als voorgaande geluiden. Gewoon goed.

#### Sound 7 - Sphere:

- Vector, die lijkt op wat de Vector nu ook heeft voor geluid.
- 4 Pleasantness, alle geluidjes zijn gewoon goed.

### Third stage - Identifying the robot action based on sound

#### Sound 1 - Critical technical alarm

- Critical safety alarm, het is een snel geluid dat elkaar opvolgt en het is continu. Het trekt veel aandacht. Ik denk dat het ergens in de kritische range zit. Grote twijfel met critical technical alarm.
- 4 Pleasantness, ondanks dat het een alarm geluid is, vind ik hem niet vervelend klinken. Wat je soms wel eens krijgt met alarmgeluiden is dat ze hoog en schel zijn. Dat zijn geen aangename geluiden. Die wil je zo snel mogelijk stop zetten.
- 4 Urgent, ik associeer het geluid denk ik ook met minder gevaarlijke dingen. Ik weet alleen niet wat. Het komt me een soort van bekend voor, maar ik kan het niet helemaal plaatsen. Misschien een spoorwegovergang.

#### Sound 2 - Start driving

- Confirmation sound, ook al zat ik ook te twijfelen tussen start driving. Hij doet me denken aan Mario Kart omdat je dat aftel geluid hebt. Tun tun tun GO! Maar het einde klinkt positief dus het kan geen alarm zijn. Maar het zou ook 1,2,3 en ik ben geconnect zijn..
- Switch: naar start driving, ik denk toch dat nummer 2 de Mario start sound is.
- 4 Pleasantness, Hij is gewoon pleasant. Misschien zou die nog plezanter klinken als die beepjes ietsje langzamer zijn. Meer tijd tussen de beepjes voor meer vloei.
- 1 Urgentie, qua toon vind ik hem niet urgent klinken omdat die een positieve spike (hoge toon) heeft. Het klinkt aan het einde alsof alles oké is.

#### Sound 3 - Critical safety alarm

- Critical technical alarm, omdat het een snel opvolgend geluid is wat aandacht vraagt. Grote twijfel tussen critical safety alarm.
- 4 Pleasantness, klinkt gewoon goed. Het is meer een gevoelskwestie.
- 4 urgentie, door de lagere toon klinkt het iets minder urgent. Door de snelheid klinkt het wel meer urgent maar niet zoals een brandalarm urgent.

#### Sound 4 - Driving

- Driving of driving backwards, Driving backwards omdat je de timing hebt van achteruit rijden die je bij auto's hebt maar minder schel zoals die je bij auto's hebt. Driving, omdat het een continu geluid is om de aandacht te trekken maar het niet storend is. Het is geen geluid waarvan je denkt, dat wil ik uitzetten dus dat werkt goed voor een rijgeluid.
- Final keuze: driving.
- 4 Pleasantness, het is wel een plezant geluidje. Het is gewoon een rustig mellow geluidje.
- 1 Urgentie, omdat het een rustig, kalm geluid is. Dit is niet een geluid waar ik naartoe zou sprinten.

#### Sound 5 - Narrow alley

- Ik twijfel tussen non-critical alarm en warning: approaching narrow alley, qua tonen zit die op dezelfde hoogte als de vorige. Daarom denk ik de warning: approaching narrow alley. Maar hij heeft het tempo van de non-critical alarms.
- Uiteindelijke keuze: warning: approaching narrow alley.
- 4 Pleasantness,
- 2 Urgentie, qua toon zit die op driving level dus dan trekt die minder aandacht. Maar de beep is snel, dus dat zorgt voor meer urgentie.

#### Sound 6 - Non-critical alarm

- Non-critical alarm, omdat die hetzelfde ritme heeft als de critical safety en technical alarm, maar hij klinkt minder kritisch.
- 4 Pleasantness, klinkt gewoon lekker.
- 3 Urgent, omdat die wel al een wat hoger ritme heeft maar qua toonhoogte niet per se heel hoog of schel is. Het geeft me niet het idee dat het super belangrijk is maar wel attentie nodig heeft.

#### Sound 7 - Confirmation

- Confirmation sound, het is een positieve toon en vergelijkbaar met confirmation geluiden die in andere dingen gebruikt worden. Het is iets meer vergelijkbaar met het connecten van een bluetooth box.
- 4 Pleasantness, een fijne toon. Niet vervelend. De juiste snelheid ook. Aan het einde kan die zo mooi uitvloeien.
- 1 Urgentie, het is een kort geluid en niet iets wat repeteert. Het klinkt ook alsof er een afronding zit aan het einde. Misschien komt het ook door het uitvloeien van het geluid. Het klinkt gewoon positief, positieve vibes.

#### Sound 8 - Driving backwards

- Driving backwards, want hij klinkt iets hoger en urgenter dan nummer 4. Nummer 4 was meer mellow. Hij lijkt op een auto die achteruit rijdt.
- 4 Pleasantness, goede toon. Niet te snel als hij voor driving backwards wordt gebruikt.
- 1 Urgentie, ik denk dat je wel een beetje moet kijken maar ik weet wat ik moet verwachten.

## Appendix E: Farmer questionnaire

This appendix shows the original format of the farmer questionnaire.

### Lely robotgeluiden

#### Robotgeluiden Lely

##### Waarom

Lely is momenteel bezig met het ontwikkelen van nieuwe robot geluiden. Graag willen wij weten hoe de nieuwe geluiden door jou worden ervaren. Het is voor deze enquête belangrijk dat je een speaker of koptelefoon ter beschikking hebt omdat sommige vragen geluid bevatten. Er zijn geen goede of foute antwoorden.

##### Duur

Circa 4 minuten.

Volg.

### Lely robotgeluiden

#### 1 - Geluiden voor koeien



Zoals je misschien weet, zijn koeien in staat om andere geluiden te horen dan mensen. Om de hoeveelheid geluiden in de boerderij voor de boer te verminderen zijn wij bezig met het ontwikkelen van geluiden die alleen de koeien kunnen horen.

Het gaat hierbij specifiek om geluiden die de koeien laten weten dat een robot in de buurt is, denk hierbij bijvoorbeeld aan het rijgeluid van de Discovery Collector. We noemen dit soort geluiden in onderstaande vragen: "informatieve geluiden".

**i** Voor deze vraag is een antwoord vereist.

\* 1. Ik stoor me aan de hoeveelheid informatieve geluiden die de robots produceren.

- Zeer eens
- Eens
- Neutraal
- Oneens
- Zeer oneens

**i** Voor deze vraag is een antwoord vereist.

\* 2. Ik wil dat de informatieve geluiden van robots binnen de hekken alleen hoorbaar zijn voor de koeien.

- Zeer eens
- Eens
- Neutraal
- Oneens
- Zeer oneens

wil dat mijn twee Astronaut robots een ander onderscheidend geluid hebben.

- Helemaal mee eens
- Eens
- Neutraal
- Oneens

## Lely robotgeluiden

### 2 - Robot klank

Iedere robot maakt op dit moment hetzelfde geluid. Om het makkelijker te maken voor boeren om de robots te onderscheiden op basis van geluid willen we elke robot een andere klank, een soort eigen "stem", geven.

