Darkening glasses through infrared

Bsc Thesis by

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TU Delft

Cover image: Light emitting glasses (https://www.onespan.com/blog/how-achieve-your-digital-insurance-vision-transformative-technology)

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by

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to obtain the degree of Bachelor of Science

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Abstract

Practicing fire scenarios in emergency response training is very hard due to various obstacles. An example is when holding a training, real fire will preferably not be used as it can become threatening. Real fire will only be used in a surrounding where safety is ensured, which is probably outdoors. An emergency responder hardly knows that it has entered an area or room with imaginary fire nor does he know the extent of the fire due to the absence of smoke. This makes it exceedingly difficult to make right decisions during the training on the spot and this might lead to failure to help employees or clients to escape the fire area or building.
This project focuses on developing glasses that can darken the view of the user, when entering an area with simulated fire and smoke. In order for the emergency responder to be able to practice in the most real possible scenario. The gain of using the glasses, is that it provides a common understanding between the instructor and trainee about the smoke situation in a training exercise. This enhances the quality of training, decreasing the possibility of making an incorrect decision when a real fire breaks out. This is done by constructing a set of darkening glasses that can darken the view, on the command of an infrared beacon that mimic the source of smoke in an area.

Preface

This thesis is written in the context of the Bachelor Graduation Project. The project was proposed by Ing. J. Bastemeijer and Ing. R. Koornneef. We created a protoype glasses that can obscure the vision by darkening a Liquid Crystal Light Valve as soon as the emergency responder enters a room, that corresponds to a room with a fire or smoke.

We would like to express our gratitude to Ing. J. Bastemeijer and Ing. R. Koornneef for their supervision and support during the project.

Ryan Cui & Lennert van Herk,
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1 Introduction

Since 1994, emergency response is obliged for employers with employees in the Netherlands. In small businesses, an employer can be the emergency response officer (ERO) himself. Emergency response officers are people who are trained to be the first to act in an emergency situation and to help employees or clients to get in safety when an emergency is occurring. The tasks consist of providing first aid in case of accidents, but also alarming and evacuating employees in case of emergencies. To become an emergency responder, a certificate has to obtained through a training. Furthermore, the emergency responder has to return annually to show that he still possesses the skill of an emergency responder and has the knowledge in how to act during emergencies in order to renew the certificate [1].
One of the challenges that emergency responders encounter during an emergency is communication. A problem frequently cited by responders is the lack of radio interoperability. Responding organizations must work together to form a cohesive plan in case of emergency to formulate the best possible response [2].

Fire emergency

In case of a fire emergency, the main cause of death is the smoke that fire generates [3]. Smoke is spreading more rapidly compared to fire [4]. The second most important factor of death during a fire outbreak is the heat of the fire. When there is a fire outbreak, the temperature can rise up to 1000 °C, as comparison, the human body starts failing to function properly from temperature around 65 °C. Furthermore, heat is hot air and always rises up, so when the temperature is getting immensely high, it can cause roof constructions to collapse more easily, which contributes to even more dangerous scenarios.

Many parameters exist that can be used to describe smoke properties, for example: temperature, mass density of products, obscuration density, transmittance, toxic and flammable gas concentrations, etc. Among these numerous variables, one of the most important for this project is the visibility in smoke [5]. Visibility is here defined as the distance that an observer can identify an object relative to the background, and obscuration is the amount that light intensity is reduced as it passes through smoke [6].
Fire smoke is the most important factor of death mostly because of 2 characteristics, carbon monoxide and density of the smoke. Furthermore, smoke can also decrease the speed of walking, which implies to a more slow escape [7].
Carbon monoxide is a product of incomplete combustion of carbonaceous substances with insufficient supply of oxygen. When inhaling carbon monoxide, it will attach to hemoglobin that prevents your blood from transporting oxygen, and when inhaling exorbitant amount of carbon monoxide will cause unconsciousness and eventually leads to suffocation.
Density of the smoke will cause the visibility to decrease, which in turn will lead to more panic and less escape options. When smoke becomes dense, the visibility of any emergency light drops and no distinguished effect of luminance flux on visibility can be seen [8]. The best option is to avoid getting in the smoke. If that is not possible, it is the best to stay as low as possible to the ground to inhale less carbon monoxide and to get the most sight [9].

Problem description

In the current state, there is no such a thing that can make the practice of fire situations during an emergency response training realistic. Fire can not be made indoors safely as that can lead to dangerous scenarios. Real fire will only be used in a surrounding where safety is ensured, which is most probable outdoors. Smoke can not be produced as that will make smoke detectors go off and even when turned off, smoke could spread to other rooms or spaces, which is inconvenient and causes damage. Practicing in this aspect is extremely difficult.
In this project we are developing prototype glasses that can obscure the vision by darkening a Liquid Crystal Light Valve (LCLV) as soon as the emergency responder enters a room, that corresponds to a room with a fire or smoke. This is done through a sensor being mounted and configured on the darkening glasses in a way that it darkens based on the received signal, that corresponds to a specific intensity. A beacon will be built using Light Emitting Diodes (LEDs) and tested. This will assist the emergency response training to become more realistic and better prepared for a real fire outbreak.

Thesis Outline

This thesis is structured as follows: Chapter 2 will describe the program of requirements. Chapter 3 will provide some possible solution and the chosen solution. Chapter 4 will provide the system overview and discuss the choices. Chapter 5 will provide the implementation of the beacon. Chapter 6 will show the implementation of the receiver and the translucency of the glasses. Chapter 7 will show the test setup and the test results. Chapter 8 provides an overview of the materials, that are used for the prototype. In chapter 9 conclusions are drawn and recommendations for future work are given. In Appendix A the code for the modulation of the transmitter in Arduino can be found. In Appendix B the code for programming the receiver in Arduino can be found. In Appendix C the code for the programming of the Small Liquid Crystal Light Valve in Arduino can be found.

2

Program of Requirements

The product should be complying with the requirements below. These are divided into general requirements, requirements for the communication and for the glasses with the sensor and microcontroller.

General requirements

- The Glasses must cost less than €25.
- The Beacon must cost less than €75.
- The product must be easy to use and setup.
- The product must be able to function in a room with maximum dimensions of 10m by 10m.
- The product must be able to function during a fire emergency training for a duration of 3 hours.
- The beacon must operate through (rechargeable) batteries, that are able to fit underneath a small tub.
- The beacon must be portable without effort and small, e.g. be able to lift it with 1 hand or fit on a hand.

Communication requirements

- The communication must be confined in a room, which means it should not be able to pass through opaque barriers.
- The communication must be suited for short-range indoor.
- The communication must not be disturbed by surroundings in a room.
- The smoke is considered uniform in a space of 10m by 10m, this implies that the intensity is indistinguishable whether you're closer to or further away from the source.

Glasses requirements

- The glasses must operate through small (rechargeable) batteries, that can fit on glasses worn like traditional glasses.
- The glasses must only turn on/operate in the Line of Sight of the transmitter.
- The glasses must be transparent when its turned off or not receiving a signal to turn dark.
- The glasses must be darkened when receiving the signal to turn dark.
- The glasses must not darken when no signal is received or the received signals originated from non-system sources.
- The glasses should (preferably) have different visibility levels.

3

Potential solutions

There are numerous potential solutions to make practicing emergency reponse training more realistic. The following provides a selection of examples.

Virtual reality glasses

Virtual Reality glasses (VR glasses) are wearable devices that provide users with an immersive virtual reality experience. They consist of a display screen or screens and sensors that track the user's head movements to create a 3D virtual environment that appears to surround the user. When wearing VR glasses, the user's vision is completely or partially obstructed from the real world, and they are visually transported to a computer-generated virtual environment. The display screens inside the glasses present images or videos that give the user a sense of depth, allowing them to perceive and interact with the virtual environment as if they were physically present within it. To enhance the immersive experience, VR glasses often include additional features such as built-in speakers or headphones to provide spatial audio, as well as input controls like buttons or touchpads for interacting with the virtual world.
Using VR glasses, different kind of scenarios can be made such that the emergency responder can experience and practice the emergency as realistic as possible.

Augmented reality

Augmented reality (AR) is a technology that combines virtual elements with the real world, enhancing the user's perception and interaction with their environment. AR technology uses the device's camera and sensors to detect and track the user's surroundings. It then superimposes virtual content onto the real-world view displayed on the device's screen or through a dedicated headset. AR enables users to interact with the virtual objects and/or information overlaid on the real world, but unlike virtual reality, which immerses users in a completely simulated environment, AR maintains a connection to the real world, enhancing it with virtual elements.

Wireless earbuds

Wireless earbuds are compact audio devices that allow users to listen to audio content without the need for wired connections. They are designed to fit directly into the ears and connect wirelessly to audio sources such as smartphones, tablets or computers using Bluetooth technology.
The wireless earbuds could be used to receive an audio signal, when the user has entered a room with fire or smoke. This is attainable as the typical range of Bluetooth is approximately 10m. If one wishes to enhance the range, more devices can be placed or Bluetooth devices of Class 1 can be used, which can reach up to 100m [10].

