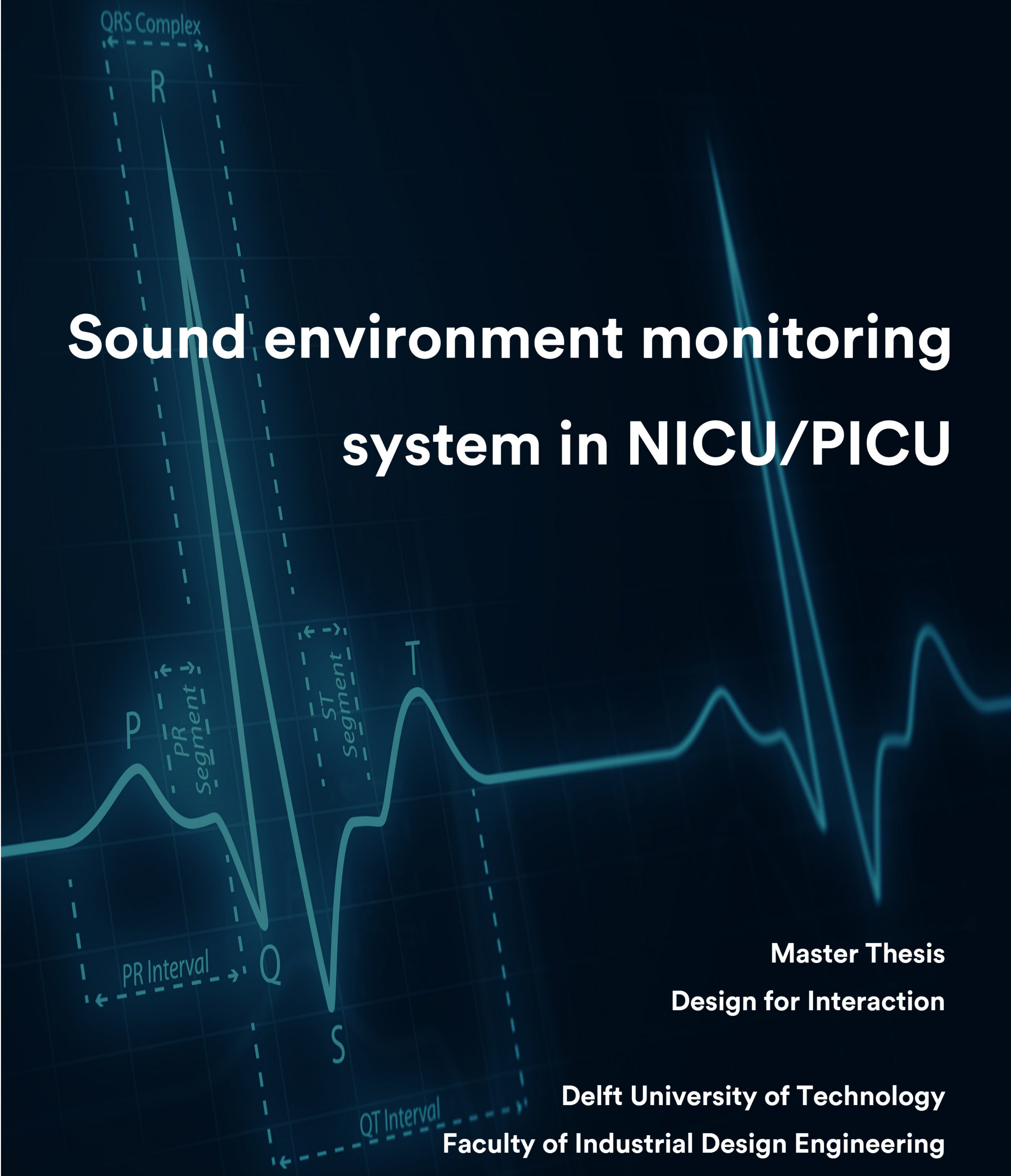


Sound environment monitoring system in NICU/PICU

Master Thesis
Design for Interaction

Delft University of Technology
Faculty of Industrial Design Engineering

Auguest 2023
Guang Lu

Delft University of Technology
Faculty of Industrial Design Engineering
MSc. Design for Interaction

Supervisory Team
Chair - Dr. Elif Ozcan Vieira
Mentor - Ir. Tom G. Goos
Ir. Eris van Twist

Author
Guang Lu

Abstract

This research project delves into the exploration of the sound environment within Intensive Care Units (ICUs), particularly focusing on Neonatal Intensive Care Unit (NICU) and Pediatric Intensive Care Unit (PICU). It aims to enhance the understanding of sound events and their impact on both nurses' decision-making and patients' sleep behaviors. By recognizing the unique challenges of the sound environment in these specialized units, the project focuses on creating a soundscape evaluation metric, incorporating sound event detection algorithms, and simulating real ICU scenarios through synthesized audio. This approach seeks to facilitate better decision-making, foster communication among nurses, improve behavior, and enhance awareness of events within the patient's room.

Utilizing an iterative process that involved technological exploration, algorithmic integration, and UI design, the project offers a novel perspective on sound quality within NICU and PICU settings. The main objective is to transform raw sound data into visually accessible formats for the nursing staff, while also addressing complexities like sound collection, data processing, information storage, deployment methods, and interaction design. The project culminates in the development of a functional product prototype that not only meets the initial goals but also reveals new opportunities and challenges for future exploration. The insights gathered contribute to the wider understanding of the sound environment within NICUs and PICUs, shedding light on potential improvements in patient care and nurse interaction within these critical healthcare environments.

Table of content

1

Background

1.1 Assignment Introduction

Problem satement

At the Neonatology Intensive Care Unit (NICU) and Pediatric Intensive Care Unit(PICU), patients and medical staff are particularly vulnerable to the negative effects of noise pollution. The NICU is specially created for premature newborns that need care to survive and are extremely vulnerable babies who are prone to illness. Considering the fragile nature of the unit, there are a lot of alarms and noise pollution, which has a bad effect on both the patients' well-being and the performance of the medical staff. Environmental noise also affects the neurodevelopment of newborns, according to studies(Graven,2000). Also, based on our previous research in PICU during the Design Research Methodology course, the sound environment affects the sleep quality of patients during night time. Through our 8-hour observation from 10pm to 6am, the patients were waken or crying due to different sound resources like door closing. From physical and mental health of patients to the working behavior of medical staff, current sound environment in ICU needs more improvement and that's where Critical Alarm Lab has been striving on in recent years.

What's more, the transition from cluster to single patient rooms also presents an opportunity. Previous projects of our lab focus more on noise control in the big and noisy room, but things will change as the layout plan. Based on Erasmus MC's plan, all NICU/PICU units will adopt the single patient room layout in several years. This makes the overall sound environment better since they separate all patients and those monitoring devices, but it's also a challenge for medical workers by making it harder to directly observe how things going on with certain patients. Accordingly, my design focus will cast on how to provide medical workers sufficient, understandable and concise information to fit in their new workflow. Promisingly, the prototype will act as an inspiration which allows stakeholders to ideate more possibilities to work with algorithm and improve their working environment.

Solution space

Within Critical Alarm Lab, there are some explorations in sound environment evaluation and monitoring, like the sound visualization project (Núria Viñas, 2021) and Cocophony Mapper (Yoon Lee,2019). It's valuable for me to inherit their insights and continue the exploration as a member of Critical Alarm Lab. For instance, due to time limitation, the sound visualization project's final outcome was UI pages which is hard to interact with and do some tests. This lead to some questions from experts like how do people implement this in real situation and how can this actually benefits medical staffs' workflow.

Main research quesiton

“How can an interactive and testable sound environment monitoring system be designed to improve the sound environment in single patient NICU/PICU units, benefiting both patients' well-being and medical staff's workflow?”

Sub reseach question 1: What are the current acoustic conditions and their impacts on patients and staff in the NICU & PICU of Erasmus MC?

Sub reseach question 2: What is the primary acoustic problem that needs to be addressed to improve the patient and staff experience?

Sub reseach question 3: How can soundscape methodologies and sound event detection algorithms be utilized to characterize and improve the sound environment?

Sub reseach question 4: What potential solutions can be generated to address the identified acoustic problem, and how can they be prototyped for testing?

1.2 NICU&PICU in Erasmus MC

Specialized Care in NICU&PICU at Erasmus MC
The Neonatal Intensive Care Unit (NICU) and Pediatric Intensive Care Unit (PICU) at Erasmus MC are specialized in providing critical care for children with a variety of conditions. Their expertise lies in monitoring and supporting brain function, respiratory support with ventilation and artificial lungs when necessary, supporting the circulatory system with specialized infusions and assistive devices, and transporting critically ill children from regional hospitals to their care.

Dealing with Severe Disorders
The units are equipped to deal with severe circulatory and respiratory disorders using ECMO (artificial lung and/or heart) and LVAD (artificial heart). They also have experience in handling cardiomyopathy (heart failure) and heart transplants, congenital disorders of the gastrointestinal tract, such as Congenital Hernia Diafragmatica (hole in the diaphragm), conditions affecting the trachea like tracheomalacia (soft trachea), and craniofacial disorders such as scaphocephaly (abnormal skull shape).

Research Focus
The NICU and PICU at Erasmus MC are not only a center for treatment but also a hub for scientific research aimed at improving the care for critically ill children in the future. Their research focuses on a variety of areas, including congenital surgical abnormalities, effective pain and unrest management, safe and effective medications, nutrition and metabolism, brain injury treatment, and long-term effects.

Outpatient Services and Consultations
In addition to their inpatient services, the units offer outpatient clinics in various specialities, including pediatric surgery, pediatric neurology, pediatric thoracic center, and home ventilation. They also offer a wide range of special consultation hours covering numerous medical conditions, providing comprehensive and coordinated care for children with complex health needs.

Advanced Treatments and Procedures
Furthermore, Erasmus MC performs specific procedures such as scoliosis surgeries and treatments like multimodal neuromonitoring that further demonstrate their commitment to providing a full spectrum of high-quality care to their patients.

Figure1. Erasmus MC Sophia Children's Hospital

1.3 Project approach

The goal of this project is to design and test a monitoring system that leverages alarm detection and sound event detection algorithms to provide a comprehensive view of the sound environment in multiple single patient rooms or terminals. This system will aim to improve the workflow of nurses, enhance stakeholder experience, and have a positive impact on stakeholders by providing real-time data visualization of sound events.
The system will be built through five steps: definition, research, ideation, realisation and evaluation.

Definition

The initial phase will employ literature review, archival research, problem framing, and gap analysis. The literature review will provide an overview of the existing knowledge on the subject, while archival research will delve into historical data to gain insights. Problem framing will establish a clear understanding and articulation of the issue at hand, and a gap analysis will help identify where improvements can be made.

Research

The research phase involves an in-depth study of the context, incorporating methodologies such as ethnography, observational studies, interviews, and case studies. It also includes a detailed soundscape study using acoustic ecology, psychoacoustics research, and auditory scene analysis to understand and map the sound environment in the ICU.

Ideation

The ideation phase is a time for creative problem solving, where brainstorming, scenario planning, rapid prototyping, sketching, wireframing, and user story mapping will be used. These methodologies will help generate and explore innovative solutions, including developing an approach to classifying sound events and visualizing environmental sounds in real-time.

Realisation

In the realisation phase, the focus is on making the ideas concrete. This includes comparing and choosing the best solutions using comparative analysis, designing the system architecture using systems design methodologies, and then building software and user interface prototypes. Throughout this process, the goal is to ensure the system is user-friendly and suitable for the ICU context.

Ev

Fi
be
ef
A
ar
pr
w
he
of
im


7.Evaluation
8.Next steps
Evaluation
Usability Testing
A/B Testing
Heuristic Evaluation
Surveys
Epert Interviews
Focus Groups
Reflection&Critical Analysis
6.Realisation
Realisation
Comparative Analysis
Systems Design
Software Prototyping
User Interface Design
5.Idea generation
Ideation
Brainstorming
Scenario Planning
Rapid Prototyping
Sketching
Wireframing
User Story Mapping
scape
arch
hy
ies
cology
ustics Research
cene Analysis

2

Explore NICU&PICU

2.1 Literature review of sound environment

Sound environment plays a pivotal role in shaping the perception and experience of patients in the healthcare setting, particularly in intensive care units (ICUs) where patients are often in a vulnerable state. While sight is a vital sensory input for humans, sound is a close second, providing an abundance of information to the brain every second (Sprouse, 2022)

Importance of Sound in Hospitals

In a hospital environment, the significance of sound becomes even more pronounced as patients are not able to choose when to 'close their ears'. This means that they are involuntarily aware of changes in the environment through variations in sound, such as alarms going on and off or people entering and leaving the room.

This heightened reliance on auditory inputs is further emphasized in cases of patients who are too weak to open their eyes or whose field of vision is restricted. For instance, ICU patients who are (partially) paralyzed cannot fully rotate to observe their surroundings, thus, sound provides essential information about the environment.

The act of listening is not always active or conscious. Casual listening, as described by Tuuri and Eerola (2012), is the most common and easily influenced mode of listening. Even when one appears not to be paying much attention, the subconscious is alert, processing the auditory inputs.

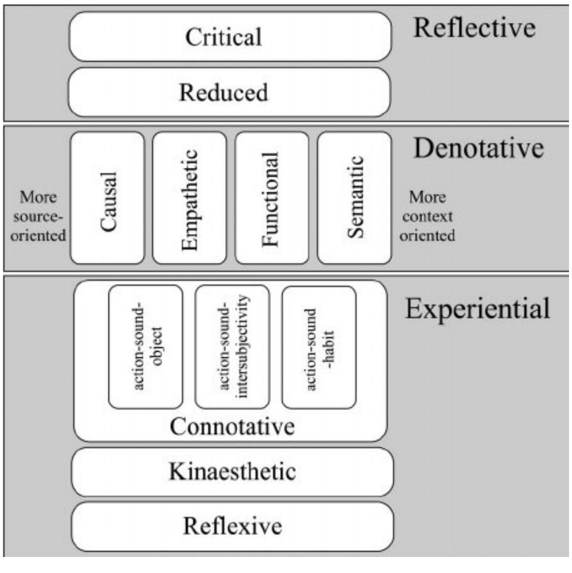


Figure 2:Overview of the revised scheme for modes of listening(Tuuri and Eerola, 2012)

Hospital Sound Environment

A complex sound environment or soundscape, as defined by Salandina, Arnold, and Kornadt (2011), encompasses both hospital staff and patients. It is the auditory equivalent of a visual landscape (Halletal. 2013), considering the meanings and implications of various sounds to the individual (Schafer, 1976; Truax, 1984).

However, the soundscape aspect is often overlooked in healthcare design. Understanding the impact of sound and the emotions it can evoke is vital for improving ICU environments (Luetz et al., 2019). The perception of sound is subjective and therefore challenging, but if harnessed correctly, it can be an ally. For instance, a properly designed acoustic environment can induce relaxation in stressful situations or provide a quiet environment conducive for recovery.

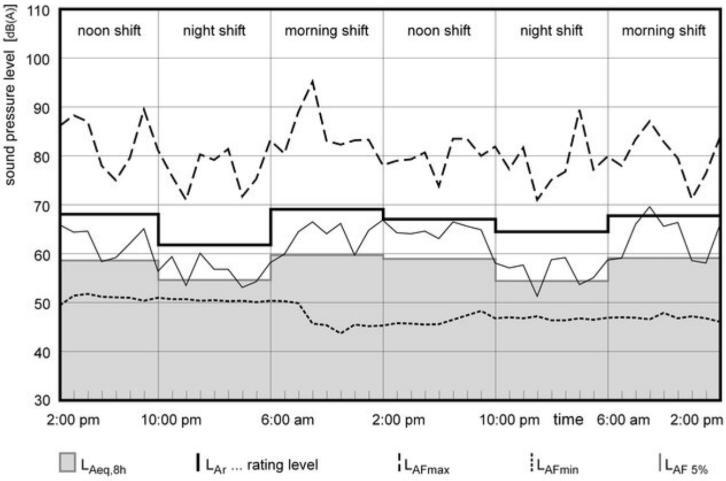


Figure 3:Sound pressure level within a day(Salandina et al.,2011)

Noise and Noise Perception in ICU

Environmental stressors, such as high-noise levels and inappropriate lighting conditions, can cause complications like delirium (Abuatiq, 2015). However, noise levels are only one aspect of the soundscape. Recent studies reveal that changes in sound level may be more disruptive than continuous sounds, particularly those arising from lower baseline sound pressure levels (Jaiswal et al., 2017).

It is important to note that the absence of sound does not necessarily create a positive environment (Truax, 1984), and there is no clear relationship between reduced sound pressure levels and physiological improvement (Drahota et al., 2012). Kamdar (2020) suggests that improving the ICU soundscape can be achieved by reducing absolute noise or attenuating the impact of noise on the patient.

Furthermore, sound's impact on the patient's perception can be not just negative (noise), but also neutral or even positive. Individuals have been found to adopt coping methods by accepting and habituating to aspects of the soundscape (Mackrill, 2013). Staff members are often major contributors to the acoustic energy in the ICU, producing 57% of the acoustic energy and 92% of the Pressure Level Peaks (PLPs) (Park et al., 2019). However, it's debatable how much of this sound is perceived as 'noise' or negative, as it could also be seen as a sign of staff presence and attentiveness.

The Influence of Sound on Patients

The soundscape in the ICU has a direct impact on patient sleep, physiology, and psychological well-being. Research has shown that high noise levels can lead to sleep disturbance, and sleep fragmentation can result in detrimental health effects such as hypertension, cardiovascular disease, impaired glucose tolerance, and obesity (Kamdar, 2020).

As well as the effects on sleep, sound can also affect physiology. For example, sudden loud sounds can increase heart rate and blood pressure, leading to increased stress and anxiety (Berglund et al., 1999). Sound can also influence the psychological well-being of patients. For instance, a study showed that ICU patients who heard ICU-specific music therapy experienced significantly less anxiety and more satisfaction with their care (Chlan et al., 2013).

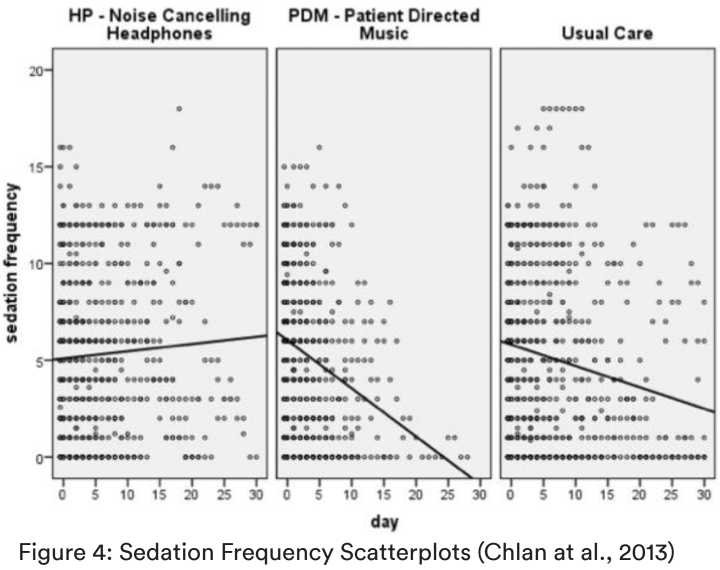


Figure 4: Sedation Frequency Scatterplots (Chlan at al., 2013)

Current sound design in ICUs

There are various ways in which the sound environment can be improved in ICUs to better the experience of patients. One of them is to reduce the number of alarms and sound signals and to adapt their volume and frequency to the patient's needs and perception. Another one is to provide patients with the possibility to listen to their preferred music or sounds, which can help them relax and distract from the hospital noise.

Sound masking, which involves adding a sound with a broad frequency spectrum to an environment to reduce the intelligibility of speech and reduce or eliminate awareness of pre-existing sounds in the environment, can also be useful.

The sound environment of ICUs could also be improved by educating healthcare workers about the importance of noise control and the impact of their behaviors on the noise level. Changes to the ICU's physical design can also make a significant difference, for example, using sound-absorbing materials and designs.

Conclusion

In conclusion, the existing literature underscores the profound influence of sound and noise on patients' experiences within healthcare settings, with a particular emphasis on ICUs. Given patients' vulnerability and reliance on auditory stimuli, sound becomes an integral part of their environmental interaction. The concept of a soundscape, representing the entirety of sounds within a healthcare environment, is pivotal but often neglected in healthcare design. It's important to note that the impact of sound is not solely dependent on noise levels; the quality and context of these sounds also play a significant role. Sounds can be interpreted as negative, neutral, or even positive, depending on their source and context.

While numerous strategies are currently in place to enhance the sound environment in ICUs, there remains considerable room for additional research and innovative solutions to elevate awareness and optimization of the acoustic environment. Moving forward, targeted field research is essential to pinpoint the specific acoustic needs within the PICU and NICU of Erasmus MC.

2.2 Field research in PICU

Purpose of research

The purpose of conducting this field research was to gain first-hand understanding of the acoustic environment and night routines in the PICU. This real-world investigation was intended to gather empirical data on the soundscape of the PICU, the sources of sound, and how these may vary over different times of the day, particularly during the night when patients are supposed to be sleeping.

By observing the night routines of the patients, I aimed to understand how the sound environment during night is like and how patients' sleep patterns are affected by the surrounding noises. This information is critical in understanding the challenges in maintaining a conducive environment for sleep in the PICU and exploring opportunities for technological interventions that could potentially enhance the night sound environment quality.

Furthermore, the observation of medical staff activities provided insights into how the necessary operations and procedures in the PICU contribute to the overall noise levels, and how these might be managed or mitigated to reduce potential sleep disruptions for patients.

Setting and Participants

The field research was conducted at the PICU of Erasmus MC Sophia Children's Hospital, which is one of the seven PICUs located in academic hospitals in the Netherlands. Each year, around 550 patients aged 0–18 years are admitted to this PICU, with more than 50% of them staying for over 56 days. The patient population is diverse, including those who have undergone major surgeries and those with significant congenital anomalies. This PICU is particularly notable for its focus on traumatic brain injury, renal transplants, scoliosis surgery, neurosurgery, and critical care for major congenital anomalies.

The participants of the study included the patients admitted to the PICU, medical staff (doctors and nurses), and other caregivers. The study strictly adhered to confidentiality and research ethical restrictions, ensuring all participants were informed about the presence of observers and the purpose of the research.

Observation Methods and Instruments

The research employed a descriptive observation method to gain insights into the patients' night routines and the acoustic environment of the PICU. Two rounds of observation were performed: a partial morning shift and a complete night shift. The first observation round on May 23rd provided an overview of the physical environment and diurnal activities of patients. The second round, performed on the night of May 30th, focused on the patients' night routines and the PICU's acoustic environment.

The observation instruments used during the study included a PICU acoustic environment observation form, floor plans of the units, and the patients' journey map. These tools helped in collecting and analyzing the data regarding the sources and levels of noise, the impact of noise on patients, and the variations in patients' responses to noise.

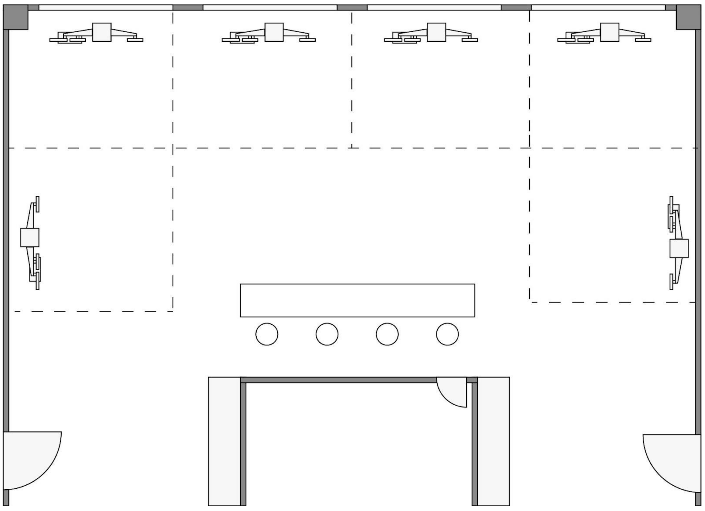


Figure 5: PICU unit plan

Insights

The activity journey map reveals that alarm noise is the most consistent sound throughout the observed period. Coupled with observations and interviews with nurses, it was found that a majority of these alarms were not deemed crucial and were often disregarded. The alarms, frequently triggered by inadvertent errors, produced continuous sounds that led to heightened negative emotions, particularly during nighttime.

Sound Intensity: Deviation from Standard Criteria

The Environmental Protection Agency of the United States stipulates that hospitals should maintain noise levels of 35 dBA at night and 45 dBA during the day. However, our measurements indicate that the average sound intensity in the PICU oscillates between 50 and 55 dBA, with certain incidents causing spikes exceeding 70 dBA. This shows a clear departure from the recommended noise levels, suggesting a need for improved acoustic management.

Patient Noise Sensitivity: Age-Related Differences

An analysis of demographic characteristics indicates that toddlers are more susceptible to noise disturbances compared to other age groups. One possible explanation is that sleep sensitivity tends to increase with age, resulting in infants having deeper, longer sleep spans and lower sensitivity to noise. Conversely, teenagers were observed to awaken easily due to noise disturbances, but often endeavored to return to sleep without much fuss.

Noise Hotspots: Nurse Station and Meeting Room

The noise heatmap reveals that the areas surrounding the nurse station and meeting room are the primary sources of sound. Conversations within the meeting room and alarm sounds at the nurse station significantly contribute to the overall nighttime soundscape. Other sources of noise, although not as frequent, include the washbasin, trashcan, and storage area, which are located adjacent to the meeting room.

Activity Peaks: Patterns and Implications

The activity journey map indicates that patient activities peak before 12 pm and after 5 am. During the period between 12 pm and 5 am, the acoustic environment largely remains consistent. Understanding these activity patterns can be instrumental in identifying potential strategies to minimize noise disturbances during critical rest periods for patients.