\* 4. Stel, je hebt twee dezelfde type robots; Bijvoorbeeld twee Astronaut robots. Geef aan in hoeverre je het eens of oneens bent met onderstaande stelling:

Ik wil dat mijn twee Astronaut robots een ander onderscheidend geluid hebben.

- Helemaal mee eens
- Eens
- Neutraal
- Oneens
- Helemaal mee oneens

\* 5. Stel, je hebt twee verschillende type robots. Bijvoorbeeld, 1 Discovery Collector (mestrobot) en 1 Juno (voeraanschuifrobot). Geef aan in hoeverre je het eens of oneens bent met onderstaande stelling:

Ik wil dat mijn Collector en Juno een ander onderscheidend geluid hebben.

- Helemaal mee eens
- Eens
- Neutraal
- Oneens
- Helemaal mee oneens

6. Als je wilt kun je hieronder je antwoorden toelichten:

Vor.

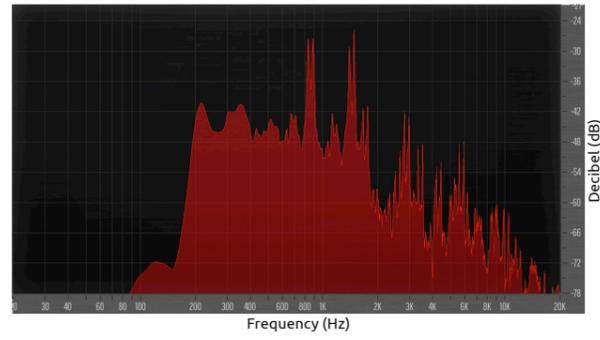
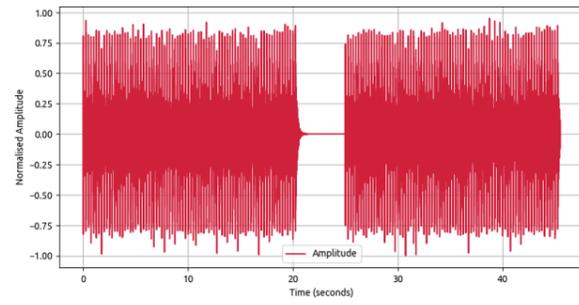
Volg.

# Appendix F: The robot voices

This appendix presents the robot voices.

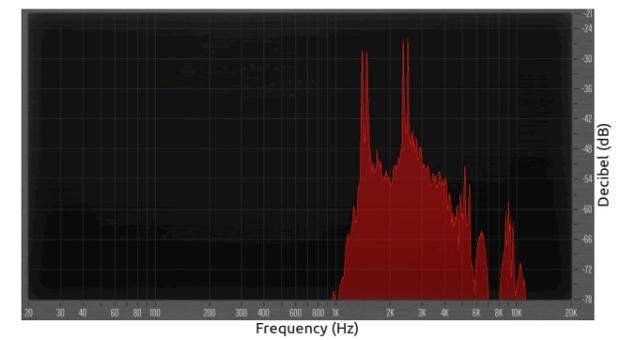
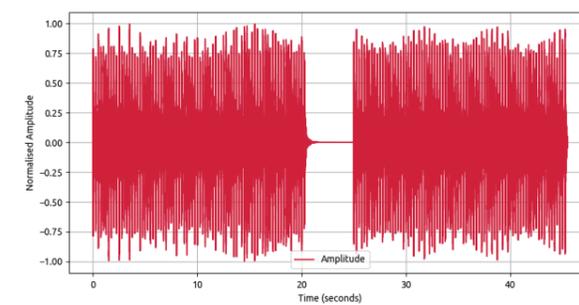
Astronaut A5

Critical safety alarm

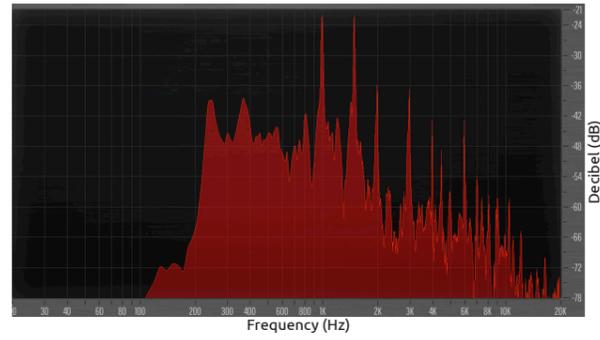
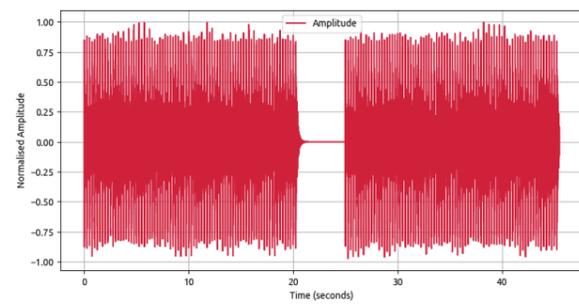


Discovery Collector

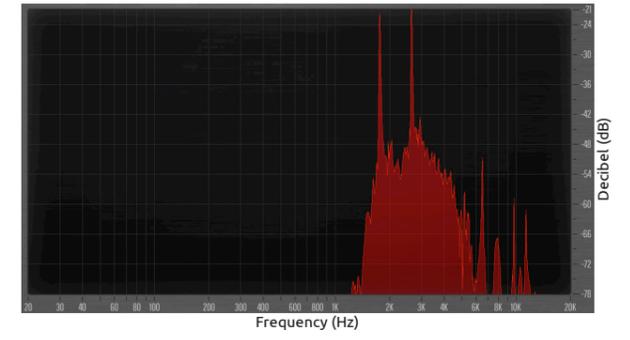
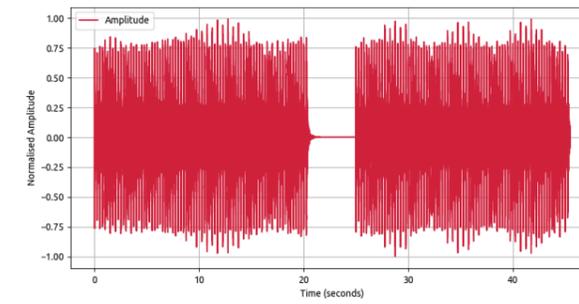
Critical safety alarm



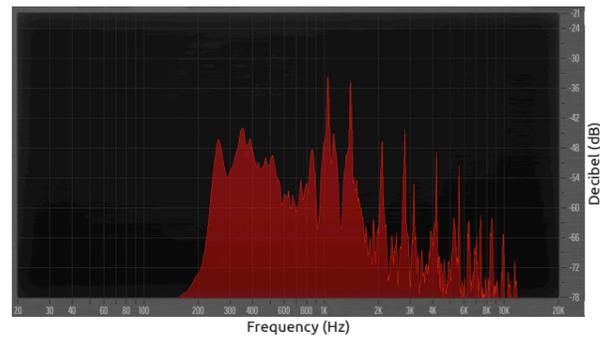
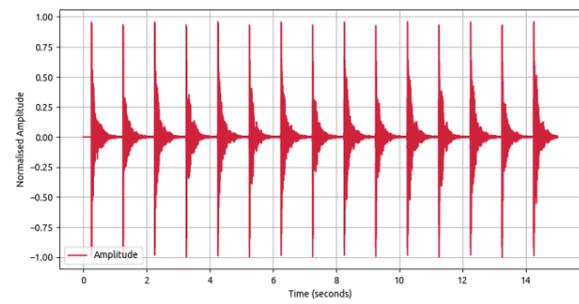
Critical technical alarm