Darkening glasses

Darkening glasses are also known as tinted or sunglasses with a photochromic lens. It works through a process called photochromism. Photochromic lenses contain special compounds that undergo a chemical reaction when exposed to ultraviolet (UV) radiation from sunlight. This reaction causes the lenses to darken, providing protection against bright light and glare. Therefore, darkening glasses are able to adjust their opacity based on the received UV light.
However, to be able to use it for emergency response training, it has to be modified. The glasses should not darken based on UV light originated from the sun, but based on some type of communication.

Chosen solution

Considering the examples given above. The decision has been made to realise the latter example. The motive behind this is due to 2 factors:

1. Price.
2. Realistic experience.

The VR glasses satisfy factor 2, as it provides the most desirable outcome. However, VR glasses are relatively expensive and purchasing 1 VR glasses can cost up to several hundred euros [11]. Furthermore, it is cumbersome to setup such a system. For every different surrounding, the VR glasses needs to be programmed repeatedly.
Augmented reality technology are even more expensive to use, it can cost from a few hundred to few thousands euros.
The earbuds are less expensive ranging from €20 to around €200. However, the earbuds are less hygienic and do not provide too much realistic experience due to smoke being something visual.
On the other hand, the darkening glasses, provides a more realistic experience and can be purchased and modified relatively inexpensive compared to the VR glasses. Hence, The choice has been made to continue with the darkening glasses.

4 System overview

The system has been divided into 2 different parts, the beacon and the receiver part with the glasses. In order for the system to work, two important choices need to be made. The communication method choice and the choice for the glasses.

4.1. Communication method choice

In order for the glasses to obscure the vision by darkening the glass on a Liquid Crystal Light Valve (LCLV) when entering a room, that corresponds to a room with fire. Some type of communication is required with a transmitter and receiver. A liquid crystal light valve is an optical device that controls the transmission of light using liquid crystals. It consists of a layer of liquid crystal material in between transparent electrodes and two polarizing filters. The liquid crystal material has the ability to change its molecular alignment and modify the polarization of light passing through it. The types of communication, in which a choice will be made are listed below:

4.1.1. Infrared radiation

Infrared radiation (IR), also known as thermal radiation, is that band in the electromagnetic radiation spectrum with wavelengths above red visible light between 780 nm and 1 mm. Infrared radiation is one of the most common wireless technologies used to localize objects or people with the help of infrared emitters, which is emitted by Infrared Light Emitting Diodes (IR LEDs), and receivers. IR radiation does not penetrate through walls, which confines the radiation inside the room. Moreover, IR technology is characterized by the absence of radio electromagnetic interference and the power of transmitted IR signal can be easily adjusted to cover only the area of interest. Nevertheless, there are also several drawbacks. For instance, IR technology requires a Line of Sight (LoS) between transmitter and receiver to function properly, so no opaque barriers [12].

4.1.2. Radio-frequency

Radio waves have a frequencies ranging from 300 GHz to as low as 3 Hz, which corresponds to wavelengths ranging from 1 millimeter to 100 kilometers. High frequencies like microwaves ranging from 300 MHz to 300 GHz have line of sight limitations in the radio spectrum. Radio frequencies in lower ranges with higher wavelengths, do not have a line of sight limitation. They can easily overcome obstacles in their path and reach their destination due to the large wavelength of the signals.

4.1.3. Ultrasonic sound

Ultrasonic sound is referred to as sound that consists of a frequency higher than 20 kHz up to several MHz. The ultrasonic sensor uses time of flight (TOF) method for distance measurement, which refers to the time taken for a pulse to travel from the transmitter to an observed object and back to the receiver. The signal attenuation is proportional to the distance and depends on the propagation medium. As a result of this, ultrasonic waves are suitable for short-range communication. All ultrasonic transducers are of finite diameter. This implies that the sound energy will be lost as a result of beam expansion. Spreading loss occurs because the total amount of energy in a wave remains the same as it spreads out from a source, so the larger the wave spread, the more energy is needed to fill it. Therefore, the further the distances, the smaller the energy [13].

4.1.4. Magnetic field

Magnetic field can also be used for wireless communication. The concept is that a transmitter coil modulates a magnetic field, which is received and measured by the receiver coil. For the transmission, the transmitting coil generates the magnetic field that carries the information to be transmitted. This information can be encoded in various ways, such as modulating the amplitude, frequency, or phase of the magnetic field. Changes in the electrical current through the transmitting coil cause corresponding changes in the magnetic field.
For the reception, the receiving coil is located within the range of the magnetic field and picks up the magnetic field fluctuations caused by the transmitting coil. The receiving coil is designed to detect and convert these magnetic field changes into an electrical signal. This signal can then be decoded to retrieve the original information sent by the transmitting coil.

4.1.5. Decision

As a technique for short-range, indoor communication, infrared radiation offers several significant advantages over radio-frequency. Infrared emitters and detectors capable of high speed operation are available at low cost. The infrared spectral region offers a virtually unlimited bandwidth that is unregulated worldwide. Infrared and visible light are close together in wavelength, and they exhibit qualitatively similar behavior. Both are absorbed by dark objects, diffusely reflected by light-colored objects and directionally reflected from shiny surfaces. Both types of light passes through glass, even though it attenuates, but it does not pass through walls or other opaque barriers. This ensures that infrared transmissions are confined to the room in which they are transmitted. This signal confinement prevents interference between links operating in different rooms [14].
Ultrasonic sound could be an option as well, but infrared is chosen over ultrasonic sound as infrared has a lower power consumption [15], which could be an important factor as it has to last the whole emergency response training. Furthermore, ultrasonic sound attenuates way more than light, which also requires more power in order to propagate longer distances. Sound is also more sensitive to humidity and temperature in the air [16]. Ultrasonic sound and infrared could also be combined, which could be an option for future work.
Furthermore, Magnetic field will also not be considered in this application as the matter of fact that the magnetic field would be interfered by magnetic objects or equipment, which could influence the communication between the transmitter and receiver.
Hence, based on the program of requirements, the predilection goes to infrared radiation. Infrared is suited for short-range indoor, the communication is confined inside opaque barriers, it has a low power usage and are in general less complex, hence infrared will be used.

4.2. Receiver

The TSOP4865 IR receiver is chosen as IR receiver, for the reason that it has a bandpass filter and amplifier, which is able to filter out the interference from the sun, since the sun has DC characteristics.

4.3. Glasses choice

The glasses that are chosen are the welding glasses [17], that are modified with Small LCLV [18]. The glasses could possibly be a normal glasses frame instead of the welding glasses. The opaqueness of the LCLV can be controlled by varying the voltage over the glass. Starting at about 1.0V the glass will start darkening up till the maximum voltage of 5V. At about 4.0V the glass will be opaque. 5.0V is the maximum recommended voltage, with dark shades in between, where almost no current is used.

5

Beacon implementation

5.1. Design of the IR beacon with LEDs

The glasses will base their darkness on the received signal. In order for the IR light to reach the whole room, there has been chosen for a semi-sphere. This is also used for testing as a prototype. The IR LEDs will be wired to the middle of the beacon to a tub underneath the quarter sphere where the battery and microcontroller and other components will be located. A sketch of the beacon can be seen in the figure below:

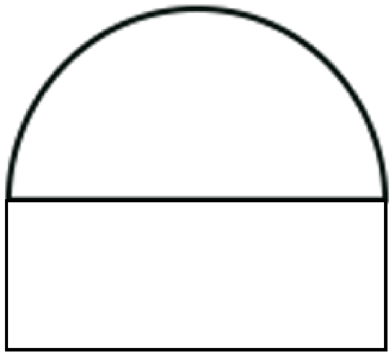

Figure 5.1: The side view of the beacon.

