Improvement of Motorcyclists' Safety:

Designing a Motorcycle Observation Assist

Remy Petrona

Supervisor: Richard Bults MSc BSc

Critical Observer: Erik Faber PhD

Programme: Creative Technology

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Abstract

The goal of this research is to find a possible way to decrease the dangers of riding a motorcycle. Where other researches focus on the perspective of car drivers and other traffic, this research is conducted from the perspective of a motorcyclist, and tries to find ways for a motorcyclist to deal with other traffic.

A literature research is done, combined with questionnaires, to signal the problem and find a direction to go and find a solution. The result of this study is that a problem is the visibility of a motorcyclist. Other studies already tried to solve this by researching the effect of fluorescent clothing and similar solutions. This research tries to find a way to decrease the dangers of riding a motorcycle, by enhancing a motorcyclist's awareness of surrounding traffic. This becomes the research question:

'How to enhance a motorcyclist's awareness of surrounding traffic, in a non-disruptive way?'

This question is answered by designing a Motorcycle Observation Assist, a system that uses sensors and auditory feedback, to notify a motorcyclist about surrounding traffic that may cause a hazardous situation. This system is realized in the form of a functional hi-fi prototype, based on Arduino.

The design process of this system is divided in three phases: Ideation, Specification and Realization. In the Ideation phase, five concepts are generated based on the requirements gathered from potential stakeholders. In the Specification phase, one of these concepts is specified and the requirements are updated accordingly. Lo-fi prototypes of the subsystems are created to check feasibility. Consequently, in the Realization phase the chosen concept is realized by creating a hi-fi prototype.

The system is then tested for functionality and accuracy with an orientation test, a running test and a questionnaire by three motorcyclists. The results of the orientation test are 100% accurate, the running test shows that the system can function properly in a simulated 'real life situation', with an accuracy of almost 70%. In the questionnaire, the three motorcyclists gave the system an average approval rating of 3,7 out of a possible 5,0. This means that there is room for improvement, but the system is reviewed positively overall.

Acknowledgements

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Next, I would like to thank my parents for always supporting me, even when things took far longer than expected and everything seemed like it was going to fail. They have always believed in me and knew that one day I was going to invent something.

Last but not least I would like to thank my girlfriend Nadine Klaver, who has been dealing with (stressed out) me during the course of this project. I was not always as nice as I could have been, partially due to the stress of this project, but she stuck with me through it all.

Without any of these people this project could not have been realized and I am grateful for their contribution.

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Chapter 1: Introduction

In this chapter the background will be explained, leading to the challenges and afterwards the research question will be stated. At the end of this chapter, a structure of the report is presented.

1.1 Background

When comparing a car to a motorcycle, it is easy to see that a car has more safety features. To begin with, the car itself is a cage that surrounds the driver (and passengers) and protects them in the event of an accident. Most cars nowadays are equipped with multiple air bags and seatbelts that keep the driver and passengers safely in place during an accident. A motorcycle does not have any of these safety features. The rider is positioned on top of the vehicle and is exposed to the 'outside'. In the event of an accident, the rider is often separated from the motorcycle, and the only safety measures that could help in such a case are protective clothing, gloves and a helmet.

There are multiple other safety features in a car, that are designed to prevent accidents from happening. These so-called 'driver assists' are systems that help by giving the driver a warning about potential hazards or by controlling the car's systems for fractions of seconds in emergencies.[1] Driver assists can be grouped in three categories:

1. **Controls and vision aids;** Systems that help the driver with controlling the vehicle or monitoring the surroundings. Examples of this first category are systems that help the driver keep his attention on the road, like controls in the steering wheel or voice command, and systems that extend the driver's sight, like a rearview camera for backing up or a infrared camera to help spot objects in the dark.
2. **Warning and alert systems;** Systems that use sensors like cameras and/or radar to detect objects and warn the driver in an audible, visual or haptic way. Examples of this second category are systems that warn when the driver is getting too close to other vehicles in front of the car, or systems that pay attention to the road and warn the driver when the car is about to leave the lane.
3. **Active controls;** Systems that can automatically engage and take over some of the functions of the car. Examples of this third category are systems that automatically slows down the car when it is on cruise control and the following distance to the vehicle in front of the car is becoming smaller, or systems that steer the car back in to the lane when the driver is not paying enough attention and leaves the lane or wants to start overtaking another car while there is a vehicle in the blind spot next to the car.

1.2 Challenges

The only driver assists some modern motorcycles are equipped with are ABS (Anti-lock Braking System) and TC (Traction Control). However, certain uses could be found for the first two categories of driver assists on a motorcycle. The third category, active controls, are systems that are not desirable on a motorcycle, because it could surprise the motorcyclist when it automatically steers or brakes and could cause an accident. ABS and TC are the only exceptions here that are used on modern motorcycles, but these systems only engage automatically in a hazardous situation.

A motorcyclist has to rely on his own senses and situational awareness to prevent accidents. Whenever a hazardous situation occurs, a motorcyclist has to rely on his own skills to prevent an accident. These skills can be trained by taking an extended driving education program, where a motorcyclist can get to know his own motorcycle and learn how to respond in certain hazardous situations, like rain or a crowded street. A motorcyclist can also be taught where to look and where to ride in specific situations to avoid accidents. However, when looking in any other direction than the driving direction, the attention could be lost for too long, giving a motorcyclist less time to respond to any object that is directly in his way.

The challenge here is to give the motorcyclist as much information as possible about surrounding traffic or upcoming obstacles, without taking the attention away from the road ahead of the motorcyclist. A motorcyclist could be given extra information about his surroundings, but when this takes away from the attention for the road, this only works counterproductive. A balance needs to be found between receiving information by looking ahead and receiving information about the surroundings.

1.3 Research question

These challenges can be formulated in the following research question:

"How to enhance a motorcyclist's awareness of surrounding traffic, in a non-disruptive way?"

1.4 Structure of the report

This report will try to answer this question by doing a literature study and presenting what is found in a 'State of the Art' chapter. After this a number of methods and techniques are described, which will be used later on in the report.

Based on the State of the Art, an Ideation chapter can be written, in which a certain number of ideas will be generated. In the next chapter, one of these ideas will be further specified, hence the name of the chapter 'Specification'.

Once this idea has been specified and (non-)functional requirements have been made and tested with lo-fi prototypes, the 'Realization' phase is next. During this phase the specified idea will be realized in the form of a functional (hi-fi) prototype, which can be tested and evaluated upon in the next chapter 'Evaluation'.

With these results, the research question can be answered in the final chapter 'Conclusion and recommendation'.

Chapter 2: State of the Art on Motorcyclist Visibility and Motorcycle Driver Assists

In this chapter the State of the Art will be examined, by doing a literature study on the subject of motorcycles and conspicuity-related accidents. To get more information and find a specific direction to start this literature study, some of the major associations that look after the interests of motorcyclists were contacted. An important association in this phase of the project is MSG (MotorSportsGroup of the University of Twente), which was contacted to get real-life experience from motorcyclists, to see if any problems could be identified. A survey was also created to approach car drivers and ask their opinion on the subject.

2.1 MSG

The MSG is the MotorSportsGroup of the University of Twente (UT) that consists of people who ride motorcycles and/or are enthusiastic about motorcycles. The MSG was contacted to help get a specific direction for the literature research. An e-mail was sent to all members with the question *if they had any experiences with not being seen by car drivers on the road, while riding a motorcycle*. Their opinion about the visibility of a motorcyclist in general was also asked. 14 people responded with their opinions and some people referred to articles about the visibility on the road of motorcyclists.

2.1.1 Data analysis

A word cloud was made to help analyze what words were mentioned most. Figure 1 presents this word cloud with the most frequently used Dutch words in the responses to the question. A filter was applied to the Dutch words to take out words like 'but' and 'and', to get only meaningful words in the word cloud. The most frequently used Dutch words are translated and presented in Table 1 below with their frequency and an explanation as to how the words are related. Because there were words that were used often, but did not have any significant meaning, only the top nine words were used.

Word (Dutch word)	Frequency	Explanation
Motorcyclist (Motorrijder)	13	As the question was asked to motorcyclists and answered from the perspective of motorcyclists, the most frequently used word in the answers was 'motorcyclist'.
To look (Kijken)	12	To get information about the surroundings, everybody in traffic has to look around.
Information (Informatie)	10	By looking around, information can be gathered about the surroundings, and processed in the brain of the motorcyclist to avoid collisions.
[To be/to have] seen (Gezien)	10	In order to avoid accidents in traffic, everybody has to be seen, but also has to have seen other vehicles. As opposed to looking, when a driver

		has seen, he has also processed the information.
Attention (Aandacht)	9	In traffic, keeping attention on the road and on other surrounding traffic is crucial to avoid collisions. Attention can also make the difference between looking and seeing.
Light (Licht)	9	Lights can help in traffic to make a vehicle more visible to others, but can also help to make other vehicles more visible in the dark.
Image (Beeld)	9	By looking around at surrounding traffic and seeing other vehicles, an image can be formed in the brain of the motorcyclist, that will help participants of traffic with making decisions.
Eyes (Ogen)	9	The eyes are used to gather information in traffic, but these can only be pointed one way. The eyes are our main way of getting information to the brain, but they do have limitations.
Self (Zelf)	9	Everybody in traffic is responsible for themselves. If another vehicle can cross a road, this does not mean that a vehicle following this vehicle can automatically also cross. The person in the following vehicle has to look and see for his or herself.

Table 1: This table shows the top four most frequently used words, with a split third and fourth place.

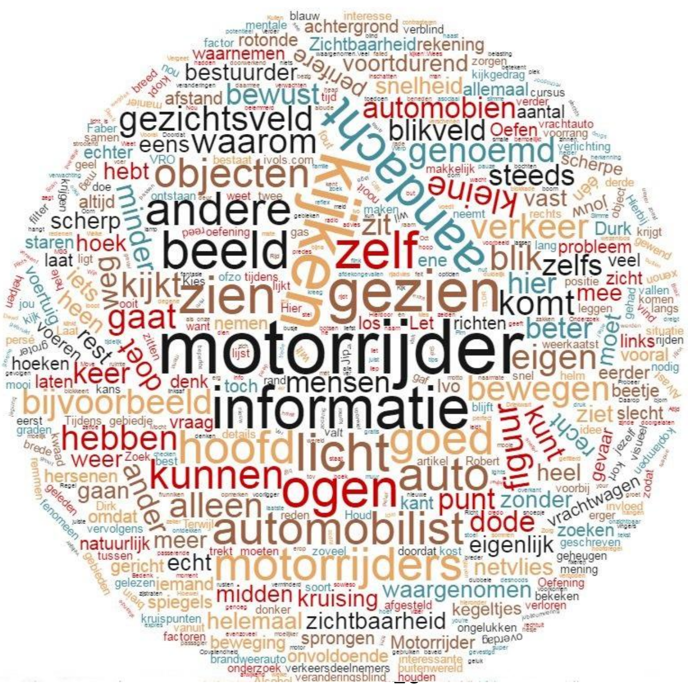

Figure 1: This word cloud shows the most frequently used Dutch words in the responses from the MSG

2.1.2 Literature research

After receiving and reading all the e-mails from the MSG and analyzing them with the word cloud, the literature study could be started in a more specific direction, using the most frequently mentioned words as Google search terms. The combination of 'motorcyclist' and 'to see' or 'attention' mostly led to articles describing the visibility of motorcyclists and how to improve this by wearing highly visible clothing. This was also mentioned in the e-mails.

A sentence that was used in the e-mails from the MSG more often but could not be discovered with the analysis of the word cloud is 'looked but failed to see'. This sentence is used to describe an accident, where the responsible driver looked in the direction of the other participant in the accident, but failed to 'see' the other vehicle. The driver responsible for the accident in this case was supposed to give way to the other vehicle, but did not do this because situational information was not registered[2].

Different articles deal with this subject, relating it to *change blindness, conversations with passengers in the car and gender*[3], or to *vehicle conspicuity*[4]. Another study that is more specific to this topic relates the principle of 'looked but failed to see' to motorcyclists' speed[5]. It shows that in 'looked but failed to see' type accidents in rural areas, the motorcyclists' speeds were higher than in other areas.

2.1.3 Conclusions

The responses from MSG helped build an understanding of possible explanations for conspicuity-related motorcycle accidents and what the perspective of motorcyclists is on their visibility on the road. The words described in Table 1 all have to do with paying attention to the road and looking around as much as possible, to get as much information as possible. This could mean that the challenge could lie in the fact that a motorcyclist has to perceive as much information as possible, while being limited by the restrictions of the eyes and the attention.

It also pointed out that it might be helpful to research what car drivers think about this issue, as the responses from MSG were mostly written from the perspective of motorcyclists, often "blaming" car drivers for failing to see motorcyclists.

2.2 KNMV and SWOV

The KNMV (Koninklijke Nederlandse Motorrijders Vereniging) is the Royal Dutch Motorcyclists Association, which facilitates riding motorcycles in the Netherlands. They organize meetings to talk about rules concerning motorcycles. They also offer extended motorcycle riding trainings, which were mentioned earlier in the introduction. When they were contacted about this project, asking them what they could offer in terms of knowledge, they referred to the SWOV (Stichting Wetenschappelijk Onderzoek Verkeersveiligheid). This is the foundation for scientific research concerning traffic safety. They often work together with the KNMV and the Ministry of Infrastructure and Environment, and they try to use scientific knowledge and research to improve safety in traffic.

2.2.1 The roles of motorcyclists and car drivers in conspicuity-related accidents

In one report the SWOV brought out in 2011[6], the roles of motorcyclists and car drivers in conspicuity-related accidents are studied. Five research questions were used, some regarding conspicuity, others regarding the roles of motorcyclists and car drivers. It was found that car drivers do not necessarily fail to give motorcyclists priority more often than they fail to give cars priority. It only happens in one specific kind of accident, where a car turns left on a major road and does not give an approaching motorcyclist priority. The situation is displayed in Figure 2. This can be related to the conspicuity of a motorcycle, as the front of a motorcycle is less wide than that of a car and there is often only one headlight, making it harder to perceive the speed at which the motorcycle is approaching.

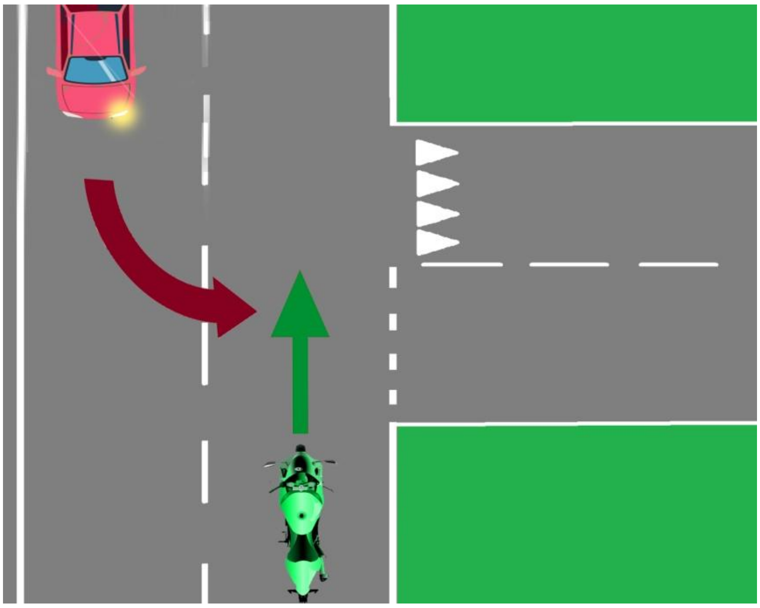

Figure 2: This image portrays the situation described above

In the report it is also found that the expectancy of car drivers plays a role in conspicuity-related accidents. Car drivers might not expect a motorcyclist, causing them to not pay attention to motorcyclists as much as to other vehicles. The report stated that emphasizing the co-existence on the road of motorcyclists during driver training might not be very effective. It could lead to an expectancy that is not met in real-life situations, therefore decreasing expectancy of motorcycles in the long term. It is stated that it would probably be more effective to focus on procedures (the example mentioned in the report is looking over the right shoulder when turning right) that help with being aware of all other surrounding traffic, instead of just motorcyclists.

The report also mentions Intelligent Transport Systems (ITS), that could alert car drivers when there is a motorcycle approaching an intersection. This solution accepts the fact that car drivers expect motorcyclists less and helps them when it is needed, instead of trying to increase expectancy.