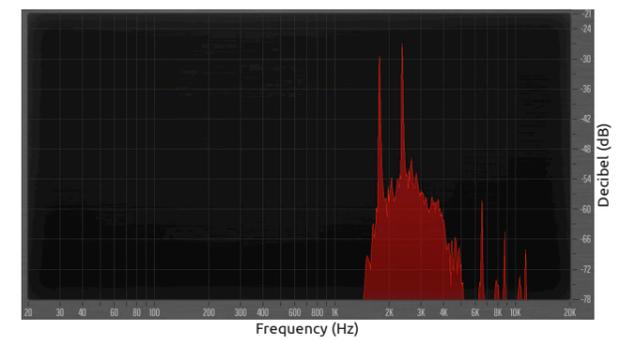
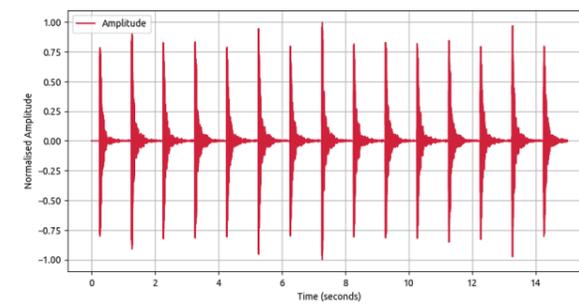
Critical technical alarm



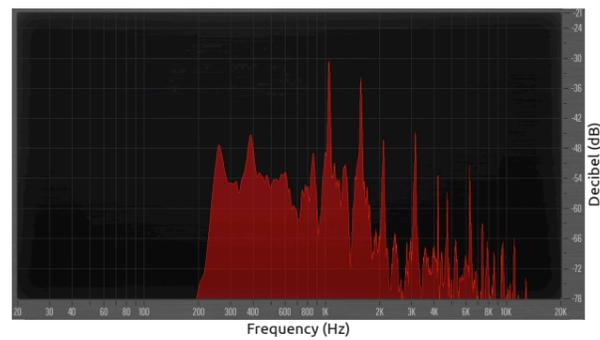
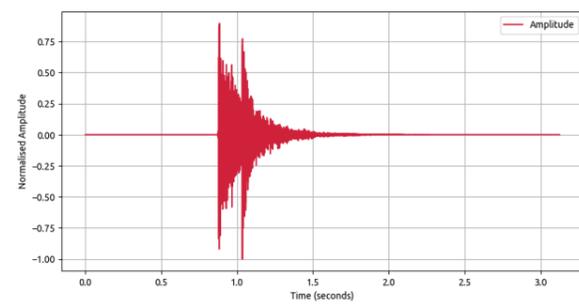
Non-critical alarm



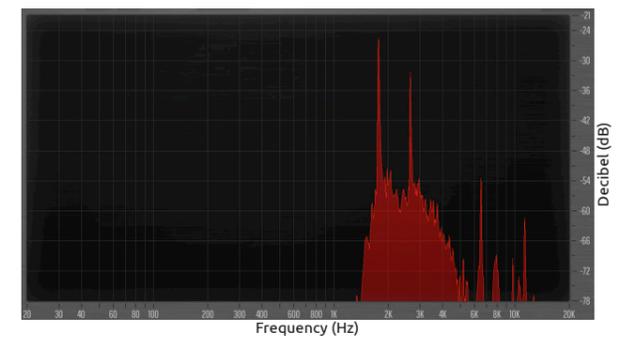
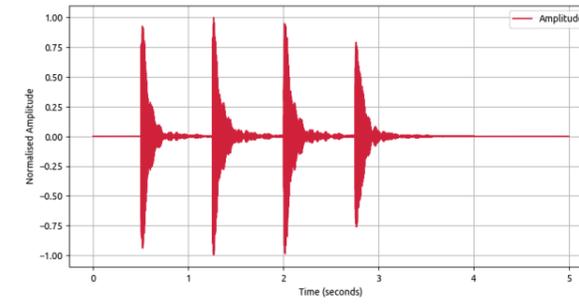
Non-critical alarm



Confirmation sound

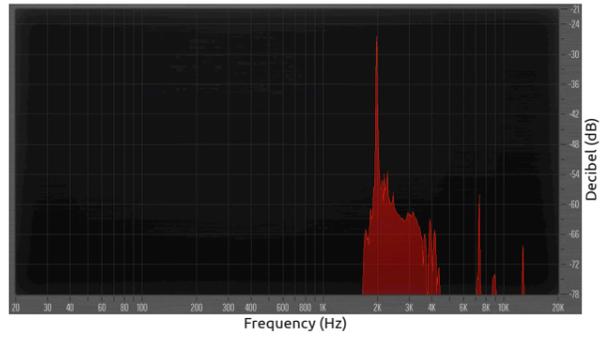
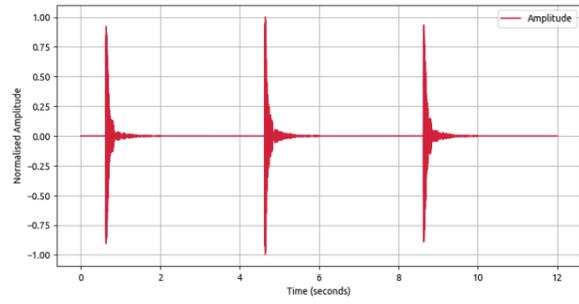


Start driving

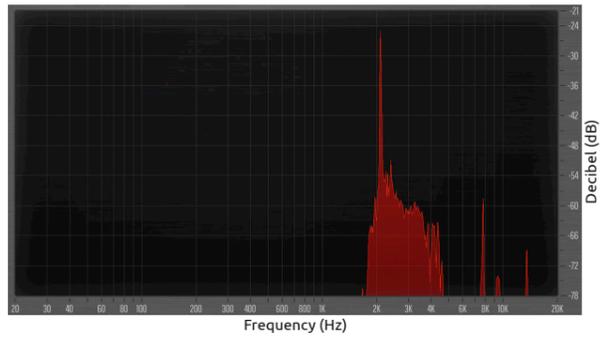
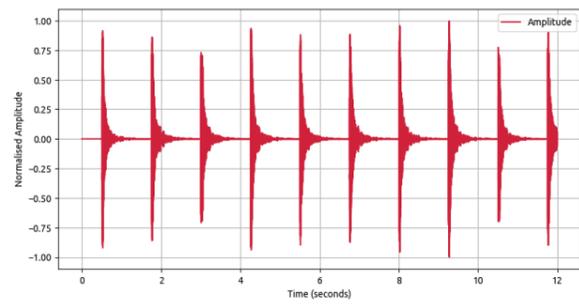