The chosen IR LEDs are standard IR LED with a 5mm lens diameter, QED223 [19]. There are also IR LEDs with a higher radiant intensity, but IR radiation from the LEDS are able to reflect on walls and other opaque barriers, which increase the range of radiation. Hence higher radiant intensity are disregarded for now and lower radiant intensity is first tested to conclude if higher radiant intensity would suit better.
The beacon is required to be small and portable referring back to the program of requirements, the semi-sphere is chosen to have a diameter of 0.08m, so that is able to fit on one or two hands and portable without effort. The tub has a height of 0.04m to provide adequate room. Moreover, the hole is chosen to have a radius of 0.015m for the wires to pass through This can be seen in the figure 5.2, with the orange dots representing the positions of the IR LEDs.
The number of IR LEDS that are chosen is 5. 1 LED at every 90° on the bottom facing outwards and 1 LED facing up to make the coverage of the IR light as big as possible.
Furthermore, the wires for the circuit can be considered negligible in resistance. This can be seen from

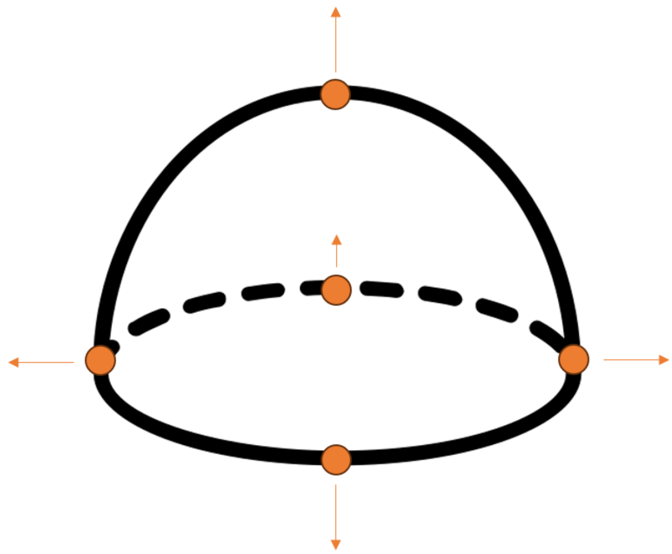

Figure 5.2: The positioning of the IR LEDs.

the electrical resistance equation, where R is the resistance, ρ is the resistivity, l the length and A the intersection of a wire:

$$R = \frac{\rho \cdot l}{A} \tag{5.1}$$

The ρ of the most common used wire, copper, is $1.68 \cdot 10^{-8}\Omega m$, while the length in this application is less than 0.5m and the intersection of the wire is relatively small, around the mm order, leads to a relatively small resistance, in the order of micro Ω, compared to the resistance in the circuit. Moreover, wire inductance will not play a role here. The inductance is negligible, when a DC voltage is applied.

The first prototype will be built using cardboard with the IR LEDs just sticking in the cardboard and pointing it in the correct degrees.

5.2. Transmitter Circuit

The beacon is required to operate stand alone, since seeking for outlets everywhere is not handy. The decision has been made to go for standard AA-batteries that can supply 1.5V and has a capacity range of 2600 - 2900mAh. The reason for this is that it is very easy accessible and is widely applicable. The microcontroller has an operating voltage range between 2.7 and 5.5V, this implies that for a battery holder, 3 AA-batteries are being used on the condition that the capacity of the 3 batteries are sufficient to operate for 3 hours. The transmitter circuit of the beacon is shown below: The circuit consists of 3 AA batteries of each 1.5V, 3 on/off switches, a microcontroller, a boost converter, 2 current limiting resistors, a NPN transistor and 5 IR LEDs.
In the circuit are 3 switches. Switch 1 is the switch turning the beacon on and off, switches 2 and 3 are the ones controlling which Pulse Width Modulation signal is sent, which corresponds to the intensity of the smoke. Two resistors are connected to switch 2 and 3, R_3 and R_4 respectively to act as pull-down resistors. The pull-down resistors are typically large in value to help maintaining a stable and defined logic low state, preventing it from floating or picking up unwanted electrical noise. Therefore, the resistors R_3 and R_4 are chosen to be $47k\Omega$.
Moreover, 5 IR LEDs are used in the circuit, which are connected in series to keep the current as low as possible and not the voltage for several reasons [20].

- Lower current corresponds to higher safety.
- Lower current generally leads to reduced power consumption.

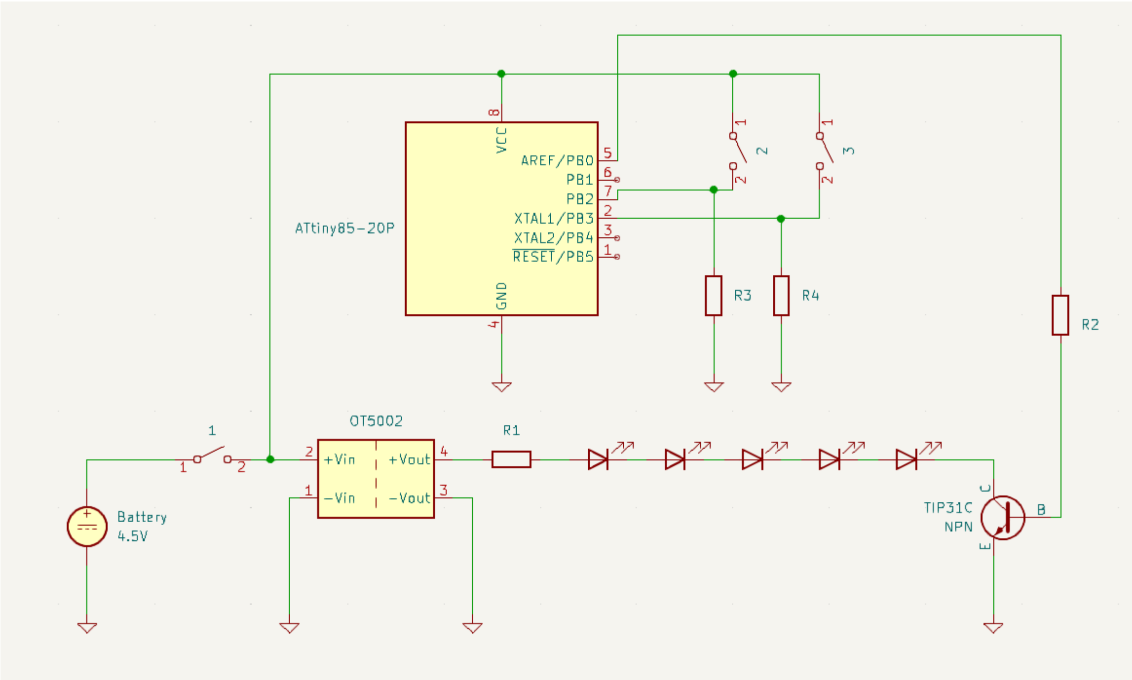

Figure 5.3: The transmitter circuit.

- High current generates more heat, so minimizing the current can prevent overheating and improve the reliability of the system.

Additionally, keeping the current constant and varying the voltage can be handy when deciding to add more LEDs. The only component that need to be adjusted in that case is the boost converter.

In order to modulate the signal being sent, the ATtiny85 microcontroller [21] will be used. The code is written in Arduino IDE and uploaded using Arduino Uno. The reason for using a microcontroller is due to the characteristic that it can execute program instructions stored in their memory, perform calculations, handle input and output operations, and communicate with other devices. They are programmable and can be customized to perform specific tasks. This might be useful for further improvements. The required output voltage of the boost converter can be calculated by multiplying the forward voltage of the IR LED, found in the datasheet, by 5, which is 1.7V * 5 = 8.5V. The V_{CE}, voltage over the collector and emitter, which is also the voltage over the transistor, is 0.2V. This voltage corresponds to a current of 100mA found in the datasheet. Furthermore, a resistor is required to limit the current of not exceeding the maximum continuous forward current, so the voltage drop over resistor R_1 is chosen to be 1V to minimize the power consumption, but yet able to limit the maximum current. Hence the total voltage is 9.7V and the continuous forward current of the IR LEDs is 100mA. The input voltage is $3 * 1.5 = 4.5$ V. Therefore, a boost converter, MT3608 [22][23], is required to step up the voltage from 4.5V to 9.7V. This boost converter has a maximum conversion efficiency of 96%. Following from the Efficiency vs Output current curve found from the datasheet is approximately 90%, the boost converter has an approximate conversion efficiency of 90%. This implies that the current is down-stepped. This can be calculated with the equation of electrical power, where "in" denotes the power entering the DC/DC converter and "out" denotes the power leaving the DC/DC converter:

$$P_{in} = 0.9 \cdot U_{in} \cdot I_{in} = P_{out} = U_{out} \cdot I_{out} \tag{5.2}$$

This can be rewritten into I_{in}, to determine the current entering the converter:

$$I_{in} = \frac{U_{out} \cdot I_{out}}{0.9 \cdot U_{in}} = \frac{9.7 \cdot 0.1}{4.05} \approx 0.24A \tag{5.3}$$

From the datasheet of the ATtiny85 microcontroller, it can be seen that the microcontroller draws a current of 5mA when the supply voltage is around 5V. Since the microcontroller is parallel connected

to the DC/DC converter, the input voltage of the microcontroller and DC/DC controller are equivalent, but the currents are summed up. The output voltage of the batteries is 4.5V and the output current is $240 + 5 = 245$ mA.
Since the typical capacity of 1 battery is 2600mAh and the batteries are connected in series, the capacity remains 2600mAh. The number of hours can be calculated using

$$E = P \cdot t = U \cdot I \cdot t = U \cdot C \tag{5.4}$$

this can be rewritten into time, shown in Equation 5.5. With P being the power of the load. The power of the transistor is voltage times current, which is 0.2V*0.1A=0.02W, the power of the 5 LEDs is 5*1.7V*0.1A=0.85W, the power of the resistor is 1V*0.1A=0.1W and the power of the microcontroller is 4.5V*0.005=0.0225W. This adds up to a power of 0.97W.

$$t = \frac{U \cdot C}{P} = \frac{4.5V \cdot 2.6Ah}{0.9925W} \approx 11h \tag{5.5}$$

The U represents the output voltage of the batteries, the C represents the capacity of the batteries and the P the power of the load.