‘Defensive driving’ is mentioned and it is said no research has been done yet into the effect of the ‘defensive driving’ of a motorcyclist in a conspicuity-related accident. This could be a way for a motorcyclist to avoid conspicuity-related accidents.

2.2.2 Conclusions

The report shows results for different researches and shows that in some cases further research is needed. Trying to raise a car driver’s expectancy for motorcyclists is one way to go, but it is also said in the report that a look needs to be taken at what a motorcyclist could do to avoid conspicuity-related accidents. Since the report mentions defensive driving, but claims that research still needs to be done, the research question of this project can add something to the research that has been done on this subject.

2.3 Survey car drivers

Because the question to the MSG was mostly answered from the perspective of motorcyclists, the perspective of car drivers in surrounding traffic was lacking. To find out what car drivers thought about the visibility of motorcyclists and motorcyclists in general, a survey was created and put online, asking car drivers to fill it in and spread it amongst their friends and acquaintances. Specifically car drivers were asked, as cars pose a potential threat for motorcyclists.

The survey consisted of ten questions, ranging from general questions like 'Do you have a driver's license for the car?' to more subject specific questions like 'How do you feel about fluorescent vests and helmets for motorcyclists?'. See Appendix I for the full list of questions.

2.3.1 Results

39 people responded to the survey, giving some interesting results. One of the results was that more than half of the respondents (51%) have had an accident with any other vehicle at some point (Figure 3). 85% of the respondents sometimes have trouble with the visibility of a motorcyclist (Figure 4), and 82% of the respondents say that fluorescent vests and helmets would actually help them notice a motorcyclist (Figure 5).

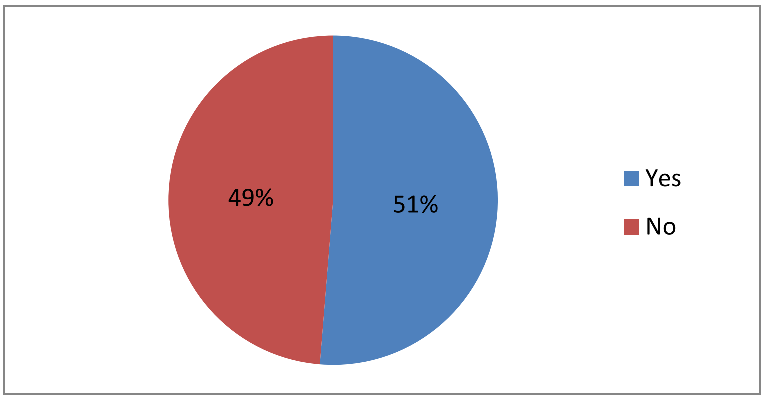

Figure 3: This chart shows the responses to the question "Have you ever been in an accident?"

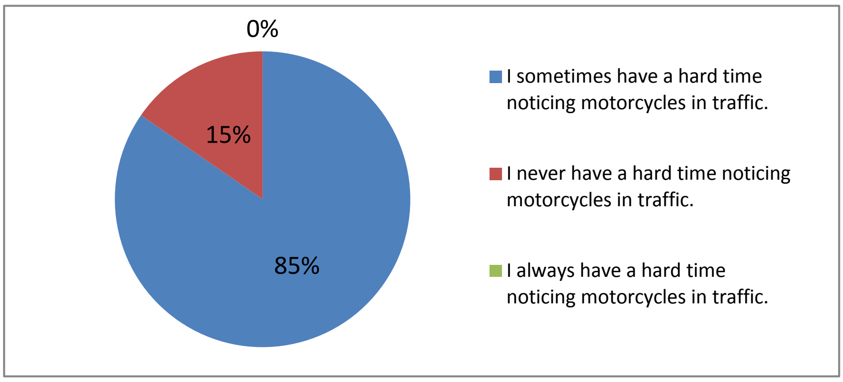

Figure 4: This chart shows the responses to the question "What do you think about the visibility of a motorcyclist?"

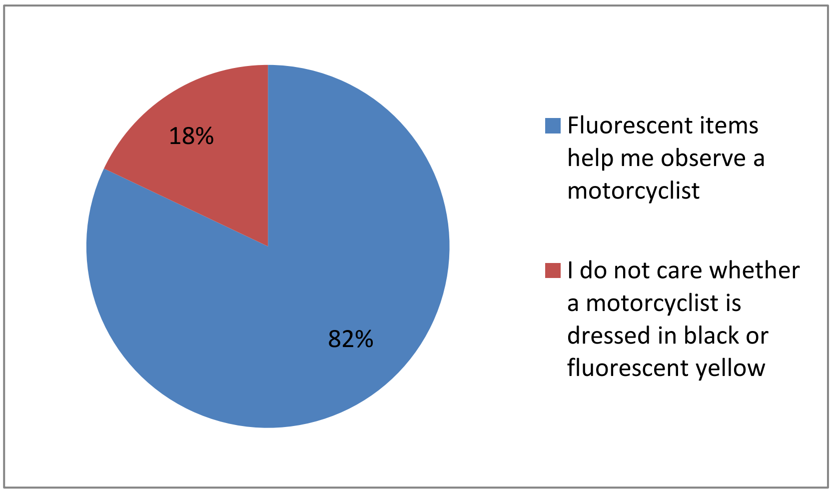

Figure 5: This chart shows the responses to the question "What do you think about fluorescent vests and helmets for motorcyclists?"

One of the questions was 'You are coming from the right (you have priority) and want to go on a road where a motorcyclist is riding with a velocity that is way higher than the maximum allowed velocity. What would you do?'. The majority of respondents would just wait (64.1%). However, 12.8% of people would actually quickly go in front of the motorcycle, 'taking' their priority (Figure 6). This shows the attitude some car drivers have towards motorcycles.

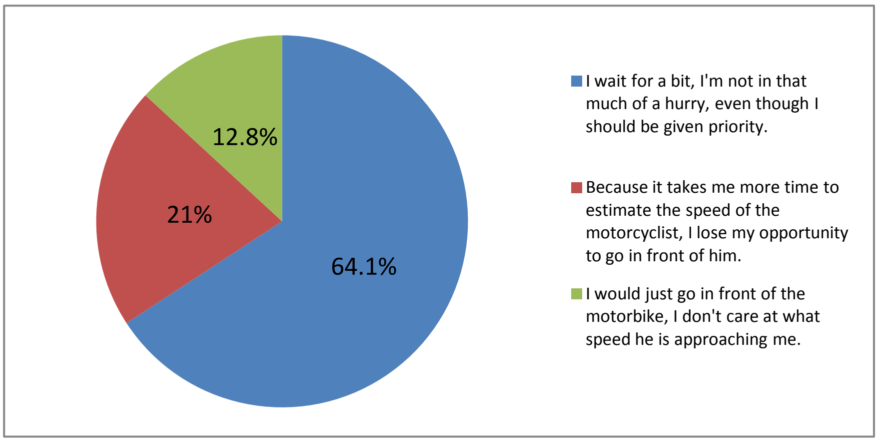

Figure 6: This chart shows the responses to the question "You are coming from the right (you have priority) and want to go on a road where a motorcyclist is riding with a velocity that is way higher than the maximum allowed velocity. What would you do?"

To see whether car drivers would be willing to invest in some form of technology that would help them with recognizing motorcyclists, the question 'Imagine there would be a technological solution in the form of a small box, that warns if there are motorcyclists nearby. Would you have this installed in your car?' was asked. 40.8% of respondents said they would actually invest in such a solution, as long as it would not exceed a price of €50. 29% of respondents said they would maybe invest, but that it would depend on how reliable the device is. 20.4% of respondents said it would only distract them so they would not invest in such a solution, and 14.3% of respondents would not invest because they have more trust in their own senses than in a machine. None of the respondents said they would invest in a device under €500 (Figure 7).

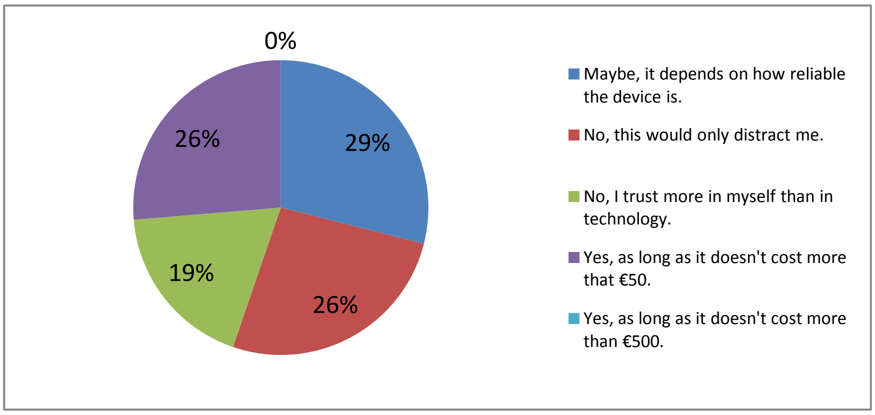

Figure 7: This chart shows the responses to the question "Imagine there would be a technological solution in the form of a small box, that warns if there are motorcyclists nearby. Would you have this installed in your car?"

2.3.2 Conclusions

The survey showed that 82% of the people think fluorescent vests and helmets do have a positive influence on the visibility of a motorcyclist. Nevertheless, there is still room for improvement as a lot of people still have a hard time seeing motorcyclists. Furthermore, the survey showed that a technological solution could be helpful, however not everyone would be willing to invest in this. The survey also showed that the relationship between motorcyclists and car drivers is not optimal, which sometimes leads to unwanted behavior in traffic, caused by expectations.

2.4 Motorcycle Drivers Assists

At this point in the literature research, it was found that multiple researches were done towards the visibility of a motorcyclist and the roles of motorcyclists and car drivers. The next step was to do research towards drivers assists for motorcyclists. The first results of the research were systems that are also available in cars, being Anti-lock Brake Systems (ABS) and Traction Control (TC).

These assists are examples of the most common type of assist that is out there for motorcycles right now, assists that help the driver control the vehicle (control and vision aids – category 1). But when a look is taken at what kind of assists there are for cars, it can be noted that a big part of modern assists for cars have not made it to motorcycles yet.

As already mentioned in chapter 1, active controls (category 3) are not desired on a motorcycle as sudden braking or throttle could surprise the motorcyclist and be more dangerous. However, Honda did come up with a self-balancing motorcycle, which has systems that interfere with the throttle and braking and even the balancing of the motorcycle[7].

This leaves the second category of assists, namely the alert and warning systems. For cars there are a lot of alert and warning systems that signal the driver of potential danger. A system that monitors the space ahead of the car and vibrates the steering wheel when a vehicle is approaching the front of the car at an alarming rate. A system that keeps track of the 'blind spot' of car drivers and indicates when there is another vehicle in the blind spot by activating a small light in the outside mirror of the vehicle. These are systems that help the driver 'see'. They extend the driver's senses by looking in places the driver cannot look for himself or while the driver is looking at something else.

This idea was executed for motorcyclists by the people of Skully[8], by adding a rear view camera and a small screen to a helmet. This way the wearer of the helmet could at all points in time see what is going on behind him, without having to look in the mirrors. The helmet supposedly also has capabilities of communicating with the wearer's smartphone, so it should be able to show the music that is currently being listened to, any calls coming in and the next navigation command. However, the company ceased to exist before the product was officially sold. With the research question in mind, it can easily be seen that the Skully has too many capabilities to only help a motorcyclist without distracting. First of all, there is a screen constantly in the motorcyclist's peripheral sight. When there are changes on this screen, it will constantly be distracting the motorcyclist. Furthermore, when the motorcyclist wants to focus on this screen, it is so close to his face that his eyes cannot focus on the road anymore. Getting calls and music information can also be seen as unnecessary distraction. Conclusion: Skully is a nice 'toy', with some fun features, but does not guarantee extended safety. It is shown in Figure 8 below.

Figure 8: This image shows a picture of the Skully helmet.

A system that was found that alerts car drivers about motorcyclists, is Motorcycle Warning System[9]. This system relies on both the car driver and the motorcyclist to install a device in their vehicle, the motorcyclist's device sends out a unique code, and the car driver's device recognizes these codes. This way the car can give the car driver a heads up when there is a motorcycle nearby. It can even recognize multiple motorcycles, because all motorcycles have their unique code. When a motorcycle is spotted, a light and sound signal will warn the car driver. The challenge with this system is that it will only work when almost every car driver has such a device in his car and all motorcyclists have this device installed as well.

As shown by the survey, some people are willing to invest in such a device, but about as many people will only buy it if it is reliable enough. Another reason this system is not a perfect solution to the research question in this project is that it still only tries to give car drivers extra information, trying to spot motorcyclists.

2.5 Overall conclusion

After doing this literature study and survey, it was found that a lot of research has already been done on the subject of motorcycle conspicuity. However, often it seems to be forgotten that the motorcyclist does not only have to be seen, but also has to see for himself. Studies point out that there is still research to be done to see if a motorcyclist can do things to avoid accidents, except for wearing highly visible clothing and adding lights to his motorcycle. It still seems that increasing a motorcyclist’s awareness of surrounding traffic would be a way to avoid accidents.

Chapter 3: Methods and Techniques

In this chapter the methods and techniques used during this project will be introduced and the relevance for this project will be explained. These methods and techniques are specifically used in the ideation and specification chapters.

3.1 Creative Technology Design Process

The Creative Technology design process begins with an idea, problem (user needs) or technological development. These three things are all related to each other, for instance when there is a problem, an idea can solve this problem, or a technological development could offer a solution. The design process can also start off with some interesting form of technology, and can be continued by finding a problem this technology could be a solution to. Once the idea for a product is complete, meaning there is a problem that it solves and a technological solution it uses to solve the problem, the ideation phase goes into the specification phase. If the idea is still not completely clear, the ideation phase can be gone through again, as it is cyclic.

In the Specification phase the idea gets specified, by using a list of (non-)functional requirements, that was created during the Ideation phase by the developer. The specification phase is cyclic like the previous phase, giving the designer the room to improve on the idea once it turns out that after specification a certain part might not be feasible. In this phase it is also important to start with early prototypes, to get an idea of how hard it can be or how long it might take to create some parts of the system.

If it turns out that the entire idea is not feasible, the designer can go back to the ideation phase and improve on the idea until it becomes possible. Another thing to do during the specification phase, is making interaction scenarios. This way the designer can start coming up with how users will use the envisioned product and improve on the idea if it turns out that it is not user friendly. Furthermore, a functional block scheme is created, in which the major building blocks and information exchange between these blocks is portrayed. Once the specification phase has been gone through and there is a clear image of what needs to be done in order to complete the envisioned product, the realization phase can begin.

In the realization phase the envisioned system gets decomposed into smaller sub-systems that can be realized and later on integrated. In this phase the exact components also get chosen and if it turns out a certain sub-system cannot be realized, the designer can go back to the specification phase or even the ideation phase to change the idea.

Finishing the realization phase leads to the evaluation phase, in which the realized system gets evaluated, to check whether it fulfills the requirements or not. If this is not the case, the previous cycles can be gone through again to alter the envisioned system to a point where it does fulfill all the requirements, or at least the ones that the designer set out to fulfill. The evaluation phase is also used to get recommendations for future work.

See Figure 9 for an illustration showing the Creative Technology design process as a model.