## Discovery Collector

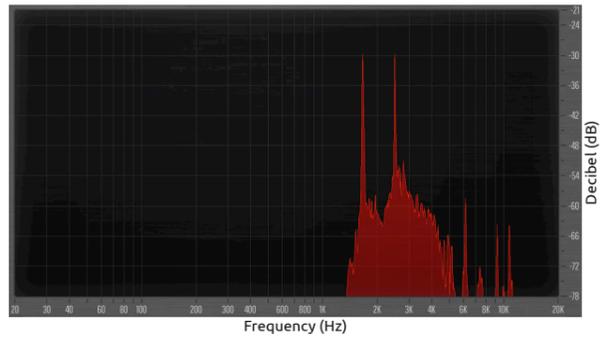
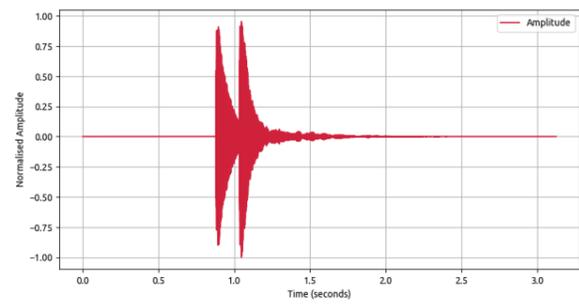
### Driving



### Driving backwards

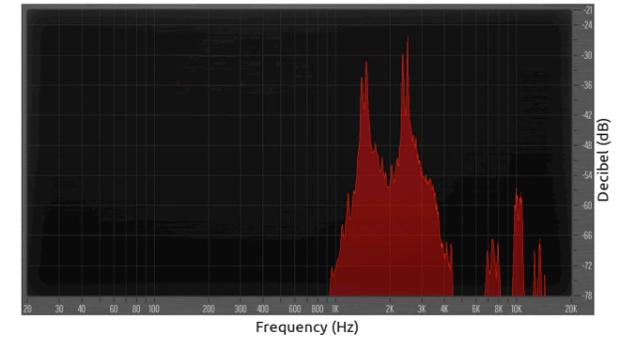
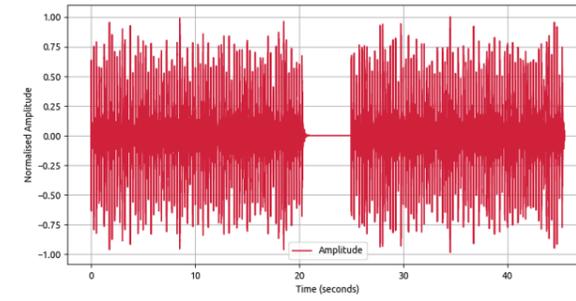


### Confirmation

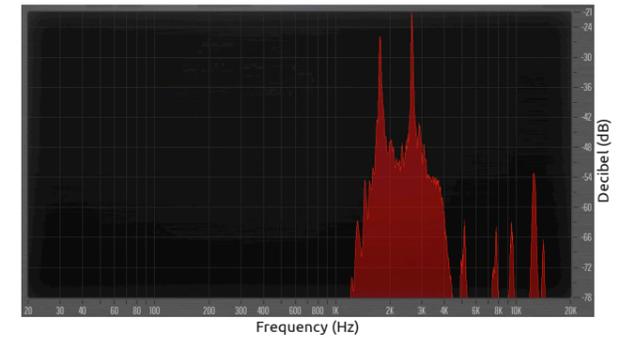
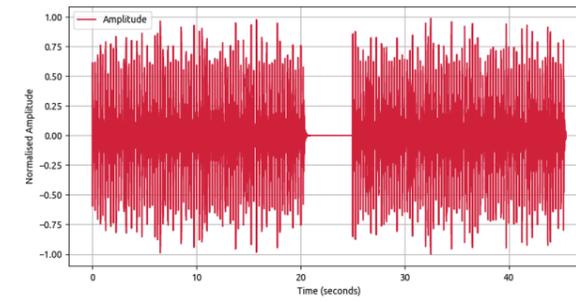


## Discovery 90SW

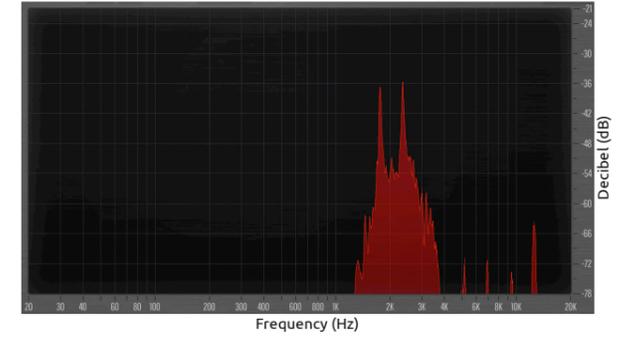
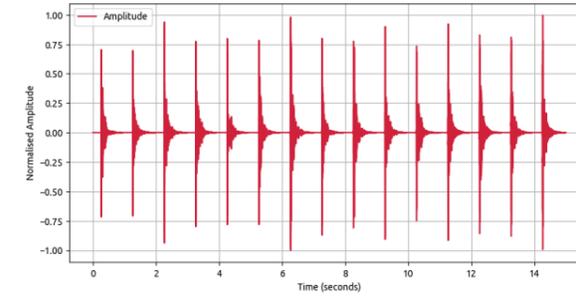
### Critical safety alarm



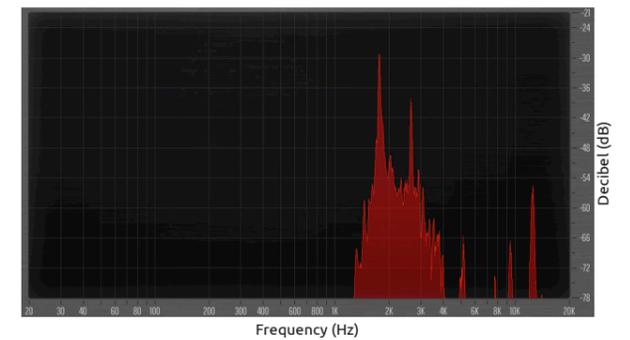
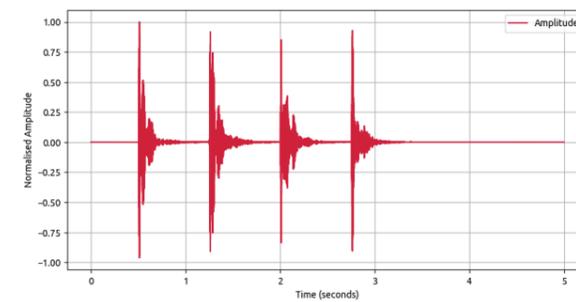
### Critical technical alarm



### Non-critical alarm

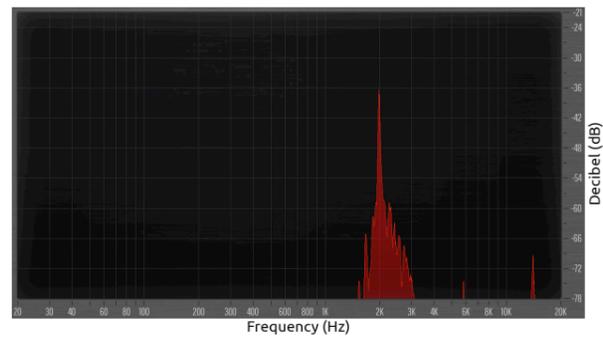
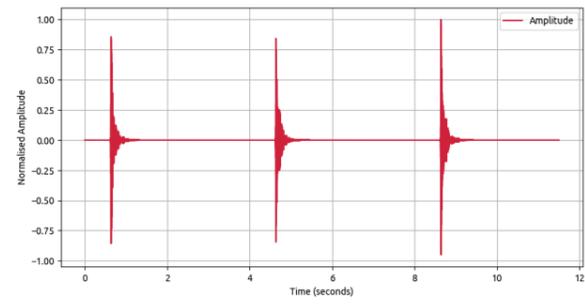