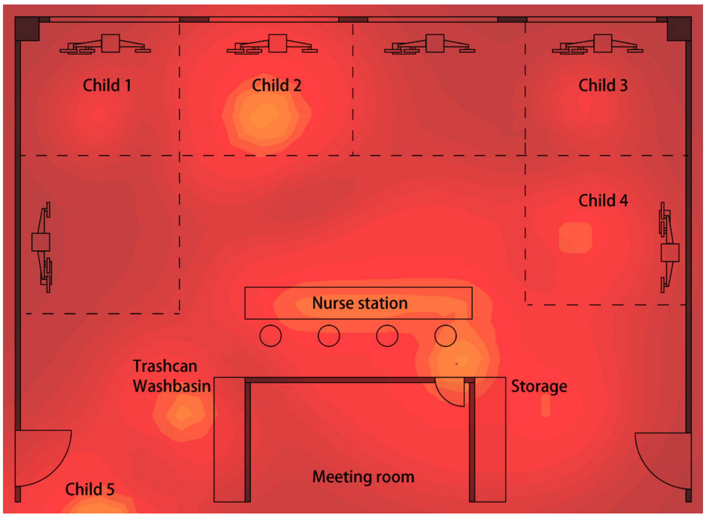


Figure 6: Sound heatmap of Unit 3

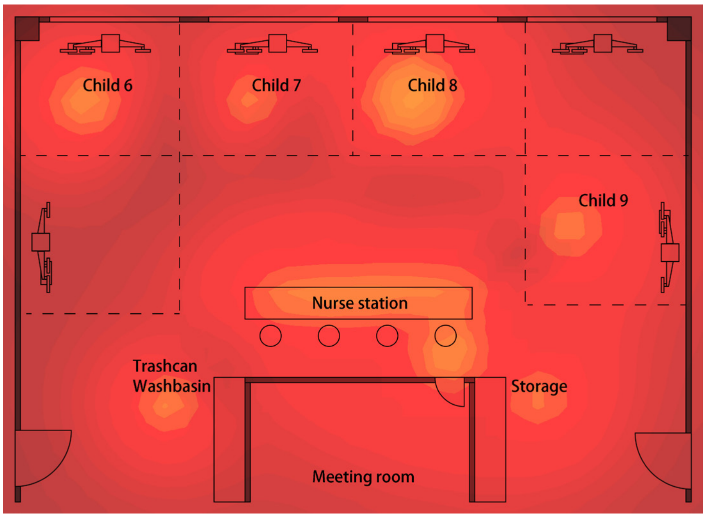


Figure 7: Sound heatmap of Unit 4

PICU PATIENTS' JOURNEY MAP Unit 3

Phase	10PM-11PM	11PM - 12AM	12AM - 1AM	1AM - 2AM	2AM - 4AM	4AM - 5AM	5AM - 6AM
Activities Patients	Most of patients (infants and toddlers) are already fall asleep, while teenager patient is awake and chatting with nurses.	All infants and toddler fall asleep, but the teenager patient is still awake and receiving treatment from the nurses.	The oddler from bed B is crying because of irritation, and the other patients are also awakened and crying.	All the patients are asleep, except for Bed B awake once and cry for 5-10 minutes	All the patients are asleep and become stable	All the patients are still asleep	All patients are still sleeping except for Bed E cries for 5 minutes
Medical staff	Night shift changing during this time slot, a lot of treatments and operations are going. Nurses and doctors have conversation in the nurse station.	Less activities after the shift changing, nurses stay at the nurse station and moniter the patients' situation constantly, checking off the alarms.	Nurses check the crying patients, comfort them, adjust the medical devices and have treatments on patients	Nurses stay in the rest room behind the nurse station and moniter unit's situation from there	Only 2 nurses stay in the rest room and only come out when there is an alarm	Nurses go back to the unit and start to prepare for the treatments	Morning shift changing: nurses walk around, talking, writing shift report, have treatment and doing some chores
Caregivers	Most of caregivers (especially infants' and toddlers') are accompanying the patients, having conversation with the nurses.	Some caregivers leave and go to the rest room, while one of the toddler's caregiver is still accompanying and talking with nurses	Caregivers of the crying patients come back to the unit and comfort their children	Most caregives leave, only Bed B's parent is still accompanying but is also fall asleep beside the bed.	All caregivers leave the unit	All caregivers leave the unit	Caregives haven't come back yet
Sound sources	Alarms*21 Talking*5 Phone call*1	Alarms*17 Treatment*2 Chores*2	Alarms*12 Child crying 20-30min Talking*4	Alarms*8 Child crying 5-10min Talking*2		Alarms*9 Talking*4	Alarms*11 Child crying 5 min Talking*2 Typing*1 Chores*2
Patient Reaction	Teenager patient has difficulties to fall asleep during to the acitivities and generated sounds in the unit	Teenager patient are influenced more by the sounds than the infants and toddlers	All the patients are largely affected by the crying sounds and awakened by them	All the patients tends to be stable and react less to the sounds	All the patients become stable	Patients start to react more to the sounds in the morning	

Sound Level (dB)

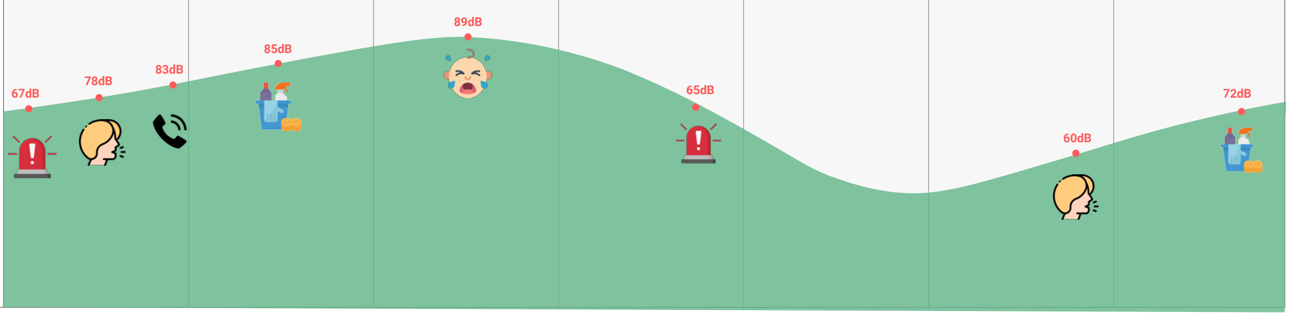


Figure 8: Patients' Journey Map of Unit 3

PICU PATIENTS' JOURNEY MAP Unit 4

Phase	10PM-11PM	11PM - 12AM	12AM - 1AM	1AM - 2AM	2AM - 4AM	4AM - 5AM	5AM - 6AM
Activities Patients	Patients 7, 8 and 9 (infant and toddlers) are constantly cring during this slot, various from 5-10 mintues and 30-40 minute.	Patient 7, 8, and 9 are still crying due to the irritation and treatments they can't fall asleep	Patient 7, 9 stopped crying at the start, while patient 8 was still crying. And after around 15min patient 7 and 9 start cry again	All the patients are asleep, except for patient 7 awake once and cry for 15 minutes	All the patients are asleep and become stable	All the patients are asleep except-for patient 7 and 9 wake up and cry for 5-10 minutes	All patients are sleeping
Medical staff	Night shift changing during this time slot, a lot of treatments and operations are going. Nurses and doctors have conversation in the nurse station.	Nurses are busy with treatments, comforting the patients, and having phone call from the other departments, this is the peak hour of the night shift.	Nurses are trying to comforting and calming down the patients that are crying with playing some music. They also has quite a lot talking in this slot	Nurses stay in the rest room behind the nurse station and only come out when patient is crying	Only 2 nurses stay in the rest room and only come out when there is an alarm	Nurses go back to the unit and start to prepare for the treatments	Morning shift changing: nurses walk around, talking, writing shift report, and doing some chores
Caregivers	Most of caregivers (especially infants' and toddlers') are accompanying the patients, having conversation with the nurses.	All caregivers are still stay in the units since their children are still awake and crying.	All caregivers are still stay in the units since their children are still awake and crying.	Most caregives leave, only patient 7 and 8's parents still accompany and talking with the nurses	All caregivers leave the unit	All caregivers leave the unit	All caregivers leave the unit
Sound sources	Alarms*28 Talking*4 Children crying 30-40min	Alarms*10 Chores*2 Children crying 15min Phone call*2	Alarms*15 Children crying 30-35min Chores*3 Talking*4	Alarms*12 Children crying 15min Talking*1		Alarms*8 Children crying 5-10min	Alarms*6 Typing*1 Chores*2
Patient Reaction	The infant & toddler patients are influencing each other because of the crying sounds, and they all have difficulties to fall asleep		All the patients are largely affected by the crying sounds and awakened by them	All the patients tends to be stable and react less to the sounds	All the patients become stable	Patients start to react more to the sounds in the morning	

Sound Level (dB)

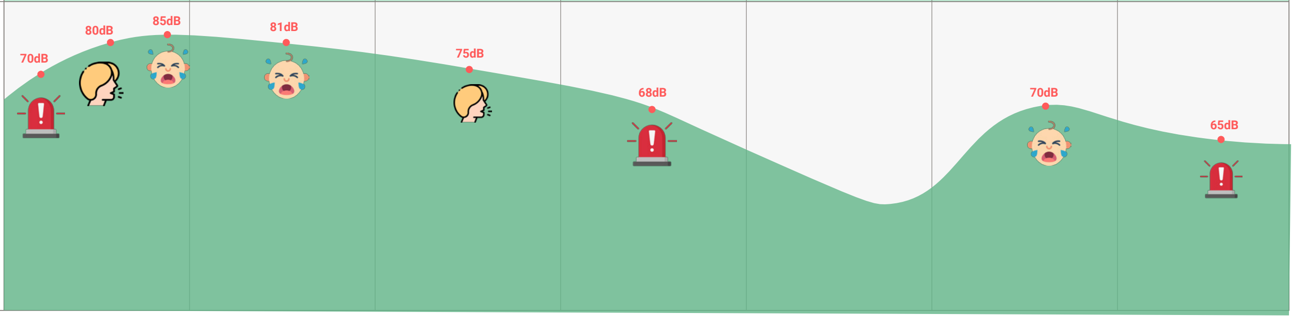


Figure 9: Patients' Journey Map of Unit 4

2.3 Field research in NICU

Purpose of Research

The objective of this field research in the Neonatal Intensive Care Unit (NICU) was to gain an in-depth understanding of the acoustic environment during daytime and observe the interactions between medical equipment, alarm systems, sound events, and nursing activities. By conducting this research during the day, we were able to capture a different aspect of the soundscape compared to the nighttime environment of the PICU. The focus was on how medical equipment contributes to the overall sound environment and how nursing activities respond to and influence these sound events.

Setting and Participants

The research was conducted in the NICU of Erasmus MC Sophia Children's Hospital. The participants included infants admitted to the NICU, medical staff, and technical experts involved in the operation and maintenance of the medical equipment. Ethical and confidentiality considerations were strictly upheld, with all participants being informed about the research and its purpose and no privacy data was recorded.

Observation Method and Instruments

A descriptive observational method was used in this research, with a specific focus on the role of alarms, sound events, and nursing activities. The study involved observing and recording the activities in the NICU during the daytime, and conducting an interview with technical experts about the influence of medical equipment on the sound environment. The research tools included an NICU acoustic environment observation form and an activity timeline that documented the nursing activities, alarm events, and corresponding sound events.

Insights

Role of Medical Equipment in the Sound Environment

The interviews with technical experts highlighted the significant role that medical equipment plays in shaping the acoustic environment in the NICU. Each piece of equipment, ranging from monitors to ventilators, contributes its unique sound, which collectively forms part of the ambient noise in the unit. Understanding the sound contributions of individual pieces of equipment can inform strategies for noise management.

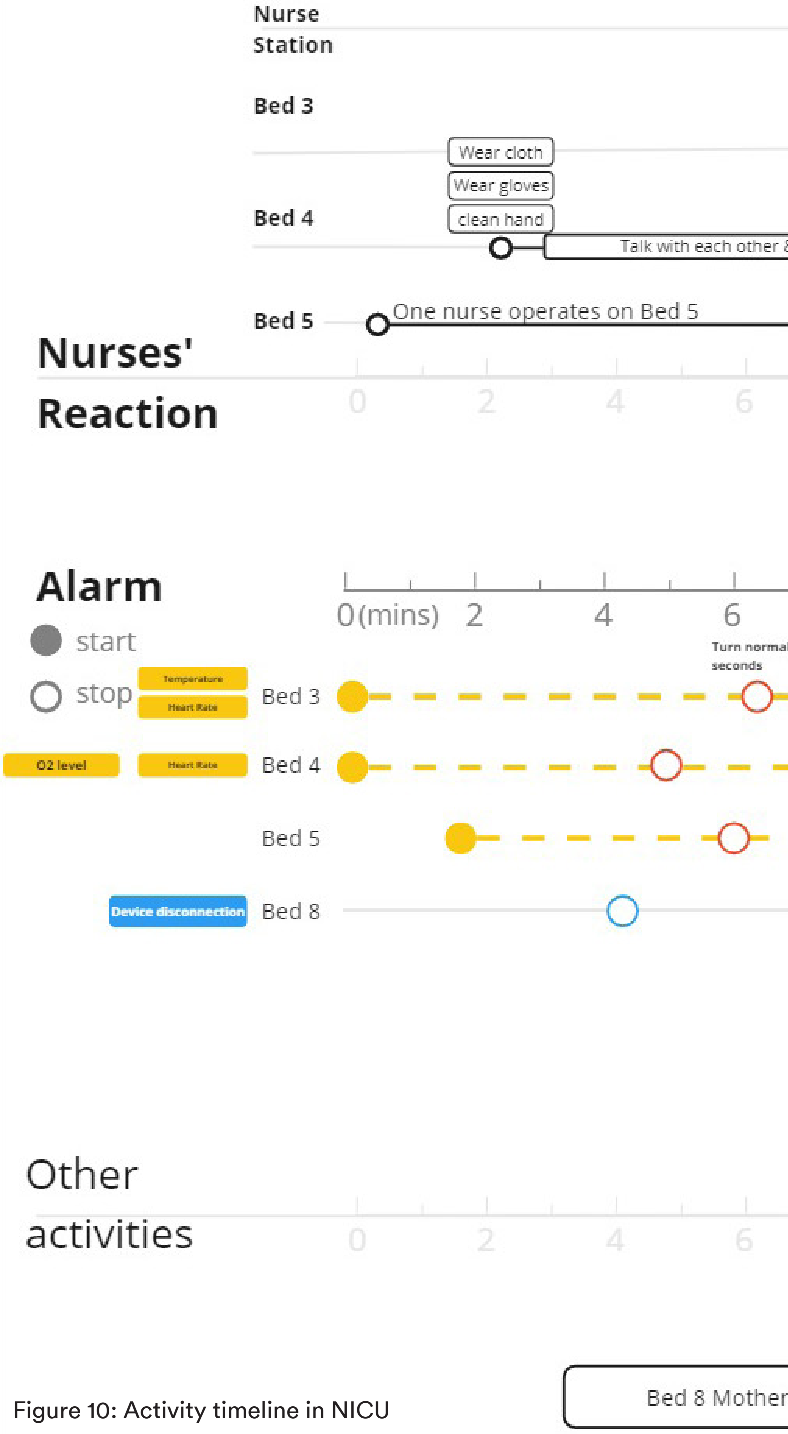
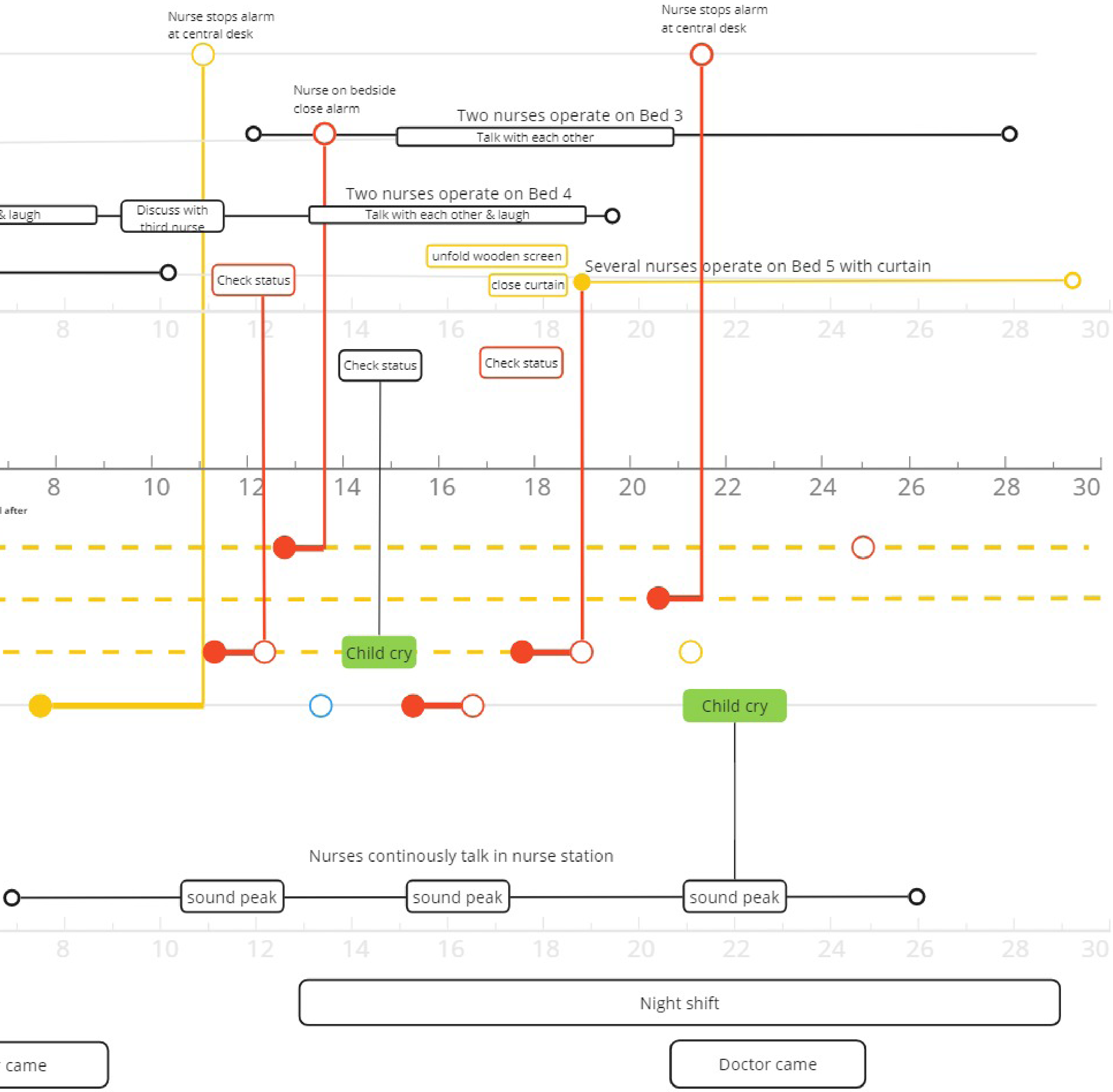


Figure 10: Activity timeline in NICU

Complex Interplay of Alarms, Nursing Activities, and Sound Events

The observational data revealed a complex interplay between alarms, nursing activities, and sound events. Alarms, whether from the central desk or bedside monitors, are a constant feature of the NICU soundscape. The activities of nurses, from operating on beds while alarms are active



to their routine tasks such as donning gloves and discussing with colleagues, intersect with these alarm sounds, often leading to temporary increases in the overall sound level.

Influence of Patient-Related Sound Events

Patient-related sound events also form a crucial part of the NICU soundscape. Events such as a child crying or a device getting disconnected can add sudden peaks to the overall sound level. This highlights the importance of considering patient-related sounds when examining the acoustic environment of NICU.

Figure 11: Equipments in NICU unit

3

Project Direction

3.1 Problem definition

Understanding Stakeholder Concerns
Different stakeholders may have varying perceptions of different sound types, which can influence their experience in the NICU. For instance, the sound of alarms may be perceived as reassuring by some, indicating that the monitoring systems are functioning correctly, while others may find them disruptive or anxiety-inducing (Bremmer et al., 2012)

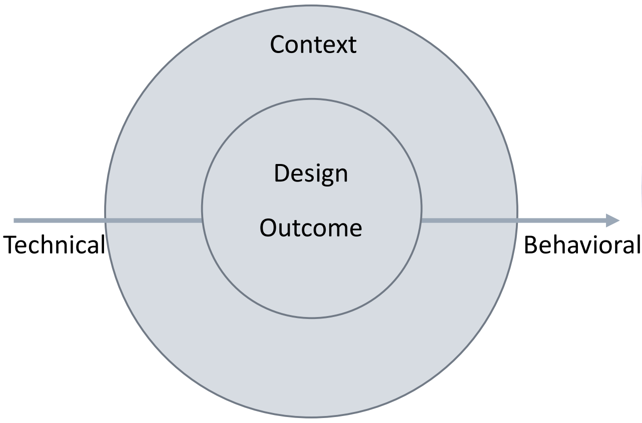
Sound attribute, alarm and Event Detection
The NICU environment is filled with alarms and various sounds, creating a challenging auditory atmosphere. It's essential to balance the functionality of alarms with their potential to cause disruption. This process requires precise identification and classification of different sound events and understanding their specific attributes, like volume and frequency. The task at hand involves improving these detection mechanisms to effectively manage the sound environment, ensuring alarms serve their purpose without causing unnecessary stress.

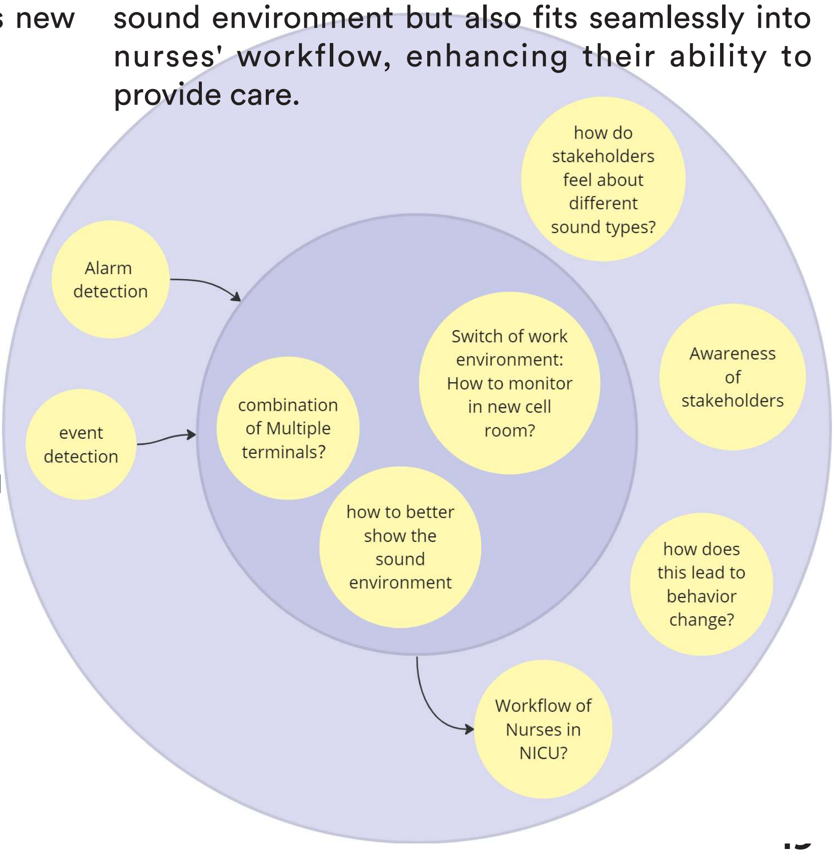
Adapting to a Changing Work Environment
The work environment in the NICU is changing, with a shift towards single-patient rooms. This change presents a new challenge: how can medical staff effectively monitor the sound environment in these individual rooms? Developing a system that can adapt to this new environment is a key part of the problem.

Stakeholder Awareness
Raising awareness among stakeholders about the importance of the sound environment in the NICU is another critical aspect. This includes educating parents about the potential impacts of noise on their newborns and informing hospital administrators about the need for sound-friendly policies and infrastructure. For instance, parents and nurses alike have expressed a desire for designs that enhance parent-infant bonding in the NICU, suggesting that there is a need for tools that can facilitate communication and interaction in this environment (van den Hoogen et al., 2018).

Integration of Multiple Terminals
The integration of multiple terminals in the NICU, each with its own set of alarms and sounds, adds another layer of complexity to the sound environment. Managing these multiple sources of sound and ensuring that they do not contribute to an overwhelming noise level is a significant challenge.

Nurse Workflow in the NICU
Finally, any solution must consider the workflow of nurses in the NICU. Nurses are key stakeholders who interact with the sound environment on a daily basis. The challenge is to design a system that not only improves the sound environment but also fits seamlessly into nurses' workflow, enhancing their ability to provide care.

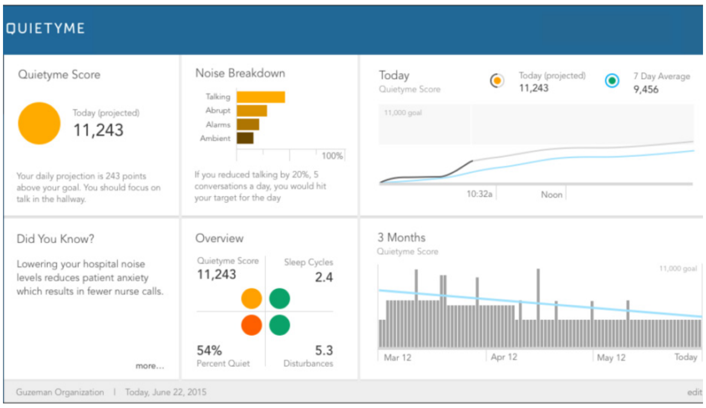




3.2 Current solution

The purpose of conducting a competitor analysis of existing products is to identify best practices from successful solutions, understand potential gaps in the market that current solutions don't address effectively, and benchmark our proposed solution against existing ones to set realistic goals. Additionally, by understanding what is already available, I can avoid duplicating efforts, focusing instead on innovative solutions that add unique value.

Quietyme
Quietyme is a noise monitoring solution that uses sensors to monitor noise, temperature, humidity, and light levels in real-time. The data is sent to the cloud where it can be accessed via a web-based dashboard. The system provides real-time alerts to staff when noise levels exceed set thresholds.



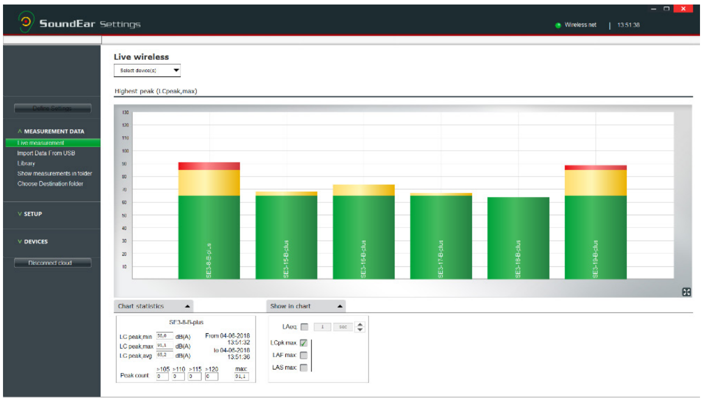
Your daily projection is 243 points above your goal. You should focus on talk in the hallway.

If you reduced talking by 20%, 5 conversations a day, you would hit your target for the day

Lowering your hospital noise levels reduces patient anxiety which results in fewer nurse calls.

Svantek SV200A
The Svantek SV200A is a noise monitoring station that is designed for long-term outdoor measurements, but it can also be used indoors. It has a built-in GSM modem for remote communication, a weather station, and GPS localization. The device is designed to be robust and reliable, with a weatherproof casing that can withstand harsh conditions.

SoundEar3
SoundEar3 is a noise monitoring system that visualizes the noise levels in an environment. It includes a range of products, including noise meters, noise loggers, and noise warning signs. The SoundEar3 software allows for detailed noise analysis, including the ability to see noise levels over time and identify when and where the noise is loudest.



Sonicu
Sonicu is a cloud-based wireless monitoring platform that offers a range of solutions for healthcare environments, including temperature monitoring, room pressure monitoring, and sound monitoring. It provides real-time alerts, simple reports, and a mobile app for remote access.

Gains from existing products:

Real-time Monitoring and Alerts:
Like Quietyme and Sonicu, the product should offer real-time monitoring and alerts to ensure immediate response to any issues.

Detailed Noise Analysis:
Taking a cue from Soundear3, the product could benefit from offering detailed noise analysis capabilities, allowing users to identify patterns and pinpoint problematic noise sources.

User-friendly Interface:
All these products offer user-friendly interfaces and dashboards. The product should also be easy to use and understand, minimizing the learning curve for busy healthcare professionals

Opportunities for my project

Customization for NICU/PICU Environment

Current products offer general noise monitoring solutions, but there exists an opportunity to tailor a product to the unique needs and challenges of the NICU/PICU environment. For instance, the shift from cluster rooms to single-patient rooms presents new requirements for monitoring systems. By focusing on these specific needs, I can create a solution that caters specifically to this context.