Even though 11h implies an ideal number of working hours, it exceeds the number of hours required for an emergency response training, which is approximately 3. The battery stops working, if the voltage drops to approximately 0.9V [24]. This indicates that the number of batteries suffice chapter 2.

So to limit the current exceeding the maximum continuous forward current, 100 mA, of the LEDs, a current limiting resistor, R_1, is placed. The value can be calculated using the voltage drop of 1V over the resistor and Ohm's law:

$$R_1 = \frac{U}{I} = \frac{1V}{0.1A} = 10\Omega \tag{5.6}$$

If the temperature of the IR LEDs increase, it can be seen from the datasheet that the forward voltage decreases and if the forward voltage decreases, the forward current decreases as well. So the current will certainly stay below 100mA.
The circuit also containts a transistor, the TIP31C NPN BJT [25]. The purpose of the transistor is to drive the IR LEDs in order to transmit the sequence. The current running from the pin-out of the ATtiny85 needs to drive the base of the transistor. The required base current for the transistor can be calculated. First, the base current can be calculated using the current gain β in the datasheet of the TIP31C. The collector current is 100mA with a temperature of 25°C and V_{CE} of 2V corresponds to a current gain of approximately 150. The base current that is required can be calculated using the equation:

$$I_B = \frac{I_C}{\beta} = \frac{100mA}{150} = 0.67mA \tag{5.7}$$

The microcontroller has an output voltage of 4.3V and maximum DC current rating is 40mA. Hence, the current limiting resistor, R_2, is placed in between the pinout and I_B to limit the current exceeding 0.67mA.
The value of R_2 can be calculated using Ohm's law:

$$R_2 = \frac{U}{I} = \frac{4.3V}{0.00067A} = 6418\Omega \tag{5.8}$$

5.3. Transmitter signal modulation

The Infrared receiver expects a carrier frequency of 56 KHz according to the datasheet [26]. It also expects a maximum duty cycle of the envelope over the carrier signal, as given in figure 8 of the datasheet. Furthermore it has to send at least 10 carrier frequency cycles per burst.

The behavior of the TSOP4856 IR receiver encourages Pulse Width Modulation (PWM) since the minimal burst length is ten carrier cycles, but a microcontroller could differentiate bits at a higher resolution then one bit per ten carrier cycles. So after the first ten cycles each cycle holds more information as compared to On-Off keying, where each bit needs at least 10 bits and the controller needs to be careful to not send too many bits corresponding with a high on the envelope since after a while the TSOP4856 will stop acknowledging those bits.

Signal ID	Number of carrier cycles	Duty cycle
3	75	69%
2	53	49%
1	32	30%
0	10	9.3%

Table 5.1: Duty cycles of number of carrier cycles.

Therefore the signal will employ PWM to send the smoke density data, where a longer pulse will mean more smoke and a shorter pulse will mean less smoke. To be able to distinguish between smoke levels easier and have more levels of smoke, higher resolutions in the PWM signal level are desired. To achieve this, the pulse width should vary as wide as possible. For the TSOP4856 this means having a maximum burst length of 75 cycles which must be the maximum duty cycle of 70% (Fig. 8)[26]. Resulting in the minimum PWM period being 75 cycles/0.7 = 107.14 cycles long. So then with the shortest PWM period of 108 cycles, a minimal burst of 10 cycles will be a duty cycle of 9.3%. Further implemented cycle numbers are found in table 5.1.

To implement this carrier frequency and PWM envelope a counter/timer from the ATtiny85, Timer1, will be used to create the 56KHz square wave[21]. The microcontroller clock will run at 8MHz. In order to convert this to 56KHz, Timer1 is set to "clear timer on compare match" mode. This means that, when the TCNT1 register reaches the OCR1C register, TCNT1 is reset to zero. TCNT1 is the register which stores the timer value and OCR1C stores the final value for the timer. Since $8MHz/56KHz = 142,8$ to get the 56KHz carrier frequency TCNT1 will take 143 steps, without a prescaler applied to the clock. So OCR1C should be set to 142.

The PWM1A and PWM1B bit are set, so that the OCR1A and OCR1B registers can be used as interrupts on compare match with TCNT1. OCR1B is used to trigger an interrupt which puts the carrier signal high again at the end of the carrier period. It also sets the output pin to the result of an AND operation between the now high carrier signal and the PWM envelope, elaborated on later, so that the transmitted signal is formed. It is also set to 142 similar to OCR1C. This carrier signal can be seen in figure 5.4 as part of the signal ID being send.

The OCR1A register is used to trigger an interrupt which puts the carrier signal low and clears the output pin. This interrupt also forms the PWM envelope. It does this by tracking how many carrier cycles it has sent and comparing that number to a value below, which the PWM envelope is set high and above which the PWM envelope is set low. When the number of past cycles reaches the amount of cycles in the period of the PWM envelope, the tracked number is set to zero.
This PWM envelope can easily be seen in figure 5.5, where signal ID 1 is being send. The carrier frequency is a lot faster and looks like a solid block on the oscilloscope.

To determine which duty cycle the envelope should have, two buttons are read to select one of four smoke levels. When both buttons are unpressed the duty cycle is set to the minimal amount of carrier cycles, when both buttons are pressed the duty cycle is set to the maximum amount of carrier cycle. The other button combinations correspond to amounts of carrier cycles in between these values. In a final product this would be replaced with a turning selector switch with more options and a resistor ladder to limit the ports required for selecting the smoke level.

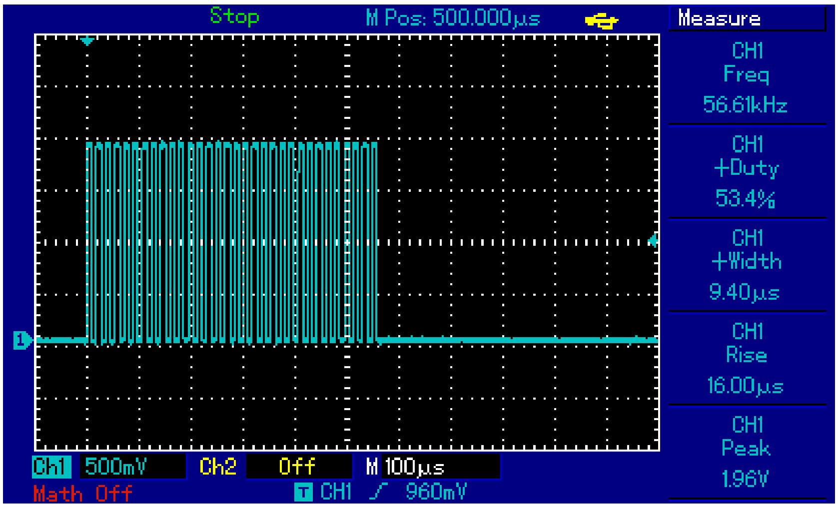

Figure 5.4: Carrier signal for IR LEDs.

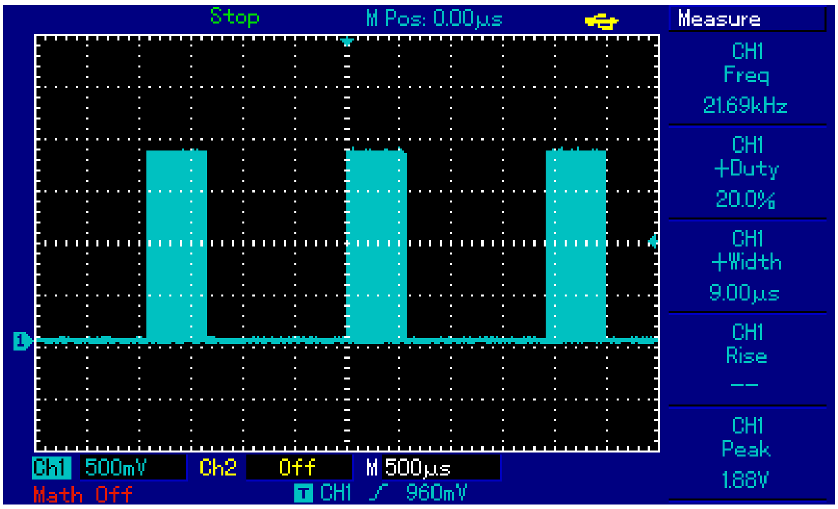

Figure 5.5: PWM envelope signal for IR LEDs.