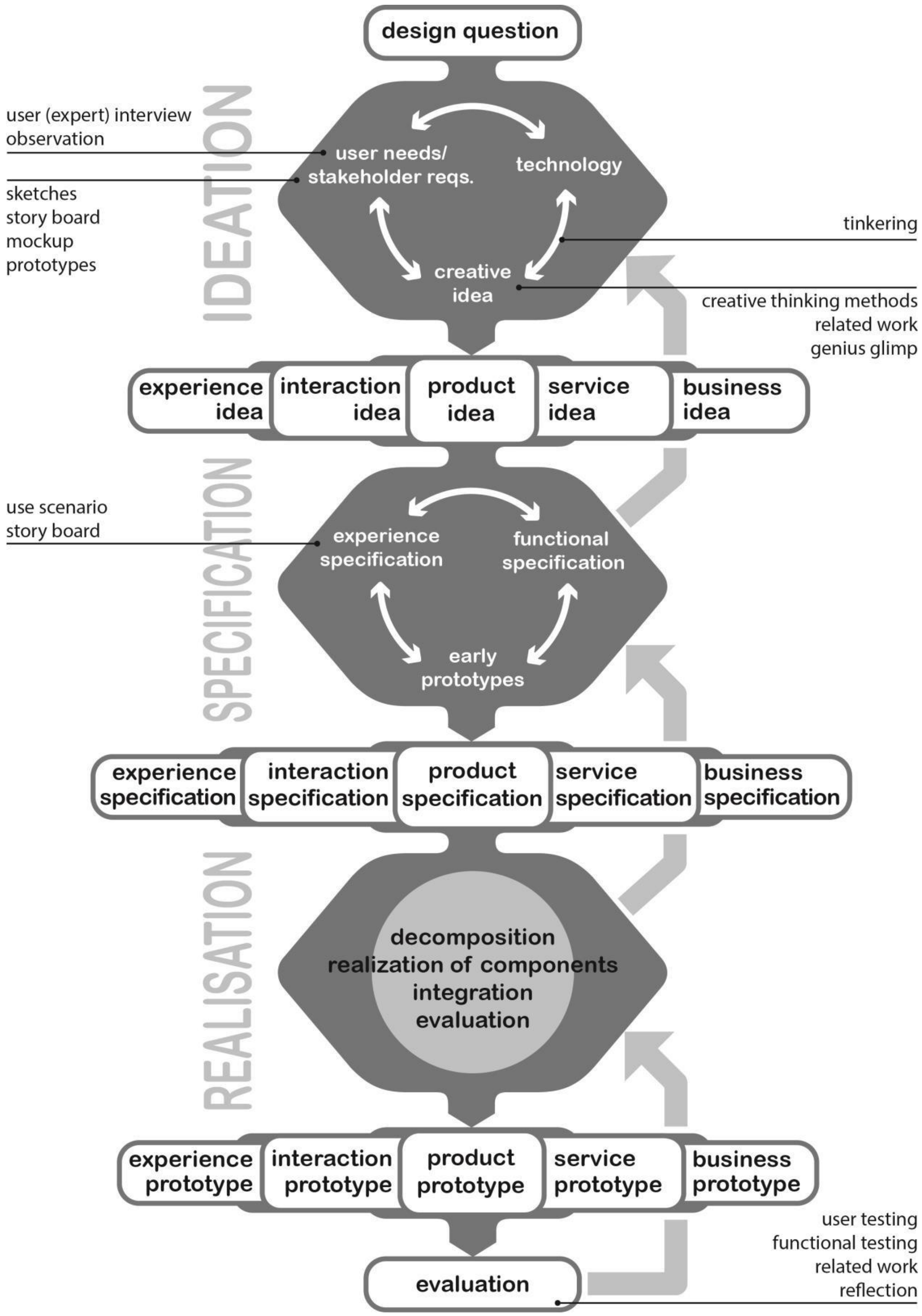

Figure 9: The Creative Technology Design Process illustrated.

3.2 Stakeholder identification

Stakeholder identification is important for the project because the stakeholders help creating requirements. It is therefore of crucial importance to have a clear insight in who or what the stakeholders are and how they relate to each other. A first way to find stakeholders is by using brainstorming techniques as explained in section 3.4.1. This gives a long list of possible stakeholders, which is probably not organized. A way to organize the stakeholders is needed to find out which stakeholder is the most important and which stakeholders are not. The method of Sharp et al[10] is a method to identify the baseline stakeholders and categorize them. The four main categories of baseline stakeholders are:

Users

The users are the people, groups or companies who will directly interact with and control the system. These are the people whose lives will directly be influenced by the system.

Developers

The developers are the people that help develop the system by having a stake in the requirements engineering process, but their role is different from that of the users.

Legislators

The legislators are the organizations that can come up with guidelines or rules that may influence the development or usage of the system.

Decision-makers

The decision-makers are people such as managers of the development team, who make the decisions relating to the system.

When all stakeholders have been identified and categorized, it becomes clear what stakeholders do not belong in this project, and what stakeholders have to be questioned to gather requirements.

3.3 Stakeholder analysis

Once all stakeholders have been identified and have been assigned a role in the project, an influence-interest matrix[11] (Figure 10) can be made to clarify which stakeholder has the most impact on the project. All stakeholders get assigned two numbers on a scale of 1 to 10, which represent their interest in the project and their influence on the project. These numbers make coordinates, which can then be used to place all the stakeholders in the matrix. When all stakeholders are placed, a pattern becomes obvious and it is easy to spot who has more influence, and who has more interest.

Figure 10: Example influence-interest matrix without stakeholders filled in. [16]

3.4 Requirement Elicitation Techniques

To gather all requirements needed for this project, different types of requirements elicitation techniques were used. The different techniques will be briefly explained in the following section, after which the preferred technique will be further elaborated on.

3.4.1 Brainstorms

The first technique used to find a general direction to go in was 'brainstorming'. There are multiple types of brainstorms, including question brainstorming[12], which does not try to come up with ideas, but with questions, which will later on lead to ideas. Another form of brainstorming is brainwriting[13], where multiple people write down a certain amount of ideas on a paper and after five minutes they pass the paper along to the next person, who will take the ideas as inspiration to come up with more ideas. The technique chosen in this case is the normal group brainstorm[14], where multiple people take the time to sit together and come up with ideas. This was chosen because there was no specific direction set yet (besides having the subjects the MSG mentioned as an inspiration), so every idea would be worth something.

3.4.2 Interviews

There are different kinds of interviews that can be done to gather information from stakeholders. The extent to which this interview is structured, determines what type of interview it is. First off, there is the structured interview[15]. In this type of interview there is a certain amount of questions made and one by one these will be answered by the interviewee. This type of interview is useful when specific answers are needed and/or expected. The next form of interview is the semi-structured interview[15], where some questions are set in advance, but new questions can be made up during the interview. This keeps the conversation somewhat structured, but also leaves room for extra subjects. The last form of interview that will be discussed here is the unstructured interview[15]. This type of interview is almost just a normal conversation, as there is no structure that is determined by questions. The subject is set in advance and the conversation is just free.

In this case the semi-structured type of interview was chosen because the subject was not all the way determined yet, but some key questions did have to be answered. The semi-structured interview is used to get as many preliminary requirements as possible from the interviewees, while still guiding the conversation in a general direction by asking a set of questions. Whenever an interviewee would come up with more answers than needed for a question, new questions could be formed and asked to keep the conversation going. Using a semi-structured type of interview, it becomes possible to slightly guide the conversation without actually creating a bias. This way some general questions can be answered, but the person being interviewed also gets the chance to say whatever they want, which might lead to new questions.

3.4.3 Requirement prioritization techniques

When all requirements are collected, a way of prioritizing them is needed. This is needed because of constraints in resources, and to minimize the risk of doing a lot of useless work. There are different methods of prioritizing requirements, including ranking, grouping, the MoSCoW method and the Hundred Dollar Method. Ranking[16] is giving every requirement a number, with 1 being the most important for the project, and 10 the least important. Grouping[16] requirements can give priority to certain groups of requirements, by making some requirements necessary and others optional. The Hundred Dollar Method[16] is a method in which all stakeholders (see 3.2) are given a hypothetical hundred dollars, and are asked to divide this 'money' over the requirements. A stakeholder can decide to 'invest' all the hundred dollars in one requirement, or divide it more evenly over all requirements. Once all stakeholders have given their division of the hundred dollars, the 'money invested' in each requirement can be counted and the total amount of 'money invested' prioritizes the requirements. The MoSCoW method is a way to prioritize requirements, developed by Dai Clegg[17]. This method divides requirements in 4 different categories:

Must

These are the requirements that must be met for the system to be considered successful. If these requirements are not met, the system fails.

Should

These are the requirements that should be met , but are not necessary for the system to be considered successful. If these requirements are not met, the system could still 'solve' the problem at hand.

Could

These are the requirements that could be implemented if there is extra time or extra resources become available. The system can be considered successful if these requirements are not met.

Won't

These requirements will not be met when developing the system. They can be recommendations for later development.

In the end the MoSCoW method was chosen because it gives the quickest and easiest results, making it clear which requirements should be realized and which requirements should be mentioned in the recommendations.

3.5 Scenario based design

Two different methods of analyzing an envisioned system are the PACT-analysis and scenario-based design. In the next sections these will be explained.

3.5.1 PACT-analysis

The PACT-analysis[18] is a technique used to analyze an idea for a new technology. It consists of four categories to analyze an idea: People, Activities, Context and Technology.
The 'People' category explains what characteristics and/or skills the users have. The 'Activities' category describes the activities done with the envisioned system by the users. The 'Context' describes the situation and environment the users will use the envisioned system in. In the last category, the 'Technology' category, the technological aspects of the envisioned system are described in plain words.

3.5.2 Scenario-based design

Scenario-based design is a technique that describes the use of an envisioned system, early on in the design process[19]. This helps the designer to develop the envisioned system in a way that suits the needs of the users.

This technique helps the designer shift the focus from a technology based design to a user based design. This way the designer can keep the users into account better when designing the system, instead of being ‘blinded’ by the technology. The technology can be a perfect solution to a certain problem, but the way the system is used in the end will be determined by the users. Therefore, if a designer keeps the users in mind from an early stage in the design process, it can be easily seen when a design becomes too complex for the users to use it, and it can immediately be altered.

These techniques force the designer to design a system for a user, instead of designing a system that solves the problem, but is too hard to use. It requires the designer to look from the point of view of a user and write a story about how the intended user would incorporate the envisioned system in his or her life and how this would be an advantage as compared to another intended user that does not use the envisioned system.

A distinction is made between a user based scenario and a designer based scenario. The former is a narrative written about a potential user of the envisioned system, that tells the story of how the envisioned system will become part of the everyday life of the user. The user is the point of focus in this type of scenario, so specific technical details are not discussed in this scenario. The interactions with the system are described in plain words and the system is seen as a ‘black box’.

A designer-centric scenario is the same story as the user-centric scenario, but focuses on the design of the system as the name implies. The interactions the user has with the system are highlighted and the designer tries to describe these interactions in a way that helps develop the system by creating requirements.

Chapter 4: Ideation

In this chapter, the ideation phase will be discussed. At the start of the ideation, all stakeholders have to be identified and analyzed and a list of preliminary functional and non-functional requirements has to be created. This list of requirements will be prioritized and used to generate concepts, which will be proposed to the most important stakeholders. This way the stakeholders stay involved in the design process and the proposed solutions can still be altered to fit the needs of the stakeholders. These proposed solutions all try to answer the design question based on the research question.

4.1 Stakeholder identification

Stakeholders are identified and categorized using the method of Sharp et al[10]. This method categorizes stakeholders in four categories: users, developers, legislators and decision-makers. Users will be the people that interact with the system. Developers are stakeholders that have a role in the requirements engineering process. Legislators are the stakeholders that create guidelines that may affect the development or operation of the system. Decision-makers are the stakeholders that make the decisions within the user organization and the development organization.

Stakeholder	**Role**
Motorcyclists	Users
KNMV	Developers
MvI&M	Legislators
SWOV	Developers
Motorcycle manufacturers	Developers, Users
CreaTe Programme	Developers, Decision-makers
Designer	Developers
MSG	Developers

Table 2: Stakeholders and their roles.

In Table 2 above the stakeholders and their roles are listed. As explained before, the motorcyclists will be the users, so their role in the project will be that of the 'users'. The KNMV helped find a direction to go in with the research and pointed towards the SWOV, therefore they took on the role of developers. The MvI&M create laws that may influence the development of the envisioned system, so they are the legislators for this project. The SWOV, as mentioned before, did a lot of research that gave this project directions to go in and problems to solve. This is why the SWOV has been given the role of developers. Because the envisioned system is something that could be integrated into a motorcycle, the motorcycle manufacturers became developers, because they could come up with requirements like for instance measurements or even color. They have two roles, as they could also become the users of the envisioned system if they integrate the system into a motorcycle. The CreaTe Programme has two roles, developers and decision-makers, because it requires the project to be finished in a certain time, therefore influencing the development. The CreaTe Programme is also a decision-maker, because at any point in time they can decide that the project is over. The designer in this project is one of the developers, as is the MSG, because they help form the project and help decide what requirements to realize.

4.2 Stakeholder analysis

To analyze the impact that the identified stakeholders have on the development process of the system, an influence-interest matrix[11] is made. This matrix (Figure 11) shows the influence on and interest in the development process that each stakeholder has, relative to each other.

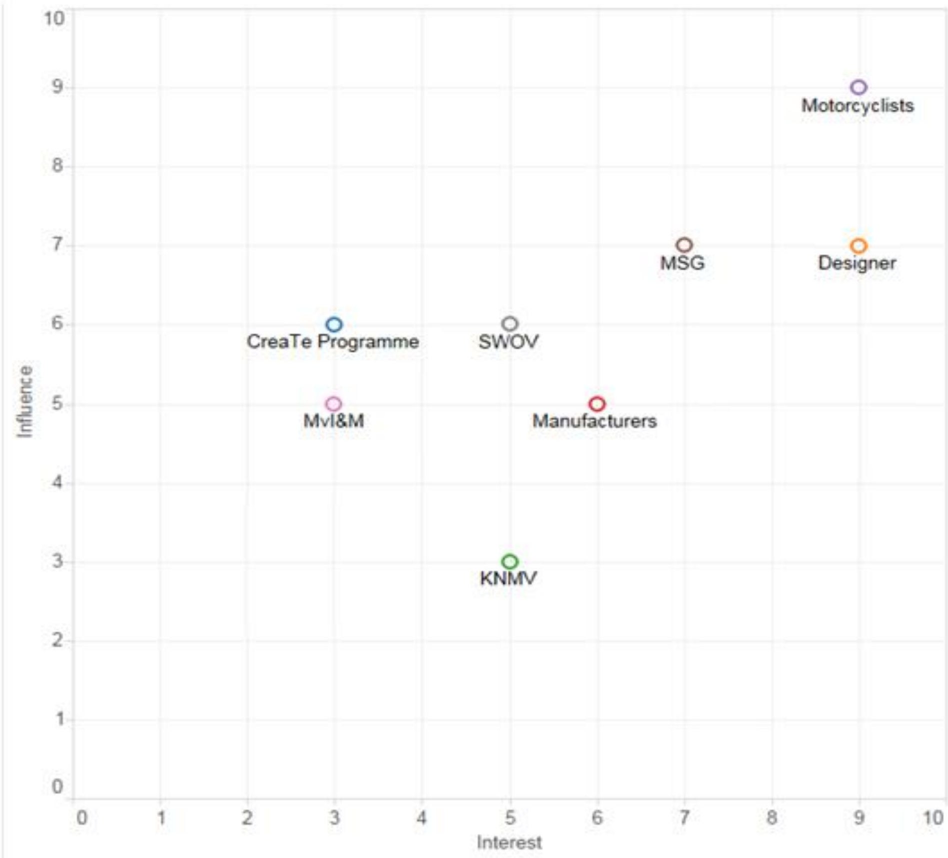

Figure 11: Influence-interest matrix of all stakeholders.

As can be seen in the matrix, the motorcyclists have the most influence. They have been given the most influence because they will be the users, who can give details about specific situations that occur while riding motorcycle, which led to requirements for the envisioned system. After the first e-mail to the MSG was answered, it became clear that they have interest in the envisioned system. These are the reasons the MSG will be actively involved in the development process, but the motorcyclists themselves will have more influence and interest.

The SWOV has also been given more influence than other stakeholders, because their research gives the development of the envisioned system direction, by showing what kind of accidents occur most and might need special attention. The interest of the SWOV has been set to neutral, because they would only want to research a system that is being used in the real world.

The MvI&M has been given a neutral influence, because they do make the laws that could influence the development of the envisioned system, but they do not directly influence the development process of the system. They are also not actively involved, as the envisioned system might not need new laws to be created, therefore they have low interest.
The motorcycle manufacturers have been given a neutral influence, because they do not necessarily influence the system itself, but they might want to influence things like shape or color when the system is finished, to make it fit their specific brand. They have some interest in the system, as having the system on the motorcycles they sell, could make potential buyers choose their brand over others that do not have the system.
The KNMV has been given a low influence because they will not directly participate in the development process of the system. They have a neutral interest, because if the system is finished and working, they could be willing to defend the system.
The CreaTe Programme has been given medium influence in the development of the system, because they have to be satisfied with the finished product for it to be considered a pass for the graduation project. The Create Programme has low interest in the project itself. We are the designers, and have the most interest because it is our graduation project and we would like to present a solution to this problem.