Combine Event Detection with Sound Attribute

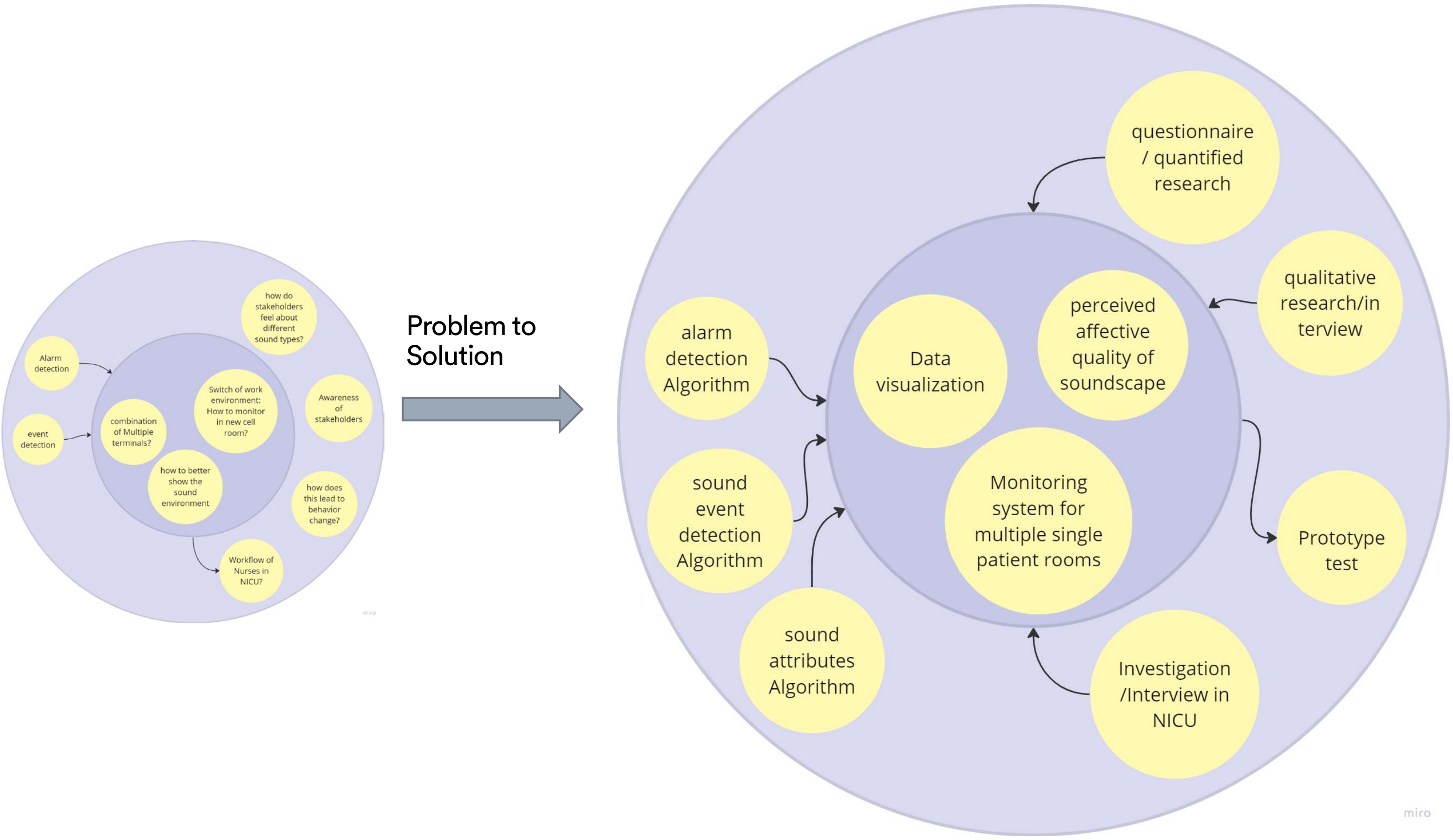
Existing solutions typically separate event detection and sound attribute analysis. I can leverage this opportunity to develop a solution that combines these two aspects, providing a more holistic and detailed understanding of the sound environment in the NICU/PICU. This could enhance the accuracy and effectiveness of noise management strategies.

Understandable and Beneficial Communication

There's a gap in the market for solutions that provide clear, beneficial communication to various stakeholders. My project could focus on delivering understandable and useful information to all users, from medical staff to parents. This could involve simplifying technical data or providing actionable recommendations based on the monitored sound data.

Integrate into Nurse Workflow

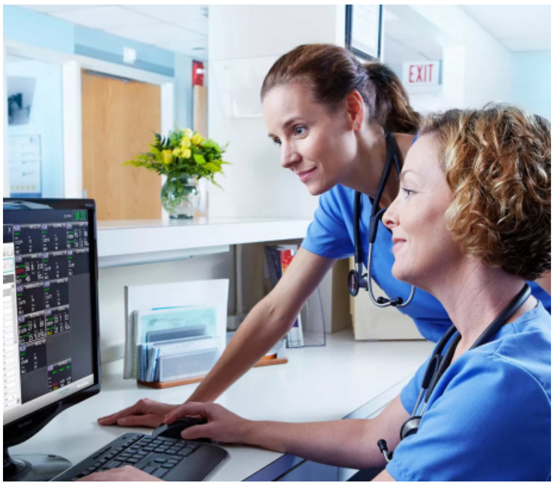
Existing solutions often overlook the importance of integrating seamlessly into the workflow of nurses. This represents an opportunity for my project to design features that fit into the nurses' workflow effortlessly. For example, integrating alerts with their existing communication tools or structuring the data in a way that it can be easily incorporated into patient reports. This could potentially enhance user acceptance and usage, thereby increasing the impact of my solution.



3.3 Design brief

Design Goal

"I want to increase the awareness of the sound environment among NICU/PICU nurses, bolster their decision-making processes, and foster improved communication with diverse stakeholders."



Design Requirements:

User-Centric Design:
The product should be intuitive and user-friendly for NICU/PICU healthcare professionals.
PICU&NICU Context based:
The product should consider specific needs in NICU/PICU contect.
Advanced Noise Analysis and Event-Detection:
The product should have advanced noise analysis and event-detection capabilities.
Workflow Consideration:
The product should align with the workflow of NICU/PICU nurses.
Data Privacy and Security:
The product should ensure data privacy and security from the initial design stages.

Design Considerations:

Feasibility:
The product should be realistic, achievable, and deliver value within the constraints of a Master's project.
Simplicity:
The product should have a simple design and functionality, even while incorporating advanced features.
Aesthetics:
The product should have a visually pleasing design that aligns with the NICU/PICU environment.
Maintenance and Updates:
The product should be designed for easy updates, improvements, and maintenance in the long term.

Design Challenges:

Balancing Functionality and Simplicity:
The balance between incorporating advanced functionality and maintaining simplicity in the design presents a considerable challenge. The system must be efficient and feature-rich, yet user-friendly and intuitive.`
Resource Constraints:
As a Master's project, there will be limitations regarding time, budget, and resources. Prioritizing different product features effectively will be crucial to achieving the intended goal within the constraints.
Data Privacy and Security:
In a sensitive healthcare setting like the NICU/PICU, ensuring data privacy and security is a paramount challenge. Particularly during the iteration phase, there may be potential conflicts between rapid development and strict data privacy requirements.
Scalability:
The product must be flexible and adaptable for future iterations. This demands a system architecture that is easily adjustable and code that can be readily re-arranged from the back-end to the front-end.

4

Soundscape Research

4.1 Soundscape study

Definition and Significance of Soundscapes
Soundscapes refer to the relationship between a landscape and its composition of sound, encompassing all the noises within a given environment, from a room to an entire region. The concept of soundscapes and their significance have been explored in various contexts, including urban planning and healthcare. In the context of urban areas, the study of soundscapes involves understanding citizens' perceptions of their sonic environment, with a focus on enhancing the acoustic environment through design and noise reduction methods.

As for healthcare environments, particularly intensive care units (ICUs), the soundscape tends to be cacophonous, a mixture of various unharmonious and unpleasant noises. This includes machinery noise, conversations, alarms, and incidental sounds. Continuous exposure to such sound environments can lead to sleep disturbances, cardiovascular diseases, and mental health impacts. Consequently, there is a growing need to manage these sound environments and keep them within the limits established by the World Health Organization (WHO). Unfortunately, it's challenging to pinpoint a single source of this cacophony in the ICU due to the multitude of overlapping sound sources.

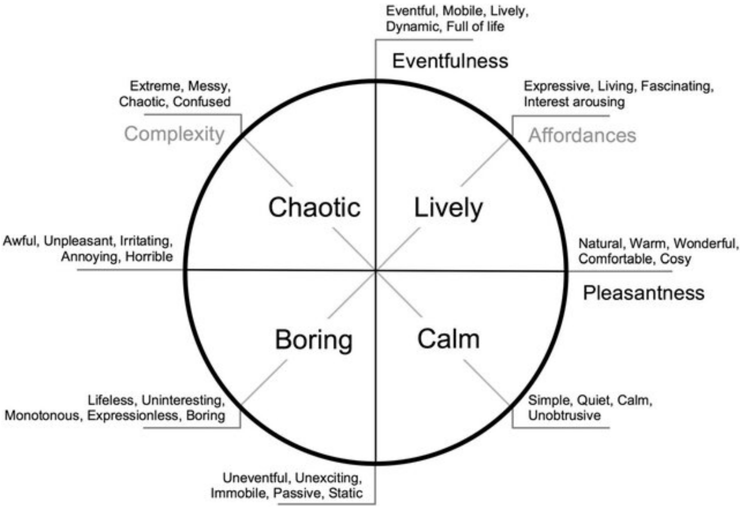


Figure 12: Four perceptual quadrants and their basic dimensions (van den Bosch et al., 2015)

Principal Components Model of Soundscape
In the broader context of soundscape studies, Axelsson, Nilsson, and Berglund developed a principal components model of soundscape perception, which identifies the primary dimensions of pleasantness, eventfulness, and familiarity. However, the familiarity component was found to have limited importance due to small variation in familiarity of soundscapes, and thus is not heavily relied upon in applied work. Pleasantness and eventfulness, on the other hand, are seen as universal across languages, cultures, and environments, and are the main dimensions used for reliable assessments of core affects, including main emotional dimensions.

Scenario and individual difference
The perception and emotional response to soundscapes are deeply personalized experiences, shaped by various factors including the scenario and individual differences. For instance, the same set of sounds can elicit differing emotional responses based on the context in which they're encountered. The rustling of leaves might be comforting in a quiet park but unnerving in an otherwise deserted city street at night.

The individual's current activity or expectations can also influence the perception of these sounds, as the same soundscape can be interpreted differently based on whether the individual is seeking tranquility or excitement. Furthermore, individual differences play a crucial role in how soundscapes are perceived and processed. Factors such as an individual's hearing ability, personal preferences, or current mood can significantly influence their experience of a soundscape. For example, a soundscape that one person finds relaxing might be perceived as monotonous or even irritating by another. This highlights the intricate interplay between soundscapes, individual characteristics, and context, underlining the subjective nature of our sonic experiences.

4.2 Sensory Pleasantness

In my project, I chose to concentrate on sensory pleasantness over perceived pleasantness. This decision was influenced by the more objective nature of sensory pleasantness. Being informed by primary auditory sensations such as roughness, sharpness, tonality, and loudness, sensory pleasantness provides a more quantifiable and concrete dimension to study. This makes it particularly suitable for integration into a monitoring system where objectivity and calculation feasibility are crucial.

In contrast, perceived pleasantness is highly individual and subjective, influenced by a wide array of factors that can vary greatly from person to person. While this makes perceived pleasantness an intriguing field of study, its subjective nature makes it less feasible for the objectives of my project. Thus, despite the complexity of isolating sensory pleasantness as a single elementary sensation, I found it to be a more appropriate focus for my study.

Calculation of Sensory Pleasantness

Zwicker's study provided a comprehensive exploration of the auditory sensations - sharpness, roughness, tonality, and loudness - and their impact on sensory pleasantness.

Sharpness was found to have a direct influence on sensory pleasantness. As sharpness increased, sensory pleasantness decreased, indicating a clear inverse relationship. Other auditory sensations, such as roughness and tonality, were also found to influence sensory pleasantness, but their effects were not as pronounced as sharpness.

Loudness was another auditory sensation examined, but its effect on sensory pleasantness was observed to be minimal until it exceeded 20 sone. Beyond this point, an increase in loudness led to a decrease in sensory pleasantness.

To encapsulate the complex relationships between these auditory sensations and sensory pleasantness, Zwicker derived an equation. This equation allows for the calculation of sensory pleasantness based on relative values of sharpness, roughness, tonality, and loudness:

$$\frac{P}{P_0} = \mathrm{e}^{-0.7R/R_0}\mathrm{e}^{-1.08S/S_0}\left(1.24 - \mathrm{e}^{-2.43T/T_0}\right)\mathrm{e}^{-(0.023N/N_0)^2}$$

This equation is a significant contribution as it facilitates the calculation of sensory pleasantness for any sound, given the values of sharpness, roughness, loudness and tonality.

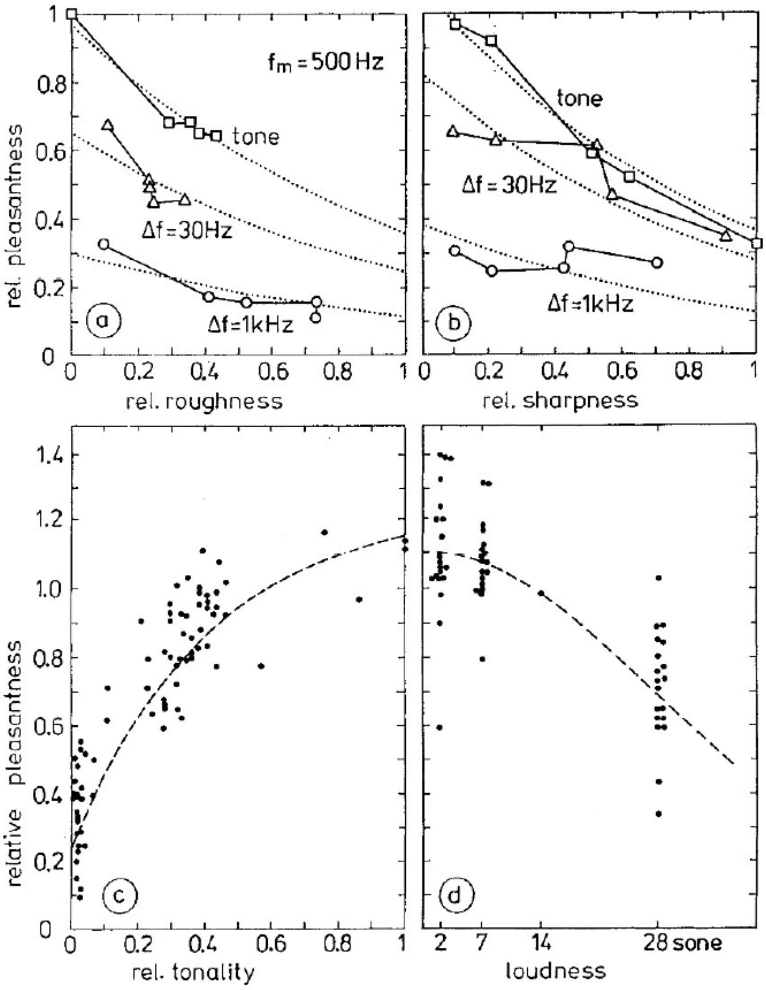


Figure 13: Relative sensory pleasantness with four factors(Fastl and Zwicker, 2007)

MoSQITo auditory analysis tool

In my soundscape research, I employ an open-source tool known as MoSQITo for the analysis of the four key auditory indexes. This tool offers a wide array of acoustic and psychoacoustic analysis methods that include, but are not limited to, loudness, sharpness, roughness, and the tone-to-noise ratio. This extensive range of capabilities makes MoSQITo a versatile asset for various audio analysis tasks.

MoSQITo aligns with numerous industry standards such as ISO, DIN, and ECMA. Therefore, it assures the reliability of the results and their comparability with outcomes obtained from other tools that comply with these standards.

The comprehensive approach of MoSQITo towards sound analysis is especially beneficial in my soundscape study. It provides a nuanced and multi-dimensional understanding of the sound environment. By quantifying unique attributes of sound like loudness, roughness, and sharpness, MoSQITo enables us to comprehend the perceived quality and characteristics of a soundscape in a more detailed manner.

Loudness

The Zwicker method is used for stationary signals. This method was introduced as a standard in the 1975 version of ISO 532 and updated in subsequent versions. The MoSQITo software is based on the BASIC program published in Zwicker and Fastl, 1991. The ISO 532-1:2017 standard provides a set of synthetic and technical signals to validate the implementation.

Roughness

This attribute refers to the perception of rapid amplitude fluctuation. The software uses the model developed by Daniel and Weber in 1997 to compute the acoustic roughness. No standardized method was proposed until recently with the ECMA 418-2. The software provides a tutorial on how to use MoSQITo to compute roughness. It uses reference values for roughness proposed by H.Fastl and E.Zwicker.

Sharpness

The DIN 45692 standard introduced the computation of acoustic sharpness. The computation is based upon the specific loudness distribution of the sound, and is weighted by ponderation functions. The MoSQITo software uses the 'din' weighting function by default, and other weighting functions are also implemented. The code is based on the 2009 version of the standard and the DIN 45692:2009 standard provides synthetic signals to validate the implementation.

Tone-to-noise ratio (TNR) and Prominence ratio (PR)

These attributes were introduced in the ECMA 418-1 standard. The calculation is based on the comparison between the level of each tonal candidate and the level of the surrounding spectrum. Two different methods have been added to detect the potential tonal components: the method by Sottek using a smoothed spectrum, and the classic method by Aures/Terhardt using the close frequency neighbours. The ECMA TR/108 has confirmed the reliability of the use of global values T-TNR and T-PR, which are calculated as the sum of individual tonal values.

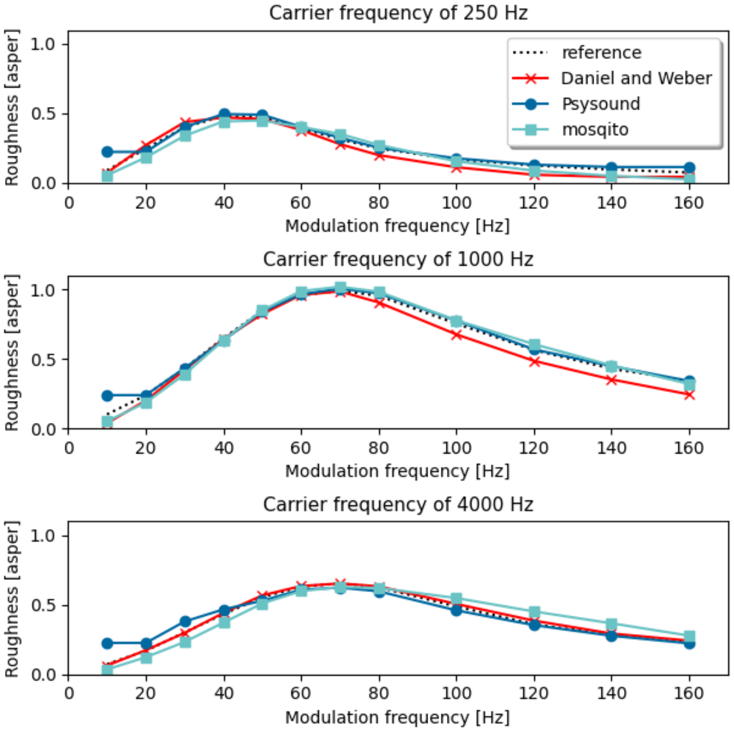


Figure 14: Different roughness implementations' results for amplitude-modulated tones. (Green Forge Coop. MOSQITO)

4.3 Eventfulness

Definition and Overview

Eventfulness, in the context of soundscapes, refers to the degree of activity or dynamic variation within a given auditory environment. The concept was established by Axelsson et al. (2010) as one of the primary dimensions for the perception and evaluation of soundscapes. More specifically, eventfulness is considered as a semantic dimension of auditory order and variation, reflecting the level of activity or busyness in a soundscape. For example, a bustling city park or a busy marketplace are typically perceived as eventful soundscapes due to the multiplicity and variability of sound sources.

Factors Influencing Eventfulness

The perceived eventfulness of a soundscape is influenced by various elements, primarily the number, variety, and dynamic characteristics of the sound sources present. Soundscapes with a higher number of different sound sources and greater variability in their temporal patterns are generally perceived as more eventful.

In addition to these objective factors, the context in which the soundscape is experienced can also significantly impact the perception of eventfulness. This includes factors like the listener's familiarity with the environment, their current activity, and their personal preferences or biases. For instance, a soundscape that is considered eventful and engaging in one context (e.g., during leisure time in a park) might be perceived as chaotic and distracting in a different context (e.g., while trying to concentrate on work in an open office).

Individual differences also play a crucial role in the perception of eventfulness. Different people may perceive the same soundscape as being more or less eventful based on their personal characteristics, such as their auditory sensitivity, attentional focus, or cultural background. For example, people who are more attuned to the auditory environment or those from cultures with more eventful soundscapes may perceive a given soundscape as less eventful compared to others.

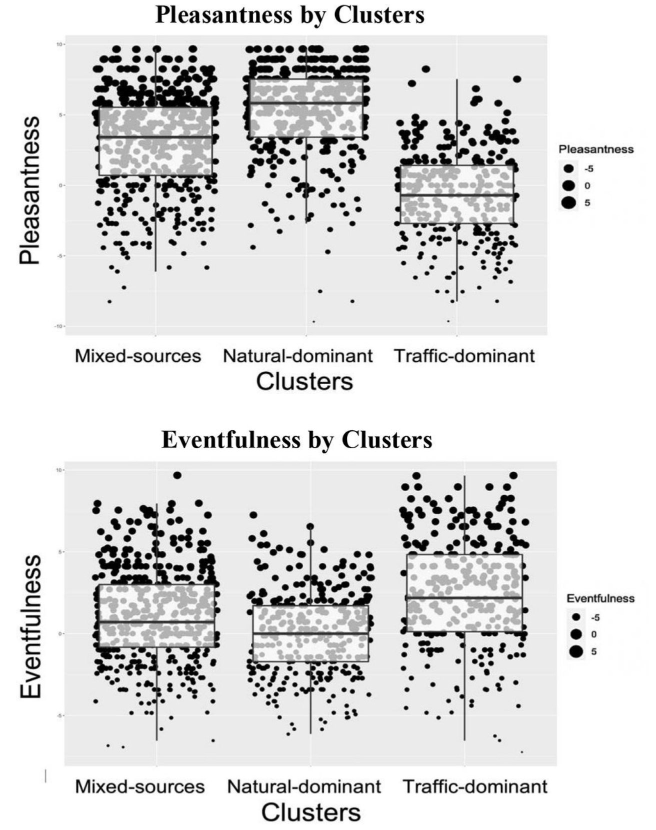


Figure 15: Boxplots of Kruskal-Wallis analyses with error bars for Pleasantness and Eventfulness (Erfanian, M et al., 2020)

Challagne in measuring eventfulness

Measuring eventfulness in soundscapes can be challenging due to the subjective nature of this concept. One common approach is to use subjective ratings, often through questionnaires or interviews, to assess individuals' perceptions of the eventfulness of a soundscape. This can provide valuable insights, but it is also subject to potential biases and inconsistencies. Objective acoustic measurements can provide more quantifiable data, such as the number and intensity of different sound sources, but these measurements may not fully capture the subjective experience of eventfulness and there isn't a clear definition of how to generate eventfulness value from audio data.

Challenges in measuring eventfulness also include the difficulty of isolating this dimension from other aspects of soundscape perception, the influence of individual and cultural differences on perceptions of eventfulness, and the potential for changes in eventfulness over time or in response to specific events.

Conclusion of literature study

In order to calculate eventfulness in my project and provide a object results in the monitoring system , it's essential to control for subjective factors and focus on measurable ones. Given that the primary users in my project are nurses and the main context is an indoor ICU environment, we can consider these users as relatively similar individuals interacting in a stable scenario.

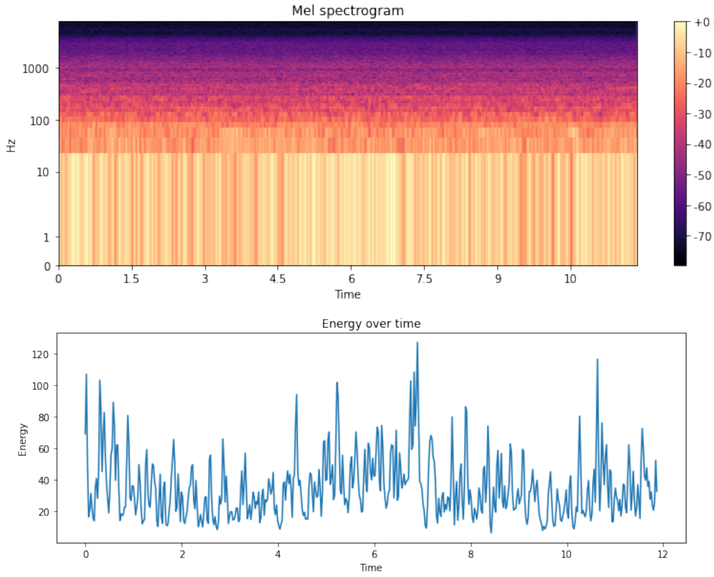
The two main measureable object fators that influence eventfulness are the number of event s and the variability in sound temporal patterns. Variability in sound temporal patterns relates to changes in the sound landscape over time, which can include fluctuations in volume, pitch, rhythm, and other sound qualities. To analyse these attributes, I further explore algorithms that can achieve the analysis.

Sound statinary analysis

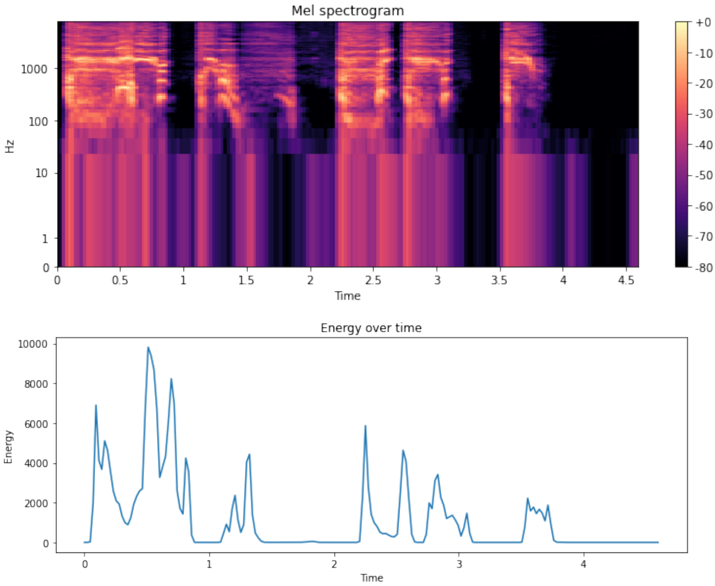
In the process of analyzing stationary sound, I've found great value in using two open-source libraries in Python, namely, librosa and statsmodels. These libraries have proven to be particularly useful due to their comprehensive functionalities and robustness in handling audio and statistical data, respectively.

First, I use librosa to load the audio file and convert the audio signal into a Mel spectrogram. The Mel spectrogram is a visual representation of an audio clip's spectral content, which is particularly useful for identifying patterns or features within the audio data. The spectrogram is divided into several time segments, and the total energy is calculated for each segment.