6

IR controlled glasses with variable opacity

6.1. Glasses overview

The electronics of the glasses have 3 main parts. The energy supply, the IR receiver and the liquid crystal light valve (LCLV) control. The requirements relating to the energy supply of the glasses are that it needs to fit on traditional style glasses and last at least 3 hours. Two CR2032 batteries in series will provide $6V$ and have a reported capacity of approximately $220mAh$. Following equation 6.1 a maximum power budget of $440mW$ is derived.

$$P_{max} = \frac{6V \cdot 220mAh}{3hours} = 440mW \tag{6.1}$$

The IR Receiver is based on the TSOP4865. The output of this component is connected to an ATtiny85 where the received signal will be decoded to obtain the smoke level of the room.
The LCLV will be controlled with another ATtiny85, this microcontroller will control both pins of the LCLV to apply an AC signal across the LCLV. One pin will be a square wave of 100Hz and the other will be the result of a XOR operation on the square wave and a PWM signal the duty cycle of which controls the opacity of the signal.
When this circuit is fully assembled and running, it draws a current of $16mA$ when connected to a bench power supply set at $5V$. This gives it a power consumption of $80mW$, which in well within the aforementioned power budget.

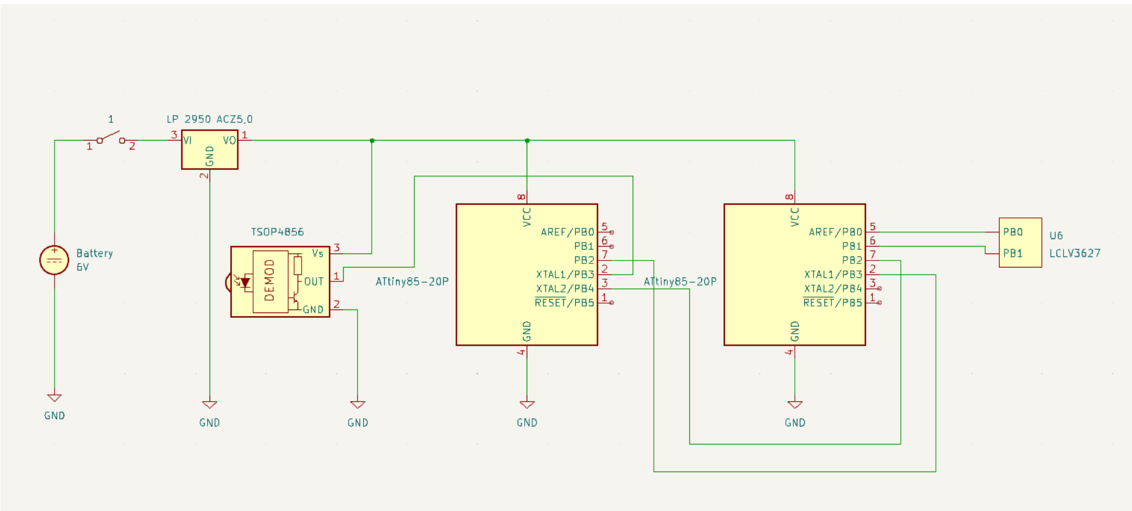

Figure 6.1: Electronics of the glasses

6.2. Signal demodulation

The TSOP4865 IR receiver together with an ATtiny85 is used to receive and demodulate the incoming signal. The incoming signal from the beacon is a PWM signal with, for now, four different duty cycles corresponding to four different smoke levels. When a signal is received by the TSOP4856, it is amplified by an automatic gain controller, losing the intensity data from the signal. The receiver filters out signals that are not close to the 56KHz required carrier frequency, with its internal bandpass filter. The receiver also has a decoder which removes the 56KHz carrier frequency putting only the digital output on the output pin. The output of the TSOP4856 is inverted, so when there is an incoming signal the output voltage is low and when there is no signal the output signal is high.
The period of the output PWM signal from the receiver can be calculated with equation 6.2. In section 5.3 the number of cycles was calculated to be 108, resulting in a period of 1.93ms.

$$T_{PWM} = \frac{N_{cycles}}{f_{carrier}} \tag{6.2}$$

With the same equation the pulse width, which ranges from 10 to 75 cycles, can be calculated to be 0.18ms to 1.34ms. Referring to the low part of the signal due to the inverting nature of the receiver. Different periods of used numbers of cycles can be found in table 6.1

Signal ID	Number of carrier cycles	Period T_N [ms]	TCNT1 value
3	75	1.34	167
2	53	0.95	118
1	32	0.57	70
0	10	0.18	22

Table 6.1: Periods of number of carrier cycles.

To determine the width of the received pulse, a timer is started when the input pin connected to the receiver sees a falling edge. When the signal rises again, the passed time, T_{Passed}, is read. From this T_{Passed} the level of smoke is determined. It does this by comparing T_{Passed} to a period in between two adjacent pulse lengths of the possible duty cycles. For example when checking if signal 3 was sent, T_{Passed} is checked to be larger then $(T_3 + T_2)/2$, as seen in figure 6.2. So in other words when T_{Passed} is closer to T_3 then T_2 it is seen as T_3. When the correct signal has been found, the microcontroller will give the signal ID to the next microcontroller over a two bit bus. It will also store the last received ID for a 100 timer cycles, in case the signal is temporarily lost. It will also clear the glasses if the beacon is turned off or out of range.

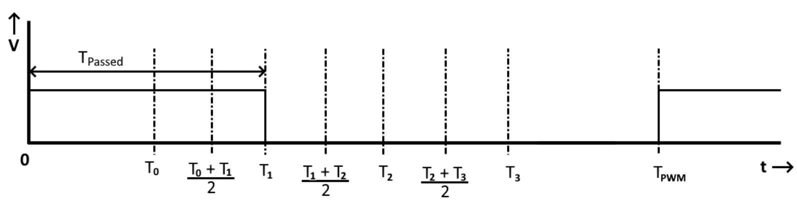

Figure 6.2: Received PWM period with time stamps.

To be able to track the time of the pulse width a prescaler needs to be applied on the clock. The precise prescaler can determined using equation 6.3 and taking the next higher available prescaler. For Timer1 in the ATtiny85 the next available prescaler is 64.

$$N_{prescaler} = \frac{T_3 \cdot f_{clk}}{TCNT1_{max}} = \frac{1.34ms \cdot 8MHz}{256} \approx 41.9 \tag{6.3}$$

By setting a number of registers as seen in the code in Appendix B.2, an interrupt is attached to any change on the PWM input pin. In this interrupt the difference between a rising and falling edge is determined by reading the PWM input pin. When it is a rising edge the time is read, stored and compared to T_N with the aforementioned method in descending order. The value of counter TCNT1 which corresponds to the correct T_N can be calculated using equation 6.4 and are shown in table 6.1.

$$TCNT1_N = \frac{T_N \cdot 8MHz}{64} - 1 \tag{6.4}$$

When the correct period is found here, the signal ID is stored. When it is a falling edge the counter is reset.
In the regular loop, the stored ID gets put on a two bit bus to the next microcontroller by controlling two output pins with the ID.

6.3. Liquid crystal light valve control

The glass, which will darken when required, in these glasses will be a pair of liquid crystal light valves. The lifespan of LCLVs like other liquid crystal elements are sensitive to DC operation, so while they function on DC, an AC signal is desired to preserve the LCLVs [27].

In DC operation the transparency of the LCLVs is easily controlled with a PWM signal. The PWM signal is directly attached to one port of the LCLVs, where the other port is connected to ground. To convert this to an AC signal a common technique is to have a slower square wave and inverting the PWM signal whenever the square wave is high. The new PWM signal is still connected to one port of the LCLVs, but the other port is now connected to the squarewave. This has the effect that the voltage is periodically reversed, thus creating an AC signal. This inverting PWM signal and squarewave can be seen in figure 6.3, in blue and yellow respectively.

The square wave is formed by Timer1 in an ATtiny85. This square wave has a frequency of 100Hz since the LCLVs draw most of their power when changing voltage, so it is recommend to work with low frequencies. To achieve this 100Hz the timer a prescaler of 512 is applied and TCNT1 counts to OCR1C which is set to 155. This works similar to the process in section 5.3. So OCR1A is set to 77 so that it can pull the square wave down at half the period and OCR1B is set to the same as OCR1C so an interrupt can be attached which sets the square wave high again and controls the output pins.