4.3 Requirements elicitation

After all stakeholders have been identified and analyzed by giving them a spot in the interest-influence matrix, requirements need to be obtained by interviewing the most important stakeholders, the motorcyclists.
MSG has the most influence, as they represent the motorcyclists that are most likely to become users of the system. Therefore, they are the first stakeholders to be interviewed about their requirements for the system.

This semi-structured interview (Appendix x) was created based on the word cloud made in chapter 2. First, an e-mail was sent to ask who wanted to take part in this interview. This was done by e-mail because it can reach a large audience at once. After getting a couple of responses and doing interviews with these people, the semi-structured interview could be altered a bit, because some questions turned out to be more important than others.
This altered version of the interview was used to interview members of ‘Wie Rijdt?’, a page on Facebook with 28.000 members, of which the biggest part are motorcyclists. This was done because a way bigger audience could be reached this way. A first general post was placed, asking if there would be interest in answering questions about the envisioned system. If they had interest, they were asked to send us a private message through Facebook Messenger. Around 20 people responded and the interview was done with 15 of those people. By asking questions about possible challenges motorcyclists face during riding, it could be found out what they thought was needed. By then asking questions about how they would want the problem to be solved, has led to additional preliminary requirements for the envisioned system. A list of (non-)functional requirements was made and prioritized using the MoSCoW model. A distinction was made between functional and non-functional requirements.

4.4 Overview of preliminary requirements

In Table 3 the (non-functional) requirements are listed according to the MoSCoW model as mentioned before. They have all been given a number for later reference, which consist of the letters FR or NFR, meaning functional requirement or non-functional requirement, and a number.

Functional requirements	
FR1	The system **must** be able to determine a safe following distance depending on the speed of the motorcycle (see safe following distances in Appendix x)
FR2	The system **must** be able to measure distance to moving/stationary objects (vehicles)
FR3	The system **must** be able to notify the motorcyclist
FR4	The system **could** be able to notify the driver of the vehicle behind the motorcyclist by generating a signal
FR5	The system **could** be able to recognize covers/lines on the road
FR6	The system **could** be able to connect to existing devices like Bluetooth headsets
FR7	The system **won't** be able to interfere with braking/throttle
Non-functional requirements	
NFR1	The system **must** not be distracting
NFR2	The system **should** be able to fit on or inside a helmet
NFR3	The system **should** be able to fit on or inside a motorcycle
NFR4	The system **should** be lightweight
NFR5	The system **should** be affordable

Table 3: Functional and non-functional requirements.

Since there is a restriction in resources, we aim to implement the 'must' requirements. The rest of the requirements could be implemented later on, if the system is further developed.

4.5 Concept generation

In this section the list of (non-)functional requirements, that was made in the previous section, will be used to generate five different concepts that fulfill multiple requirements. The requirements used are listed before the concept is explained.

4.5.1 Distance Reminder

Requirements: FR1, FR2, FR3, FR6, NFR1, NFR3

A distance sensor is placed on the motorcycle, pointing forward and constantly measuring the distance to the vehicle in front of the motorcycle. Another sensor is placed pointing to the rear, which is also constantly measuring the distance to the vehicle behind the motorcycle. These sensors should have a threshold, which should be determined by the speed of the motorcyclist. The faster the motorcyclist is riding, the more distance there should be between the motorcycle and the vehicles behind and ahead of the motorcycle. If a vehicle is spotted within the threshold of the sensor, this should be registered and a feedback should be given to the motorcyclist in the form of a vibration in the helmet. This vibration can become stronger, the closer the vehicle comes. This system can be useful when the attention is lost for a brief moment and the vehicle in front of the motorcycle suddenly slows down, or when the motorcycle slows down and the driver of the vehicle behind the motorcycle is not paying enough attention. See Figure 12 for an illustration of this concept.

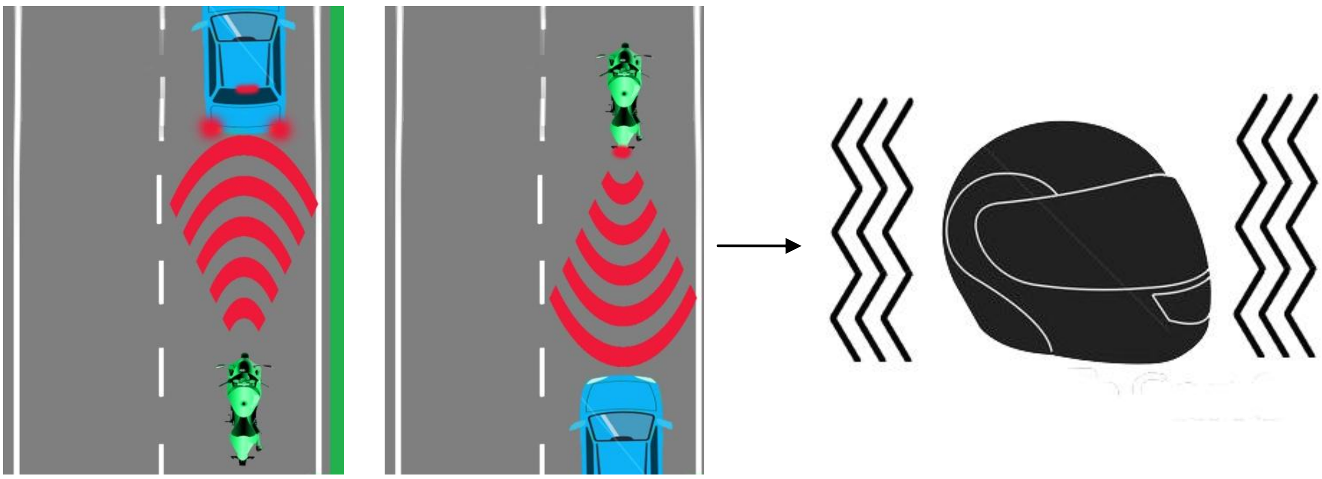

Figure 12: Distance Reminder illustrated.

4.5.2 Side Street Assist

Requirements: FR1, FR2, FR5, NFR2

A sensor is placed on the front right hand side of the motorcycle, facing forward at an angle. This sensor will be aimed at the stripes on the side of the road some distance ahead of the motorcyclist, to be able to recognize streets from the side and vehicles coming from there. A small screen is placed on the handlebars or in the cockpit, which can show a red, an orange and a green light. In a normal situation, the green light would burn. When approaching streets on the right with adapted speed, the green light would still burn. However, when a street on the right is coming up and the speed is not adapted, the orange light will burn, to notify the motorcyclist that the speed needs to be altered or the motorcyclist should at least pay attention. If a vehicle is recognized in an upcoming street from the right, the red light will burn/blink, notifying the motorcyclist to pay even more attention. The same system could be applied in a highway situation, when the motorcyclist is in the left lane overtaking another vehicle. The system would still be aimed at the stripes, noticing when the motorcyclist changes to the left lane. If a vehicle crosses the line some distance in front of the motorcyclist, the red light will start blinking. See Figure 13 for an illustration of this concept.

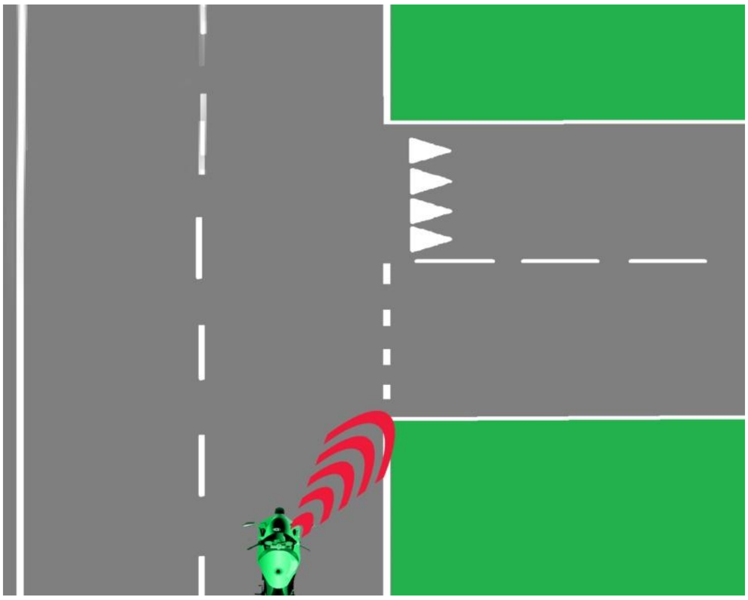

Figure 13: Side Street Assist illustrated.

4.5.3 Rear Traffic Assist

Requirements: FR2, FR3, NFR3

A rear view camera is placed on the back of the motorcycle/helmet. Small lights are placed in both mirrors. The system should be able to process the images from the rear view camera and recognize an empty road or a road where a vehicle behind the motorcycle is at a safe following distance. When a vehicle is detected that comes at the motorcycle too fast, the lights in the mirrors light up. If the motorcyclist detects a traffic jam and has to keep his attention forward, the rear view camera can help detect car drivers coming up from behind who are not paying attention. The lights in the mirror can start blinking, indicating a greater form of danger and giving the motorcyclist a small stimulation to look in the mirror while still paying attention to what is developing in front of the motorcycle. See Figure 14 for an illustration of this concept.

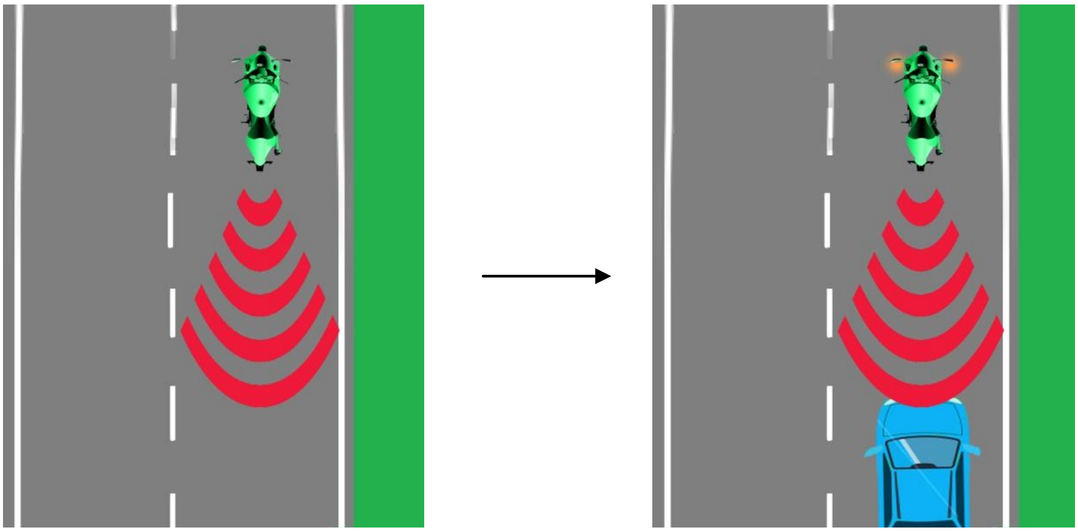

Figure 14: Rear Traffic Assist illustrated.

4.5.4 Blind Spot Helper

Requirements: FR2, NFR1, NFR3

A distance sensor is placed at the rear of the motorcycle, facing backwards at an angle (on both sides of the motorcycle). This way it can be measured whether there is an object in the blind spot of the rider (area not visible in the mirrors). Small lights are placed in both mirrors that light up when an object is detected in the blind spot. This way the system always reminds the motorcyclist of a vehicle in the blind spot, for when the motorcyclist wants to switch lanes. It also helps detect vehicles that are passing the motorcyclist, but are in the blind spot at the time the motorcyclist looks for them. See Figure 15 for an illustration of this concept.

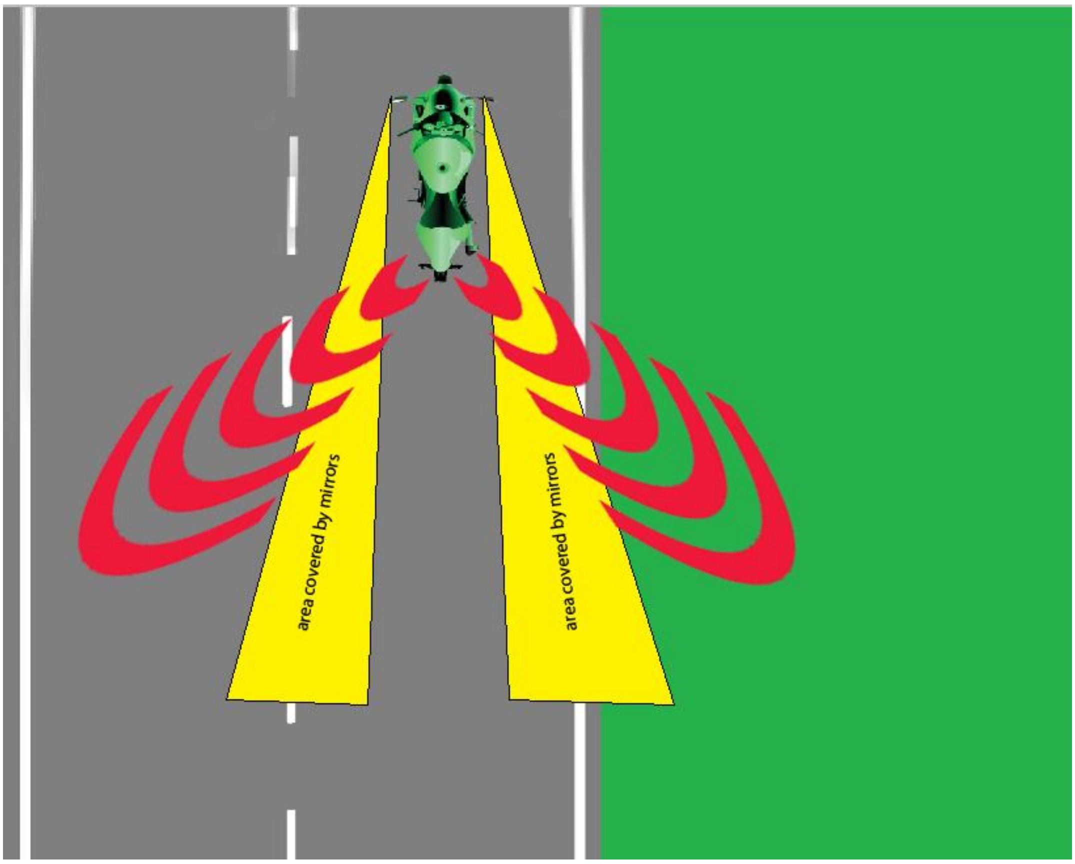

Figure 15: Blind Spot Helper illustrated.

4.5.5 Corner Speed Reminder

Requirements: FR3, FR5, NFR1, NFR3

A camera is placed on the motorcycle, facing forward. It is set to black and white to make the lines on the road stand out, to help the system recognize these lines. The bend in the line is measured to determine the severity of the corner. The sharper the corner is, the more the lines on the side of the road will bend. Based on this, an estimated speed is advised to the motorcyclist by showing a small number next to the speedometer before the corner is reached. When the motorcyclist checks his speed before entering the corner, he can tell whether he is going too fast or slow enough to make the corner. If the speed is extremely high before the corner, the small number can start blinking. See Figure 16.