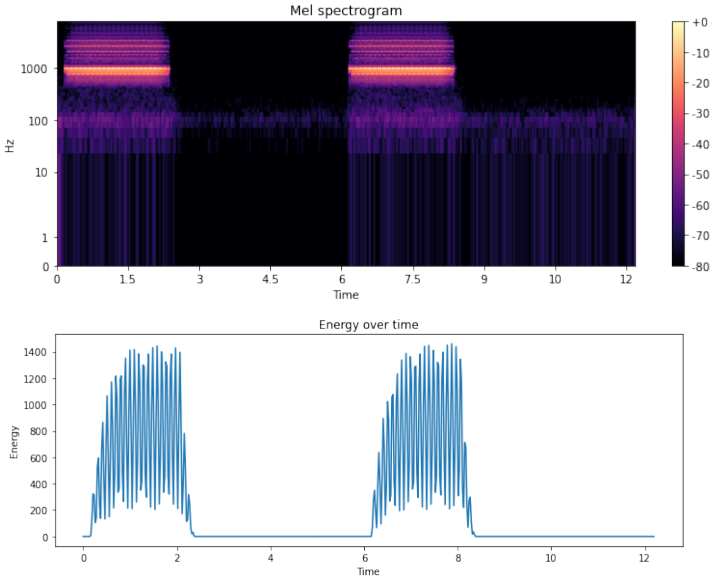
For testing the stationary of audio series, I chose statsmodels, specifically the adfuller function, because of its capabilities in conducting robust statistical tests. The Augmented Dickey-Fuller (ADF) test, which is provided by this library, is a type of statistical test called a unit root test. The intuition behind this test is that it determines how strongly a time series is defined by a trend. In my case, I use it to test the energy sequence's stability. The ADF statistic value and p-value can indicate whether the energy sequence is stationary or not, which is crucial for further sound analysis.



Ventilation sound - Mel spectrogram and Energy charts
ADF Statistic: -3.641753, p-value: 0.005011



Cough sound - Mel spectrogram and Energy charts
ADF Statistic: -3.185445, p-value: 0.020843



Phone ring sound - Mel spectrogram and Energy charts
ADF Statistic: -2.747947, p-value: 0.066102

Evaluation of Stationary Analysis Algorithms
In an effort to verify the effectiveness of the combination of two stationary analysis algorithms, I selected three single-event audio clips for assessment: sounds from ventilation, a cough, and a phone ringing.

My subjective assessment of the degree of sound stationarity across the three clips was as follows: the ventilation sound was the most stationary, followed by the cough sound, with the phone ring sound being the least stationary. The ventilation maintains a uniform pattern, the phone ring is somewhat distinctive and less frequent, and the cough, while somewhat distinctive, occurs more frequently.

Interpretation of Analysis Results
The Augmented Dickey-Fuller (ADF) test was employed to obtain a more objective measure of the sound stationarity. The results, as depicted in the Mel and energy charts, led me to the following conclusions:

For the ventilation sound, the ADF statistic was -3.641753 and the p-value was 0.005011. Since the p-value is less than 0.05, the null hypothesis - that the time series is non-stationary - can be rejected. As a result, the ventilation sound is considered to have a stationary time series.

As for the cough sound, the ADF statistic was -3.185445 and the p-value was 0.020843. The p-value is also less than 0.05, implying it too can be considered a stationary time series. However, the ventilation sound has a higher absolute ADF statistic and a lower p-value, suggesting it is more strongly stationary than the cough sound.

The phone ring sound, with an ADF statistic of -2.747947 and a p-value of 0.066102, has a p-value greater than 0.05. Consequently, the null hypothesis cannot be rejected, suggesting that the phone ring sound cannot be definitively deemed a stationary time series. When compared to the ventilation and cough sounds, the phone ring sound emerges as the least stationary.

In conclusion, when ranking the three sounds from most to least stationary, the order aligns with my initial impressions: ventilation sound > cough sound > phone ring sound.

Event detection algorithm
In my project, I've chosen to use sound event detection algorithms, specifically Pretrained Audio Neural Networks (PANNs). Sound event detection, as a critical component of audio pattern recognition, encompasses various tasks such as audio tagging, acoustic scene classification, speech emotion classification, and of course, sound event detection. By using a sound event detection algorithm, I can effectively identify and count the number of sound events in an audio file, providing valuable insight into the audio pattern's soundscape.

The decision to use PANNs is motivated by its excellent performance and versatility. Recent advancements in machine learning have seen neural networks successfully applied to audio pattern recognition tasks, and PANNs have proven to be exceptionally capable in this area. They are trained on the large-scale AudioSet dataset and can be transferred to various other audio-related tasks, which makes them a powerful and flexible tool for my project. Additionally, the architecture I'm utilizing, known as Wavegram-Logmel-CNN, uses both log-mel spectrogram and waveform as input features, allowing for a comprehensive analysis of audio.

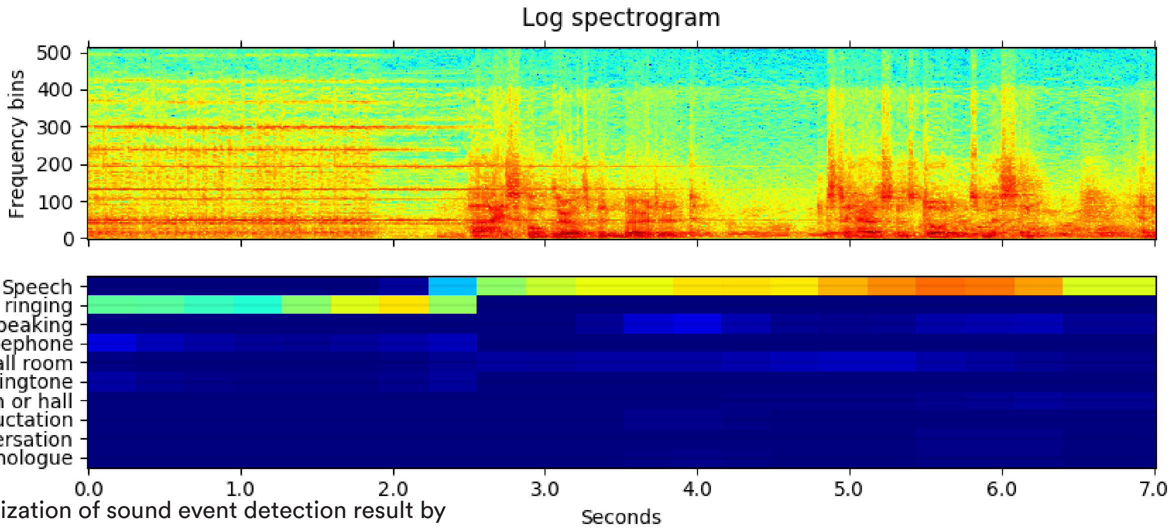


Figure 16: The visualization of sound event detection result by PANNs. (Kong, Q et.al, 2020)

4.4 Sound event classification

Despite the PANNs' accurate sound event detection, I encountered some challenges when testing it with various sound clips from an ICU setting.

Overwhelming events types
Firstly, the model's focus on identifying as many event types as possible, currently supporting 526 sound events, becomes a hindrance in real-world application. Many of these sound types are seldom encountered in the ICU environment, leading to difficulties in comprehension and calculation. For example, there is no need in an ICU context to distinguish between different music genres and instruments.

Overlapped sound detection
Secondly, the model has a propensity to detect overlapping sounds. When a laughing sound is played, the algorithm may classify it as a child's laugh, an adult's laugh, a female's laugh, and so on, simultaneously. This not only fills the "top 5" or "top 10" list when a certain sound is dominant, but also introduces unnecessary confusion—such as the difference between the sounds of liquid, a water drop, and water flow.

Inaccurate detection
Lastly, some inaccuracies in sound detection were noted. There are certain types of sounds that require semantic and scenario information for proper identification. For instance, the alarms in the NICU at Erasmus have different tones compared to the pre-training data of the model; they are generally less piercing. At times, a single tone may vary in frequency, making it sound like a melody to those unfamiliar with the ICU environment—let alone a pre-trained algorithm.

The inherent complexities of the algorithm make its direct application to the project challenging. To tailor it to better suit my project needs, I undertook the following steps:

Literature research about sound classifaction

A study conducted by Oliver Bones in 2018 offers a framework that leverages descriptive words to classify a variety of sounds. This framework holds promise for application within an ICU setting, where descriptive words from healthcare professionals or patients can be used to categorize the diverse sounds typically encountered. This approach could pave the way for a more comprehensive and standardized sound classification system within the ICU.

Furthermore, a 2022 study by Elif on Acoustic Biotopes in operating rooms introduces a classification scheme for categorizing sound sources in any acoustic environment. This approach underscores the role of context in the perception of soundscapes and the human reaction to them. The sound map presented in this study also inspired me to establish several clusters to accommodate different sound sources.

Drawing from these studies, I realized the importance of context comprehension when constructing a sound event classification system

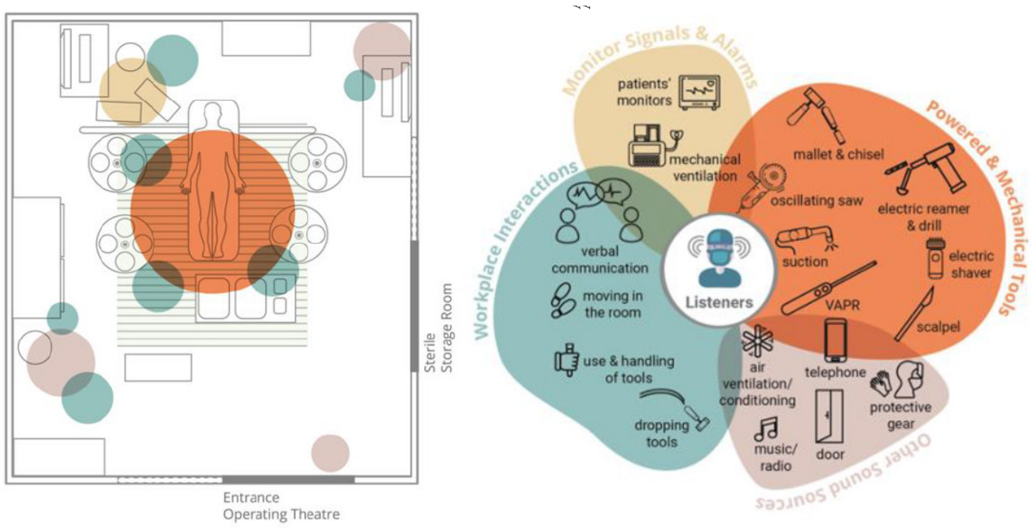


Figure 17. The sound map of an OR with the acoustic impact of sound events.(Özcan E et.al, 2022)

for my project. Ensuring that the system can precisely classify sounds based on their sources and the environments they are present in is of paramount importance.

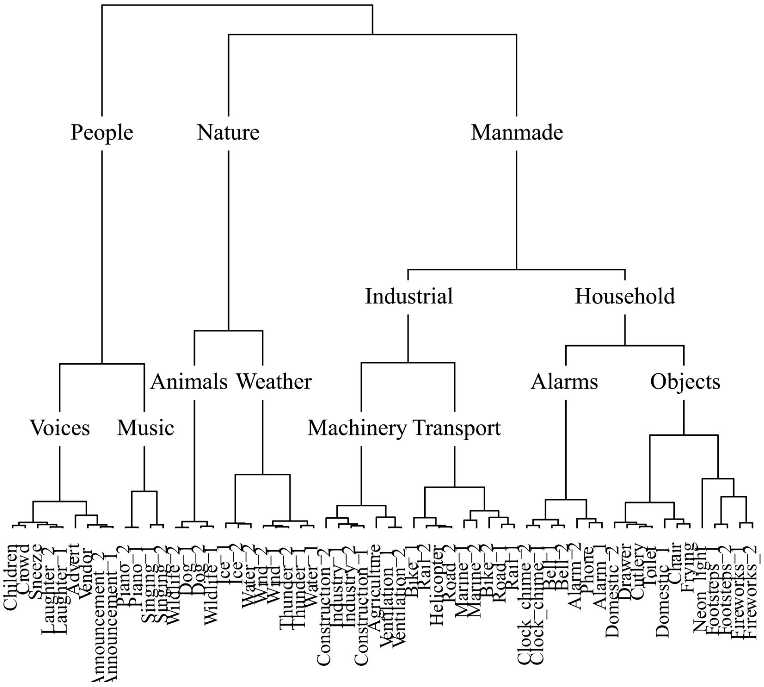


Figure 18: The soundscape taxonomy generated by hierarchical cluster analysis of the principal dimensions resulting from correspondence analysis. (Bones, O et.al, 2018)

Merging and reducing sound event categories
To manage the overwhelming number of sound event types, they were amalgamated and trimmed down into the following broader categories based on study from :

Verbal sound:
Speech, Crying, Laughter, Singing, Moaning, and other verbal sounds.
Activity sound:
Impact sounds, Use of Tools, Footsteps, Tools (specifically the sound of tools being moved or manipulated), Sliding sounds, and other activity-related sounds.
Device sound:
Alarms, Ventilation systems, Monitoring systems, Phones, and other device-related sounds.
Environment sound:
Ambience, Liquids, Nature, Animals, and other environment-related sounds.

Correct the alarm category detection

During the tests using sound clips from an ICU scenario and manually tagging sound events, several mis-detections, such as alarms being mistaken for music and the sound of an infant crying being mistaken for a cat, were identified and corrected.

4.5 Conclusion of soundscape research

As an influential instrument for illustrating the auditory environment, the concept of a soundscape augments the capabilities of my project. Rather than relying solely on single decibel levels or complex sound attribute description indices, it offers a comprehensive yet understandable method for assisting nurses in grasping the circumstances of each unit. Moreover, it paves the way for discussions about the overall and trending sound environment with a range of stakeholders.

Traditionally, soundscape studies have depended on subjective rating methods to measure levels of pleasantness and eventfulness. However, by combining insights from literature reviews with algorithmic explorations, I've pinpointed several key metrics that allow us to extrapolate these levels from raw audio data. The MoSQITo Python library is employed to describe sensory pleasantness using metrics like loudness, sharpness, roughness, and tonality. To depict eventfulness, the number of sound events and the stationarity of the sound are analyzed using the PANNs sound event detection model and the ADF test in the statsmodels library.

In the subsequent sections, I will further explore how this "objective" soundscape approach is reflected within the User Interface. This will include the methods of visualization and the various ways users can engage with the data. I am confident that implementing these soundscape description methods will yield intriguing results when incorporated into a product and evaluated by users.

5

Idea Generation

5.1 User Scenario

Scenario1: Assisting Nurses in Analyzing, Reviewing, and Accessing the Sound Environment Data

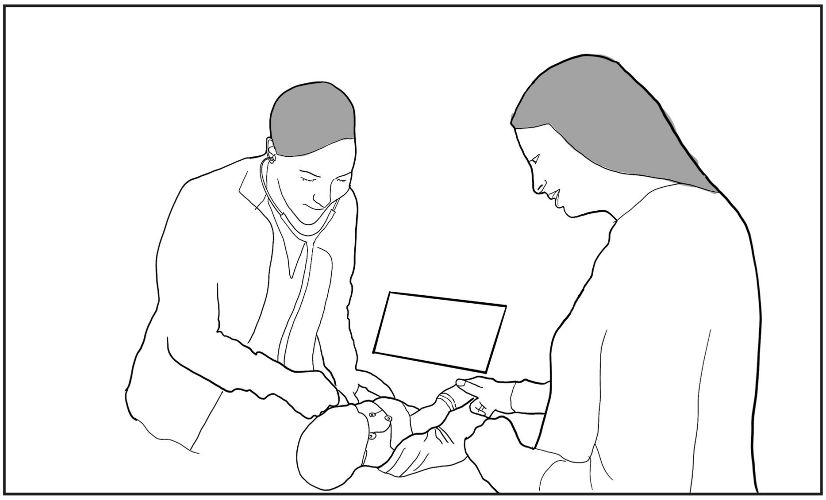
This scenario centers around the application of the product as a tool to monitor, analyze, and understand the auditory environment in NICU/PICU settings. The choice of this scenario arises from the need to provide healthcare professionals with a user-friendly method to manage sound levels and events effectively in these critical care settings. The primary issue the product aims to address in this context is the lack of quantitative data and metrics concerning the auditory environment. By delivering clear, intuitive data visualizations, the system will help manage noise levels, evaluate intervention effectiveness, and enhance communication with

Statistics for Auditory Environment Management

The product will offer detailed and comprehensive statistics on sound quality and events, serving as an essential tool for monitoring the auditory environment in the NICU/PICU. Its soundscape analysis and event-detection features will provide data that is easily digestible and clear to medical professionals.

Staff Training & Feedback

The system will serve as an effective instrument in assessing the impact of interventions during staff training sessions. By providing feedback based on data and analysis, it will help healthcare providers to refine their practices, thereby contributing to a more optimized auditory environment.



Enhancing Communication

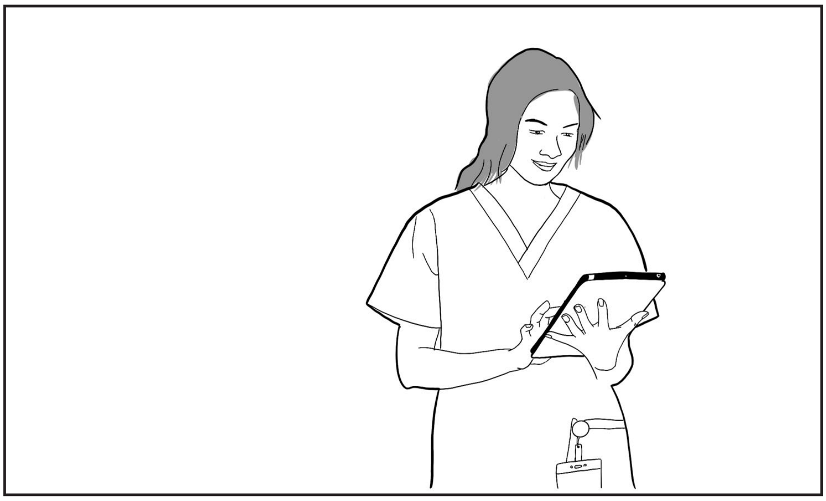
With user-centric design in mind, the system will also work as a medium to enhance communication between staff and families. Its intuitive interface and easy-to-understand data visualization will incorporate feedback from families, making them more involved in the care process, thereby fostering improved communication among all stakeholders.

Scenario2: Assisting in Daily Work Decision-Making Processes

The second scenario concentrates on the utilization of the product as a supportive tool for daily work decision-making. The rationale behind this scenario is the need for a system that can help filter through the large amount of information present in NICU/PICU environments, allowing nurses to focus on the most critical tasks. The product is primarily designed to address the challenge of alarm fatigue and information overload in these settings. By complementing existing alarm systems with context-specific information, it will help nurses understand patient room situations beforehand and raise awareness about the auditory environment during operation procedures. This, in turn, would contribute to more effective management of patient care and improved operational efficiency.

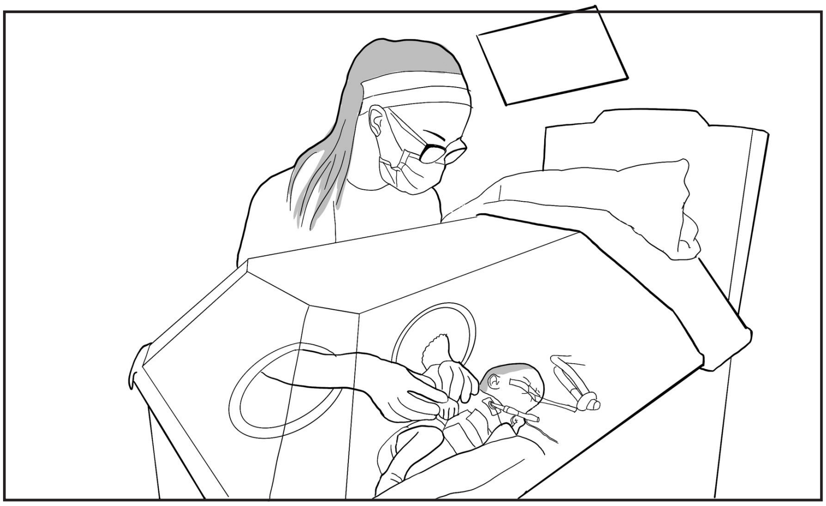
Complementary Alarm System

While the alarm systems in NICUs/PICUs are essential, they can sometimes be overwhelming. The product, designed with workflow considerations in mind, will supplement these systems by providing context-specific information. This could help nurses filter out non-essential alarms and focus on the most critical tasks at hand.



Preemptive Situational Understanding

By analyzing the sound environment in patient rooms, the system will help nurses understand the situation beforehand. This context-sensitive information will be invaluable, allowing for prompt responses and more effective management of patient care.



Raising Auditory Environment Awareness

The system will actively raise awareness about the importance of the auditory environment, particularly during operation procedures. With its advanced noise analysis features, it will flag potential disturbances and help maintain an optimal sound environment for both patients and staff.

5.2 User Interface prototype

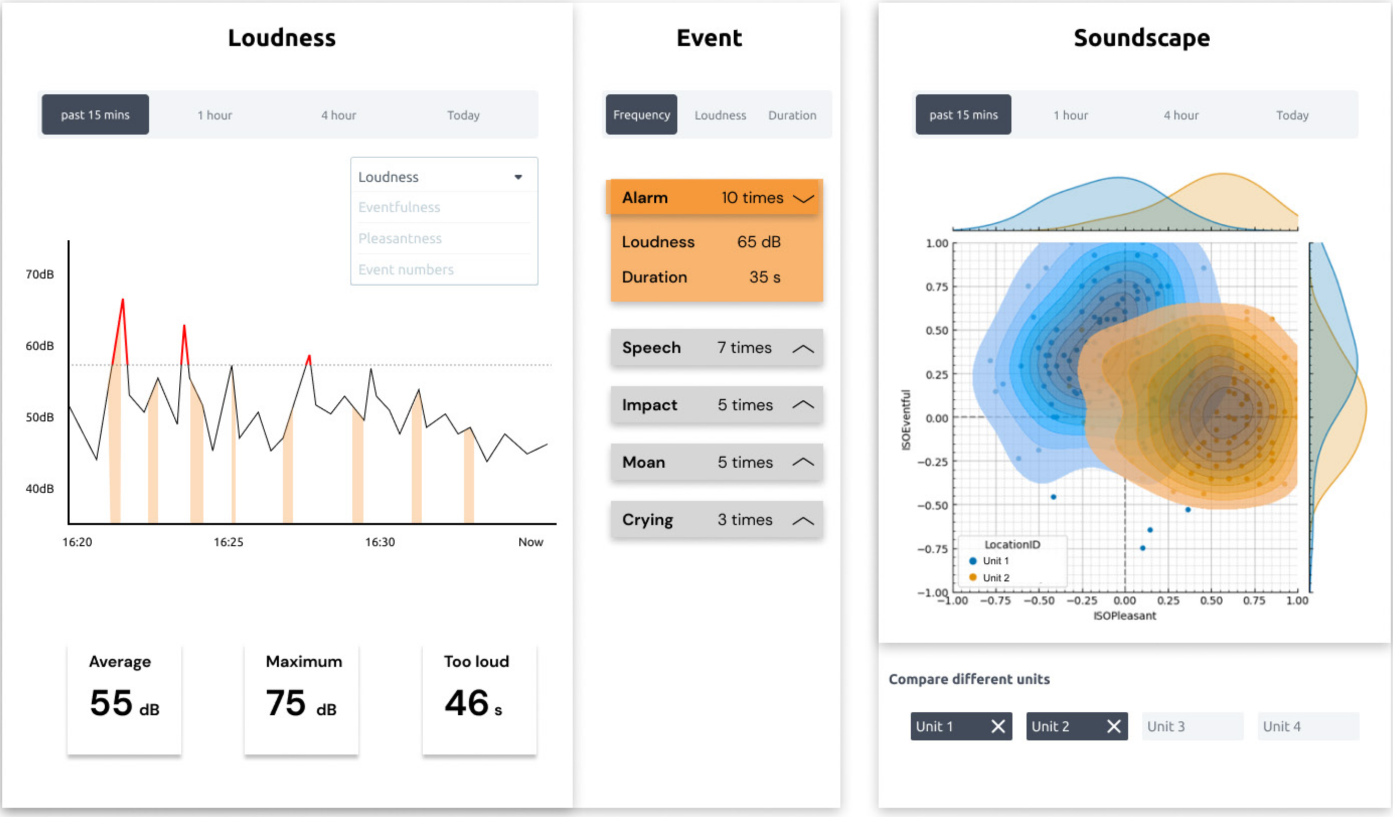
Sound environment report prototype

Sound environment report prototype primarily addresses the first scenario: Assisting Nurses in Analyzing, Reviewing, and Accessing the Sound Environment Data.

This UI is comprised of three main sections: a data trend graph, event information cards, and a soundscape plot.

The data trend graph enables users to select different time scopes for plotting. It is integrated with the event cards, correlating the event detection results with the sound attribute plots.

The soundscape plot facilitates comparisons of soundscapes across different units and varying time lengths. Additionally, the plot itself presents both a plot and scatter density map, assisting users in comprehending the overall distribution of the soundscape.



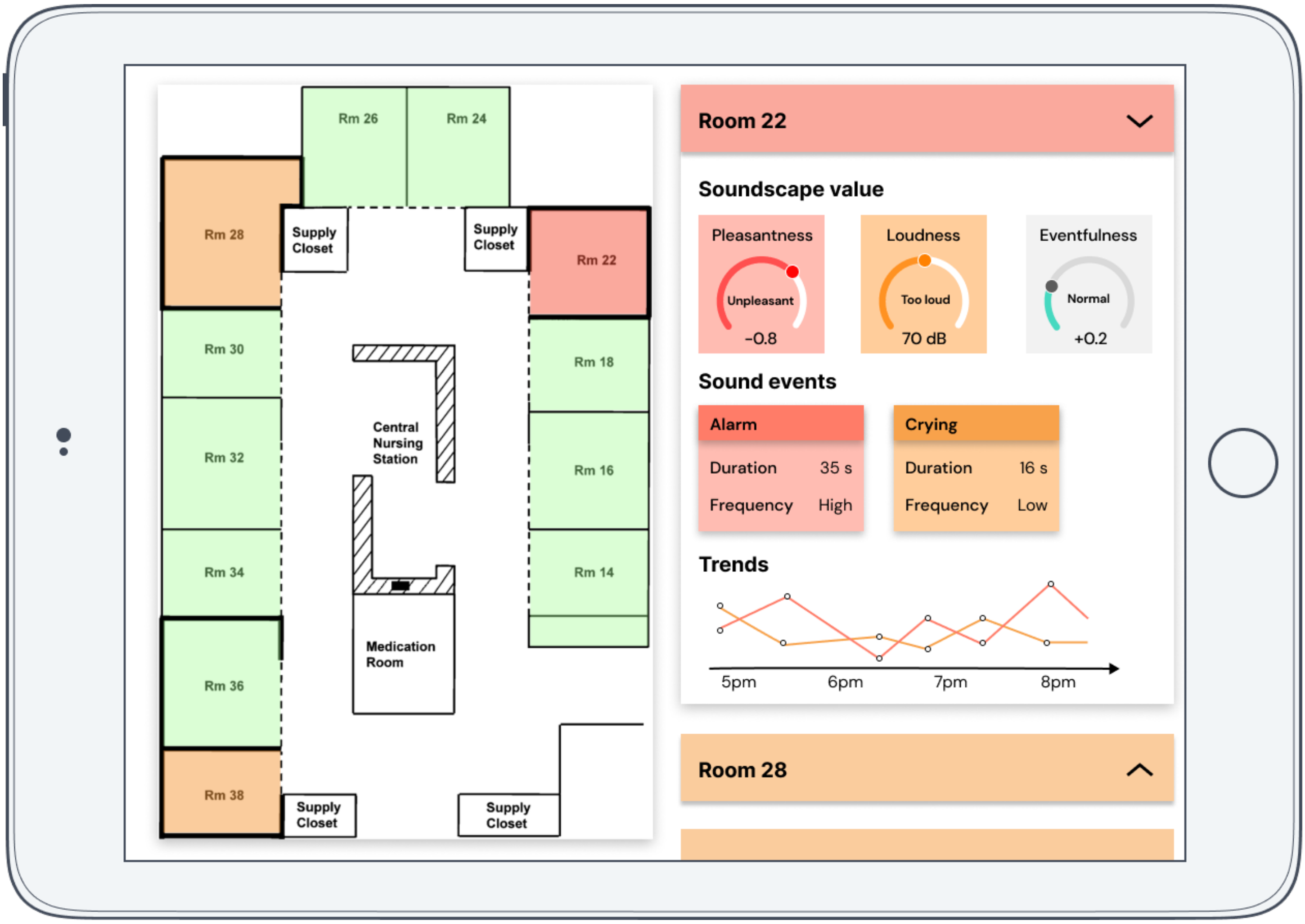
Real-time monitor

The prototype for the real-time monitoring user interface (UI) is primarily designed for the second scenario: Assisting in Daily Work Decision-Making Processes. It features two primary sections: a heatmap for all units and an information card for each unit.