The PWM signal is formed by Timer0. Similarly to the square wave this signal operates in low frequencies in order to conserve power. The PWM signal will operate on 1KHz in order to have a few periods of the PWM signal in the period of the square wave. The prescaler for Timer0 is set to 256 and the OCR0A register is set to 29. This gives a PWM frequency of 1KHz as according to equation 6.5.

$$f_{PWM} = \frac{CLK}{N_{Prescaler} \cdot (OCR0A + 1)} = \frac{8MHz}{256 \cdot (29 + 1)} = 1.0KHz \tag{6.5}$$

Register OCR0B will set the duty cycle and is itself set by a function which gets the signal ID from the two bit bus.

To get the periodically inverted PWM signal for the AC behavior. A simple XOR operation is applied between the square wave and PWM signal. The result of which can be seen in figure 6.4.

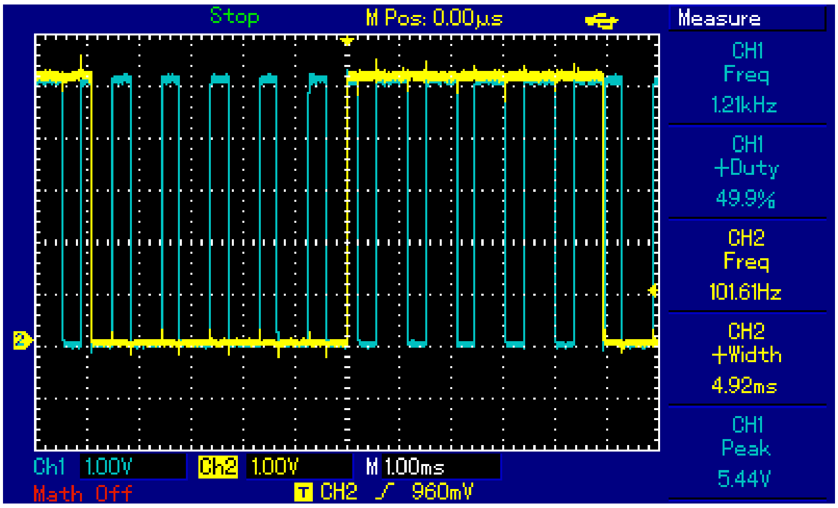

Figure 6.3: Signal, in blue, and CLK, in yellow, output pins

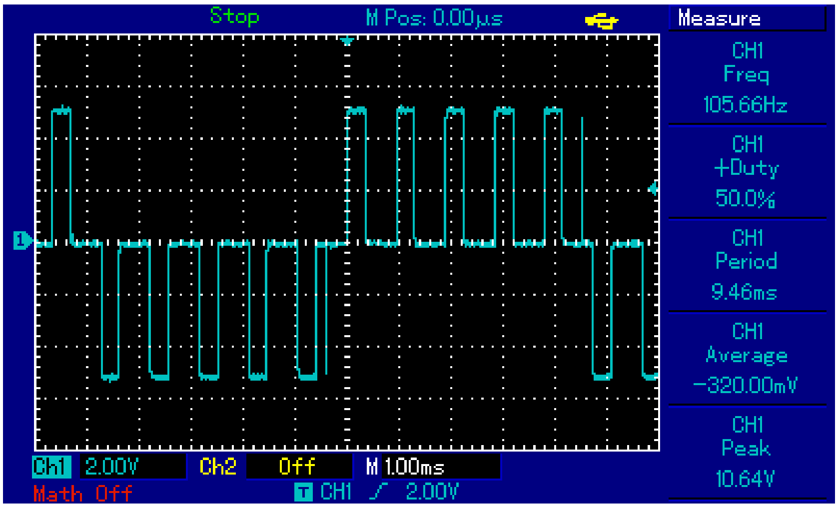

Figure 6.4: Voltage over the LCLV.

7 Tests and results

To see if the glasses as designed meet the program of requirements two tests are taken. Since the glasses need to be able to reach any place in a room of $10m$x$10m$, so from one corner to the opposite $\sqrt{10m^2 + 10m^2} \approx 14.1m$. It is required that the range of the IR communication is tested. This is done by slowly increasing the distance between the beacon and receiver, in order to find the distance at which the signal is lost. The glasses also need to be reliable in order to operate properly in a training session. Since the TSOP4856 IR receiver shuts down if a signal is sent for too long, each send signal is tested by running the signal is run for at least a minute. This is long enough for the aforementioned behavior to take effect.

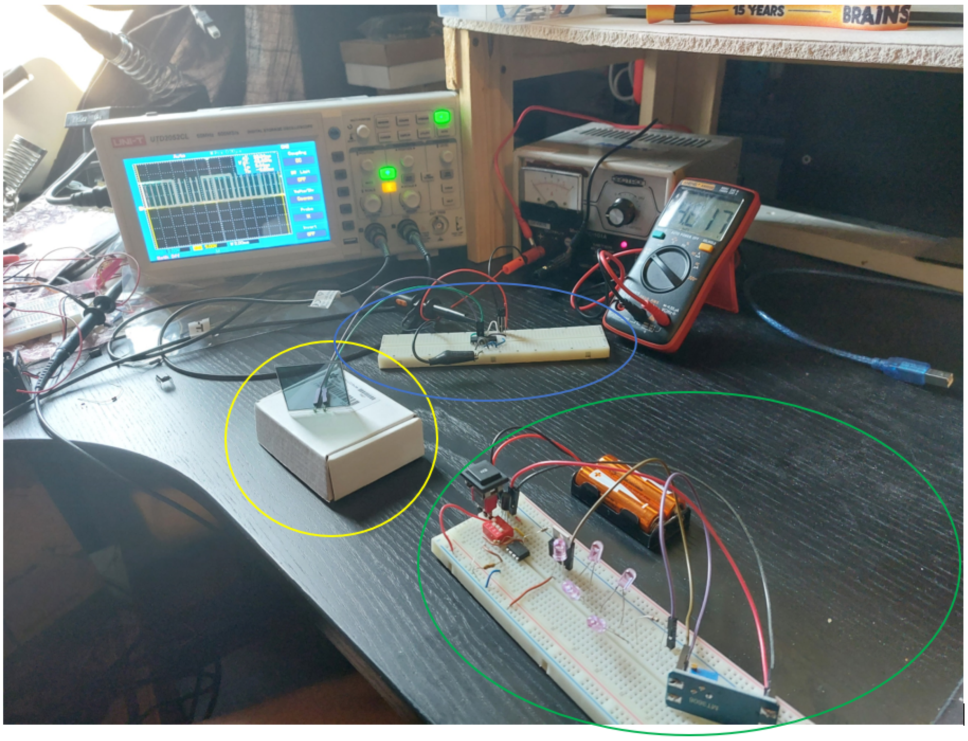

Figure 7.1: The test equipment.

The tests are taken with the equipment seen in figure 7.1. This equipment includes an oscilloscope, to see tested signals, a variable DC power supply, to power the receiver, the green oval highlights the beacon, the blue oval highlights the receiver and the yellow circle highlights the LCLV.

7.1. Range test

The range of the IR signal is influenced by a few factors. To account for these factors the test is done with control over several variables. The direction of the LEDs on the beacon has an effect of the intensity of the IR beam toward the receiver. In order to see this effect the directions of the LEDs will be put in three different positions.

- 1 LED points straight at the receiver and 4 LEDs point 90° away from the receiver.
- 1 LED points straight at the receiver and 4 LEDs point 45° away from the receiver.
- 5 LEDs point straight at the receiver.

Since the IR receiver is influenced by ambient IR irradiation and even through windows the sun is a significant source of IR radiation, the test will be conducted both with the curtains open and closed. The window is turned away from the sun, so there is no direct sunlight.

An oscilloscope is attached to the signal pin from the LCLV, in order to make it easier to see from far whether the receiver has received and identified the right signal. The beacon is set to the low smoke level, signal ID 1 from table 6.1. The test should be held during the day when the sun can interfere with the signal. First the tests are taken with curtain open. The LEDs are set to position, then from 1m the beacon is moved back until the signal is no longer received or a different signal is seen. This is repeated for each LED configuration, after which the curtains are closed and all tests are repeated.