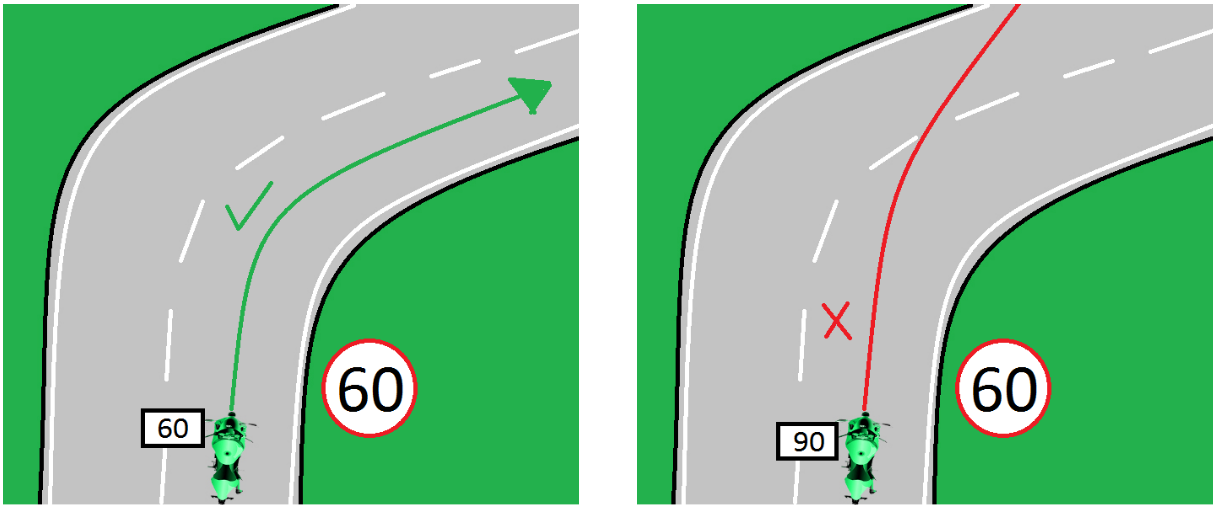

Figure 16: Corner Speed Reminder illustrated.

4.6 Chosen concept

The chosen concept is concept 4.5.1, the Distance Reminder. This concept has been chosen because it can be an answer to the research question and it is feasible to realize within the available resources. The technology used for this concept is available and a proof of principle can be achieved with affordable technology. For a better function of the final system, more expensive technology can be used.

4.7 PACT-analysis

The PACT-analysis is used here to make a setup for the user based scenario.

People

Motorcyclists taking part in modern day traffic.

Activities

Using the Distance Reminder to help spot potentially dangerous situations by increasing situational awareness.

Context

The Distance Reminder is placed on the motorcycle and uses the electrical power supplied by the motorcycle battery. It is intended for use inside the city, in rural areas and on the highway.

Technology

An add-on motorcycle appliance that is capable of measuring distance in four directions (front, rear, left and right) to (moving) objects while driving, and providing feedback to the motorcyclist to increase the situational awareness of the motorcyclist.

4.8 User based scenario

Bob is a 52 year old teacher for a high school, who is enthusiastic about riding motorcycles in his spare time. He does this together with his friend Tim, who is 54 years old and also a teacher at the same school. Bob has had his motorcycle driving license for 8 years now, and Tim has had his license for 15 years. Both like the feeling of freedom a motorcycle can give, but neither of them has an extreme need for speed. They like casual cruises on Sunday afternoons, preferably along the beach and smaller roads just outside of town. If they come across a highway, they do not avoid it, but try to get back to a smaller road as soon as possible. They both like enjoying the scenery.

Today started as any normal day in the life of Bob. He woke up at 7am, took a shower and made some coffee while getting dressed. He always has to bring his briefcase with him to his job, so going by motorcycle is not an option. He goes by car and leaves at 8am sharp every morning, to arrive at his work at 8:13, so he has some time left to prepare the class before the students walk in. Today he has to prepare himself to tell the class that everybody failed last week's exam. This has been bothering Bob, as it could potentially be his fault that everybody failed.

At 8:30 all students have arrived and Bob tells everyone that they failed. He gets some serious resistance from the students and they all blame him for not explaining the subject properly. He continues giving the class and the rest goes well, but it keeps bothering him that it is his fault everybody failed.

Bob meets his coworker Tim during the break at 11:00 and has a cup of coffee with him while discussing the results from Tim's class. Tim reassures Bob that the subject matter was just too hard for the student and half of his class also failed. Bob calms down but is still not one hundred percent convinced that it was not his fault.

Bob finishes his last class at 14:20 and starts packing his stuff to go home. Tim walks in and asks Bob if he wants to go for a ride later today. Bob agrees and goes home. Tim agrees to go home to pick up his stuff and then come to Bob's house. Bob arrives home and drops off his stuff. He feels like riding his motorcycle might relieve some of the stress caused by the failed exam.

At 15:00 Tim arrives at Bob's house with all his protective gear on. Bob is just finishing putting his gear on. They walk outside together and Tim walks to his own motorcycle (no Distance Reminder). Bob gets his motorcycle (with Distance Reminder) from the garage. They start the ride by going through the city, towards the rural areas. When they get to the rural roads, they start sightseeing. Tim notices a weirdly colored cow, and tries to point this out to Bob. Because Tim does not have a way of communicating (e.g. headset / walkie talkie), it is hard for Bob to figure out what Tim means. Tim is paying attention to the road again, while Bob is still looking for what Tim meant. Bob loses his attention to the road for a split second and starts shifting away from the centre, slowly going towards the side of the road. His Distance Reminder notifies Bob, giving him the chance to regain attention and correct his speed. Bob lives to see another day.

After almost two hours of riding, Bob and Tim decide to go back home. To get back home, they have to go on the highway for a bit. Because it is almost 5pm, the roads are getting busy with people going home from work. Bob is slightly tired and his mind is still not fully focused on the road, as the reactions from his students are still in the back of his head. As his thoughts start to drift away, he does not notice the traffic jam forming in front of him. Bob continues riding the same speed. His Distance Reminder notifies him and he gets the chance to brake and switch to the left lane. Tim is also tired, but his focus is still there. However, he notices the traffic jam a bit too late because he was paying attention to the vehicle behind him and has to brake quite hard while performing an evasive maneuver .

At 17:14 Bob and Tim arrive at Bob's house and Bob puts his motorcycle back in the garage. They sit and talk about the ride for a while. Tim tries to remind Bob of the moment where he almost crashed into the back of the traffic jam, but Bob does not remember this as his Distance Reminder made it a normal non-scary situation for him.

Chapter 5: Specification

In the previous chapter a list of requirements was made, which has lead to five different concepts. One of these concepts was chosen and a user-centric scenario was written. In this chapter, the chosen concept will be specified and its functionality will be explained. When this is done, a lo-fi prototype can be made and tested, to improve the list of requirements and create a hi-fi prototype based on those additionally found requirements.

5.1 Analysis of user based scenario

In section 4.8 a scenario is written about Bob. In this scenario he interacts with the system at two different moments in time. In this section, these two situations will be analyzed from a designer's perspective.

The first moment is when Bob loses attention for a while, when looking at the countryside. At this point in time, the system is constantly sensing/measuring to the side of the motorcycle to check whether the road next to the motorcycle is clear. It constantly sends "pulses" to the side and waits for the echo of these pulses to come back. It then calculates the distance to the closest object. If an object is within a set 'safe zone' (dependent on the speed of the motorcycle) the system must be able to recognize this and notify Bob. This alert should give Bob enough information about where the danger is coming from, while at the same time notifying Bob to undertake action.

The second moment Bob interacts with the system is when he is riding on the highway and a traffic jam forms in front of him. The system senses the speed Bob is traveling at, to calculate the 'safe zone' in front of and behind him. Because of the traffic jam, the system senses objects in front of the motorcycle, coming within the 'safe zone'. Because Bob does not alter his speed, the combination of speed and objects in the 'safe zone' is registered as a potentially dangerous situation by the system. It processes this information and notifies Bob. This tells Bob that a dangerous situation is in either in front of or behind him and a good thing to do would be to look forward, to determine whether he should steer or brake.

Analyzing these situations from a designer's point of view shows that the system needs to perform three main tasks:

1. Measuring distance to (moving) objects
2. Calculating 'safe zones'
3. Giving feedback

In the next few sections, these three main tasks will be analyzed and divided into smaller tasks to acquire additional (more specific) requirements for the envisioned system. These new requirements will be listed at the end of each section.

5.2 Measuring distance to (moving) objects

Starting with the first part of measuring, it can be seen that multiple sensors will be needed to accomplish the task of measuring distance to (moving) objects.

5.2.1 Side Distance Module

For the sides of the motorcycle, the sensors need to be able to at least measure the width of one lane on the road. The smallest width of a lane in the Netherlands is 2,75m, the widest lane is 4,50m[20]. Therefore, the sensors must be able to sense at least this far. On most roads, interactions on the sides with other road users mostly occur when switching lanes, for instance when a vehicle wants to overtake another vehicle. This means that the speed at which a vehicle approaches the motorcycle is usually not very high, as it would be when a vehicle would be coming at the motorcycle from a side street. This means that this speed is not very important, the important piece of information here is the distance between the approaching vehicle and the motorcycle. See Figure 17 for a schematic view of the module.

Requirements for Side Distance Module:

1. The module must be able to measure distances up to 4,5 meter

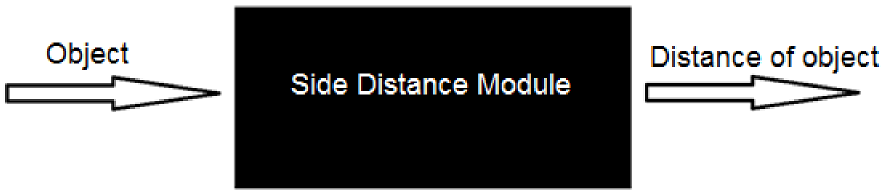

Figure 17: A schematic view of the Side Distance Module

5.2.2 Front and Rear Velocity Module

The Front and Rear Velocity Module needs to be able to measure over a larger distance than the Side Distance Module, because these are the directions that the speed is usually directed in. When the motorcycle is riding, everything in front of the motorcycle can be seen as coming towards the front of the motorcycle, while when the motorcycle is braking, moving objects behind the motorcycle can be seen as coming towards the rear of the motorcycle. Therefore, in this case it is not the distance to the (moving) object that is required, it is the velocity at which the moving object is coming towards the motorcycle that is useful.

Another requirement for the Front and Rear Velocity Module is that it needs to be dependent on the velocity of the motorcycle. The faster a vehicle is going, the more time it needs to brake. A general rule is to keep two seconds of distance, making the following distance dependent on the velocity that both vehicles have. Because stopping distance is based on vehicle mass, tire friction and braking force, and a motorcycle only has very little of each, its stopping distance can be longer than average. Therefore, it is recommended to keep three seconds of following distance when riding on a motorcycle.

When keeping three seconds of distance, the distance covered while braking – even on a wet road – is still smaller than the following distance, meaning the motorcyclist would be able to brake in time and stop in time, given that he is paying attention and actually brakes immediately. See Appendix II for data and calculations on following and stopping distance. See Figure 18 for a schematic view of the module.

Requirements for Front and Rear Velocity Module:

1. The module must be able to measure the velocity of an object
2. The module must be able to measure over a large distance (±100m)

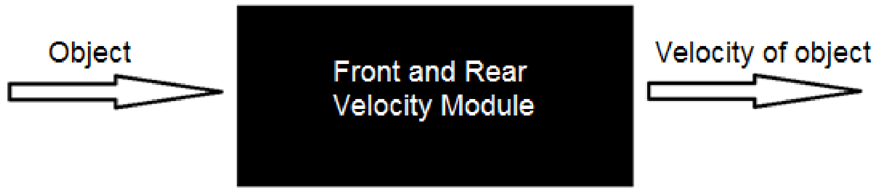

Figure 18: A schematic view of the Front and Rear Velocity Module

5.2.3 Speedometer

To determine the speed that the motorcyclist is riding with, a module is required that can measure this speed. This information will be used to calculate 'safe zones'. See Figure 19 for a schematic view of the module.

Requirements for the Speedometer module:

1. The module must be able to measure the velocity of the motorcycle

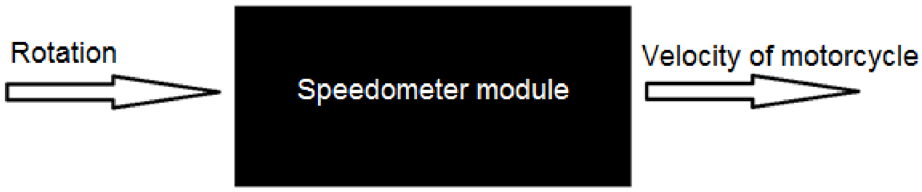

Figure 19: A schematic view of the Speedometer Module

5.3 Calculating 'safe zones'

For the processing part, a processing module should be created. This receives the data from all the sensing modules and processes this data to determine whether the situation is safe, or unsafe. A processing module is needed here because the raw data coming from the sensors needs to be processed, before it can be useful to the user of the system.

The processing starts with retrieving the velocity of the motorcycle from the speedometer module. With this information the 'safe zone' can be calculated. For the Side Distance Module, the 'safe zone' can be three different options:

- 50 centimeters under 10 kilometers per hour
- 100 centimeters between 10 and 20 kilometers per hour
- 150 centimeters over 20 kilometers per hour

This means that a 'free space' of at least 50 centimeters has to be measured when the motorcycle is riding up to 10 kilometers per hour. This also means that an object that is measured at for instance 60 centimeters, will be considered safe when passed with a velocity of 10 kilometers per hour, but will be considered unsafe when passed with a velocity of for instance 15 kilometers per hour.

For the Front and Rear Velocity Module, the 'safe zone' is determined with a calculation.
As mentioned before, when the motorcycle is going forward, all objects in front of the motorcycle can be seen as coming towards the motorcycle. If the motorcycle is going towards a wall at 10 kilometers per hour, it means that the wall can be seen as coming at the motorcycle at 10 kilometers per hour. If this wall is replaced by a car that is traveling at 10 kilometers per hour in the same direction as the motorcycle, it can be seen as a stationary object because the distance between the motorcycle and the car will remain the same. This means that the difference in velocity determines whether the situation can be considered safe or not. The higher the motorcycle's own velocity, the lower the difference can be, as more time is needed to brake.

After these 'safe zones' are calculated, the information from the other sensing modules is retrieved and compared to the 'safe zones', to determine whether the values are within or out of this 'safe zone'.

If this comparison leads to the conclusion that all values of the sensing modules are within the 'safe zone', nothing happens and the situation can be considered safe. If it leads to the conclusion that one of the values is outside of the 'safe zone', the processing module triggers the Feedback Module as the situation could be considered hazardous. See Figure 20 for a schematic view. See Figure 21 for a flowchart of this process.

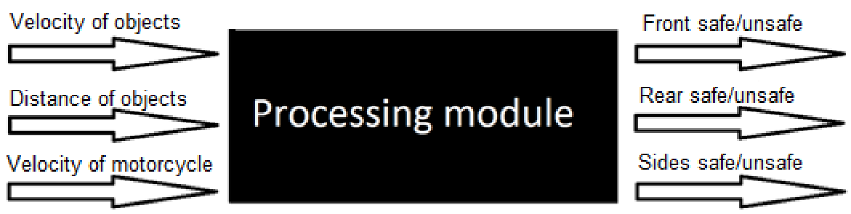

Figure 20: A schematic view of the Processing Module

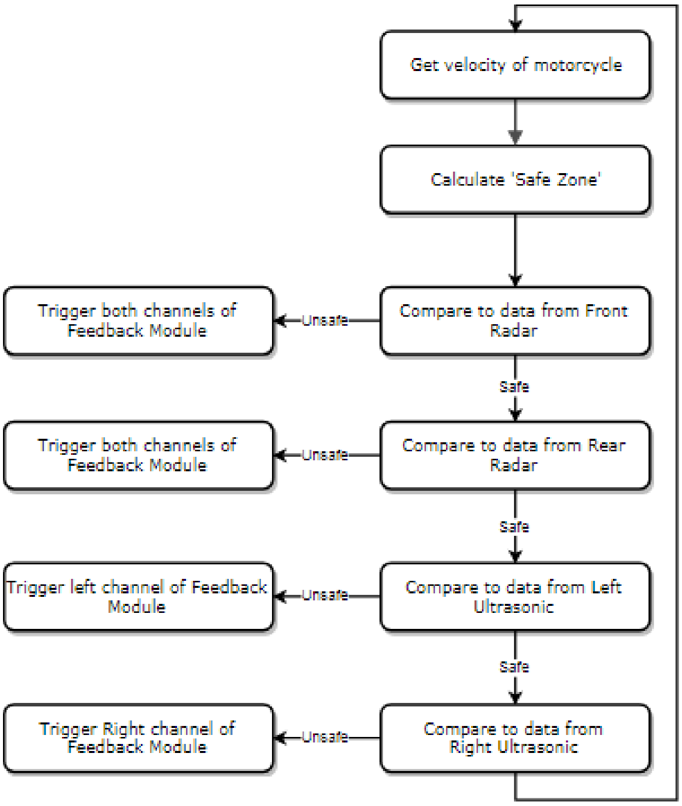

Figure 21: A flowchart that describes the process of the Processing Module.