The heatmap utilizes three distinct colors: green, yellow, and red to signify the varying levels of sound quality in different units.

The information card for each unit, by default, remains collapsed and only expands upon user interaction, such as clicking the arrow, or when the sound quality hits a preset warning threshold.

This UI is intended to complement the existing monitoring system, aiming to reduce the additional information burden on nursing staff and provide only the necessary notifications when required.



Room 22

Soundscape value

Pleasantness	Loudness	Eventfulness
Unpleasant	Too loud	Normal
-0.8	70 dB	+0.2

Sound events

Alarm		**Crying**	
Duration	35 s	Duration	16 s
Frequency	High	Frequency	Low

Trends

Room 28

5.3 Event detection prototype

While developing the soundscpe prototype, I faced hurdles related to the performance constraints of the PC and the intricate task of unifying all the components. Consequently, I decided to construct individual prototypes for event detection and for the analysis of pleasantness and decibels.

Furthermore, for each prototype, I generated two variations: a real-time model that records sound from the microphone, conducts an analysis, and exhibits the data instantly, and another model that scrutinizes audio files in .wav format and showcases plot images. This methodology enabled me to tackle the technical obstacles and examine the capabilities of each prototype more efficiently.

Audioflie-Plot prototype

Utilizing the PANNs sound event detection algorithm, I initially built a prototype that reads the audio file and generates a chart with the "Top-5" most recurring events. By testing it with sevral ICU scenario audio recordings(see in the figure), the prototype accurately displays the analysis results from the algorithm based on probability values.

However, for most users, their initial perception of this chart is that the higher an event's y-value, the more dominant it is. For instance, at the start of this audio, the sound of a telephone ringing is much louder than speech. Yet, since speech is more distinguishable, it is depicted higher on the chart.

This realization prompts me that in future iterations, it's essential to integrate event detection with other indices like the Sound Pressure Level (SPL) or frequency to make it more intuitive and comprehensible. This combination might also unearth potential relationships between sound events and other factors in the sound environment.

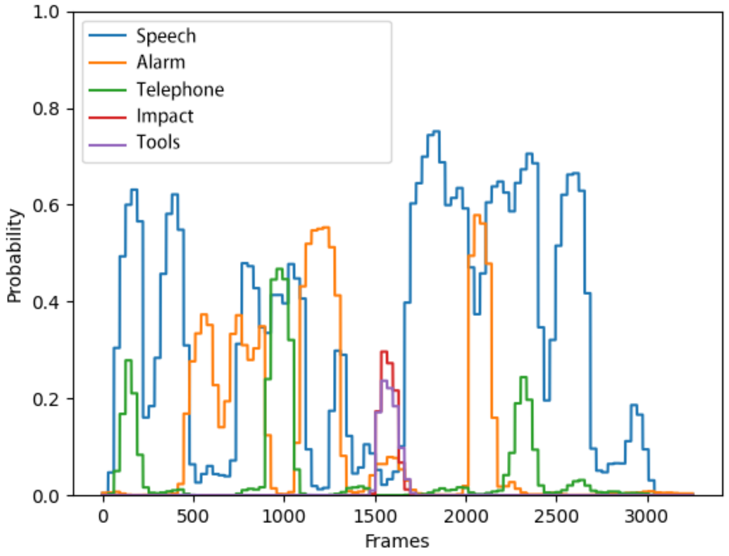


Figure 19. Analysis results of eventful hospital recording

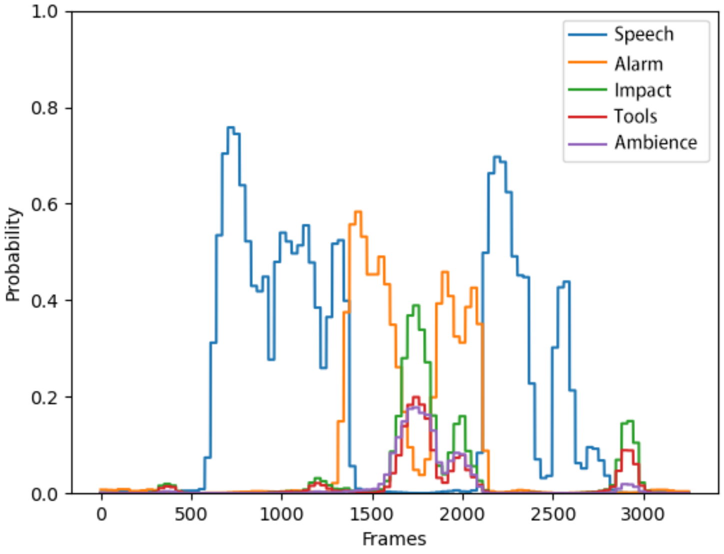


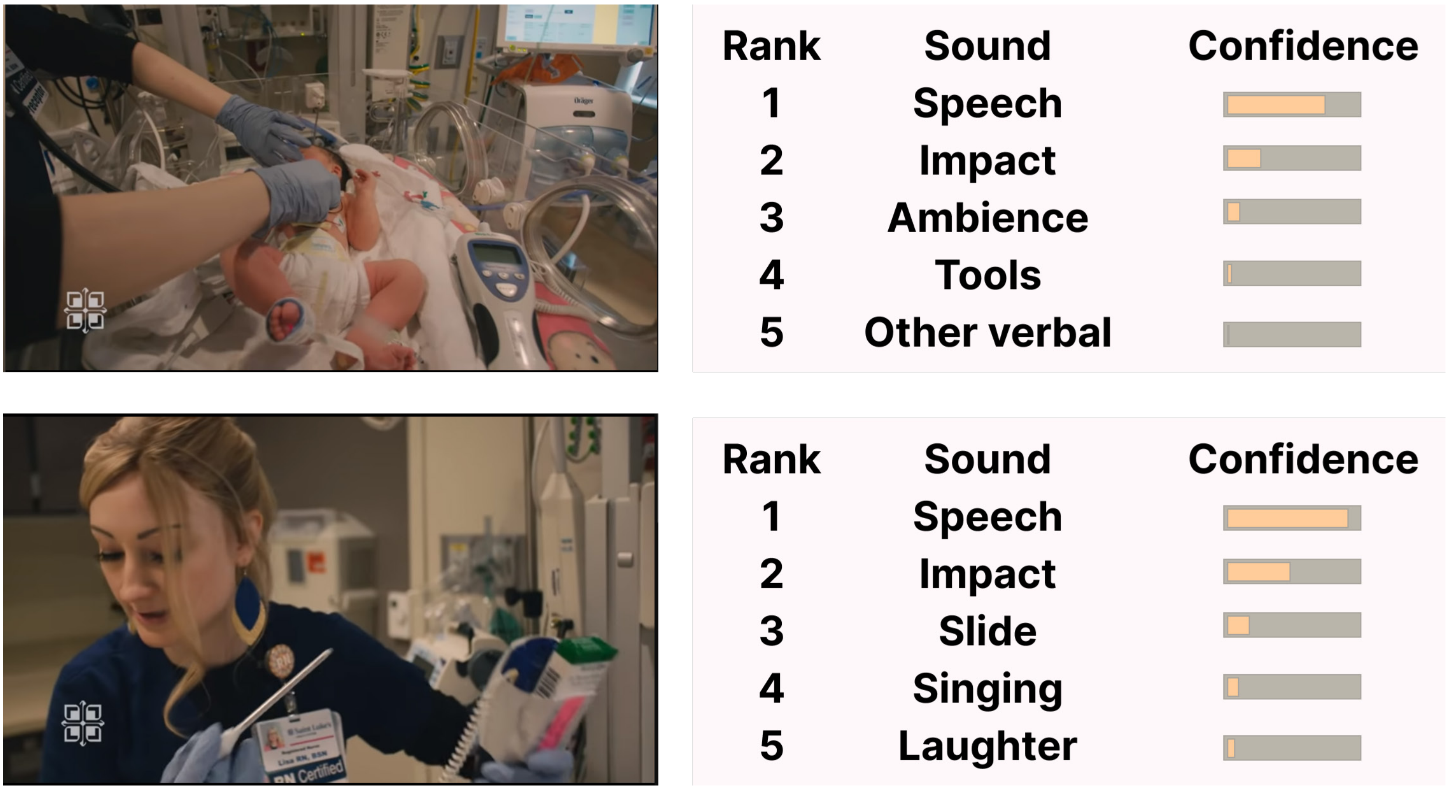
Figure 20. Analysis results of uneventful hospital recording

Real-time analysis prototype

Following the development of the plot-making prototype, I successfully created a real-time analysis prototype. This prototype captures sound from a microphone and instantaneously displays event detection results on the screen. I tested the prototype using several Neonatal Intensive Care Unit (NICU) videos from YouTube.

An insight from the prototype testing was the necessity for a threshold. Events with low confidence quickly updated at the bottom of the top list, drawing significant attention and making it challenging to focus on the key results.

Additionally, considerations need to be made for the real-time prototype's analysis sample size and the user interface's refresh rate. If the refresh rate is too high, users may find it difficult to catch or remember the information. Conversely, if it's too low, some rapidly occurring events, like impacts or tool noises, might be missed.



Rank	Sound	Confidence
1	Speech	
2	Impact	
3	Ambience	
4	Tools	
5	Other verbal	

Rank	Sound	Confidence
1	Speech	
2	Impact	
3	Slide	
4	Singing	
5	Laughter	

Figure 21. Real-time event detection prototype, test with NICU videos from Youtube

Insights from event detection prototypes

In conclusion, comparing these two methods, the events trending chart enables users to identify major events within a certain audio segment. However, it can make it difficult for users to relate the results to the actual situation or sound. The probability calculation algorithm operates differently from the human brain, which considers multiple factors like context and the level of prominence. Instead, the algorithm is more akin to how well the sound fits with pre-trained data.

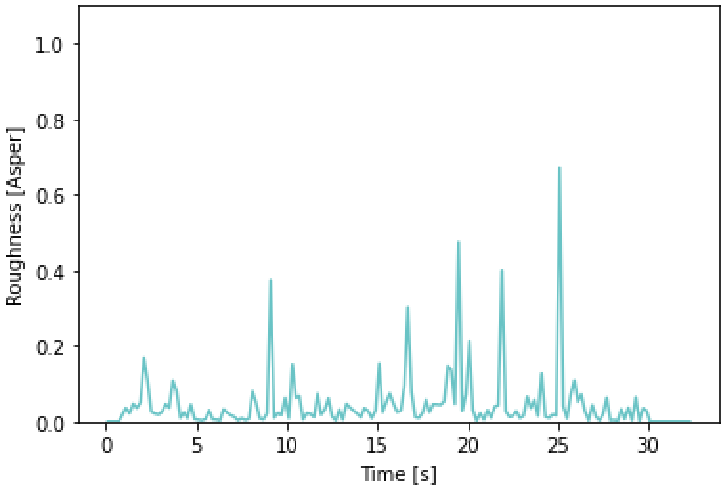
The real-time prototype excels at providing immediate data, but it demands considerable attention and might pose a memory burden. The dilemma of the refresh rate might be best resolved by integrating other charts or components, allowing the real-time prototype to serve a complementary role.

5.4 Audio attributes prototype

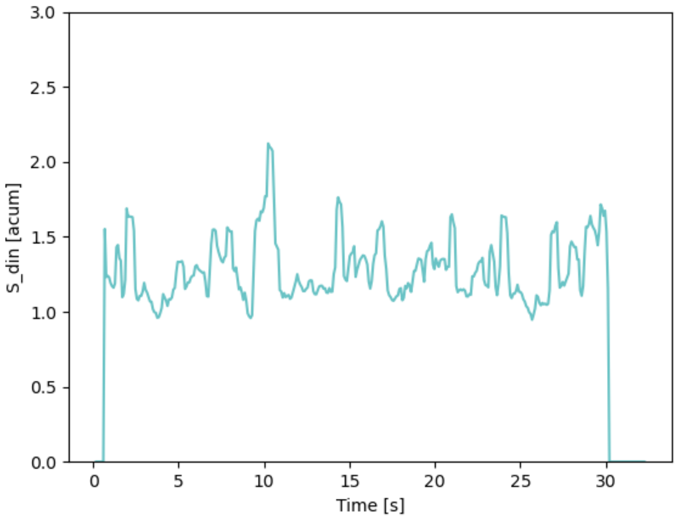
Audioflie-Plot prototype

Utilizing the previously mentioned Python libraries, Librosa and Mosqito, I successfully crafted several prototypes. These prototypes are designed to read .wav audio files, analyze them, and subsequently generate the results in the form of plots. The analysis focuses on four core attributes: roughness, sharpness, loudness, and tonality, in addition to other indices such as SPL and noisiness.

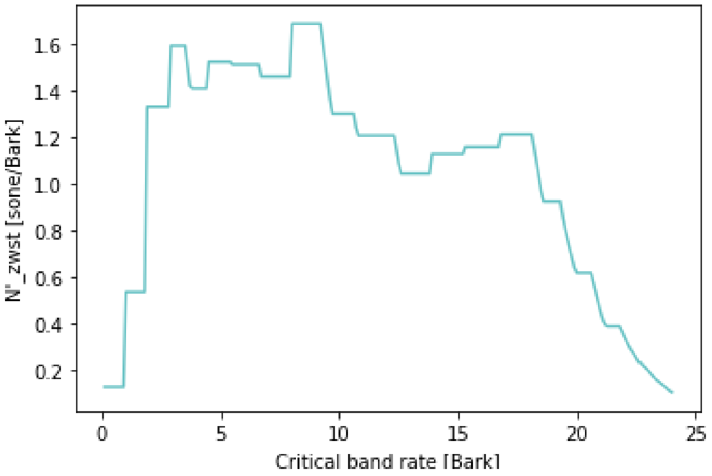
The subsequent portion includes the results from analyzing the same audio file, titled "eventful hospital recording". From these plots, it's challenging to extract useful information directly about the quality of the sound environment. These four values require additional processing to be converted into pleasantness. This data then needs to be combined with the event detection and SPL plots.



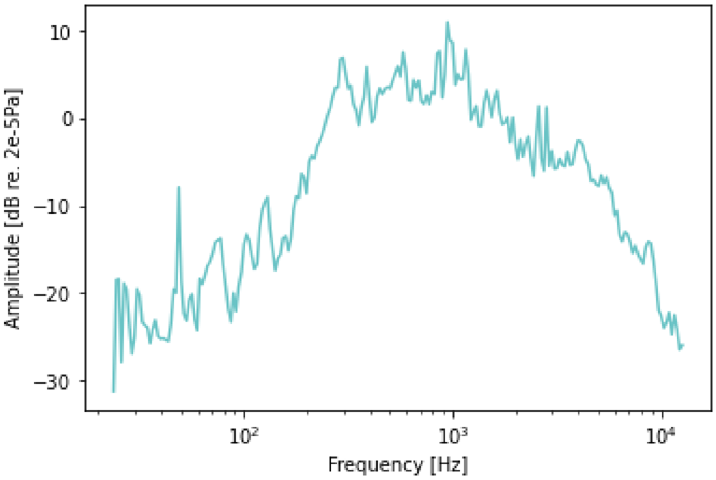
Roughness



Sharpness



Loudness



Tonality

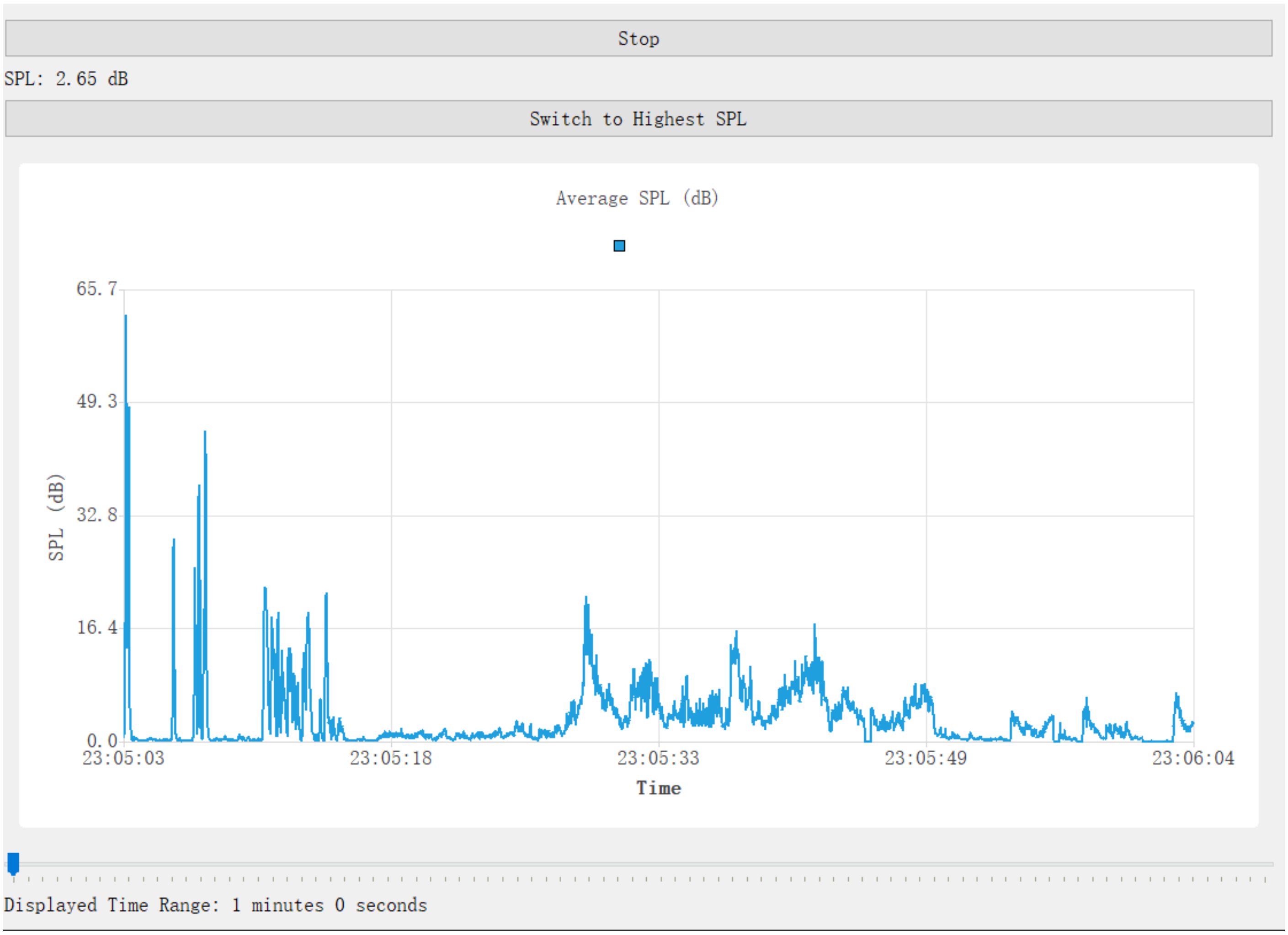
Microphone-Plot prototype

In the Microphone-Plot prototype, I experimented with various interactive components for the plot.

The Dropdown component enables users to switch between different sound attributes that are displayed on the plot, such as dB(A), sharpness, loudness, and so on. These attributes typically don't need to be compared and are aptly displayed individually on the plot.

I also incorporated a Slider component to allow users to switch between different time scopes. For example, users can choose to display data from the previous 10 minutes or 1 hour. The Slider component is ideal for controlling time attributes, although the optimal step length needs further investigation.

Additionally, I utilized several Checkbox components in some prototypes to select indices that might require comparison. For instance, different sound sources, which represent different units in real scenarios, can be chosen. This allows users to view data from a single source or compare data from multiple sources.



SPL: 2.65 dB

Displayed Time Range: 1 minutes 0 seconds

Figure 22. Real-time SPL detection prototype, test with PC microphone

6

Relisation

6.1 Comparision of methods

Choosing Between Real-Time and Pre-Process

Privacy implications

Real-time audio capture, particularly in intensive care unit (ICU) settings, can raise serious privacy concerns. On the other hand, Pre-Processed Audio utilizes open-source audio files available on the internet, which can be further anonymized if needed.

Deployment challenges

Implementing real-time voice recording across different units necessitates dedicated rooms to avoid interference. Connecting the microphone to a central processor via WiFi or other wireless means introduces additional complexities.

PC capabilities

My current computer, powered by an Intel i7-10875H CPU and RTX 3070 GPU, cannot concurrently manage audio attribute analysis, event detection algorithms, and plot generation and updating in real-time. Given that the project seeks to process and visualize data from multiple units at once, it necessitates a PC performance that surpasses my current system's capacity.

Balancing multiple aspects

Adopting a pre-processed approach for this prototype allows for the rapid creation of a testable product while avoiding potential privacy and technical issues. Nonetheless, this method has its constraints. It does not facilitate testing the impact of microphone quality and positioning, for instance. Also, the captured audio resembles a controlled experiment more than a complex, real-world scenario.

Final decision

Although the real-time method proved technically feasible during the prototyping stage—with the microphone picking up the sound, the processor conducting the analysis, and the display presenting the results—the aforementioned factors led me to choose a pre-processed method for my final project. This approach involves using various .wav files to mimic scenario sounds and pre-processing the data for display on the user interface. Furthermore, the stored data enables swift user interaction with the UI, as well as recording and comparison of user feedback in identical situations.