### Start driving

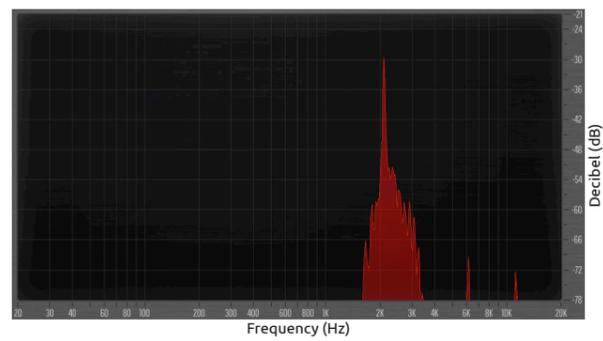
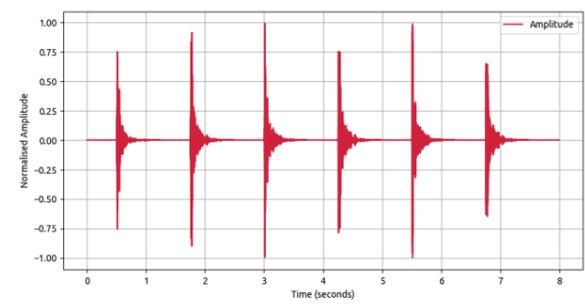


## Discovery 90SW

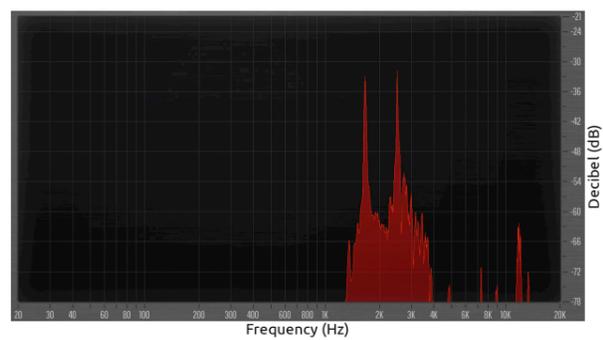
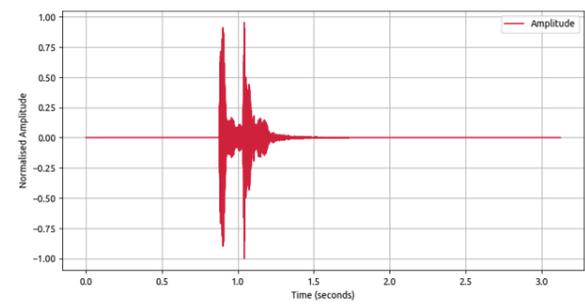
### Driving



### Driving backwards

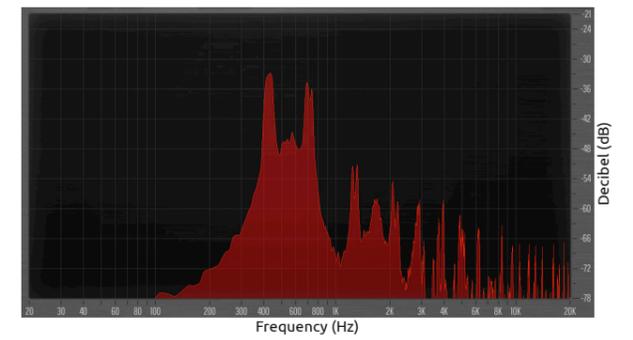
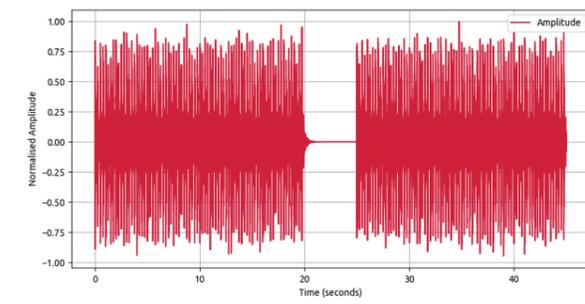


### Confirmation

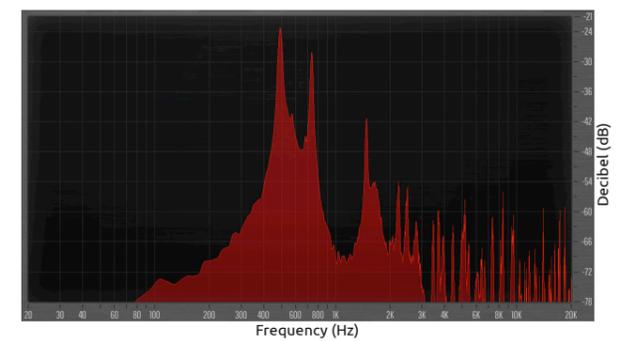
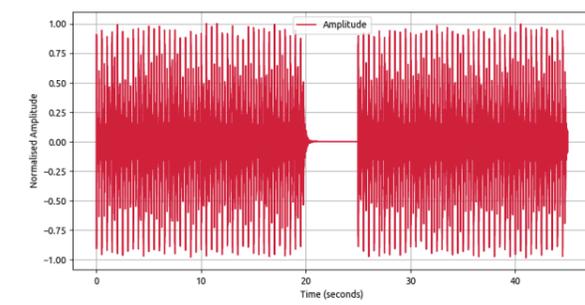


## Sphere

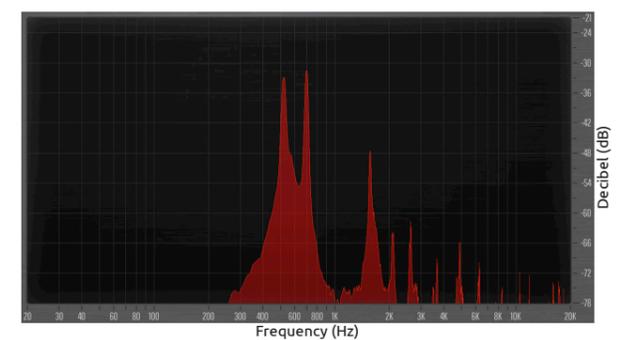
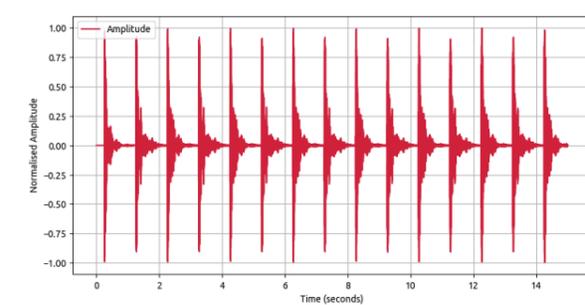
### Critical safety alarm