5.4 Feedback

When all data is received by the sensing modules and processed by the processing module, the last step is to give the user of the system feedback about the situation. This could be done in multiple ways, being:

- Tentative feedback
- Auditory feedback
- Visual feedback

Being on a motorcycle at speed already gives a lot of vibrations, making tentative feedback almost impossible to notice. The motorcyclist needs to keep his attention and therefore his eyes on the road at all times, so trying to give visual feedback in the form of a light or any other way of trying to get the users attention with visual signals, will only be counterproductive as it takes the users attention away from the road. This leads to the conclusion that auditory feedback is the only feasible option in this situation.

This auditory feedback can also be used to distinguish between left and right. When the Processing Module triggers the Feedback Module, it has already processed which sensing module gave the 'unsafe signal'. It transfers this information into auditory feedback from the left, right or both sides of the stereo audio system that is used as a Feedback Module. When the left Side Distance Module determines that a situation is unsafe, the Processing Module triggers the Feedback Module, which makes a sound on the left side. The same goes for the right Side Distance Module and the right side for the Feedback Module. When the Front and Rear Velocity module determines that a situation is unsafe, the Processing Module triggers the Feedback Module, which starts making sound on both sides. See Figure 22 for a schematic view of the Feedback Module.

Requirements for the Feedback Module:

1. The module must be able to deliver stereo audio to the ears of the user

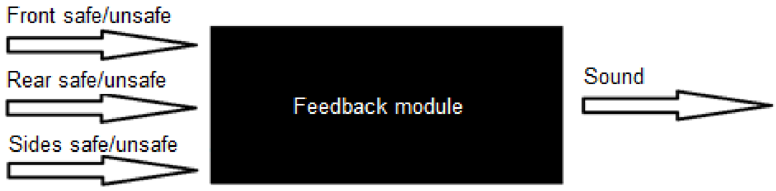

Figure 22: A schematic view of the Feedback Module

5.5 Overview of Updated Requirements

In this next section all requirements to this point will be listed, starting with the updated preliminary requirements from section 4.4, followed by the additional requirements acquired in the previous sections. In Table 4 these requirements are listed with a number according to the same principles as before.

Functional requirements	
FR1	The system **must** be able to determine a safe following distance depending on the speed of the motorcycle (see safe following distances in Appendix II)
FR2	The system **must** be able to measure distance to moving/stationary objects (vehicles) **over a distance of at least 1,5 meter[sides]**
FR3	The system **must** be able to measure velocity of moving objects (vehicles) **over a distance of at least 100 meter[front and rear]**
FR4	The system **must** be able to notify the motorcyclist **through stereo audio, making a distinction between left, right and front/rear**
FR5	The system **should** be able to connect to existing devices like Bluetooth headsets
FR6	The system **won't** be able to interfere with braking/throttle
Non-functional requirements	
NFR1	The system **must** not be distracting
NFR2	The system **should** be able to fit on or inside a helmet
NFR3	The system **should** be able to fit on or inside a motorcycle
NFR4	The system **should** be lightweight
NFR5	The system **should** be affordable

Table 4: Functional and non-functional requirements.

Chapter 6: Realization

In the previous chapter "Specification", a functional specification was made by coming up with functional requirements and a user interaction scenario. In this chapter, this functional specification will be realized by implementing a prototype of the full system. In this chapter, each section explains how the different subsystems are realized.

6.1 Measuring/sensing

The first part of the system that will be realized are the sensing modules, which are responsible for receiving the information that will later on be processed. In the next few sections, the different sensor modules will be realized according to their functional specification.

6.1.1 Sides Distance Module

For the part of the system that monitors the sides of the motorcycle, a distance sensor is needed with a range of at least 1,5 meter, so that it is able to sense one side of a lane on the road if the motorcycle is riding in the middle of the lane (see section 5.2.1). If the motorcyclist is not riding in the middle of the lane, but slightly more to the left as motorcyclists tend to do, the sensor on the right hand side needs to cover more distance. Thus, the range that the distance sensors need to be able to cover, is increased to 2,5 meter at least.

A HC-SR04 ultrasonic sensor[20] with a reach of approximately 4,50m, that returns the distance to an object within this range, fulfills the requirements for the side sensors. When one of these sensors is placed on either side of the motorcycle, an area of 9 meters with the motorcycle in the middle can be covered by the sensors. When a distance of at least 1,5m on either side is obstacle-free, it can be assumed that the situation is safe, as most lanes are 3 meters wide on average. The required range and the actual range of the sensor is illustrated in Figure 23.

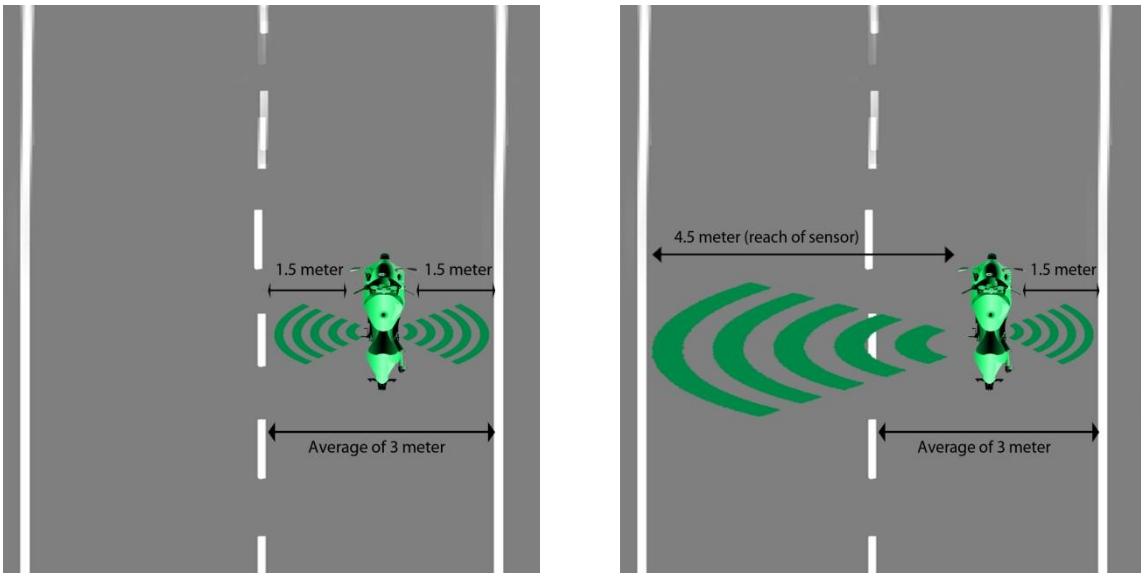

Figure 23: The range of the ultrasonic sensors placed on the motorcycle

The transmitting part of the HC-SR04 sends out an ultrasonic pulse and waits for its echo. When this pulse hits an object and is reflected, the receiving part of this device gets this pulse back and it is registered. The time it took for the pulse to go back and forth is then used to calculate the distance to the object. The total time it took for the pulse to go back and forth is divided by two, because the pulse went back and forth.

The speed of sound at 20°C is 343 m/s and 331,2 m/s at 0 °C.[22] Because the system will be used outside in the Netherlands, it is more likely that the average temperature is closer to 10°C than to 20°C. Therefore, it would be wise to calculate what the speed of sound would be at 10°C. The speed of sound can be calculated with the formula $v = 331m/s + 0.6m/s/C * T,$ where v is the speed of sound and T is the temperature in degrees Celsius[23]. Entering 10 °C as the temperature in the formula, gives 337 m/s as the speed of sound. This value is used to calculate how much distance the pulse has traveled in the time measured. The ultrasonic sensor returns the time and the Arduino code calculates the distance. This distance is then compared to the value calculated for the 'safe zone'. If the distance to the object is smaller than the 'safe zone', the situation is considered unsafe. How the value for this 'safe zone' is calculated is explained in section 5.3 and will be further elaborated in section 6.1.3, where the Speedometer Module of the system is explained.

See Appendix III for the Arduino code for the Sides Distance Module.

6.1.2 Front and Rear Velocity Module

The first requirement, as explained in section 5.2.2, for the front and rear sensors can be fulfilled by a IPM-165 radar sensor[24], as it measures and returns the speed at which a detected object is coming towards the sensor. The second requirement cannot be fulfilled at this point in time, because the Front and Rear Velocity Module has to measure the velocity of objects over a distance that can go up to more than 100 meters. However, radar technology is still very expensive, so with the constraints of money in mind, the choice was made for a somewhat cheaper version of the radar module, which can measure up to 15 meters and would be able to notify the motorcyclist in time, while riding up to **50 kilometers per hour**. This does mean that the highway is no longer part of the places where the system can be safely and reliably used.

The IPM-165 radar sensor works by sending out a radio pulse and waiting for it to return. When nothing is detected, the sensor puts out a signal between 2 and 4 volts. When the radio pulse bounces off of an object and returns, the sensor puts out a clear signal in the form of a square block wave. This is illustrated in Figure 24. The duty cycle is used to calculate the velocity of the object. The duty cycle is the ratio of time a signal is 'high' or 'low', and is measured in percentage of 'high' time.

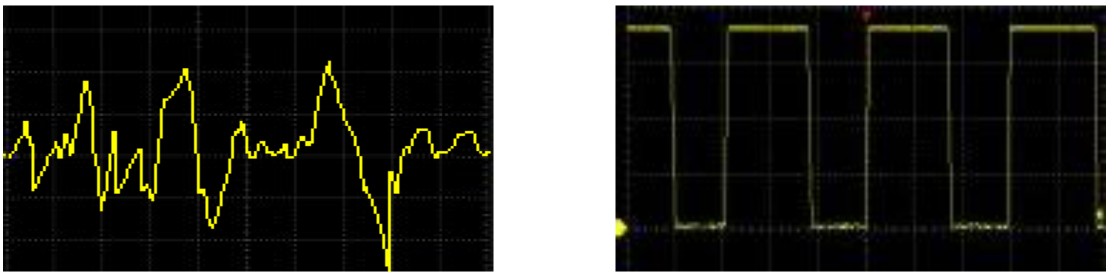

Figure 24: The output the IPM-165 sensor gives, left when no object is detected, right when an object is detected.

See Appendix III for the Arduino code for the Front and Rear Velocity Module.

6.1.3 Speedometer Module

The sensor for the speedometer module has to fulfill the requirement mentioned in section 5.2.3, being that it must be able to measure the velocity of the motorcycle, so that the system can calculate a safe following distance. Furthermore, it should not interfere with the balance of the wheel or with the brakes, so a sensor is required that does not affect the wheel.

A sensor that deals with the problem of not being able to be in or on the wheel, while still doing what is required, is an optic reflective sensor. In this case the OPB-372[25] is used. This uses an infrared LED and an infrared sensor to determine whether something is reflecting the infrared light or not. If something is reflecting the infrared light, the sensor notices that something is in front of it. This is illustrated in Figure 25.

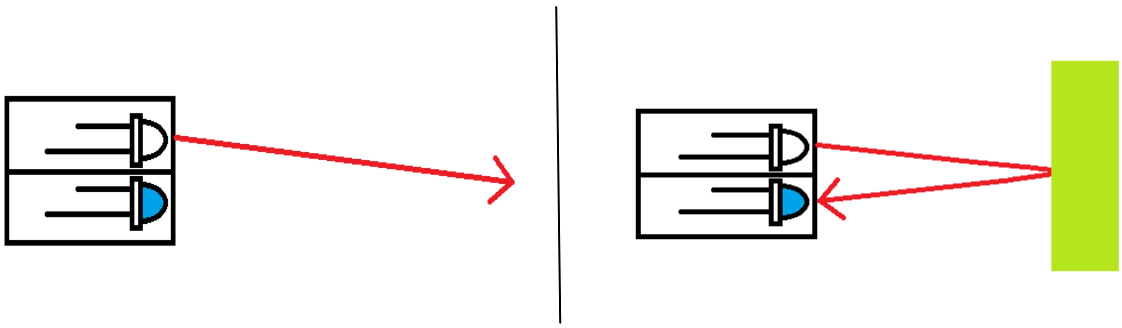

Figure 25: An illustration of how the optic reflective sensor works, left with no detected object, right with detected object.

When this sensor is placed on the swing arm of the motorcycle, facing the wheel, it can detect the spokes of the wheel. This means it can count the amount of times a spoke passes by the sensor. When this data is combined with the amount of spokes the wheel has and the diameter of the wheel, the distance travelled per time span can be calculated. From this, the speed can be calculated. The speed can then be used to determine a 'safe zone', as mentioned earlier.

This 'safe zone' is a zone around the motorcycle that has to be clear of objects before it can be called safe. This zone needs to be bigger as the velocity of the motorcycle gets higher, because braking and steering will take up more space and time.

See Appendix III for the Arduino code for the Speedometer Module

6.2 Processing Module

The Arduino Uno R3 is in this case the link between measuring and user feedback, as it takes measurements from the sensor modules of the system and gives signals to the Feedback Module of the system. There are four Arduinos in the system, each one functions as a subsystem and is implemented as a detachable module. There is one main Arduino (Arduino 1 in Figure 21) that hosts the communication and requests data from the other three Arduinos. This host Arduino also handles the digital audio controller for the feedback, which will be explained in the next section.

The other three client Arduinos are:

- Arduino 2
  - Handles one radar module, sends out the speed at which a detected object is coming towards the radar.
- Arduino 3
  - Handles one radar module, sends out the speed at which a detected object is coming towards the radar.
- Arduino 4
  - Handles two ultrasonic sensors and the speedometer, sends out a Boolean that is true when an object is spotted for both sides and the speed of the motorcycle.

How these Arduinos are connected to each other and their sensors is shown in Figure 26.

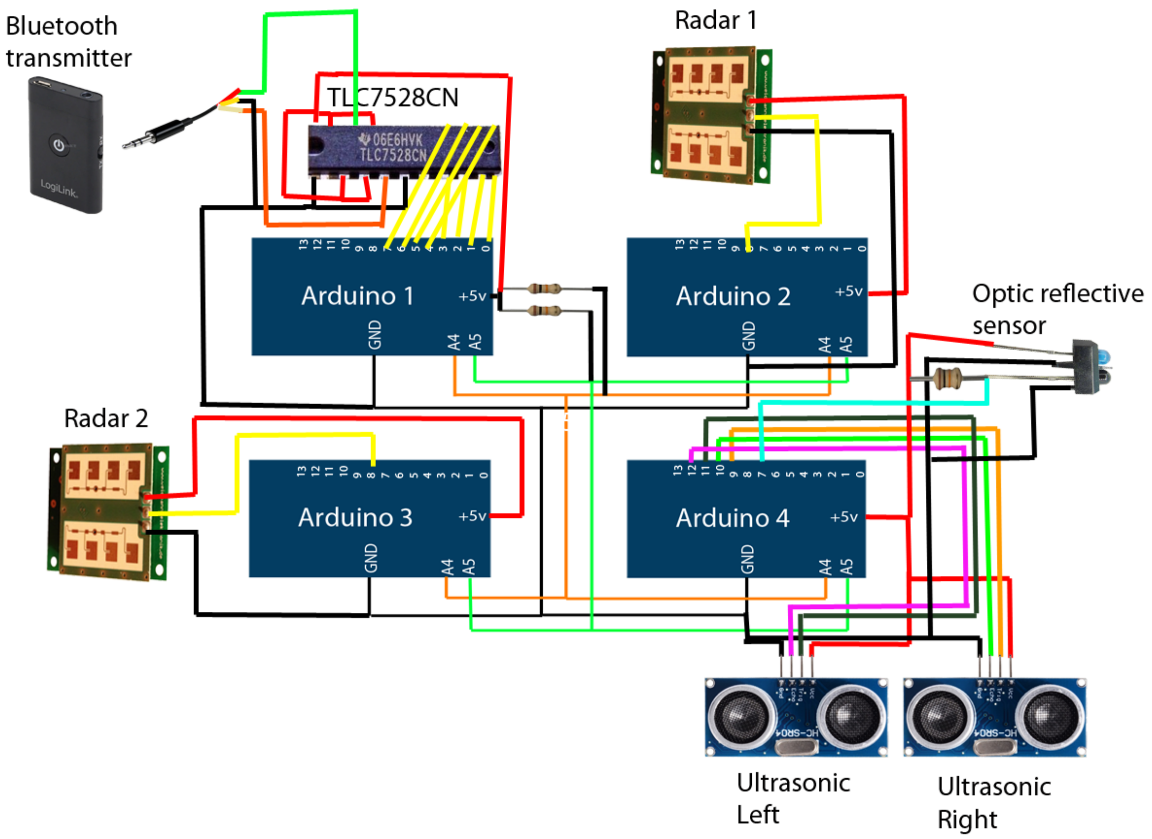

Figure 26: A wiring diagram of the connections between the Arduinos and the sensors.