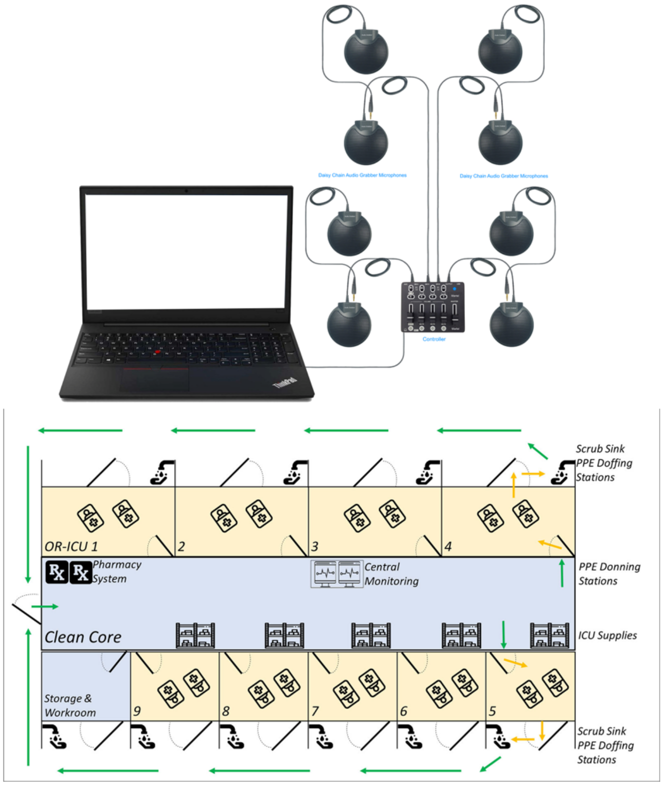


Figure 23. Real-time method

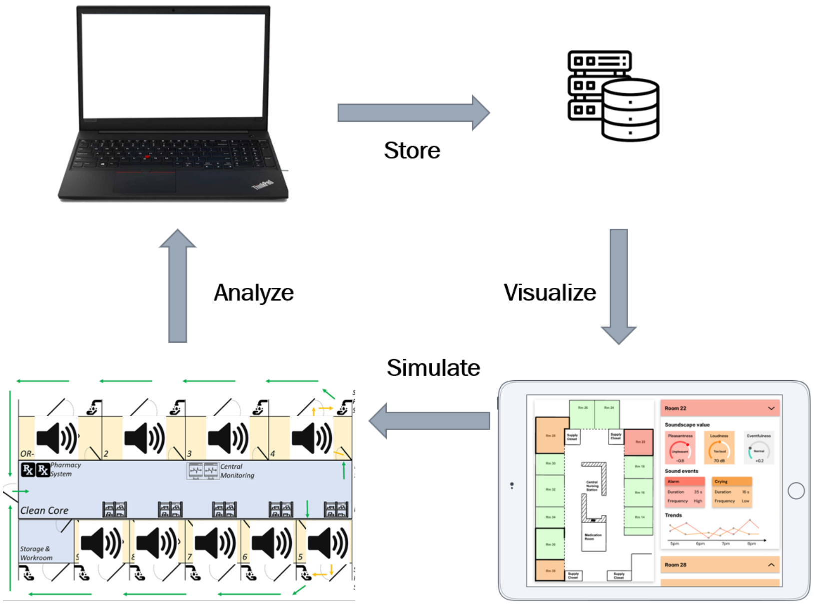


Figure 24. Pre-process method

6.2 System architecture

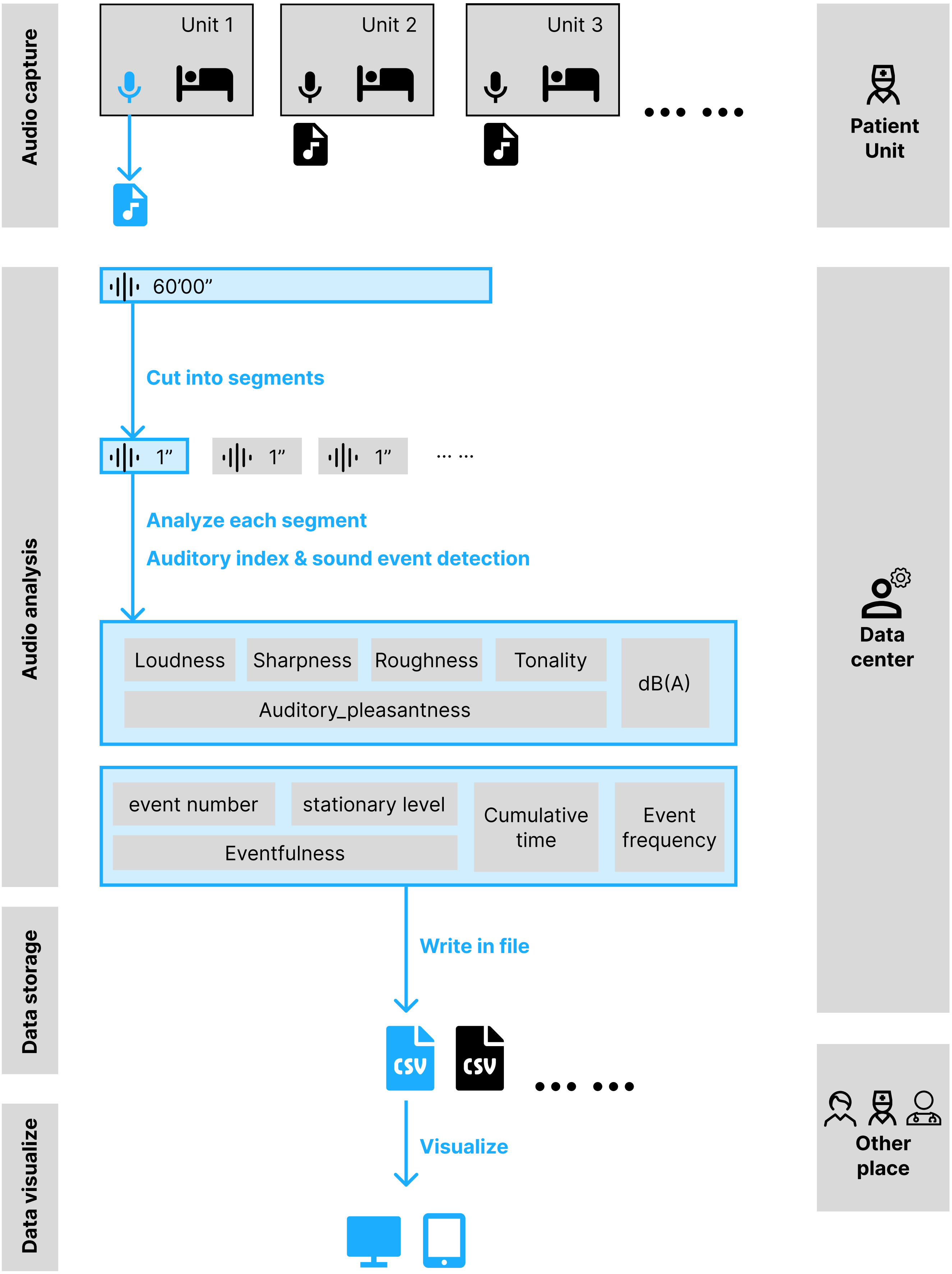


Figure 25. System architecture

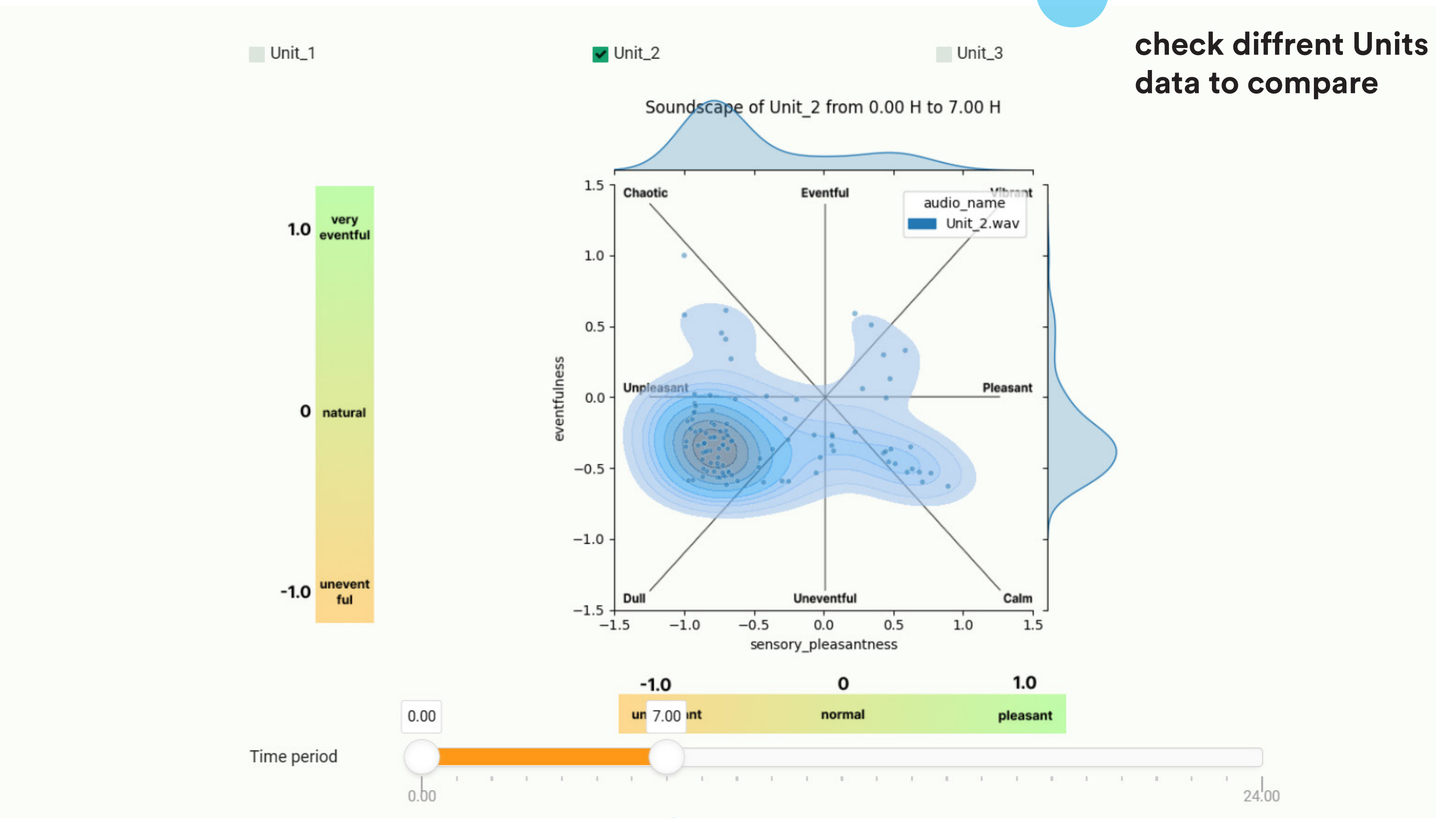
6.3 WebUI deployment

Soundscape page

Auto-update
Whenever different unit checkboxes are selected or deselected, or the slider's position is altered, the plot automatically updates itself. It does so by displaying new data after filtering, and the title is updated to reflect the chosen unit and time range.

Soundscape scale
Given that the concept of a soundscape is relatively new to most nurses and is not commonly seen in daily life like SPL, two soundscape scales have been placed alongside the soundscape plot. These scales help to elucidate the meanings of 'eventfulness' and 'pleasantness' values.

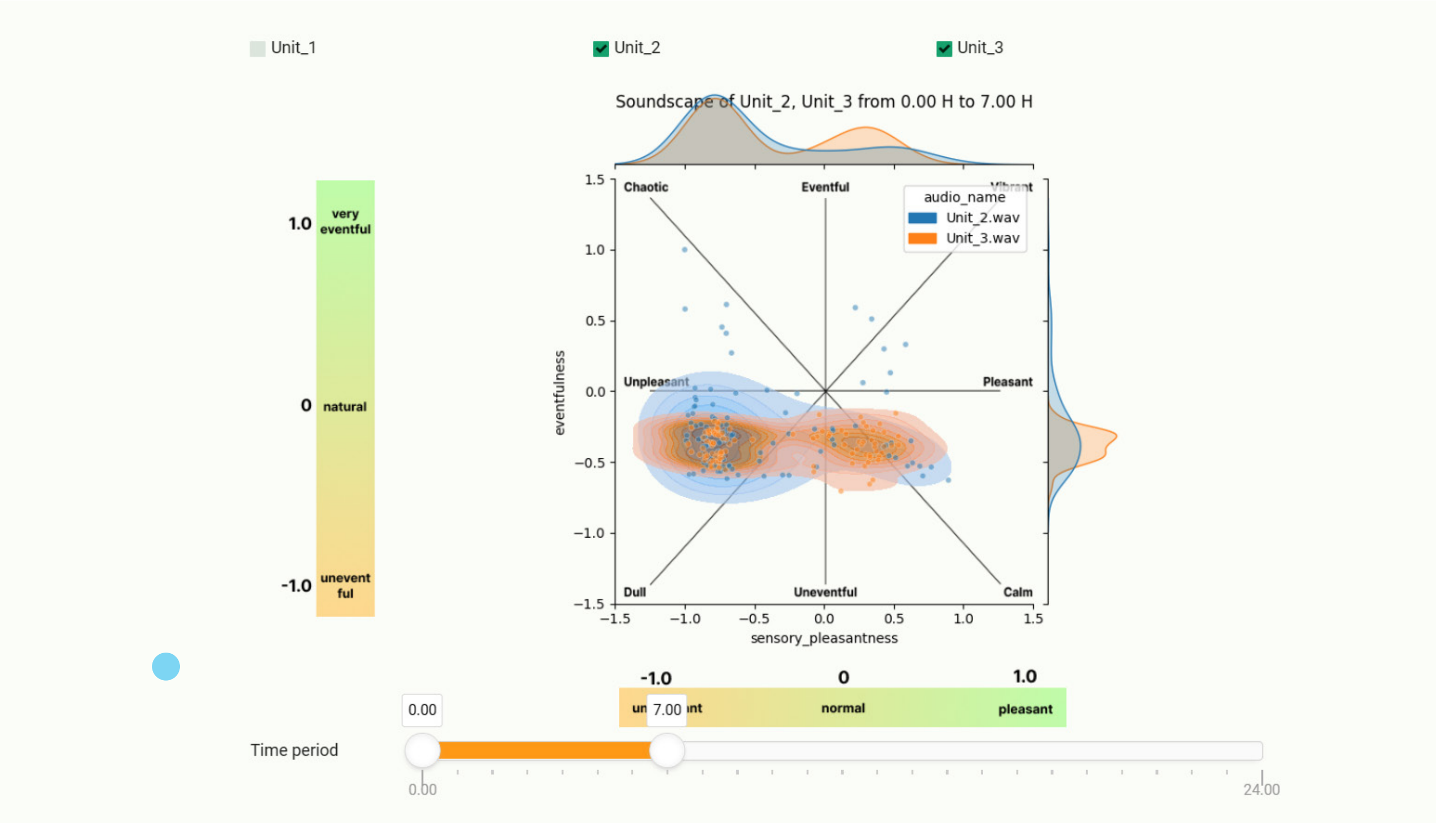
Time range slider
The time range slider, designed with two handles, allows users to control the range of display time on the plot. The slider is divided into 24 steps, corresponding to the 24 hours of a day, and it displays the values of the handles.

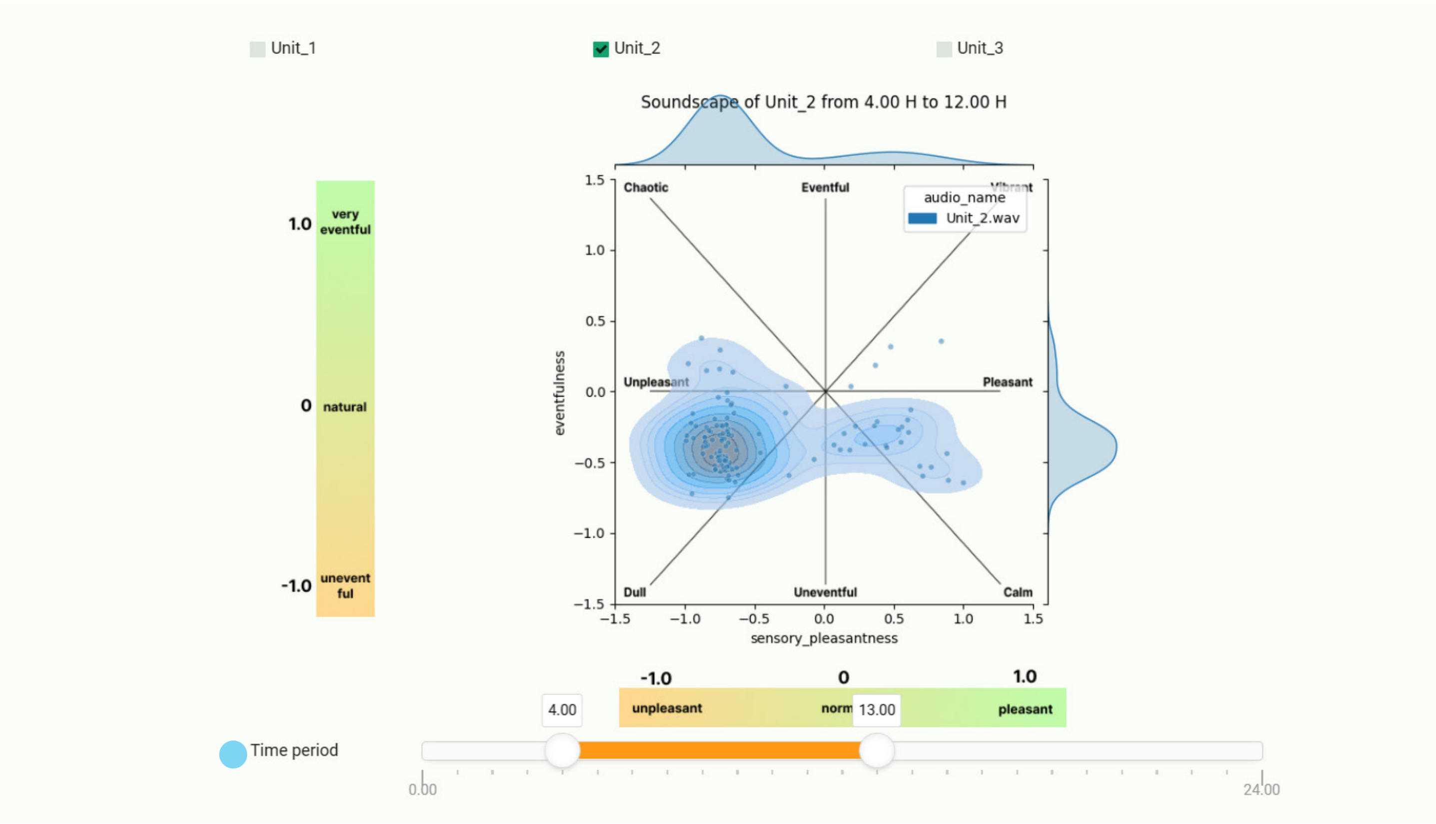


check diffrent Units data to compare

Figure 26. Soundscape page UI

pull the slide handle to change display time range


☐ Unit_1
☑ Unit_2
☑ Unit_3
Soundscape of Unit_2, Unit_3 from 0.00 H to 7.00 H
1.0 very eventful
0 natural
-1.0 uneventful
Chaotic
Eventful
Vibrant
Unpleasant
Pleasant
Dull
Uneventful
Calm
audio_name
Unit_2.wav
Unit_3.wav
eventfulness
sensory_pleasantness
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
-1.0
0
1.0
unpleasant
normal
pleasant
0.00
7.00
Time period
0.00
24.00


☐ Unit_1
☑ Unit_2
☐ Unit_3
Soundscape of Unit_2 from 4.00 H to 12.00 H
1.0 very eventful
0 natural
-1.0 uneventful
Chaotic
Eventful
Vibrant
Unpleasant
Pleasant
Dull
Uneventful
Calm
audio_name
Unit_2.wav
eventfulness
sensory_pleasantness
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
-1.0
0
1.0
unpleasant
normal
pleasant
4.00
13.00
Time period
0.00
24.00

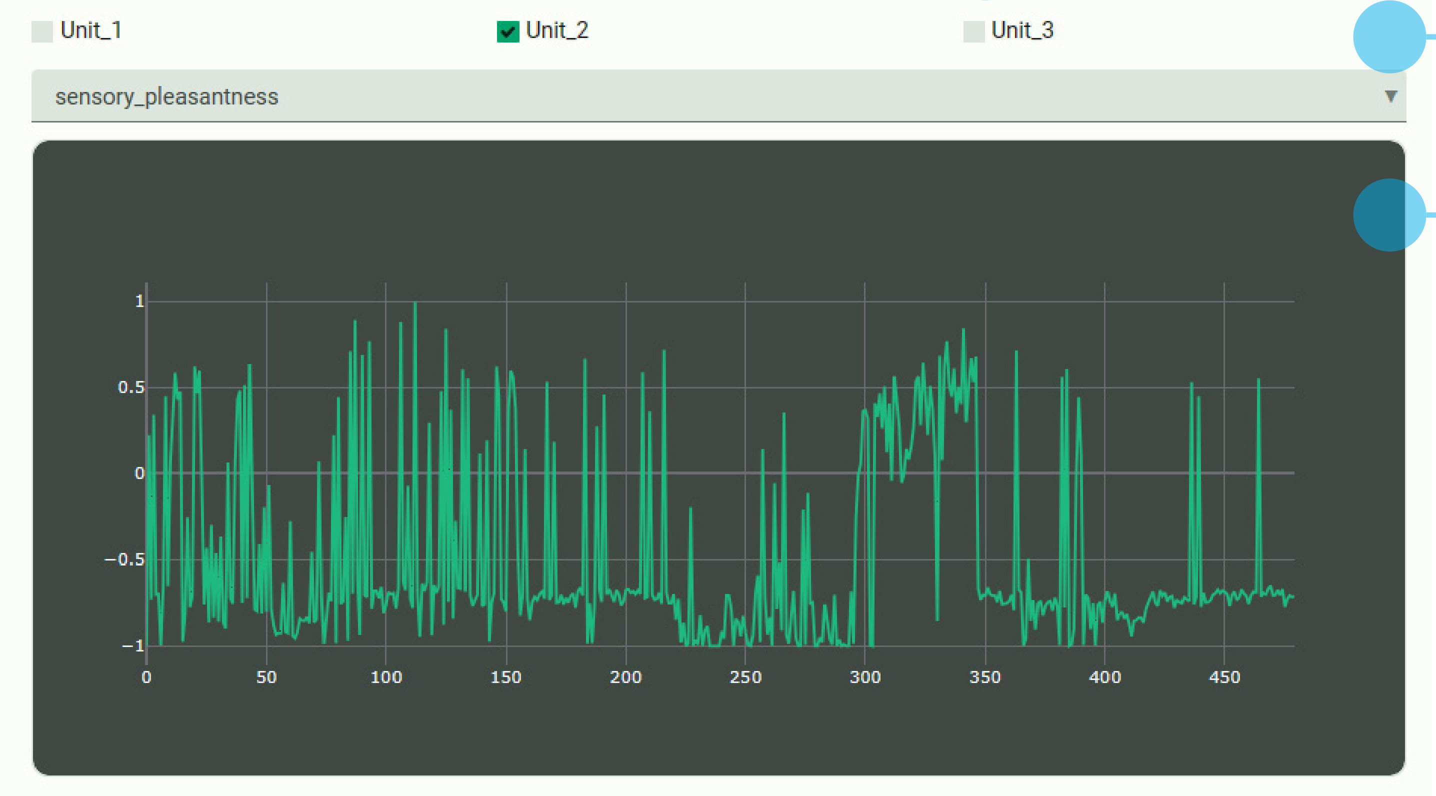
Sound attributes trend page

Sound Attributes Dropdown
As various unit checkboxes are selected or deselected, or when the slider is adjusted, the plot will automatically refresh to display the newly filtered data.

Unit Checkbox
The unit checkboxes provide users with the ability to select or deselect different unit data that they wish to display on the plot.

Interactive Plot
Constructed with the Plotly library, this trend chart supports various operations such as zooming in/out and autoscaling. These features enable users to examine the data from diverse ranges in detail.

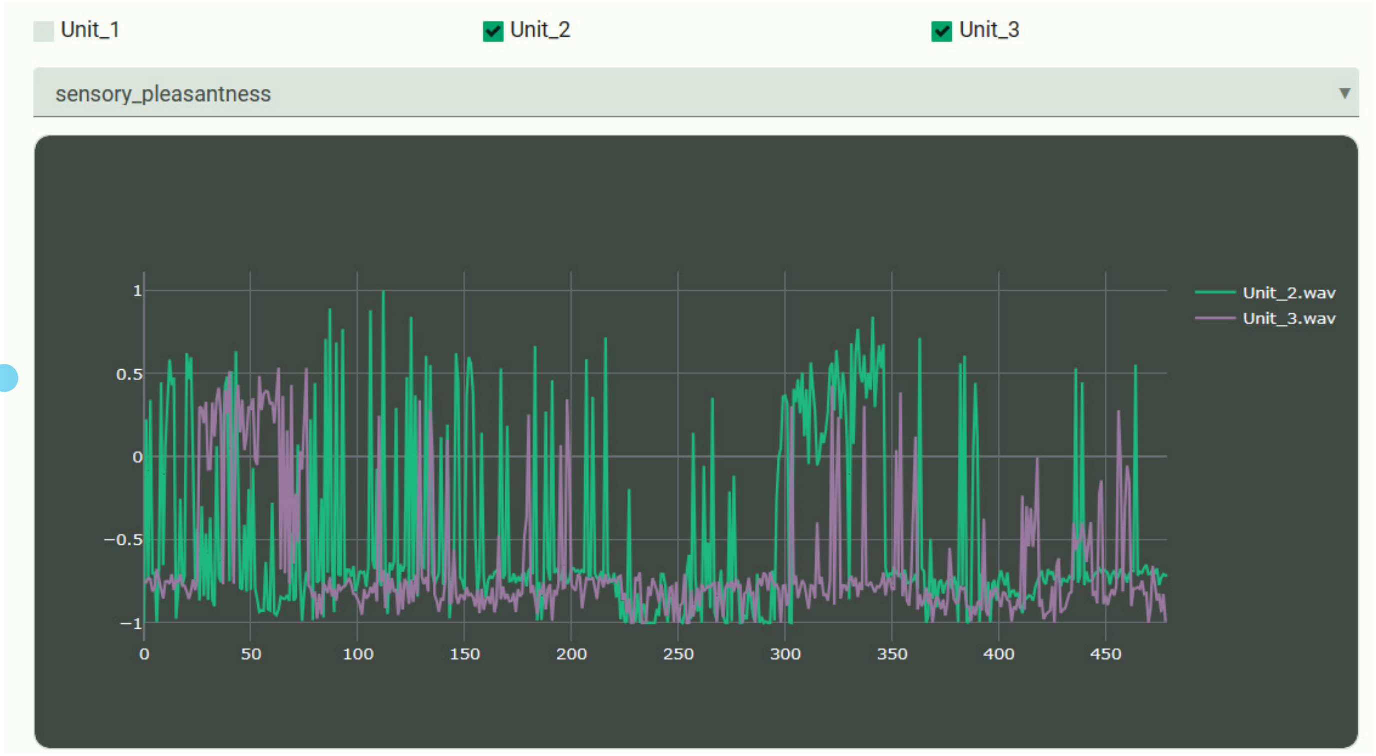
check diffrent Units data to compare



☐ Unit_1 ☑ Unit_2 ☐ Unit_3

sensory_pleasantness ▾

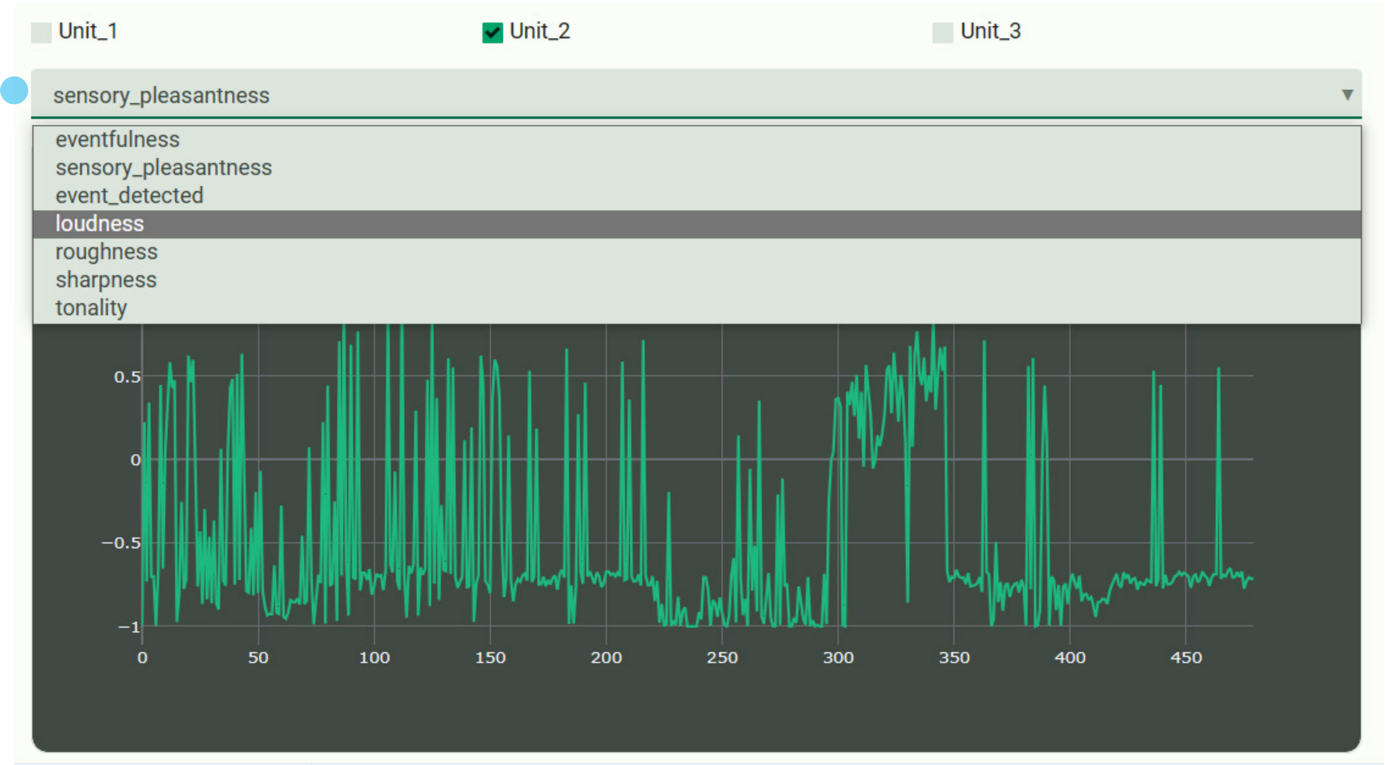
Figure 27. Sound attribute trend page UI



☐ Unit_1 ☑ Unit_2 ☑ Unit_3

sensory_pleasantness ▼

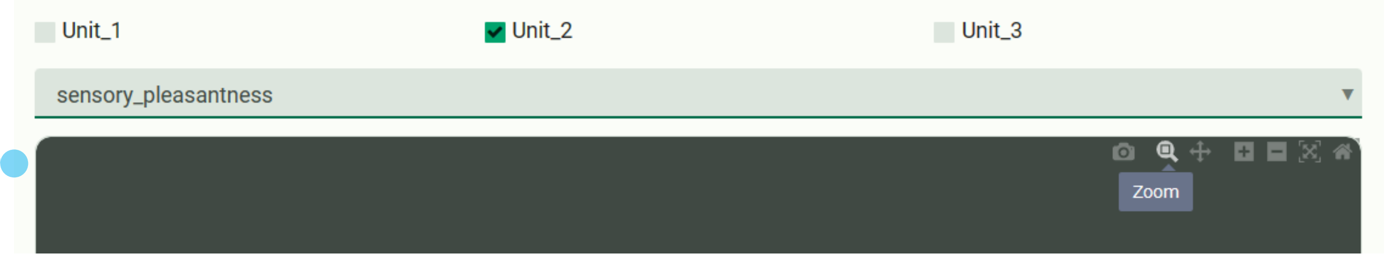
choose different data types



☐ Unit_1 ☑ Unit_2 ☐ Unit_3

sensory_pleasantness ▼

plot toolkits



☐ Unit_1 ☑ Unit_2 ☐ Unit_3

sensory_pleasantness ▼

Sound events detection page

The Sound Events Detection page serves as a multifaceted analytical platform, meticulously crafted to visualize the intricate outcomes of the event detection algorithm. Utilizing a two-tiered approach, this page presents insights through both line charts and bubble charts, each offering a unique perspective into sound event analysis.