LED configuration	Curtain position	Range [m]
1 LED straight, 4 LEDs at 90°	Open	5
1 LED straight, 4 LEDs at 45°	Open	5
5 LEDs straight	Open	6
1 LED straight, 4 LEDs at 90°	Closed	7
1 LED straight, 4 LEDs at 45°	Closed	7
5 LEDs straight	Closed	8

Table 7.1: Range of IR communication for different LED and curtain configurations

The results of this test can be found in table 7.1. From this information it is clear that the current setup is unable to reach the required $14.1m$. To get to this range the intensity of the LEDs needs to be increased. The current LEDs have a intensity, E_{IR}, of $25mW/sr$ in the forward direction, at 100mA [19]. The TSOP4856 IR receiver first was assumed to turn on at an incoming intensity, $E_{minThreshold}$, of $0.12mW/m^2$ [26]. The operating range of this setup would be calculated with equation 7.1. This range is $14.4m$ which would be enough, however the actual sensitivity of the TSOP4856 IR receiver varies with ambient irradiance.

$$R_{IR} = \sqrt{\frac{E_{IR}}{E_{minThreshold}}} \tag{7.1}$$

Figure 6 from the TSOP4856 datasheet[26] gives the reaction of the threshold with differing levels of ambient irradiance. It also gives the solar irradiance to be $10W/m^2$, this results in a sensitivity of $1mW/m^2$, however this is likely to be lower during the test, since the sunlight is filtered through a window and the window in the room where the test took place was facing away from the sun. When measuring the current through the LEDs it was found to be 50mA instead of the expected 100mA. This results in a intensity of $12.5mW/sr$ (Fig. 3)[19]. The cause of this discrepancy has not been found, since it was discovered just before the publication of this document. When assuming that the ambient irradience form the sun is 70% less due to the presence and position of the window, resulting in a $E_{minthreshold}$ of $0.5mW/m^2$, the range of this set up can be calculated with equation 7.1 to be $5m$, which is more in line with the results seen with the curtain open. To still achieve the $14.1m$ range with this sensitivity level the new emitted power level is calculated with equation 7.2 to be $200mW/sr$.

$$E_{IR} = E_{minThreshold} \cdot R_{IR}^2 \tag{7.2}$$

7.2. Reliability test

To test the reliability of the receiver a short duration test is taken in order to confirm that the TSOP4846 receiver isn't seeing the signal as noise at some point and blocking it. In order to perform this test the beacon is placed at two arbitrary chosen different distances from the receiver, $30cm$ and $3.3m$, to see if the intensity has an influence on reliability. The TSOP4856 receiver and 1 LED are pointed at each other. One probe of the oscilloscope is attached to the signal pin from the LCLV, in order to see which signal was recognized by the microcontroller and an other probe is attached to the output from the TSOP4856 receiver, so that the output from the TSOP4856 receiver can be checked for faults.

During the test a signal ID is selected and left running for a minute. This is repeated for each signal ID. The oscilloscope is monitored for faults.

Distance [m]	Signal ID	Test result
0.3	0	PASS
0.3	1	PASS
0.3	2	PASS
0.3	3	PASS
3.3	0	PASS
3.3	1	PASS
3.3	2	PASS
3.3	3	PASS

Table 7.2: Reliability test results

From table 7.2 can be seen that the IR communication functions properly and is reliable for longer times.

8

Bill of Materials

The bill of materials can be seen for the beacon and the glasses. This can be referred back to the program of requirements.

8.1. The beacon

The beacon		
Component	Component name	Price
1x 3D print of the beacon	-	-
5x IR LEDs	QED223	€6.25
3x AA Batteries	-	€4.95
1x Microcontroller	ATTINY85-20PU	€2.31
4x Resistors	-	$\approx$ €0.05
1x on/off switch	-	€0.55
1x Boost converter	MT3608	€1.45
1x DIP switch	-	€0.24

The price of the prototype beacon is €15.80 excluding the 3D print of the beacon. The reason herefore is, it is somewhat difficult to determine the price of a specific 3D print without an definitive design. However, the construction of the beacon is relatively simple, only consisting of a half sphere with a hole in the middle and a cylinder. Therefore, it should not be too expensive. The current IR LEDs, do not suffice, so other IR lights might be used, but the price will most probable remain under €75. Hence, in the prototype state it completely satisfies the program of requirements.

8.2. The glasses

The glasses		
Component	Component name	Price
1x Welding glasses	-	€8.95
1x IR receiver	TSOP4856	€1.10
2x Button cell battery	CR2032	€1.96
2x Microcontroller	ATTINY85-20PU	€4.62
1x Voltage regulator	LP2950ACZ-5.0G	€0.90
2x LCLV	Controllable Shutter Glass Adafruit 3627	€12.40
1x on/off switch	-	€0.55

The price of the prototype glasses is €30.48. The choice of the welding glasses was made for the reason that the initial idea was to use the welding glasses to obscure the vision, but afterward we found out that using a LCLV is much more practical. This implies that the welding glasses are superfluous and can be disregarded. Alternatively, 3D printed glasses could be used, which is inexpensive. Hence in the prototype state, the glasses do not satisfy the program of requirements when welding glasses are used, but if inexpensive 3D glasses are used, it should comply with the program of requirements.

9 Conclusion and Discussion

The purpose of this thesis is to design and build a prototype of glasses, that can darken based on a received signal from a chosen communication method. The communication method has been chosen for the transmitter and receiver, which is infrared. Furthermore, the transmitter, receiver and the LCLV have been designed, modified and built. However, the chosen IR LEDs do not suffice as it is not able to reach $14.1m$ in order to cover a $10m$x$10m$ room, but $5m$ to $8m$ depending on circumstances. In conclusion, the project is still considered a success, because the prototype beacon, receiver and the glasses are able to meet all of the requirements listed in chapter 2, except for the range. The solution of this, could be choosing IR LEDs with higher intensity, placing more IR LEDs or getting a more sensitive IR receiver.

In the current prototype, the beacon is able to transmit different sequences through the use of Pulse Width Modulation (PWM), with each of the sequences associated with its corresponding intensity. This can be implemented as the intensity of smoke inside a room of 10m by 10m is uniform according to one of the requirements (chapter 2). Research has been done on the beacon transmitting a IR signal based on intensity The difference between these two methods is in the current method, the receiver only needs to receive the IR to determine the intensity based on the sequence. In the interim the other method, requires the receiver to receive and measure the intensity from the transmitter. The advantage of the latter method is, it is able to divide the room into different gradients. The closer you are to the source, the higher the density of the smoke, which implies to a higher smoke density. This is more realistic in a bigger space, where the smoke takes time to spread out. A disadvantage is that it requires more equipment and greater amount of IR LEDs. The reason for this is that it completely relies on the intensity received, so intensity has become an important factor.
Another possible future work, could be modifying the beacon to communicate with an identical beacon. The cause for this is that it can be expanded to a bigger room or outside a room. The idea is that the source beacon can turn on the other beacon with a delay, which mimics the behaviour of the dispersion of smoke to an extended area within a spacious room or its external environment.
The Final product should have a turning switch with more options for different intensities. By using a resistor ladder one port with ADC capability could be used instead of multiple digital ports.

9.1. Recommendations

For the purpose of making a functioning prototype in this project, there are features that are not realised due to the time constraints. Some of the features that have been considered but ultimately not implemented are listed below:

- Modifying the beacons, such that beacons can communicate with each other, which can lead to expanding to more beacons inside a bigger room or outside the 10m by 10m room.
- Building beacons to simulate the smoke coming out from the bottom of a closed door and/or from an open door.
- 3D designing the beacon, so that it can be 3D printed.

- 3D designing the glasses, so that it can be 3D printed.

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Appendices

A

Arduino code for the microcontroller modulating the transmitter

A.1. Main code

```
#include <avr/io.h>
#include <avr/interrupt.h>

#define LEDs 0
#define IDpin0 2
#define IDpin1 3
#define minDutyCycleValue 10
#define maxDutyCycleValue 75
#define PWMperiod 108

bool PWMsig = false;
bool clkSig = false;
bool LEDsig = false;

int ID0 = 0;
int ID1 = 0;
int ID = 0;

int currenthCycle = 0;
int dutyCycleValue = minDutyCycleValue;
int nextDutyCycleValue = minDutyCycleValue;

void setup() {
  set_ports();
  set_timer_settings();
}

void loop() {
  ID0 = ((PINB & (1 << IDpin0)) >> IDpin0);
  ID1 = ((PINB & (1 << IDpin1)) >> IDpin1);
  ID = ID0 + 2*ID1;
  switch(ID){
    case 1:
      nextDutyCycleValue = 32;
      break;
    case 2:
      nextDutyCycleValue = 53;
      break;
    case 3:
      nextDutyCycleValue = maxDutyCycleValue;
      break;
    default:
      nextDutyCycleValue = minDutyCycleValue;
      break;
  }
```

```
}
```