All Arduinos have a Proto Shield attached on top, on which the components and wires for the sensors are soldered. The protocol that is used to communicate between the Arduinos is the built-in protocol Wire[26]. This requires ports A4 and A5 (see Figure 19) of every Arduino that is connected and a common ground. Two pull-up resistors – one on line A4 and one on line A5 – are needed to prevent distortion of the signal. Each client Arduino is manually assigned its own unique address and the host requests data from this specific address.

The host Arduino takes the speed that it receives from the Ultrasonic Arduino and uses it to determine the 'safe zone'. It sets the value of the 'safe zone' for the ultrasonic sensors to either 50, 100 or 150 centimeter for velocities of up to 10 km/h, between 10 and 20 km/h and up to 30 km/h respectively.

See Appendix III for the Arduino code for the Processing Module.

6.3 Feedback Module

To give feedback to the motorcyclist, a Feedback Module is designed. It uses Arduino to send electrical signals to a Digital to Analog Converter (DAC), which in its turn converts these electrical signals to sound. A TLC7528CN[27] is a DAC that has two channels and can therefore send out stereo signals, which can be used to distinguish dangers on the left and right side of the motorcycle. If an object is spotted on the left side, the Arduino only activates the left channel of the DAC and a sound is produced on the left channel. The other way around works the same, if an object is spotted on the right side, the Arduino only activates the right channel of the DAC. If an object is spotted by one of the radars, both channels are activated and a sound is produced on both sides. It is assumed that the motorcyclist is usually looking forward, and if he is not looking forward and gets notified, his first response is to look forward. If an object is detected in front of the motorcycle, the motorcyclist can see this immediately. If the object is detected behind the motorcycle, the motorcyclist will not be able to see anything in front of him, and can therefore conclude that the object must be behind him.

The sounds that are produced need to be heard by the motorcyclist, so a Bluetooth headset that is built in to the helmet can be used to achieve this. This does mean that between the DAC and the Bluetooth headset, a Bluetooth transmitter has to be placed. The LogiLink Bluetooth Transmitter/Receiver[28} is a device that can perform this task. This Bluetooth transmitter can take the sounds that are produced and send them (through Bluetooth) to the built-in headset.

Chapter 7: Evaluation

In this chapter the hi-fi prototype that was created in the previous section will be evaluated. An explanation of the test procedure will be given and the results of the test will be discussed and analyzed to create a last set of requirements that can be used for further development.

7.1 Functional test

The first set of tests consists of functional tests based on the requirements listed in section 5.5. Every module in the hi-fi prototype gets tested separately to check whether the specific requirements per module are fulfilled.
In the next few sections the tests of the separate modules will be described and a conclusion will be drawn from every test.

7.1.1 Front and Rear Velocity Module

The point of this test is to check the functionality and accuracy of the Front and Rear Velocity Module. The requirement for this module is that it must be able to measure the velocity of an obstacle over a distance of 15 meters and return the velocity of this object to the Processing Module.

The Front and Rear Velocity Module is placed on a table with the radar pointing out from the table towards an open area of 15 meters long and 3 meters wide. The module is connected to a laptop and the Arduino software is showing the Serial monitor, which displays the measured speed.

The tester simulates an approaching object by holding a square piece of paper and moving it towards the radar. This action is repeated at several distances and different speeds. The speeds are set around 2, 5 and 10 kilometers per hour. These speeds are estimates, that are simulated by very slow walking, somewhat faster walking and full on sprinting. If the module returns the right speeds, or at least a speed very similar to the speed expected, at all different distances with a maximum of 15 meters, the module can be considered functional.

The setup of this test is shown in Figure 27. The speeds and distances are shown in Table 5.

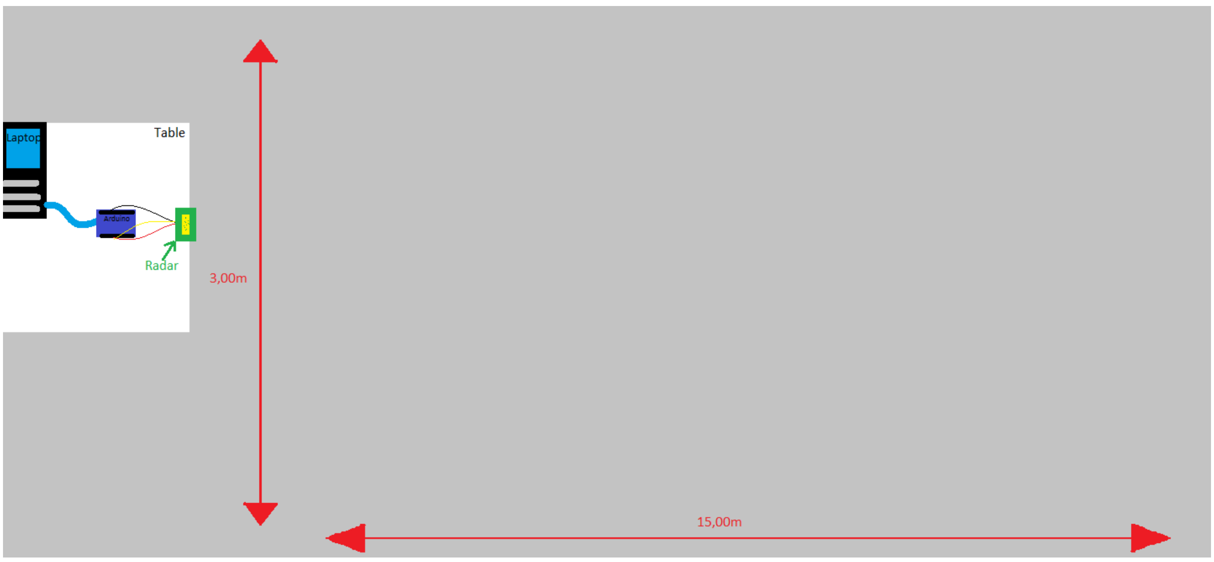

Figure 27: The test setup for the Front and Rear Velocity Module

Speed	Distance	Detected
2 km/h	5m	√
5 km/h	5m	√
10 km/h	5m	√
2 km/h	10m	√
5 km/h	10m	√
10 km/h	10m	√
2 km/h	15m	√
5 km/h	15m	√
10 km/h	15m	√

Table 5: The speeds and distances that were used during the testing of the Front and Rear Velocity Module.

The conclusion of this test is that the Front and Rear Velocity Module returns the velocity of an approaching object and the velocity that is returned is accurate enough, and therefore the Front and Rear Velocity Module fulfills its functional requirement.

7.1.2 Sides Distance Module

The point of this test is to check the functionality and accuracy of the Sides Distance Module. The requirement for this module is that it must be able to measure the distance to a stationary object over a distance of at least the width of an average lane in the Netherlands (3 meters) and up to 4,5 meters and return this to the Processing Module.

The Sides Distance Module is placed on a table with both ultrasonic sensors pointing out from the table towards open areas of 5 meters long and 3 meters wide. The module is connected to a laptop and the Arduino Software is showing the Serial monitor, which displays the measured distances. A tape measure is placed across the area that is covered by the sensors.

The tester simulates an object by holding a square piece of paper. This action is repeated at different distances on both the left and the right side. If the module returns the right distance at all different distances on both sides with a maximum of 4,5 meters, the module can be considered functional.

The setup of this test is shown in Figure 28. The distances are shown in Table 6.

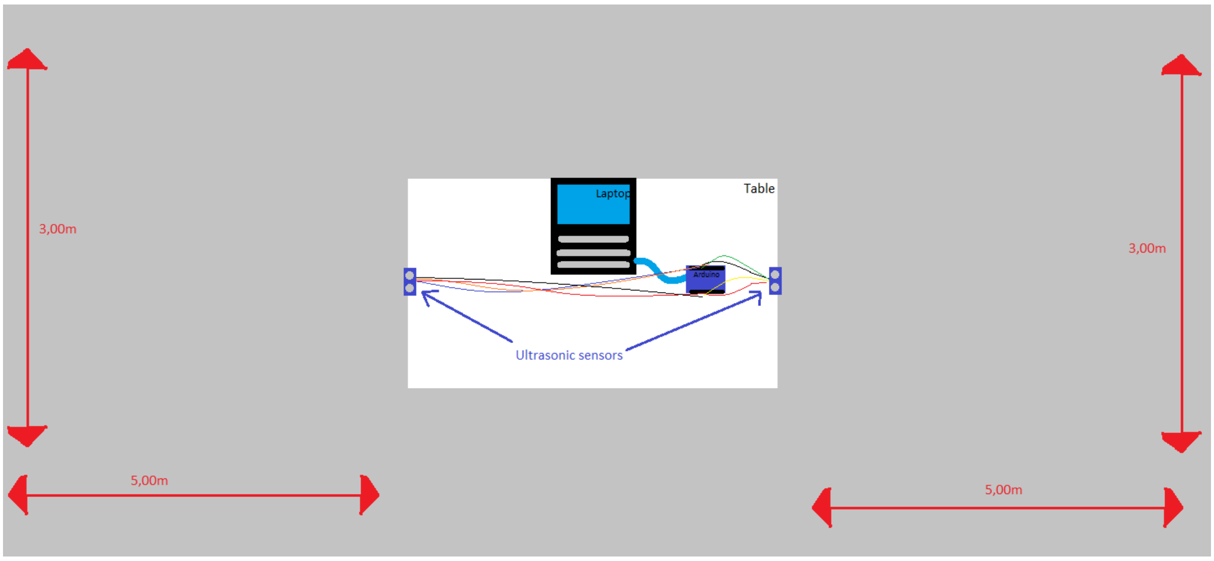

Figure 28: The test setup for the Sides Distance Module

Distance	Distance measured
0,1m	0,1m
0,2m	0,21m
0,5m	0,49m
0,75m	0,75m
1,0m	1,01m
1,25m	1,25m
1,50m	1,50m
2,0m	2,01m
2,5m	2,5m
3,0m	2,99m
3,5m	3,51m
4,0m	4,0m
4,5m	4,46m

Table 6: The distances that were used during the test of the Sides Distance Module.

The conclusion of this test is that the Sides Distance Module returns the distance to an object accurately, and therefore fulfills its requirement.

7.1.3 Speedometer Module

The point of this test is to check the functionality and accuracy of the Speedometer Module. The requirement for this module is that it must be able to measure the velocity of the motorcycle and return this to the Processing Module.

The Speedometer Module is placed on a table, while the sensor is attached to the front fork of a bicycle that is turned upside down. The sensor is facing the wheel, which has several spokes taped together to simulate the spokes of a motorcycle wheel. Figure 22 illustrates the tape in the wheel. A standard bicycle computer (Sigma BC 5.16[29]) is attached to the same bicycle.

The tester spins the wheel at different speeds, starting off slowly and gradually increasing speed. If the speed that is shown in the Serial monitor matches the speed that is shown by the bicycle computer, the module can be considered functional.

The setup of this test is shown in Figure 29.

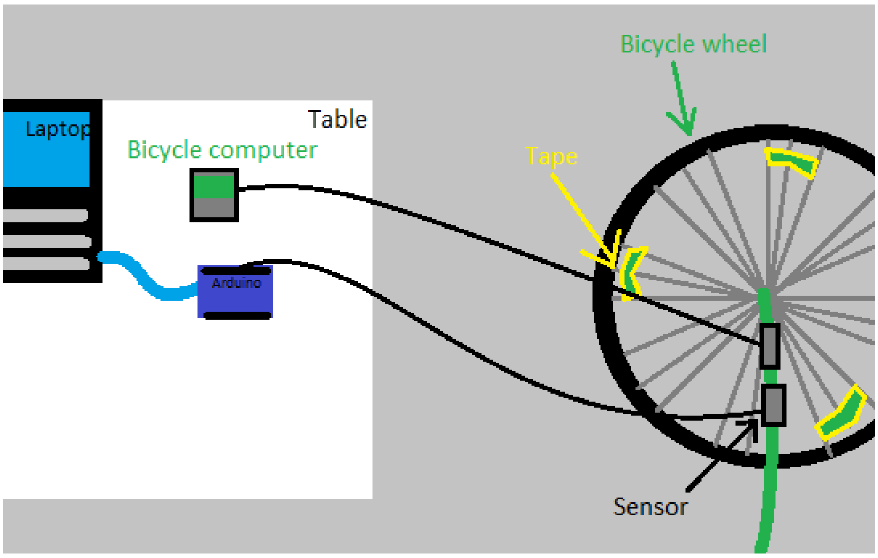

Figure 29: The test setup for the Speedometer Module.

The conclusion of this test is that the Speedometer module returns the speed accurately within a 5% margin in relation to the bicycle computer, and therefore fulfills its functional requirement.

7.1.4 Processing Module

The point of this test is to check the functionality of the Processing Module. The requirement for this module is that it must be able to receive data from the sensor modules (Front and Rear Velocity Module, Sides Distance Module and Speedometer Module), process this data by calculating 'safe zones' based on the speed and checking whether the data coming from the front, rear and both sides is within these 'safe zones'. If the situation is 'unsafe', the processing module must be able to trigger the Audio Feedback Module.

The Processing Module is placed on a table with the Sides Distance Module and Front and Rear Velocity Module connected to it. The Processing Module is also connected to a laptop that is showing the Serial Monitor of the Arduino IDE. A local variable simulates the data that would come in from the Speedometer Module. The data coming in from the sensor modules is printed in the Serial

Monitor. Two LEDs on a breadboard are connected to the Processing Module to simulate the left and right channel of the Audio Feedback Module.

The tester repeats the tests explained in section 7.1.1 and 7.1.2 to generate data from both sensor modules. The speed that is simulated is different for the first four tests than for the last four tests, to make sure that the first four give a ‘safe’ result and the last four give an ‘unsafe’ result. There are four different results the module needs to achieve to be considered functional:

- ‘danger’ on the left side should lead to the left LED burning.
- ‘danger’ on the right side should lead to the right LED burning.
- ‘danger’ from the front should lead to both LEDs burning.
- ‘danger’ from the read should lead to both LEDs burning.

‘Danger’ in all four of these scenarios is caused by data coming from the sensors outside the ‘safe zone’. In the first four tests, the speed is set to 0. In the last four tests, the speed is set to 15 kilometers per hour. The distance to the sides is set at 1 meter.

The conclusion of this test is that the Processing Module can receive the data, process this data and trigger the Audio Feedback Module, and therefore fulfills its functional requirements.

Test	**Expected result**	**Result**
Test 1: 0 km/h left	LEDs not lit	LEDs not lit
Test 2: 0 km/h right	LEDs not lit	LEDs not lit
Test 3: 0 km/h front	LEDs not lit	LEDs not lit
Test 4: 0 km/h rear	LEDs not lit	LEDs not lit
Test 5: 15 km/h left	Left LED lit	Left LED lit
Test 6: 15 km/h right	Right LED lit	Right LED lit
Test 7: 15 km/h front	Both LEDs lit	Both LEDs lit
Test 8: 15 km/h rear	Both LEDs lit	Both LEDs lit

Table 7: The different speeds for the test of the Processing Module.

7.1.5 Audio Feedback Module

The point of this test is to check the functionality of the Audio Feedback Module. The requirement for this module is that it must be able to deliver stereo audio through Bluetooth to the ears of the motorcyclist.

The Audio Feedback Module is placed on a table and a breadboard with two buttons on it is connected to it. The buttons simulate the signals coming from the Processing Module (left and right). A Bluetooth headset is connected to the Audio Feedback Module and placed on the head of the tester.

The tester first presses the buttons one at a time, and subsequently presses both buttons at the same time. The Audio Feedback Module can be considered functional if it creates a sound on the left side if the left button is pressed, on the right side if the right button is pressed, and on both sides if both buttons are pressed. It should not make a sound when none of the buttons are pressed.

Button pressed	**Expected side**	**Actual side**
Left	Left	Left
Right	Right	Right
Left + Right	Left + Right	Left + Right

Table 8: The results of the test of the Feedback Module.