Line Chart

The line chart provides an interactive and detailed view, enabling users to explore the TopN events, with the default value set at the Top5. This feature ensures that you can easily visualize and comprehend the most significant events with the highest probability within a selected time frame.

Bubble Chart

Taking visualization a step further, the bubble chart fuses the event detection algorithm with sound attributes analysis algorithm. In this chart, each bubble's size signifies either how long a specific sound event persists or the average sound pressure level during the continuous sound event.

Figure 28. Sound events detection page UI

7

Evaluation

7.1 Purpose of evaluation

Explore nurses' acceptance for soundscape
The primary purpose of this evaluation is to understand how nurses react to the concept of soundscape. This involves gauging their level of acceptance and willingness to incorporate such a concept into their daily workflows.

Identify interaction needs
By studying how nurses interact with the soundscape tool, I can identify the need for specific features, adjustments, or enhancements. Understanding these interaction needs will help in optimizing the user experience and improving the overall functionality of the tool.

Determine visual preferences
The evaluation also aims to discern the visual preferences of nurses when engaging with the soundscape tool. This can influence the design and layout of the tool, ensuring it is visually appealing and intuitive to use.

Integrate insights into current workflow
By gathering and analyzing feedback from nurses, the evaluation aims to provide insights on how the soundscape tool can be seamlessly integrated into their current workflows. This will allow us to create a tool that not only serves its purpose but also complements and enhances existing practices.

7.2 Evaluation plan

Participants
8 NICU/PICU nurses in Xiamen University's Affiliated Women and Children's Hospital's NICU department (a mix of experienced workers and newcomers)

Evaluation matrix
According to the design objectives and specifications, 10 characteristics have been selected to assess the product's performance in fulfilling its intended purpose. These attributes are:Awareness, Decision Making, Communication, User-Centric Design, Advanced Noise Analysis, Workflow Consideration, Data Privacy, Feasibility, Simplicity, Maintenance, Balancing Functionality.

Procedure:

Preparation Phase
Schedule Appointments: Schedule individual sessions with each participant, ensuring minimal disruption to their work schedule.
Consent: Obtain informed consent from all participants.
Pre-Evaluation Survey: Administer a brief pre-evaluation questionnaire to gauge the current working situation and baseline awareness.

Demo Implementation Phase
Product Introduction: Introduce the demo product to the participant, explaining its intended features and functionalities.
Guided Exploration: Allow the participant to explore the demo with guidance as needed, simulating potential real-world usage.
Observation: Observe the participant's interaction with the demo, noting any immediate reactions, questions, or concerns.

After Questionnaire and Interview Phase
Post-Evaluation Survey: Administer a post-evaluation questionnaire to assess the perceived impact and usability of the product.
Interview: Conduct a brief interview with the participant to gather qualitative insights, ask follow-up questions, and clarify any points from the survey.

Figure 29. Introduction before test among nurses

7.3 Evaluation results

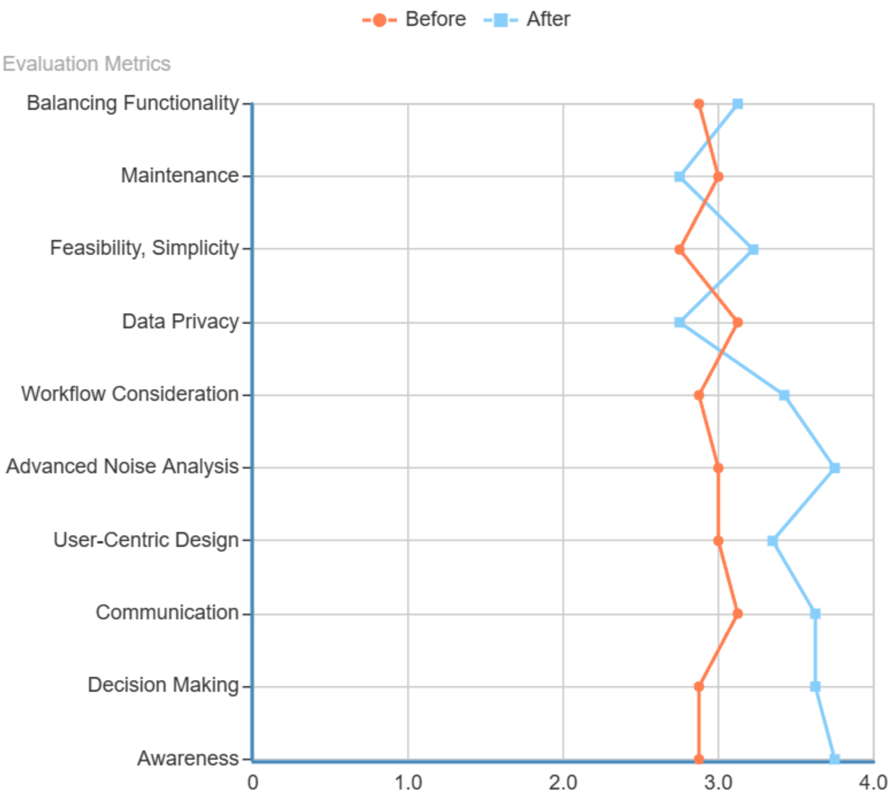


Figure 30. Evaluation results

Key factors in design goal
According to the assessment results, there has been a significant improvement in the three key indicators within the design goals: Awareness, Decision Making, and Communication.

Through interviews with the nurses, we found that both the indicators of Pleasantness and Eventfulness are relatively easy to accept and understand. At the same time, when communicating with each other through this product, the nurses now have quantifiable metrics to measure the quality of the living environment. Compared to their previous methods of recording work, which could not accurately quantify the quality of the living environment, this has further facilitated their communication with each other and decision-making regarding key behaviors.

Additionally, the event prediction algorithm has helped them quickly analyze events that have occurred over a period and the main factors affecting the biological environment, without having to listen to the entire recording, which would consume a lot of time and energy. Moreover, the combination of the event prediction analysis algorithm with Pleasantness and Eventfulness helps them quickly identify the reasons for changes in sound environment indicators, allowing for timely and precise adjustments.

Data privacy
The indicator value for Data Privacy has declined. Through subsequent interviews with the nurses, we found that this is mainly due to the use of recording and analysis functions in this product. The nurses are uncertain where their recordings are saved, the location of the recording devices, and the recording time. This brings them additional concerns about data privacy and security.

Maintenance
Another declining indicator is Maintenance. The nursing community is very pleased with the new dimensions this product brings to the analysis of the living environment and the assistance it provides to their work capabilities. However, at the same time, due to a lack of understanding of the operating mechanism of this new product, the nurses have some concerns. They worry about whether the introduction of this product will bring them additional workload, and whether they will need to spend extra time and effort to maintain and use this system.

7.4 Expert interview

Prof.Chen Yi
Chen Yi is an Associate Professor at Xiamen University's School of Creative and Innovation, specializing in visual communication design. He holds degrees from Xiamen University and the China Academy of Art. His work has been recognized with awards such as the Best Excellence Award at the Impression Huizhou International Poster Invitational Exhibition.

Prof.Dr. Chen Yan
Chen Yan is an Associate Professor at Jiangnan University's School of Design, specializing in the emotional experience and multi-channel sensory interaction of intelligent products. Her research has led to over ten professional publications and multiple awards, and she has been involved in significant projects, including one with the Chinese Academy of Engineering. With rich experience in graduate student guidance and complex design project management.

Prof.Dr. Wu Jinzhun
Wu Jinzhun is an Associate Professor at Xiamen University's School of Medicine, specializing in Pediatrics and Respiratory Asthma. With over 20 years of experience in the field, he conducts research on the impact of particulate pollutants on asthma and the clinical application of salivary pepsin. He also serves as the Deputy Dean of Xiamen University's Affiliated Women and Children's Hospital.

Key Insights

Awareness

The experts recognize the innovative approach of "Soundscapes in ICU" in creating optimal healing conditions. They particularly appreciate the focus on NICU/PICU but express concerns about the potential complexity for nurses. Recommendations include specialized training and simplification of tools to make the project more practical and effective in real-world implementation.

Strengths:
- "Your project's focus on sound environment awareness is vital for creating optimal healing conditions in ICU settings." (Dr. CY)
- "The specific emphasis on NICU/PICU aligns well with specialized care requirements." (WJ)

Weaknesses:
- "The current lack of training modules within the project might hinder effective implementation." (Dr. CY)
- "Potential overwhelming complexity for nurses without proper guidance." (WJ)

Recommendations:
- "Incorporate specialized training within the project scope for effective implementation." (Dr. CY)
- "Simplify tools and guidelines for nurses in NICU/PICU." (WJ)

Decision Making

The product is acknowledged for enhancing critical decision-making in intensive care units, especially aligning with the unique requirements of neonatal care. The experts praise the initiative but also highlight challenges in integrating it into existing workflows. They stress the importance of stakeholder education, alignment, and direct engagement with medical staff for successful application.

Strengths:
- "Real-time audio analysis in your project enhances critical decision-making in ICU." (Dr. CY)
- "Aligns with the unique decision-making processes in neonatal care." (WJ)

Weaknesses:
- "Challenges in integrating with existing

workflows may limit its application." (Dr. CY)
- "The current design may face resistance if not explained well." (WJ)

Recommendations:
- "Invest in stakeholder education and iterative design to align with ICU needs." (Dr. CY)
- "Engage directly with medical staff in the design process." (WJ)

Communication

Communication is identified as a strength of the product, especially in enhancing patient comfort and understanding through sound management. However, the experts point to potential complexities in communication if not implemented thoughtfully. They recommend revising the project to emphasize clarity and collaboration and iterating on design with end-user feedback.

Strengths:
- "Your project enhances patient comfort and understanding through sound management." (Dr. CY)
- "The initiative has potential for improved communication with families and medical teams." (WJ)

Weaknesses:
- "Possible communication complexities if not implemented thoughtfully." (Dr. CY)
- "The present structure might complicate stakeholder communication." (WJ)

Usability

The user-centric approach of the product resonates well with healthcare goals, and its focus on NICU/PICU ensures practical functionality. The experts recommend a close collaboration between the tool and user needs and emphasize the importance of real-world testing within the ICU environment. They stress incorporating medical staff in the design process for refined usability.

Strengths:
- "The user-centric approach in your project resonates with healthcare goals." (Dr. CY)
- "The focus on NICU/PICU ensures practical functionality." (WJ)

Weaknesses:
- "Potential disconnect between tool and user needs without proper collaboration." (Dr. CY)

Recommendations:
- "Conduct iterative user testing within the actual ICU environment." (CY)

Figure 31. Interview with medical expert

8

Next steps

8.1 Conclusion

The inception of this project was anchored in a precise observation of the sound environment within the ICU, specifically the NICU and PICU, and a comprehensive understanding of how sound events influence the decision-making process of nursing staff and affect patients' sleep behaviors.

During the process of observation, we continually refined our focus, ultimately concentrating on nurses, the core group in the care environment of both NICU and PICU. As the primary caregivers with direct interaction with patients and their families, nurses navigate a complex working environment characterized by unique workflows. The shift in hospital layouts from large multi-bed rooms to single, independent rooms has brought new challenges to monitoring patient conditions in these specialized units.

Recognizing these multifaceted challenges, extensive literature research was conducted, leading to the identification of the soundscape as an essential sound environment evaluation metric, and the sound event detection algorithm. When combined, these elements opened up a novel avenue for nurses in NICU and PICU to understand the specific sound events within the enclosed rooms. This understanding, in turn, might facilitate better decision-making, fosters communication among nurses, improves their behavior, and enhances awareness of events within the patient's room.

Unlike previous soundscape research that remained on the subjective level, such as inviting testers to evaluate sound pleasantness and eventfulness, this project required an objective evaluation based on physical recordings. This necessitated implementing the purpose algorithmically, paving the way for an exploratory technical phase in the project.

The initial stages were largely dedicated to the technological exploration of how to analyze audio to derive key parameters for eventfulness and pleasantness in the NICU and PICU settings. Codes were crafted to assess sound attributes such as loudness, roughness, sharpness, and harmoniousness, and an event prediction algorithm was integrated to evaluate the likelihood of various sound events. This amalgamation allowed for an objective calculation of eventfulness and pleasantness from a new perspective.

In the concluding phase, the focus was geared towards transforming raw data into visually accessible formats, making the information more understandable and manageable for the nursing staff in NICU and PICU. Continuous refinement of algorithms and computational formulas was also a significant part of this stage.

Furthermore, compared to mere UI (User Interface) design, the more profound aspect of demo development involves complexities like sound collection, data processing, information storage, deployment methods, and interaction design. These aspects have required continuous learning and overcoming technological barriers to actualize a functional product prototype, a process during which new opportunities and challenges have consistently emerged.

For instance, in the implementation phase, due to constraints such as project duration and personal computer performance, I opted to use synthesized audio to simulate the real sound environment of ICU, including NICU and PICU. This approach had distinct advantages for the testing phase of the product, requiring lower computational performance from the system and avoiding issues such as remote connectivity of recording devices and privacy concerns related to conversation content (problems that were beyond the main scope of the project). However, after completing the testing as per the anticipated plan, I realized that real-time analysis through authentic microphone recordings had its necessity. Factors such as the positioning and performance of recording equipment and the nurses' acceptance of the recording devices could significantly impact the soundscape analysis results. These new insights necessitate further testing and validation. Both synthetic and real audio paths may be suitable for different use scenarios or may complement each other within the same system.

In conclusion, this master's student project, by integrating soundscapes and sound event prediction algorithms, has provided valuable insights into auditory analysis within the specialized units of NICU and PICU. Through the application of data visualization, frontend development, and rigorous testing validation with the nursing community, the initial goals of the project have been realized. The exploration of both synthesized and authentic sound capturing has demonstrated the potential of sound as a nuanced tool for analysis and communication in these critical healthcare environments. This endeavor has not only allowed a deeper understanding of the complex auditory dynamics within NICU and PICU but also contributed to a humble step towards enhancing nursing practice in these specialized care settings.

8.2 Recommendation for future

Utilize more authentic audio samples
To enhance the realism and applicability of the tool in daily healthcare scenarios, incorporating additional audio samples reflective of genuine real-world conditions would be beneficial. This approach could significantly boost the tool's acceptance and utilization by nurses within the NICU and PICU.

Presently, the International Soundscape Database offers ratings on various sound attributes such as eventfulness, pleasantness, loudness, sharpness, and others. These have been employed to refine the precision of the soundscape calculation equation within the project. However, difficulties arise due to disparities in recording devices, analysis algorithms, and the unavailability of raw code and recordings. These constraints limit the ability to leverage this data further.

The International Soundscape Database has mentioned plans to add raw recording data in the future, which could serve as a vital resource for constructing the eventfulness calculation method and enhancing the sound event detection algorithm. As such, closely monitoring updates from this database and integrating this forthcoming data into future iterations of the tool could be a valuable strategy. This would not only align the tool closer to real-world applications but also contribute to the continuous improvement and fine-tuning of the auditory analysis capabilities in specialized care settings like NICU and PICU.

Integrate real-time processing capabilities
The incorporation of real-time processing capabilities into the tool could significantly elevate its dynamism and responsiveness to the immediate environment within NICU and PICU settings. By utilizing real-time data, the soundscapes provided by the tool would be more relevant and closely aligned with the actual conditions that nursing staff encounter.

However, the pursuit of this real-time approach is not without challenges. During the project, constraints such as computer performance, time limitations, and other factors restricted my ability to progress beyond the pre-processing stage. Nonetheless, the vision for a real-time processing version of this tool remains very much alive.

The insights from expert interviews underscored the importance of real-time analysis in capturing the fluid nature of sound within an ICU context. With the continuous advancements in technology, better computational devices, and refined coding logic, there's strong potential to realize this future version. Not only could this provide immediate insights into the soundscape but also foster quicker and more informed decisions among the nursing staff, enhancing patient care and overall efficiency.

Increase the assessment of eventfulness and pleasantness

Building on the project's foundation, there's an opportunity to enrich the tool by adding more nuanced measures of eventfulness and pleasantness. These dimensions could offer valuable insights into the perceived quality of different soundscapes within NICU and PICU.

Expert interviews emphasized that a more comprehensive understanding of these aspects could greatly aid in optimizing the tool's output. By integrating detailed metrics that encapsulate various characteristics of sound, such as texture, tone, and emotional resonance, the tool could provide a richer and more insightful analysis.

In tandem with the insights gained from the International Soundscape Database and real-world sound data, these expanded assessments of eventfulness and pleasantness could contribute to a more user-friendly and actionable tool. They could facilitate personalized adjustments and foster a more conducive sound environment that resonates with the unique needs and preferences of nursing staff. Consequently, the alignment of these attributes with the real-time conditions of NICU and PICU could lead to improved working conditions for caregivers and a more comfortable environment for patients and their families.

These two enhancements reflect an aspirational direction for the project, grounded in both the practical lessons learned during development and the insights from domain experts. Together, they provide a roadmap for ongoing refinement and innovation, positioning the tool as a valuable asset in the specialized and complex world of NICU and PICU care.

8.3 Personal reflection

My graduation project has been a remarkable journey, filled with learning and growth. I embarked on an ambitious path to detect sound events and calculate various sound attributes, such as loudness and sharpness, and successfully incorporated these into an interactive chart in the User Interface (UI).

The interim results were encouraging, and I owe much of this success to the guidance and expertise of my chair, Elif Ozcan Vieira, and my mentors, Tom Goos and Eris. Their insights into sensory design, real-life clinical scenarios, and practical advice were instrumental in shaping my approach and refining my ideas.

While I made significant progress in the technical aspects of the project, I recognized the need for further refinement in design quality. My mentors provided constructive feedback, emphasizing the importance of a consistent design with research outcomes and a clean GUI. Their support helped me navigate the complexities of acoustic modeling and communication of relevant parts in an attractive way.

The planning phase was a learning curve, and I realized that defining a soundscape was more intricate than I initially thought. I had to consider various factors, and the iterations and explorations on the soundscape component were worthwhile. My chair and mentors were there every step of the way, providing encouragement and guidance, helping me stay on track, and ensuring that I met the project's goals.

On a personal level, I am grateful for the wealth of knowledge I gained about auditory design, machine learning algorithms, and front-end programming. My chair and mentors saw my passion for the project and nurtured my growth in knowledge and capabilities.

I cannot overstate my appreciation for the invaluable assistance provided by Elif, Tom, and Eris. Their expertise, encouragement, and unwavering support played a vital role in my success. They were not just supervisors but true mentors, guiding me through challenges and celebrating my achievements.

In conclusion, the graduation project was an enriching experience, filled with challenges and triumphs. The support and guidance from my chair and mentors were the cornerstone of my success. I am proud of what I have achieved and deeply grateful for the opportunity to learn and grow under their mentorship. The skills and insights I have gained will undoubtedly serve me well in my future endeavors.

Reference

1. Bremmer, P., Byers, J. F., & Kiehl, E. (2012). Noise and the premature infant: physiological effects and practice implications. Journal of Obstetric, Gynecologic, & Neonatal Nursing,33(4), 447-454.
2. van den Hoogen, A., Teunis, C. J., Shellhaas, R. A., Pillen, S., Benders, M., Dudink, J., & van der Heijden, F. (2018). Enhancing Parent-Infant Bonding in the Neonatal Intensive Care Unit: A Field Study of a Socially Interactive Robot. Journal of Perinatal & Neonatal Nursing, 32(2), 168-177.
3. van den Bosch, K., & Andringa, T. (2014). The effect of sound sources on soundscape appraisal. In ICBEN.
4. Tuuri, K. & Eerola, T. (2012). Formulating a revised taxonomy for modes of listening. Journal of New Music Research, 41(2), 137-1521.
5. Salandin, A., Arnold, J., & Kornadt, O. (2011). Noise in an intensive care unit. Journal of the Acoustical Society of America, 130(6), 3754-37602.
6. Halletal. (2013). Acoustic environment and patient satisfaction in a hospital. Environment and Behavior, 45(2), 227-244.
7. Schafer, R. M. (1976). The tuning of the world. New York: Random House.
8. Truax, B. (1984). Acoustic communication. Norwood, NJ: Ablex Publishing Corporation.
9. Luetz, A., Balzer, F., Radtke, F. M., Jones, C., Citerio, G., Walder, B., Weiss, B., Wernecke, K. D., Spies, C. (2019). Delirium, sedation and analgesia in the intensive care unit: a multinational, two-part survey among intensivists. PLoS One, 14(11), e0223941.
10. Abuatiq, A. (2015). Patients' sleep in an intensive care unit: a phenomenological study. Journal of Intensive and Critical Care, 1(1).
11. Jaiswal, S. J., Garcia, S., Owens, R. L., Kushida, C. A., & Guilleminault, C. (2017). Changes in ambient noise levels affect sleep in ICU. Chest, 152(4), A184.
12. Drahota, A., Ward, D., Mackenzie, H., Stores, R., Higgins, B., Gal, D., & Dean, T. P. (2012). Sensory environment on health-related outcomes of hospital patients. Cochrane Database of Systematic Reviews, (3).
13. Kamdar, B. B. (2020). Noise in the ICU. Journal of Intensive Care Medicine, 35(6), 529-536.
14. Mackrill, J. (2013). Considering sound in healthcare environments: A psychoacoustic approach to auditory and cross-modal effects on patients and staff. Ph.D. Thesis, Department of Mechanical Engineering, University of Bath.
15. Park, M., Koh, Y., Jeong, Y., & Jeon, K. (2019). Noise in hospital rooms and sleep disturbance in hospitalized medical patients. Environmental Health and Preventive Medicine, 24(1), 55.
16. Berglund, B., Lindvall, T., & Schwela, D. H. (1999). Guidelines for community noise. World Health Organization.
17. Chlan, L. L., Weinert, C. R., Heiderscheit, A., Tracy, M. F., Skaar, D. J., Guttormson, J. L., & Savik, K. (2013). Effects of patient-directed music intervention on anxiety and sedative exposure in critically ill patients receiving mechanical ventilatory support: a randomized clinical trial. JAMA, 309(22), 2335-2344.
18. Van der Starre, C. (2011). Patient safety in pediatrics: A developing discipline.
19. Sadeh, A. V. I., Mindell, J. A., Luedtke, K., & Wiegand, B. (2009). Sleep and sleep ecology in the first 3 years: a web-based study. Journal of sleep research, 18(1), 60-73.
20. Bathory, E., & Tomopoulos, S. (2017). Sleep regulation, physiology and development, sleep duration and patterns, and sleep hygiene in infants, toddlers, and preschool-age children. Current problems in pediatric and adolescent health care, 47(2), 29-42.
21. Centers for Disease Control and Prevention (CDC). Sleep and sleep disorders. CDC features website. 2010. http://www.cdc.gov/features/sleep/. Accessed September 25, 2011
22. Bathory, E., & Tomopoulos, S. (2017). Sleep regulation, physiology and development, sleep duration and patterns, and sleep hygiene in infants, toddlers, and preschool-age children. Current problems in pediatric and adolescent health care, 47(2), 29-42.
23. Berger, J. A., & Kudchadkar, S. R. (2021). Sleep in the Pediatric Intensive Care Unit. In Sedation and Analgesia for the Pediatric Intensivist (pp. 259-273). Springer, Cham.
24. Corser, N. C. (1996). Sleep of 1-and 2-year-old children in intensive care. Issues in Comprehensive Pediatric Nursing, 19(1), 17-
25. Bruce, N. S., & Davies, W. J. (2014). The effects of expectation on the perception of soundscapes. Applied Acoustics, 85, 1-11. doi:10.1016/j.apacoust.2014.03.0162.
26. Axelsson, Ö., Nilsson, M. E., & Berglund, B. (2010). A principal components model of soundscape perception. The Journal of the Acoustical Society of America, 128 (5), 2836–

2846. doi:10.1121/1.34934363.

27. Soundscape in Times of Change: Case Study of a City Neighbourhood During the COVID-19 Lockdown (source citation incomplete).

28. Jeon, J. Y., & Hong, J. Y. (2022). Soundscape perception and design in urban open spaces. Environment and Planning B: Urban Analytics and City Science, 49(1), 60-76. doi:10.1177/239980832110631204.

29. Van der Starre, C. (2011). Patient safety in pediatrics: A developing discipline.

30. Sadeh, A. V. I., Mindell, J. A., Luedtke, K., & Wiegand, B. (2009). Sleep and sleep ecology in the first 3 years: a web-based study. Journal of sleep research, 18(1), 60-73.

31. Bathory, E., & Tomopoulos, S. (2017). Sleep regulation, physiology and development, sleep duration and patterns, and sleep hygiene in infants, toddlers, and preschool-age children. Current problems in pediatric and adolescent health care, 47(2), 29-42.

32. Centers for Disease Control and Prevention (CDC). Sleep and sleep disorders. CDC features website. 2010. http://www.cdc.gov/features/sleep/. Accessed September 25, 2011

33. Berger, J. A., & Kudchadkar, S. R. (2021). Sleep in the Pediatric Intensive Care Unit. In Sedation and Analgesia for the Pediatric Intensivist (pp. 259-273). Springer, Cham.

34. Corser, N. C. (1996). Sleep of 1-and 2-year-old children in intensive care. Issues in Comprehensive Pediatric Nursing, 19(1), 17-31.

35. Richardson A, Allsop M, Coghill E, Turnock C: Earplugs and eye masks: do they improve critical care patients' sleep?. Nurs CritCare. 2007, 12: 278-286. 10.1111/j.1478-5153.2007.00243.x.

36. Berglund B, Lindvall T, Schwela DH, World Health Organization. Occupational and Environmental Health Team. Guidelines for community noise. London: World Health Organization (1999).

37. Garcia Guerra, G., Joffe, A. R., Sheppard, C., Pugh, J., Moez, E. K., Dinu, I. A., ... & Vohra, S. (2018). Sedation Withdrawal and Analgesia Team (SWAT); Canadian Critical Care Trials Group (CCCTG). Prospective cohort study on noise levels in a pediatric cardiac intensive care unit. J Crit Care, 44, 318-22.

38. Parthasarathy, S., & Tobin, M. J. (2009). Sleep in the intensive care unit. Applied Physiology in Intensive Care Medicine, 191-200.

39. Parthasarathy, S., & Tobin, M. J. (2009). Sleep in the intensive care unit. Applied Physiology in Intensive Care Medicine, 191-200.

40. Kennisgeving voor omleiding. (2013). NICHD Pediatric Terminology,.https://www.google.com/url?q=https://www.nlm.nih.gov/research/umls/sourcereleasedocs/current/NCI_NICHD/index.html%23:%7E:text%3DThe%2520NICHD%2520Terminology%2520provides%2520standardized,trials%2520and%2520other%2520research%2520activities.%26text%3DThe%2520terminology%2520is%2520a%2520core,of%2520a%2520broader%2520terminology%2520framework&sa=D&source=docs&ust=1656005020590934&usg=AOvVaw1FRU6WnL0bu6wsa9miR7_s

41. van den Bosch, K. A., Vlaskamp, C., Andringa, T. C., Post, W. J., & Ruijssenaars, W. A. (2016). Examining relationships between staff attributions of soundscapes and core affect in people with severe or profound intellectual and visual disabilities. Journal of Intellectual and Developmental Disability, 41(1), 21-30.