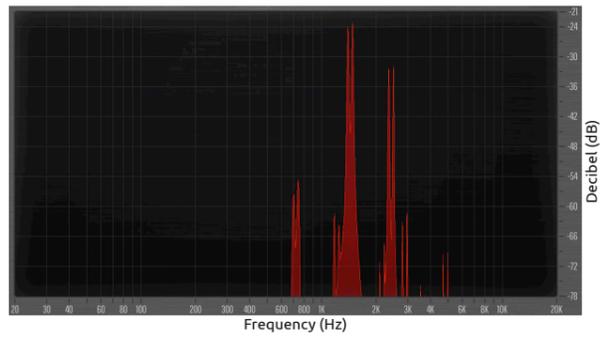
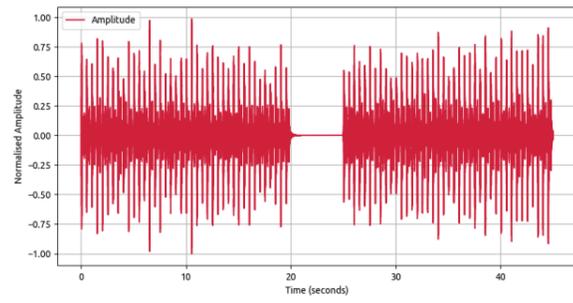
### Critical technical alarm



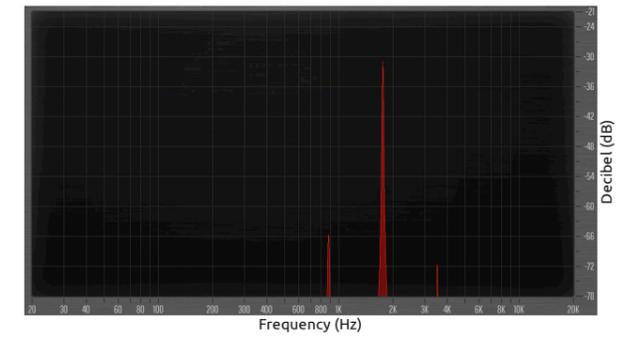
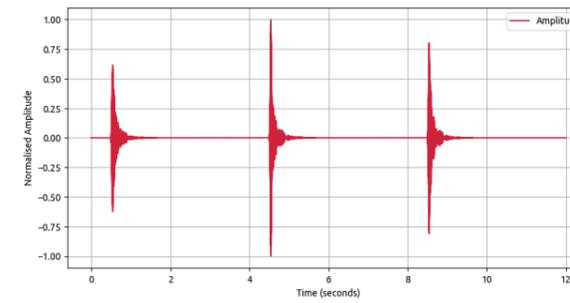
### Non-critical alarm



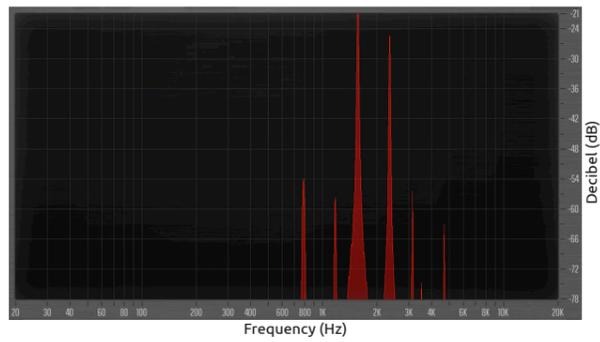
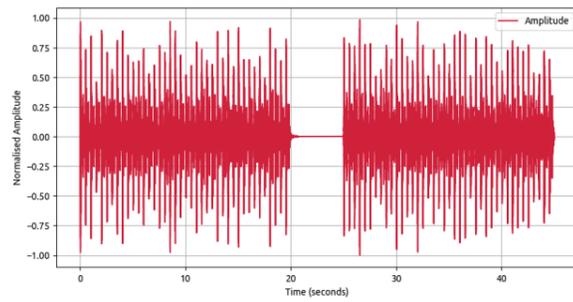
Critical safety alarm



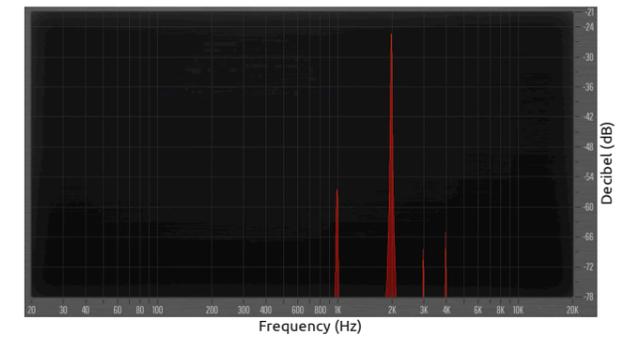
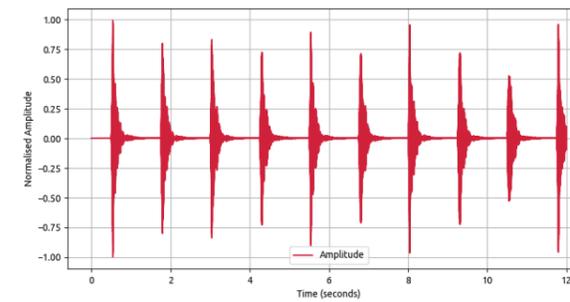
Driving



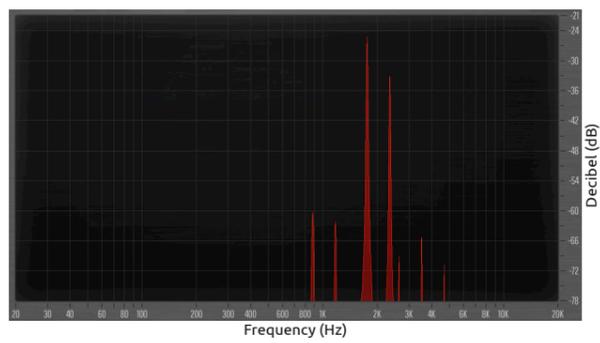
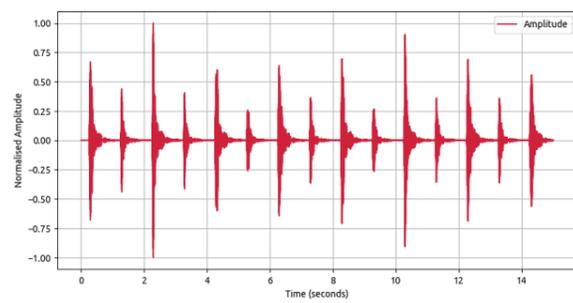
Critical technical alarm