A.2. Function code

```
void set_ports(){
  DDRB = (1 << LEDs);// -, -, DDB5, DDB4, DDB3, DDB2, DDB1, DDB0 when set output, when clear input
  PORTB = 0b00000000;// -, -, PORTB5, PORTB4, PORTB3, PORTB2, PORTB1, PORTB0 when output is port output, when input clear = no pull up, set = yes pull up
}

void set_timer_settings(){
  /* This function sets up timer1 according to the datasheet: https://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-2586-AVR-8-bit-Microcontroller-ATtiny25-ATtiny45-ATtiny85_Datasheet.pdf
   *
   * Timer1 will produce a 56KHz signal
   *
   * Timer1 counts to OCR1C  8MHz/56KHz = 142,8
   * Timer1 prescale = 1 (0001)(table 12-5, P.89)
   *
   */

 TCCR1 = 0b11000001; // Set CTC1, PWM1A, COM1A1, COM1A0, CS13, CS12, CS11 and CS10 (12.3.1, P.89)
 GTCCR = 0b01000000; // Set TSM, PWM1B, COM1B1, COM1B0, FOC1B, FOC1A, PSR1, PSR0 (12.3.2, P.90)

 OCR1A = 71; // Setting OCR1A for duty cycle 50%
 OCR1B = 142; // Set for interrupt 1B
 OCR1C = 142; // Setting OCR1C for carrier frequency = 56KHz
 TCNT1 = 0; // Start counter at zero

 SREG = 0b10000000; // Enable interrupt
 TIMSK = 0b01100000; // Specify compare match 1A, 1B, 0A & 0B interrupt
}

ISR(TIMER1_COMPA_vect) {
  clkSig = false;
  PORTB = (clkSig << LEDs);
  if(currenthCycle < dutyCycleValue){
    PWMsig = true;
    currenthCycle++;
  }else{
    PWMsig = false;
    if(currenthCycle >= PWMperiod-1){
      currenthCycle = 0;
      dutyCycleValue = nextDutyCycleValue;
    }else{
      currenthCycle++;
    }
  }
}

ISR(TIMER1_COMPB_vect) {
  clkSig = true;
  LEDsig = PWMsig & clkSig;
  PORTB = (LEDsig << LEDs);
}
```

B

Arduino code for the microcontroller receiver

B.1. Main code

```
#include <avr/io.h>
#include <avr/interrupt.h>

#define IRsense 2 // interrupt pin
#define IDPin0 4
#define IDPin1 3

#define T3 167
#define T2 118
#define T1 70
#define T0 22

#define maxDecayDelayCycles 100

int PWMinput = 0;
int Tp = 0;
int ID = 0;
int decayDelayCycles = 0;


void setup() {
  set_ports();
  set_timer_settings();
  set_external_pin_interrupt();
}

void loop() {
  setID();
}
```

B.2. Function code

```
void set_ports(){
  DDRB = (1 << IDPin0)|(1 << IDPin1);// -, -, DDB5, DDB4, DDB3, DDB2, DDB1, DDB0 when set
      output, when clear input
  PORTB = 0b00000000;// -, -, PORTB5, PORTB4, PORTB3, PORTB2, PORTB1, PORTB0 when output is
      port output, when input clear = no pull up, set = yes pull up
}

void setID(){
  if(ID == 3){
    PORTB = (1 << IDPin0)|(1 << IDPin1);
  }else if(ID == 2){
```

```
    PORTB = (1 << IDPin1);
  }else if(ID == 1){
    PORTB = (1 << IDPin0);
  }else{
    PORTB = 0;
  }
}

void set_timer_settings(){
  /* This function sets up timer1 according to the datasheet: https://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-2586-AVR-8-bit-Microcontroller-ATtiny25-ATtiny45-ATtiny85_Datasheet.pdf
   *
   * Timer1 prescale = 64 (0111)(table 12-5, P.89)
   */

 TCCR1 = 0b00000111; // Set CTC1, PWM1A, COM1A1, COM1A0, CS13, CS12, CS11 and CS10 (12.3.1, P.89)
 GTCCR = 0b00000000; // Set TSM, PWM1B, COM1B1, COM1B0, FOC1B, FOC1A, PSR1, PSR0 (12.3.2, P.90)

 TCNT1 = 0; // Start counter at zero

 SREG = 0b10000000; // Enable interrupt
 TIMSK = 0b00000100; // Enable timer1 overflow interrupt
}

void set_external_pin_interrupt(){
  MCUCR = 0b00000001; // Set ISC0[1:0] to to have any change of INT0 trigger an interrupt
  GIMSK = 0b01000000; // Set INT0 to enable interrupt
}

ISR(INT0_vect){
  PWMinput = ((PINB & (1 << IRsense)) >> IRsense);
  if(PWMinput == HIGH){ // Rising edge
    Tp = TCNT1;
    getID();
  }else{ // Falling edge
    TCNT1 = 0; // Reset counter
  }
  decayDelayCycles = 0;
}

ISR(TIMER1_OVF_vect){
  if(decayDelayCycles < maxDecayDelayCycles){
    decayDelayCycles++;
  }else{
    ID = 0;
    decayDelayCycles = 0;
  }
}

void getID(){
  if(Tp > (T3+T2)/2){
    ID = 3;
  } else if(Tp > (T2+T1)/2){
    ID = 2;
  } else if(Tp > (T1+T0)/2){
    ID = 1;
  } else {
    ID = 0;
  }
}
```

C

Arduino code for controlling the light valve

C.1. Main code

```
#include <avr/io.h>
#include <avr/interrupt.h>

#define opacityPin 0
#define clockPin 1
#define IDpin0 2
#define IDpin1 3

bool PWMsig = false;
bool clkSig = false;
bool LCLVsig = false;

int ID0 = 0;
int ID1 = 0;
int ID = 0;


void setup() {
  pinMode(opacityPin, OUTPUT);
  pinMode(clockPin, OUTPUT);
  pinMode(IDpin0, INPUT);
  pinMode(IDpin1, INPUT);
  set_timers();
}

void loop() {
  ID0 = digitalRead(IDpin0);
  ID1 = digitalRead(IDpin1);
  ID = ID0 + 2*ID1;
  switch(ID){
    case 1:
      OCR0B = 10;
      break;
    case 2:
      OCR0B = 20;
      break;
    case 3:
      OCR0B = 28;
      break;
    default:
      OCR0B = 0;
      break;
  }
}
```

C.2. Functions

```
void set_timers(){
  /* This function sets up the timers according to the datasheet: https://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-2586-AVR-8-bit-Microcontroller-ATtiny25-ATtiny45-ATtiny85_Datasheet.pdf
   *
   * Timer1 will produce a 100Hz signal
   * Timer0 will produce a PWM signal at 1KHz
   *
   * Set COM0A0, COM0A1, COM0B0 and COM0B1 all to zero, in reg TCCR0A, for normal port operation (table 11-2, P.78)
   * set WGM00 and WGM02 to zero and WGM01 to one, in reg TCCR0A and in reg TCCR0B, for CTC (table 11-5, P.79)
   * for the prescaler set CS00 and CS01 to zero and CS02 to one, in reg TCCR0B, for prescaler = 256 (table 11-6, P.80)
   * Set OCR0A register to steps (section 11.9.5, P.80)
   * For interrupt, set global interrupt SREG[7] to one and for compare match A set TIMSK[4] to one.(P.9, P.81)
   *
   * Timer1 counts to OCR1C
   * COM1A0, COM1A1  (table 12-1, P.86)
   * COM1B0, COM1B1 toggle OC1A (pin 6) (table 12-4, P.89)
   * Timer1 prescale = 512 (1010)
   *
   */

 TCCR0A = 0b00000010; // Set COM0A0, COM0A1, COM0B0, COM0B1, WGM01 and WGM00
 TCCR0B = 0b00000100; // Set WGM02, CS00, CS01 and CS02

 TCCR1 = 0b11001010; // Set CTC1, PWM1A, COM1A1, COM1A0, CS13, CS12, CS11 and CS10 (12.3.1, P.89)
 GTCCR = 0b01000000; // Set TSM, PWM1B, COM1B1, COM1B0, FOC1B, FOC1A, PSR1, PSR0 (12.3.2, P.90)

 OCR0A = 29; // Setting OCR0A for PWM frequency
 OCR0B = 0; // Set OCR0B for duty cycle
 TCNT0 = 0; // Start counter at zero

 OCR1A = 77; // Setting OCR1A for ac LCLV duty cycle 50%
 OCR1B = 155; // Set other register to 0
 OCR1C = 155; // Setting OCR1C for ac LCLV frequency
 TCNT1 = 0; // Start counter at zero

 SREG = 0b10000000; // Enable interrupt
 TIMSK = 0b01111000; // Specify compare match 1A, 0A & 0B interrupt
}

ISR(TIMER0_COMPA_vect) {
  PWMsig = true;
  LCLVsig = PWMsig ^ clkSig;
  digitalWrite(opacityPin, LCLVsig);
}

ISR(TIMER0_COMPB_vect) {
  PWMsig = false;
  LCLVsig = PWMsig ^ clkSig;
  digitalWrite(opacityPin, LCLVsig);
}

ISR(TIMER1_COMPA_vect) {
  clkSig = false;
  LCLVsig = PWMsig ^ clkSig;
  digitalWrite(opacityPin, LCLVsig);
  digitalWrite(clockPin, clkSig);
}

ISR(TIMER1_COMPB_vect) {
  clkSig = true;
  LCLVsig = PWMsig ^ clkSig;
  digitalWrite(opacityPin, LCLVsig);
```

```
  digitalWrite(clockPin, clkSig);
}
```