42. Green Forge Coop. MOSQITO [Computer software]. https://doi.org/10.5281/zenodo.5284054

43. Erfanian, M., Mitchell, A., Aletta, F., & Kang, J. (2020). Psychological Well-being, Age and Gender can Mediate Soundscapes Pleasantness and Eventfulness: A large sample study. bioRxiv, 2020-10.

44. Kong, Q., Cao, Y., Iqbal, T., Wang, Y., Wang, W., & Plumbley, M. D. (2020). Panns: Large-scale pretrained audio neural networks for audio pattern recognition. IEEE/ACM Transactions on Audio, Speech, and Language Processing, 28, 2880-2894.

45. Bones, O., Cox, T. J., & Davies, W. J. (2018). Sound Categories: Category Formation and Evidence-Based Taxonomies. Frontiers in psychology, 9, 1277. https://doi.org/10.3389/fpsyg.2018.01277

46. Brown, A. L., Gjestland, T., & Dubois, D. (2016). Acoustic environments and soundscapes. Soundscape and the built environment, 1-16.

47. Bones, O., Cox, T. J., & Davies, W. J. (2018). Sound categories: Category formation and evidence-based taxonomies. Frontiers in psychology, 9, 1277.

48. Özcan E, Broekmeulen C L H, Luck Z A, et al. Acoustic Biotopes, Listeners and Sound-Induced Action: A Case Study of Operating Rooms[J]. International Journal of Environmental Research and Public Health, 2022, 19(24): 16674.

Appendix

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name Lu 6305
initials G.L. given name Guang
student number
street & no.
zipcode & city
country
phone
email

Your master programme (only select the options that apply to you):

IDE master(s): ○ IPD ● DfI ○ SPD

2nd non-IDE master:

individual programme: - - (give date of approval)

honours programme: ○ Honours Programme Master

specialisation / annotation: ○ Medisign

○ Tech. in Sustainable Design

○ Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair Elif Ozcan Vieira dept. / section: HCD - DA
** mentor Tom Goos dept. / section:
2nd mentor
organisation:
city: country:

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Elif Ozcan Vieira date 03 - 03 - 2003 signature Digitally signed by Elif Ozcan Vieira - IO Date: 2023.03.03 17:14:41 +01'00'

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 11 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 11 EC

List of electives obtained before the third semester without approval of the BoE

● YES all 1st year master courses passed

○ NO missing 1st year master courses are:

name Robin den Braber date 06 - 03 - 2023 signature Robin den Braber Digitaal ondertekend door Robin den Braber Datum: 2023.03.06 12:49:45 +01'00'

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ● APPROVED ○ NOT APPROVED

Procedure: ● APPROVED ○ NOT APPROVED

comments

name Monique von Morgen date 21 - 03 - 2023 signature

Sound environment monitoring system in NICU/PICU project title

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

start date 17 - 02 - 2023

07 - 07 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

At the Neonatology Intensive Care Unit (NICU) and Pediatric Intensive Care Unit(PICU), patients and medical staff are particularly vulnerable to the negative effects of noise pollution. The NICU is specially created for premature newborns that need care to survive and are extremely vulnerable babies who are prone to illness. Considering the fragile nature of the unit, there are a lot of alarms and noise pollution, which has a bad effect on both the patients' well-being and the performance of the medical staff. Environmental noise also affects the neurodevelopment of newborns, according to studies(Graven,2000). Also, based on our previous research in PICU during the Design Research Methodology course, the sound environment affects the sleep quality of patients during night time. Through our 8-hour observation from 10pm to 6am, the patients were waken or crying due to different sound resources like door closing. From physical and mental health of patients to the working behavior of medical staff, current sound environment in ICU needs more improvement and that's where Critical Alarm Lab has been striving on in recent years.

Within Critical Alarm Lab, there are some explorations in sound environment evaluation and monitoring, like the sound visualization project (Núria Viñas, 2021) and Cocophony Mapper (Yoon Lee,2019). It's valuable for me to inherit their insights and continue the exploration as a member of Critical Alarm Lab. For instance, due to time limitation, the sound visualization project's final outcome was UI pages which is hard to interact with and do some tests. This lead to some questions from experts like how do people implement this in real situation and how can this actually benefits medical staffs' workflow.

What's more, the transition from cluster to single patient rooms also presents an opportunity. Previous projects of our lab focus more on noise control in the big and noisy room, but things will change as the layout plan. Based on Erasmus MC's plan, all NICU/PICU units will adopt the single patient room layout in several years. This makes the overall sound environment better since they separate all patients and those monitoring devices, but it's also a challenge for medical workers by making it harder to directly observe how things going on with certain patients. Accordingly, my design focus will cast on how to provide medical workers sufficient, understandable and concise information to fit in their new workflow. Promisingly, the prototype will act as an inspiration which allows stakeholders to ideate more possibilities to work with algorithm and improve their working environment.

Based on previous projects and research, I'll focus on build an interactive and testable prototype of sound environment monitoring system with the sound event detection algorithm ,data visualization methods and front-end UI. It's able to gather information from the environment and have interaction with stakeholders like nurses and parents. Besides, I'll also research on how different sound event or attributes lead to emotion change based on the components model of acoustic perception(Simone, Rossano, et al 2020). The dimension of pleasure and eventful can provide a more instinct way to describe the sound environment.

The limitation exists that currently nurses still work in the big cluster room in NICU/PICU OF Erasmus MC, and we need to refer to other hospitals' working condition in single cell room layout to imagine the future scenario. Also the sound event detection algorithm act as a prototype ather than the main focus of the project, the accuracy might not satisfy real implementation.

space available for images / figures on next page

Initials & Name G.L. Lu 6305

Title of Project Sound environment monitoring system in NICU/PICU

introduction (continued): space for images

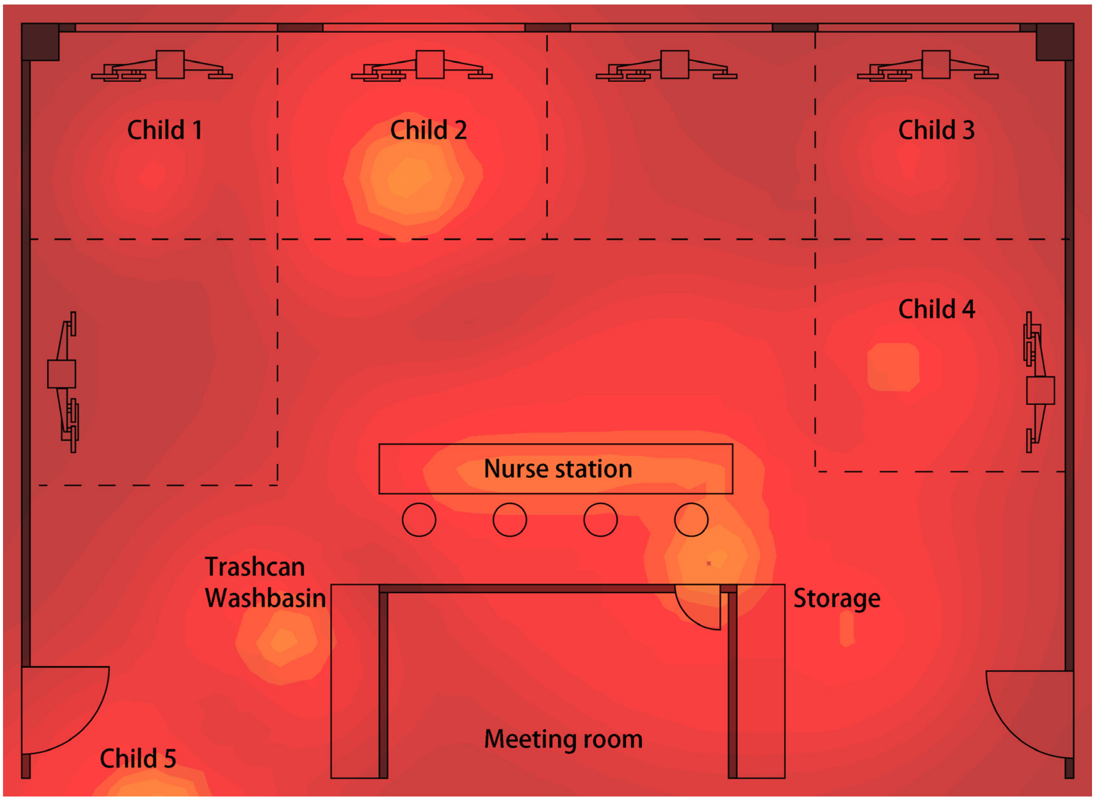


image / figure 1: Sound environment heat map in PICU

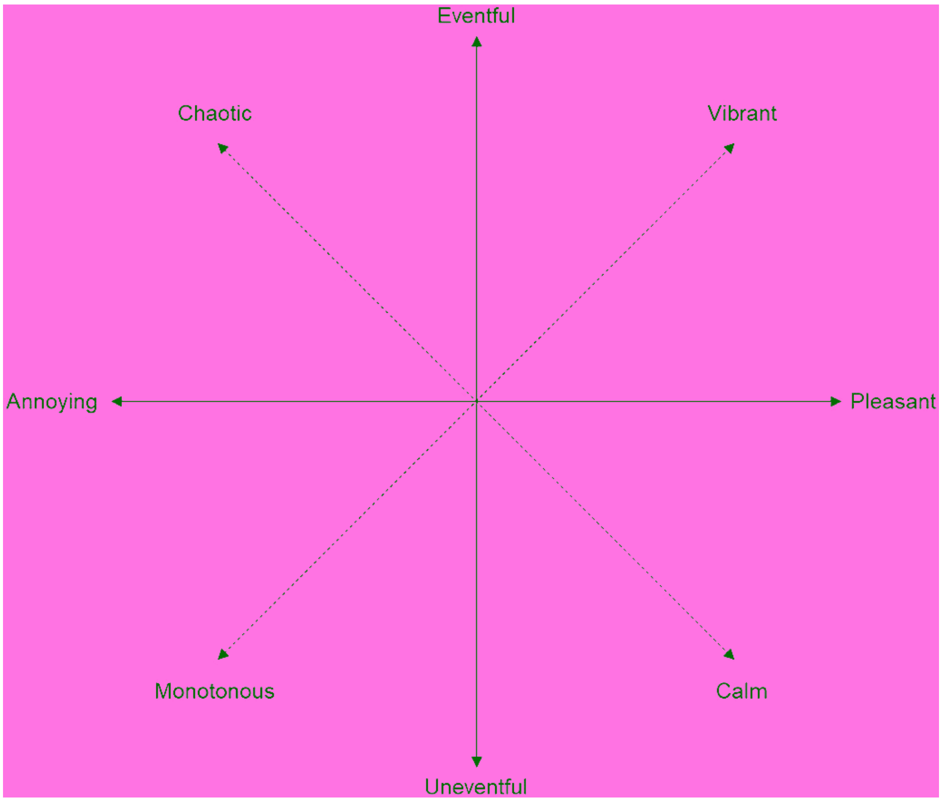


image / figure 2: Model of affective response to outdoor soundscapes from ISO/TS 12913–3:2019

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

This project concentrates on build a sound environment monitoring system using sound event detection and data visualization to help medical workers manage the sound environment and benefit their workflow.

1.Affective response to soundscape. how do stakeholders feel about different sound resources? Can we find certain index that can measure the level of pleasure/eventfulness?

2.Event detection algorithm. Since the algorithm part is not main direction of the project, it's necessary to find the suitable one that provide satisfactory accuracy. Also we need to find out how different algorithms works together, do they have the same audio resources and can be integrated into one system?

3.Cassification of sound events. Regular algorithm will generate hundreds of sound event types, for them the more is better. But if we apply this in real situation to generate useful report for the medical staffs' workflow, it's necessary to categorize abundant sound events into several concise and meaningful groups. How to define the sound event classes need further exploration.

4.Data visualization and workflow. Since the system is focusing on providing useful information to medical staffs and benefit their work flow, when and how do they need those data need to be explored. Through the understanding of their work pattern, the proper methods to present the data should be discussed.

5.Terminal and interaction. Currently Unit4 in NICU has deployed portable device in their system. After getting a deeper understanding of how it works, I need to find out should the system run on desktop or portable device and how can users interact with it(like switching between different graphs or using filter.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

The goal of this project is to design and test a monitoring system that leverages alarm detection and sound event detection algorithms to provide a comprehensive view of the sound environment in multiple single patient rooms or terminals. This system will aim to improve the workflow of nurses, enhance stakeholder experience, and have a positive impact on stakeholders by providing real-time data visualization of sound events.

The system will be built through four steps: research, ideation, iteration and evaluation. (details in planning part)

By conducting quantified research and observation in field, a circumplex model of affect that integrates sound events in ICU into a map will be built. And I'll try to find index to measure the eventfulness and level of pleasant. Besides I'll identify suitable algorithms for sound event detection and alarm detection and try to combine them. The algorithms' accuracy will be tested by voice gathered in ICU.

The ideation phase aims to build an iterative prototype that collects and visualizes environment sounds in real time using Python and Django, and explore possible data visualization strategies. In the meanwhile, the question about how to classify sound events will be researched.

In the iteration phase, I'll optimize a scenario-focused prototype that meets users' needs in the ICU context and has a deeper understanding of how the project can be more useful by conducting generative session and usability tests.

In the end, by expert interviews and product evaluation test, I'll gather effectiveness and recommendations for improving the system based on the results.

Initials & Name G.L. Lu 6305

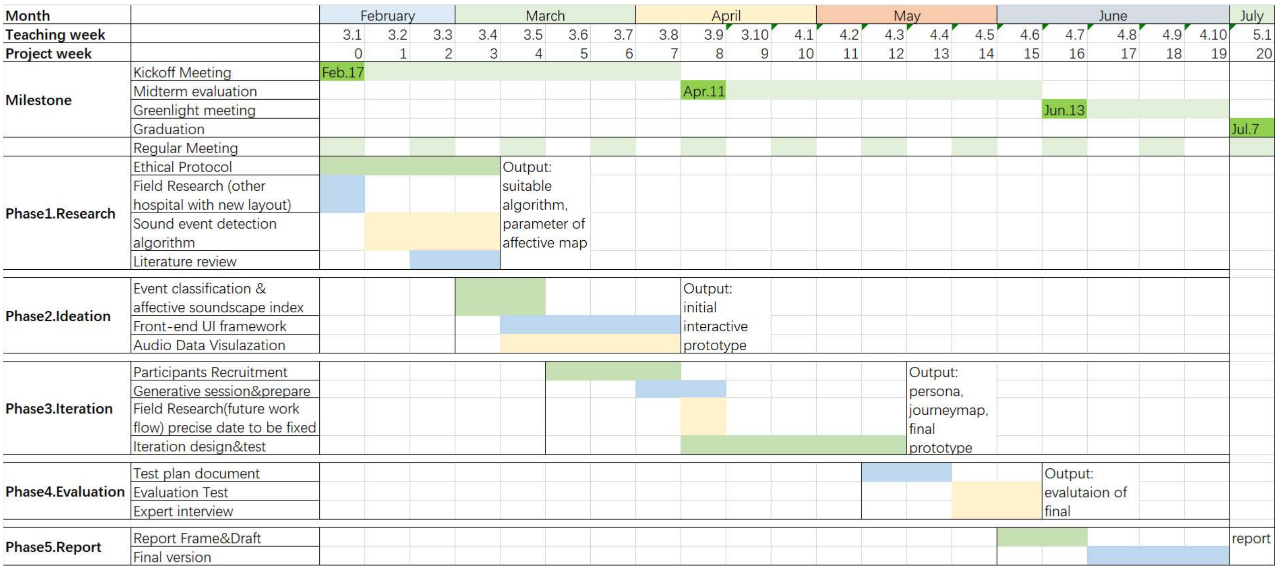
Title of Project Sound environment monitoring system in NICU/PICU

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and 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 activities.

start date 17 - 2 - 2023

7 - 7 - 2023 end date



Month		February			March				April				May				June					July
Teaching week		3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	3.10	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	4.10	5.1
Project week		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Milestone	Kickoff Meeting	Feb.17	🟩	🟩	🟩	🟩	🟩	🟩	🟩													
	Midterm evaluation									Apr.11	🟩	🟩	🟩	🟩	🟩	🟩	🟩					
	Greenlight meeting																	Jun.13	🟩	🟩	🟩	
	Graduation																					Jul.7
	Regular Meeting	🟩		🟩		🟩		🟩		🟩		🟩		🟩		🟩		🟩		🟩		🟩
Phase1.Research	Ethical Protocol	🟩	🟩	🟩	🟩	Output: suitable algorithm, parameter of affective map																
	Field Research (other hospital with new layout)	🟦																				
	Sound event detection algorithm		🟨	🟨	🟨																	
	Literature review			🟦	🟦																	
Phase2.Ideation	Event classification & affective soundscape index				🟩	🟩				Output: initial interactive prototype												
	Front-end UI framework					🟦	🟦	🟦	🟦													
	Audio Data Visulazation					🟨	🟨	🟨	🟨													
Phase3.Iteration	Participants Recruitment						🟩	🟩	🟩						Output: persona, journeymap, final prototype							
	Generative session&prepare								🟦	🟦												
	Field Research(future work flow) precise date to be fixed									🟨												
	Iteration design&test									🟩	🟩	🟩	🟩	🟩								
Phase4.Evaluation	Test plan document													🟦	🟦			Output: evalutaion of final				
	Evaluation Test															🟨	🟨					
	Expert interview																					
Phase5.Report	Report Frame&Draft																🟩	🟩				report
	Final version																		🟦	🟦	🟦	

I plan to follow the general principle of the "Human-centered Design Approach for Healthcare" in the design process of the sound environment monitoring system at Erasmus MC. Being a DFI student, I am particularly interested in ensuring that the user experience and interaction design are given utmost priority in the project. To tackle the issues that have been identified, the following approaches will be implemented:

1.Literature Review: articles about affective response to soundscapes helps me to find the proper parameter to measure pleasure and eventfulness, with which I can analyze the audio data and generate matrix of affective response;

2.Field Research. By paying visits to Erasmus MC, observing and talking with medical staffs, and also researching about other hospitals that adopt single cell room layout, I can have a deeper understanding of design background and users needs. After this, the ICU medical staff personas,empath map and journey map will be generated to facilitate the design;

3.Generative session . After the initial prototype is generated, the generative session will be held with medical workers. The prototype act as an inspiration and other prototype tools like example of different data visualization and interaction methods will be used to facilitate stakeholders' ideation.

4. Agile iteration. The iteration stage will use the Agile way of working, which means using the minimal testable prototype to quickly cooperate with medical users and improve it.

Initials & Name G.L. Lu 6305

Title of Project Sound environment monitoring system in NICU/PICU

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

My inspiration for starting this project stems from a desire to create solutions that improve people's lives, as well as an interest in healthcare technology. The icu environment has a tremendous impact on the well-being of patients, parents, and healthcare personnel. I aim to help improve this atmosphere by developing a sound and alarm detection system that is tailored to the critical care situation.

In terms of competencies, my MSc degree provided me with a solid foundation in sound design, as well as a thorough understanding of medical design and ICU expertise through DRM(Design Research Methodology) and extra-curricular activities. However, I want to expand on this understanding by investigating how it may be applied to real-world challenges. I specifically want to hone my skills in multi-terminal design and IoT, hardware prototyping, and data visualization in order to create a holistic solution to the ICU acoustic environment's difficulties.

My personal learning goals for this project include learning more about sound design for a medical setting, expanding my knowledge of multi-terminal design and IoT, and exploring with hardware prototyping. Furthermore, I wish to develop a better grasp of the significance of data visualization in healthcare, as well as how it can be used to effectively communicate information to diverse stakeholders.

By completing this project, I hope to not only achieve the learning objectives of my Graduation Project, but also to broaden my skill set and knowledge in areas that will be useful in my future work as a healthcare designer.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Evaluation Plan - Experts

Interview Guide for NICU Doctor (Therapy Expert)

Specialized in neonatal care and therapy, focusing on the sensory environment in intensive care units.

Introduction:
Brief about the project: "Soundscapes in ICU: Exploring Real-Time Audio Analysis."
Purpose of the interview: To gather insights from a medical professional with direct experience in the ICU, focusing on sound management and therapeutic considerations.

Questions:

Understanding Soundscapes in NICU:
Can you describe the typical soundscape in an NICU and how it might differ from other ICU settings?
How do you perceive the role of sound in the NICU, both positively and negatively, particularly concerning neonatal care and therapy?

Therapeutic Considerations:
How might soundscapes influence therapeutic outcomes in the NICU?
Are there specific sound attributes that you consider more therapeutic or disruptive in this setting?

Real-Time Audio Analysis:
What are your thoughts on a tool that provides real-time analysis of the soundscape within an NICU?
How could such a tool be integrated into daily care routines, and what might be the potential benefits or challenges?

User Interaction and Interface Design:
Considering your experience in an NICU setting, what features would you find most valuable in a real-time audio analysis tool?
How could the user interface be designed to provide essential information without adding cognitive load to the healthcare providers?

Privacy and Ethical Considerations:
Given the sensitive nature of neonatal care, what are your thoughts on privacy and ethical considerations in capturing and analyzing sound within the NICU?

Future Development and Collaboration:
What would you like to see in the future development of this project to better align with the unique needs of an NICU?
How could collaboration between medical professionals, designers, and technologists be fostered to create a more effective tool?

Closing Thoughts:
Is there anything else you would like to share that we haven't covered, particularly concerning the relationship between soundscapes, therapy, and neonatal care?

Interview Guide for Prof. Rik van Egmond

Associate Professor in the Department of Industrial Design Engineering at TU Delft, focusing on sensory perception and product experience.

Introduction:

Brief about the project: "Soundscapes in ICU: Exploring Real-Time Audio Analysis."

Purpose of the interview: Gathering expert insights on sensory perception and user experience in the healthcare context.

Questions:

Sensory Perception in Healthcare:

How do you see the role of soundscapes in influencing the sensory perception of healthcare workers, particularly in an ICU setting?

Can you elaborate on how audio attributes can be more effectively understood and managed in such environments?

Real-Time Audio Analysis:

From your perspective, what are the potential benefits and challenges of real-time audio analysis in an ICU context?

How might real-time analysis impact the daily work of nurses and doctors?

User Experience and Interface Design:

Considering your expertise in product experience, how would you evaluate our current UI prototype in terms of usability and sensory integration?

What would be your suggestions to enhance user interaction with our tool, keeping in mind the intense and demanding environment of an ICU?

Ethical Considerations and Privacy:

What are your thoughts on the ethical considerations, particularly regarding privacy, in capturing and analyzing sound in a medical environment?

Future Directions:

Based on your insights, what future developments would you suggest for this project, from both a sensory perception and user experience standpoint?

Interview Guide for Dr. Jack Bourgeois

Associate Professor, focusing on Design and Innovation.

Introduction:

Brief about the project: "Soundscapes in ICU: Exploring Real-Time Audio Analysis."

Purpose of the interview: To gather expert insights on design innovation, technology integration, and their applications in healthcare.

Questions:

Design Innovation in Healthcare:

How do you perceive the application of design innovation, particularly in healthcare settings like ICU?

How can soundscapes contribute to a more innovative approach to patient care?

Technology Integration:

Given your expertise in technology and innovation, what are your thoughts on integrating real-time audio analysis into existing healthcare workflows?

What challenges do you foresee in deploying such technologies in a complex environment like ICU?

Interdisciplinary Collaboration:

How essential do you think interdisciplinary collaboration is, especially when designing a technologically-driven project for healthcare?

What roles should various stakeholders play in the development and implementation of this project?

Assessment and Metrics:

How should we approach evaluating the effectiveness of the real-time audio analysis tool in the context of ICU?

What metrics would you recommend for assessing success and areas for improvement?

Future Possibilities:

Based on your insights into design and innovation, what future directions do you envision for our project?

How can we ensure that our project remains aligned with technological advancements and healthcare needs in the future?

Evaluation questions - Nurses

Before Using the Product (Current Working Situation):

1. Awareness:

On a scale of 1-5, how aware are you of the sound environment in NICU/PICU? (1 = Not aware, 5 = Extremely aware)

2. Decision Making:

On a scale of 1-5, how confident are you in your decision-making processes regarding noise analysis in NICU/PICU? (1 = Not confident, 5 = Very confident)

3. Communication:

On a scale of 1-5, how effective is your current communication with stakeholders about sound issues in NICU/PICU? (1 = Not effective, 5 = Very effective)

4. User-Centric Design:

On a scale of 1-5, how user-friendly are your current tools for NICU/PICU healthcare? (1 = Not user-friendly, 5 = Extremely user-friendly)

5. Advanced Noise Analysis and Event-Detection:

On a scale of 1-5, how effective are your current noise analysis and event-detection methods in NICU/PICU? (1 = Not effective, 5 = Very effective)

6. Workflow Consideration:

On a scale of 1-5, how well do your current tools align with your workflow in NICU/PICU? (1 = Not aligned, 5 = Perfectly aligned)

7. Data Privacy and Security:

On a scale of 1-5, how confident are you in the current data privacy and security measures in NICU/PICU? (1 = Not confident, 5 = Very confident)

8. Feasibility, Simplicity, and Aesthetics:

On a scale of 1-5, how feasible and visually pleasing are your current tools within the NICU/PICU environment? (1 = Not feasible/pleasing, 5 = Extremely feasible/pleasing)

9. Maintenance, Updates, and Scalability:

On a scale of 1-5, how easy is it to update and scale your current tools in NICU/PICU? (1 = Not easy, 5 = Very easy)

10. Balancing Functionality and Simplicity, Resource Constraints, and Scalability:

On a scale of 1-5, how well do your current tools balance functionality, simplicity, and scalability in NICU/PICU? (1 = Not well, 5 = Very well)

After Using the Product:

1. Awareness:

On a scale of 1-5, how has this product increased your awareness of the sound environment in NICU/PICU? (1 = No increase, 5 = Significant increase)

2. Decision Making:

On a scale of 1-5, how has the product influenced your decision-making processes regarding noise analysis in NICU/PICU? (1 = No influence, 5 = Significant influence)

3. Communication:

On a scale of 1-5, how has the product improved communication with stakeholders about sound issues in NICU/PICU? (1 = No improvement, 5 = Significant improvement)

4. User-Centric Design:

On a scale of 1-5, how user-friendly do you find the product for NICU/PICU healthcare? (1 = Not user-friendly, 5 = Extremely user-friendly)

5. Advanced Noise Analysis and Event-Detection:

On a scale of 1-5, how effective are the product's noise analysis and event-detection capabilities in NICU/PICU? (1 = Not effective, 5 = Very effective)

6. Workflow Consideration:

On a scale of 1-5, how well does the product align with your workflow in NICU/PICU? (1 = Not aligned, 5 = Perfectly aligned)

7. Data Privacy and Security:

On a scale of 1-5, how confident are you in the product's data privacy and security measures? (1 = Not confident, 5 = Very confident)

8. Feasibility, Simplicity, and Aesthetics:

On a scale of 1-5, how feasible and visually pleasing do you find the product within the NICU/PICU environment? (1 = Not feasible/pleasing, 5 = Extremely feasible/pleasing)

9. Maintenance, Updates, and Scalability:

On a scale of 1-5, how easy is it to update and scale the product in NICU/PICU? (1 = Not easy, 5 = Very easy)

10. Balancing Functionality and Simplicity, Resource Constraints, and Scalability:

On a scale of 1-5, how well does the product balance functionality, simplicity, and scalability in NICU/PICU? (1 = Not well, 5 = Very well)