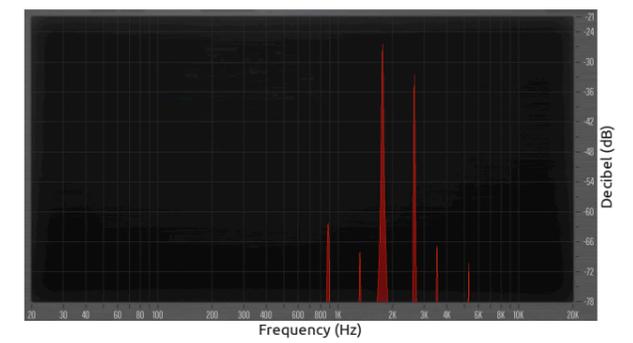
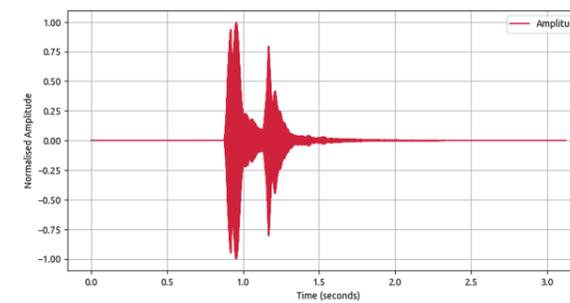
Driving backwards



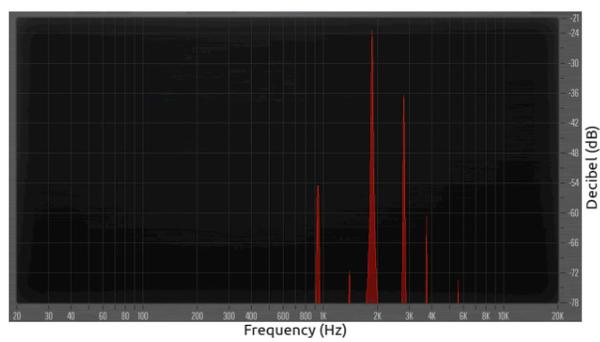
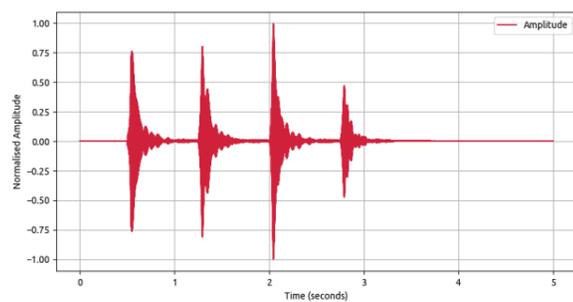
Non-critical alarm



Confirmation

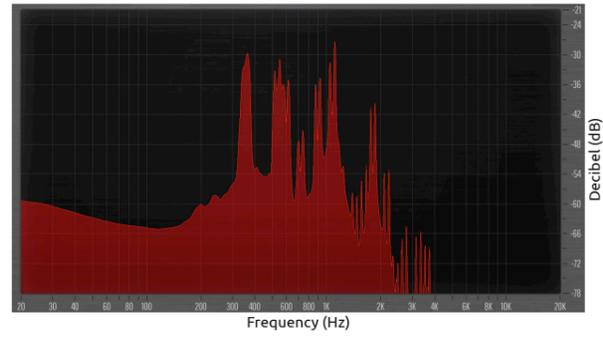
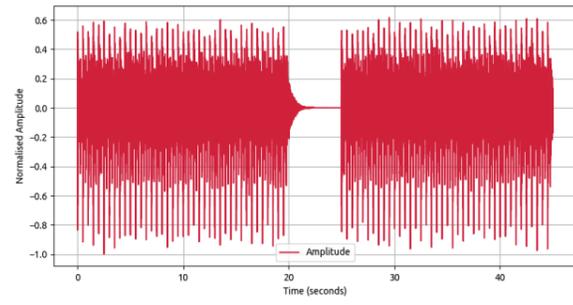


Start driving

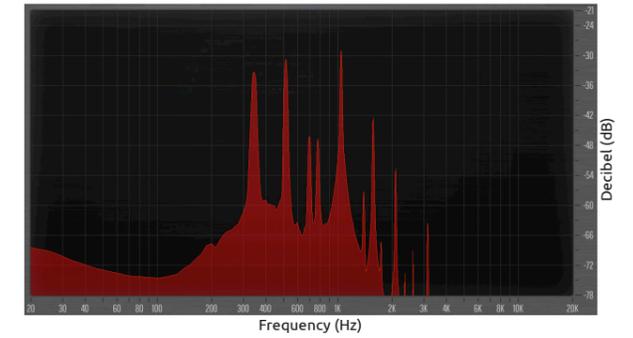
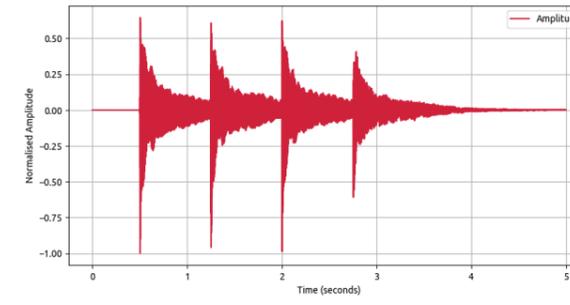


# Vector MFR

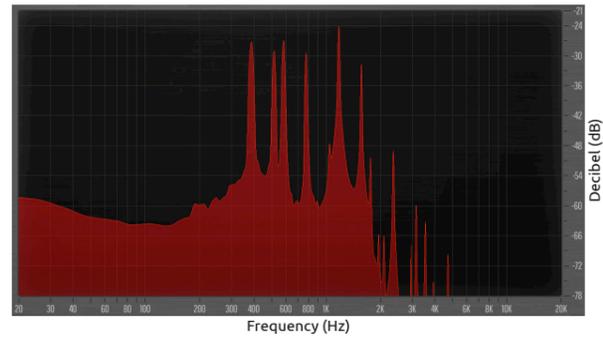
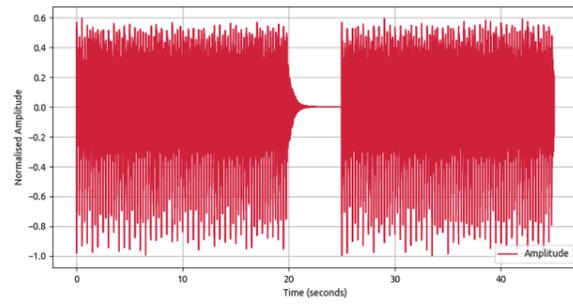
## Critical safety alarm



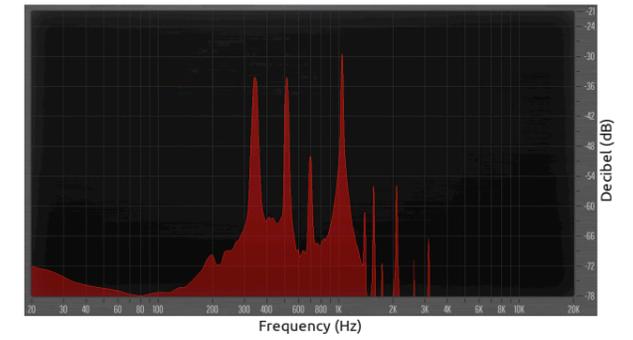
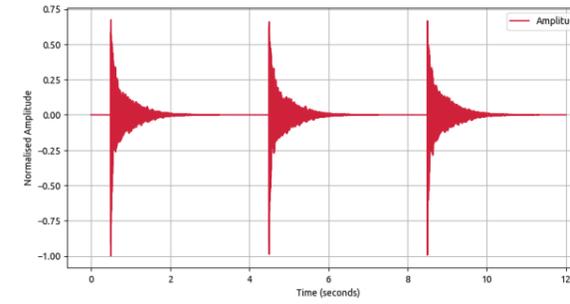
## Start driving



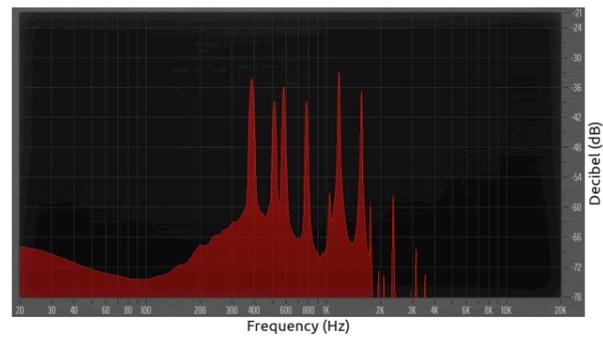
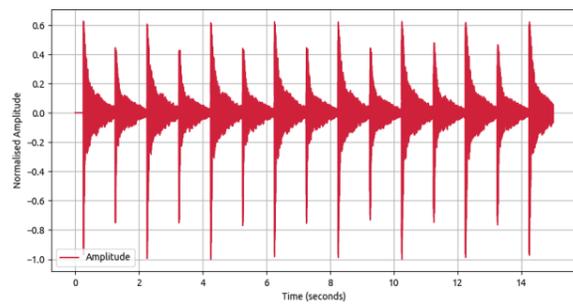
## Critical technical alarm



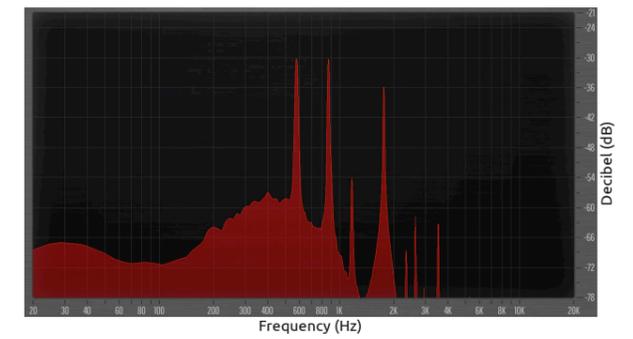
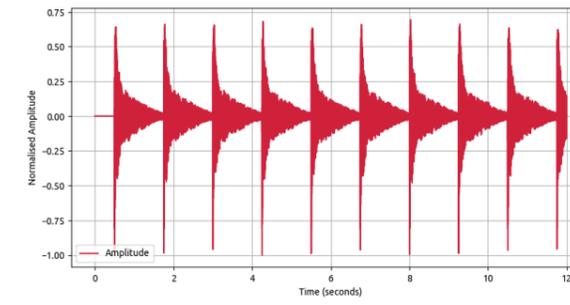
## Driving



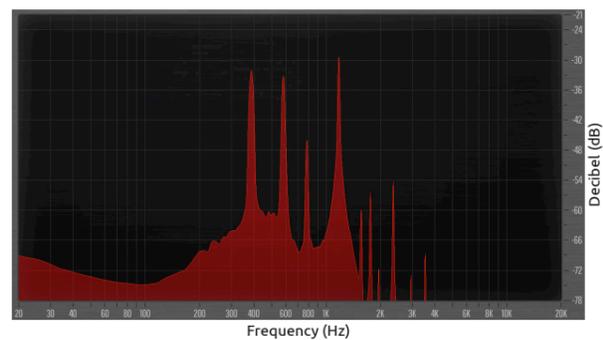
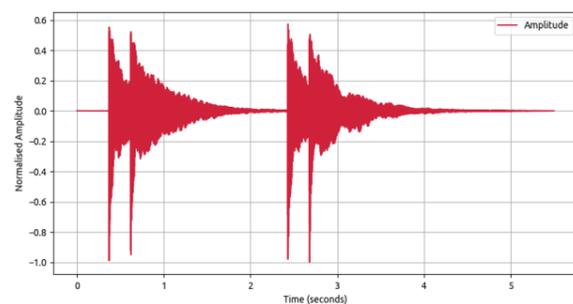
## Non-critical alarm



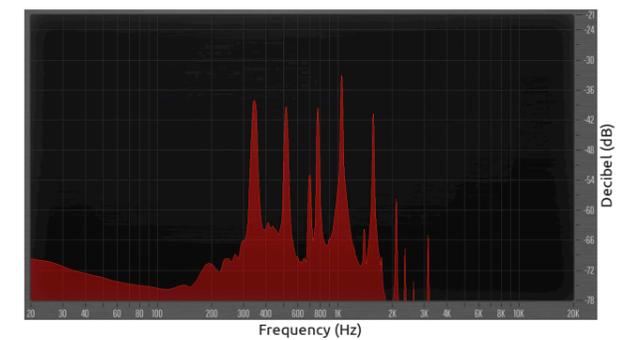
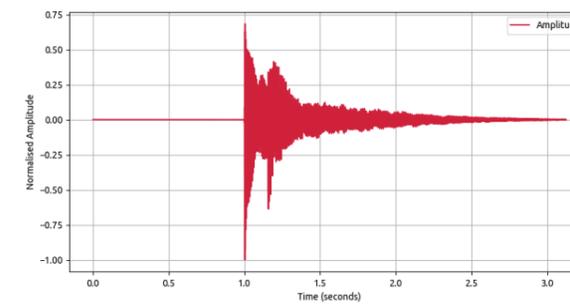
## Driving backwards



## Warning: approaching narrow alley



## Confirmation



## Appendix G: Buzzer guidelines

This appendix presents the guidelines for the buzzer sounds.



### Critical safety alarm

The critical safety alarm consists of three 0.25-second beeps with a 0.25-second rest in between, followed by five 0.25-second beeps with no rest in between. This pattern repeats for 20 seconds, with a five-second interval between each set. The alarm stops once it is acknowledged by the user. If the alarm is not acknowledged after 5 minutes, the robot will cease operation.



### Critical technical alarm

The critical technical alarm consists of 0.25-second beeps with a 0.25-second rest in between. The alarm repeats for 20 seconds, with a five-second interval between each set. If the alarm is not acknowledged after 5 minutes, the robot will cease operation.



### Non-critical alarm

The non-critical alarm consists of a 0.25-second beep, followed by a 0.75-second rest between each beep. The alarm repeats for 15 seconds, with a one-minute interval between each repetition. It will continue until acknowledged by the user. If the issue remains unresolved, the alarm will eventually escalate to a critical technical alarm.



### Confirmation sound

The confirmation sound consists of a 0.13-second beep, directly followed by a 0.25-second beep.



### Warning: approaching narrow alley

The “warning: approaching narrow alley” sound consists of two sets of a 0.19-second beep followed by a 0.5-second beep, with a 0.06-second rest between the two beeps. There is a 1.3-second rest between the two sets.



### Start driving

The “start driving” sound consists of four beeps. The first three beeps are 0.25 seconds long, with a 0.5-second rest between each beep. The fourth beep lasts for 0.75 seconds.



### Driving

The “driving” sound consists of a repeating 0.19-second beep with a 3.75-second interval.



### Driving backwards

The “driving backwards” sound consists of a repeating 0.56-second beep with a 0.56-second interval.