The conclusion of this test is that the Audio Feedback Module delivers stereo audio feedback to the ears of the motorcyclist, and therefore fulfills its functional requirement.

7.1.6 Conclusion functional test

All different modules of the hi-fi prototype proved to be functional and fulfilled the requirements. This means that the hi-fi prototype in its current form is ready for user testing.

7.2 User test

Once the hi-fi prototype proved to be functional, a user test could be performed. This test was done to introduce the system to the participant and to check whether the hi-fi prototype would function according to the needs of the user in a simulated 'real life situation'. The hi-fi prototype is shown in Figure 30. In the next section the test procedure will be explained, after which the different parts of the test will be discussed and the results will be analyzed.

Figure 30: The hi-fi prototype.

7.2.1 Test procedure

The user test starts off with an introduction, in which the background of the project is explained and the system is introduced to the participant.

After this, the tests are explained to the participant. In the first test the participant is asked to name the direction he or she thinks the 'danger' is coming from. In the second test the participant is asked to cycle around in laps and brake when the hi-fi prototype gives feedback. Further explanation on the full procedures of these tests can be found in section 7.2.2 and 7.2.3.

Once both tests have been explained to the participant, he or she receives Bluetooth headphones which are connected to the hi-fi prototype and the orientation test can be started. In this test the participant fills out the form while doing the test.

After the orientation test has been concluded, the participant gets on the bicycle while still wearing the headphones to start the running test. After this test has been done, the participant fills out the running test evaluation form and the questionnaire.

When both of these have been filled out, there is some room for a small after test discussion in which the participant can give some general remarks on (their interaction with) the hi-fi prototype. This discussion is the final part of the test, after which the participant is thanked for their participation and can leave. The steps that have been explained in this section are listed in Table 9, with the time in minutes indicating when the next step is supposed to start.

Time in minutes	**Activity**
0	Welcome and introduction
2	Explanation of tests
	Participant receives headphones
5	Orientation test
7	Participant does 5 laps on the set course
	Fill out running test evaluation form
15	Participant fills out questionnaire
18	After-test discussion
20	End of test

Table 9: The different steps in the test procedure and their start times in minutes

7.2.2 Orientation test

The point of the orientation test is to get the participant familiar with interacting with the system and to check the accuracy of the hi-fi prototype.

The participant receives Bluetooth headphones which are connected to the hi-fi prototype. The bicycle with the hi-fi prototype attached to it is not in sight of the participant at this point. The participant receives the evaluation form which has a table with three columns: Left, Right and Front/Rear. These columns represent the three directions that can be distinguished through the audio feedback, being left or right or both at the same time. The tester goes to the bicycle which has the hi-fi prototype attached to it and starts triggering the sensors in a set order, for ten times. The participant is asked to cross out the column representing the direction they think the 'danger' is coming from.

The order that the sensors were triggered in is as follows: Front, Rear, Left, Right, Left, Right, Rear, Right, Left, Front. As can be seen in Appendix III, which holds the evaluation forms as filled in by the participants, all three participants answered all ten questions for the orientation test correctly.

The conclusion of this orientation test is that participants understand how the system works and get the right information from it. The test also points out that the distinction between left and right is clear enough, and it is also clear when both sides make a sound at the same time.

7.2.3 Running test

The point of the running test is to assess how well the hi-fi prototype functions in a simulated 'real life situation'.

The test begins with allowing the participant to take place on the bicycle and showing them the set out route. This route is a simple square around four pillars, in the middle of which the tester is positioned. The participant is asked to cycle a lap at low cycling speed, starting clockwise and alternating between clockwise and anti-clockwise each lap. A simple illustration of the situation is shown in Figure 31.

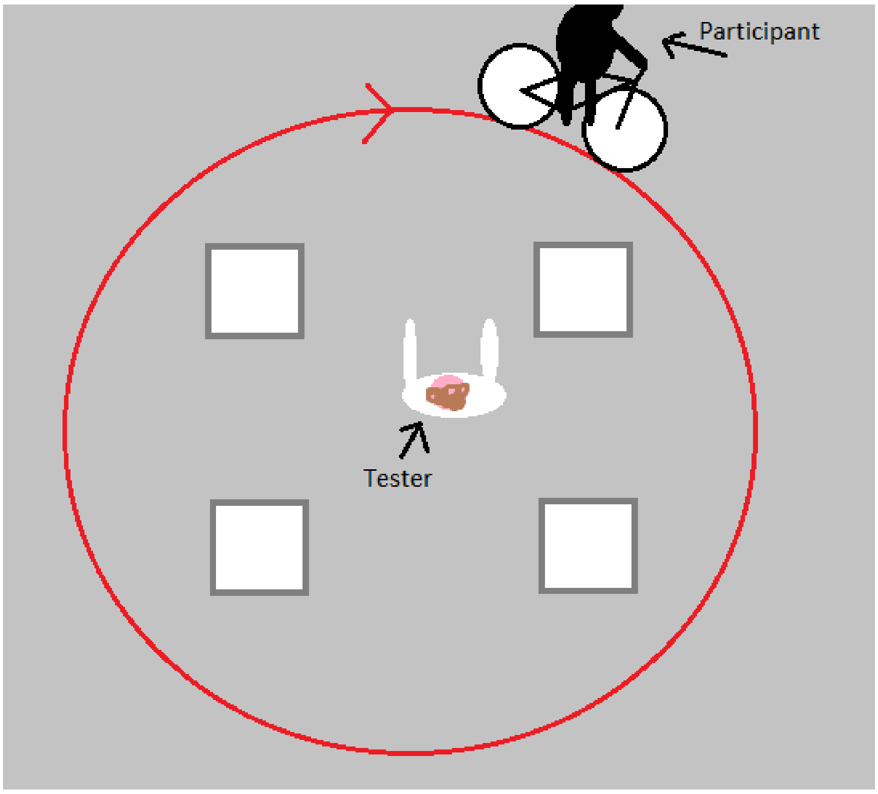

Figure 31: The test setup for the running test.

Each lap the tester picks a direction to come in from to trigger the sensors. The participant is asked to brake whenever they hear a sound or spot the danger themselves.

The results of this test are available in Appendix III.

The conclusion of this test is that there is room for improvement when it comes to accuracy of the system. It turns out that in the cases where people stopped, but did not hear a sound, they saw the tester before the system did. This is not necessarily a bad thing for the system, because it means people still pay attention themselves and do not fully rely on the system. It also turns out that when people did not hear a sound and did not stop in time, the tester might not have been in the area that is monitored by the sensors. This could lead to the conclusion that the sensor's range needs to be increased in width.

Although the accuracy can be increased a lot, the amount of times the system worked like it was supposed to shows that a larger scale test could prove beneficial.

7.2.4 Questionnaire

After both tests are finished, the participant is asked to fill out a questionnaire. This questionnaire is designed in such a way that all statements are positive about the hi-fi prototype. The participant can agree or disagree with the statements, in answers ranging from 1 to 5 as follows:

1. Fully disagree
2. Disagree
3. Neutral
4. Agree
5. Fully disagree

By designing the questionnaire in this specific manner, analyzing the results has been made easier. Because all the answers have been assigned a value, these values can be added together and divided by the amount of answers to get the average. The closer to 5 this average is, the more positive the participants are about (their experience with) the hi-fi prototype.

The statements as presented to the participants are listed in Table 10.

No.	**Statement**	**1**	**2**	**3**	**4**	**5**
1	I like the idea of having a system that assists me in monitoring the surroundings.					
2	The system can help prevent hazardous situations.					
3	The system is intuitive.					
4	The system is easy to use.					
5	The system would enhance my awareness of surrounding traffic.					
6	The system did not distract me.					
7	Auditory feedback is more logical than tactile or visual feedback for this system.					
8	The auditory feedback was loud and clear.					

9	The distinction between left and right was clear.					
10	There was a logical connection between the feedback and the surroundings.					

Table 10: The statements as presented to the participants.

7.2.5 Results user test

After all three tests have been conducted, a conclusion can be drawn from the user tests. This conclusion says something about the usability of the system and the interactions of the users with the system.

Given the results of the first orientation test, it can be said that the system is intuitive enough for users to understand what the feedback does and act accordingly. All three participants named all 10 directions correctly and therefore could tell where the 'danger' was coming from. This means that in a hazardous situation, their awareness would have been enhanced, as they could not see the bicycle at the time of the orientation test. It also means the distinction between left, right and front or rear is clear and the auditory feedback is the right form of feedback.

The results of the running test show that the system could properly function in a real life situation, meaning it would enhance the user's awareness of surrounding objects. Even though the results were not 100% accurate, a proof of principle has been made by showing that the sensors could sometimes enhance awareness and help spot danger in time to stop. Users would be notified in time to still respond, even if their attention is somewhere else at the moment.

The questionnaire resulted in an average approval rating of 3,7 out of 5, meaning that the system would be sufficient in the eyes of the user, but there is some room for improvement. The participants all answered the first statement with a 4 or a 5, meaning they like the idea of having a system that is functionally similar to this system.

7.3 Overview of requirements for future development

After all tests have been performed, the list of requirements can be updated yet again. This time the requirements are for future development. In Table 11 below the updated requirements are shown.

Functional requirements	
FR1	The system **must** be able to determine a safe following distance depending on the speed of the motorcycle (see safe following distances in Appendix II)
FR2	The system **must** be able to measure distance to moving/stationary objects over a distance of 4,5 meter (vehicles)**[sides]**
FR3	The system **must** be able to measure velocity of moving objects over a distance of 100 meters (vehicles)**[front and rear]**
FR4	The system **must** be able to notify the motorcyclist **through stereo audio**
FR5	The system **should** be able to connect to existing devices like Bluetooth headsets
FR6	The system **won't** be able to interfere with braking/throttle
Non-functional requirements	
NFR1	The system **must** not be distracting
NFR2	The system **should** be able to fit on or inside a helmet
NFR3	The system **should** be able to fit on or inside a motorcycle
NFR4	The system **should** be lightweight
NFR5	The system **should** be affordable

Table 11: Overview of requirements for future development.

Chapter 8: Conclusion and recommendation

The last chapter of this research paper is the Conclusion and Recommendation. In section 8.1, a conclusion is drawn from the research, and in section 8.2 recommendations are given for future work.

8.1 Conclusion

In this section the conclusion will be drawn. The first part of this section is a brief description of the goal of the research, after which the research question is repeated and answered, and an overall conclusion is drawn.

The goal of this research was to find out possible ways to decrease the danger of riding a motorcycle. Literature research pointed out that some research has been done already. However, these researches were all done from the perspective of everybody but the motorcyclist. The goal of this research was to take the perspective of the motorcyclist and think about what a motorcyclist can do to increase his own awareness, instead of trying to be more visible for other road users.

This goal lead to the research question "How to **enhance** a motorcyclist's **awareness** of surrounding traffic, in a **non-disruptive** way?".

The short answer to this question is 'By designing a Motorcycle Observation Assist.'
A Motorcycle Observation Assist was designed and realized in the form of a prototype, which could be user tested. The results of the test were positive (as explained in Chapter 7), so the research question was answered. With a Motorcycle Observation Assist, a motorcyclist's awareness of surrounding traffic can be enhanced, and it can even be done in a non-disruptive way.

Even though the restraints in money caused the prototype to be limited, a proof of principle was shown and the system can be further developed. This research also shows that a lot more research can be done towards the dangers of riding a motorcycle, and that the focus of these researches can be shifted from the perspective of everybody but the motorcyclist to the motorcyclist himself.

8.2 Recommendation

In this final section of this research paper, recommendations are made for future work. After all the steps in the design process and all the tests, it turned out that the system was functional, but more as a proof of concept. This means that it would not yet function in the envisioned context. For this to happen, several things are needed.

First off, the range and accuracy of the sensors – mostly the radars – has to be improved, simply by investing in more high-end sensors, for instance the HDR-100 from NavTech. This will greatly increase the functionality of the system, because it can be used at far higher speeds.

Furthermore, the system architecture can be simplified to a certain extent. For now, the system is built up out of four separate Arduino Unos. This is not only a work-around, it takes in a lot of space. A device (microcontroller) needs to be found that can handle the input of all the sensors at the same time, process all of this information and deliver feedback. This will save programming code, processing time, space and money.

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Appendix I

Enquête motorfietsen in het verkeer

Korte enquête over hoe motorrijders worden ervaren in het verkeer door automobilisten.
*Vereist
1. Heeft u rijbewijs B? *
Markeer slechts één ovaal.
Ja
Nee
2. Heeft u een eigen auto? *
Markeer slechts één ovaal.
Ja
Nee
3. Hoeveel jaar heeft u uw rijbewijs al? *
4. Hoeveel kilometer rijdt u ongeveer gemiddeld per jaar? *
Markeer slechts één ovaal.
5000
10.000
20.000
50.000
100.000+
5. Heeft u wel eens een aanrijding gehad? *
Markeer slechts één ovaal.
Ja
Nee
6. Wat denkt u van het gedrag van motorrijders in het algemeen? *
Markeer slechts één ovaal.
Ze zijn deel van het verkeer, ik heb er niet veel meer last van dan bijvoorbeeld van een andere auto of een vrachtwagen
Er zijn momenten waarop motorrijders te snel rijden, maar dit hoort erbij.
Motorrijders rijden vaak te dicht op me, duiken vaak snel nog voor mijn auto en rijden veel te snel, maar niet allemaal doen ze dit.
Alle motorrijders rijden altijd te hard en duiken gevaarlijk tussen auto's door in files, het zou verboden moeten worden.
7. U komt van rechts (u heeft voorrang) en wilt een weg opdraaien waar een motor met veel te hoge snelheid aan komt rijden. Wat doet u? *
Markeer slechts één ovaal.
Ik wacht eventjes, zoveel haast heb ik niet, ook al heb ik voorrang.
Omdat het mij langer kost om de snelheid van de motorfiets in te schatten, ben ik al te laat om ervoor te rijden.
Ik ga er gewoon voor, ik heb voorrang en het maakt me niet uit hoe hard die motor aan komt.
Ik wacht nog extra lang en duik er op het laatste moment alsnog voor, zodat deze motorrijder misschien eens beseft dat hij niet zo hard moet rijden.
8. Wat denkt u over de zichtbaarheid van een motorfiets? *
Markeer slechts één ovaal.
Ik heb nooit moeite met het waarnemen van motoren in het verkeer.
Ik heb soms moeite met het waarnemen van motoren in het verkeer.
Ik heb altijd moeite met het waarnemen van motoren in het verkeer.
9. Wat denkt u over fluorescerende vestjes en helmen voor motorrijders? *
Markeer slechts één ovaal.
Opvallende items helpen mij bij het waarnemen van een motorfiets.
Opvallende items leiden mij af in het verkeer.
Het maakt mij niet uit of een motorrijder in het zwart of in fluorescerend geel is gekleed.
10. Wat denkt u over extra uitleg met betrekking tot motorrijders bij het behalen van rijbewijs B? (bijv. extra lessen waarbij puur gelet wordt op motorrijders, of een extra gedeelte bij de theorie) *
Markeer slechts één ovaal.
Ik denk dat het geen verschil maakt of je op auto's, vrachtwagens of motoren let, je moet

alles zien.
Ik denk dat het nuttig zou zijn voor sommige mensen, maar de meeste mensen letten wel genoeg op.
Ik denk dat het een groot verschil zou maken als mensen extra worden gewezen op de aanwezigheid van motoren in het verkeer.

11. Stel er zou een technologische oplossing gevonden worden in de vorm van een klein apparaatje dat u waarschuwt wanneer er een motorrijder in de buurt is. Zou u dit in laten bouwen in de auto?

Markeer slechts één ovaal.

Ja, als het maar niet meer dan €500 kost.
Ja, als het maar niet meer dan €50 kost.
Ja, als het maar niet meer dan €50 kost.
Misschien, ligt eraan hoe betrouwbaar het apparaatje is.
Nee, ik vertrouw meer op mezelf dan op technologie.
Nee, dit zou mij juist alleen maar afleiden.

Appendix II

Stopping distance compared to following distance

Emergency stop with a deceleration of - 8 m/s² (dry road surface)			
Speed	**Braking distance In meters**	**Reaction time distance (1 second reaction time)**	**Stopping distance In meters**
10 km/h = 2,78 m/s	0,48	2,78	3,26
30 km/h = 8,33 m/s	4,34	8,33	12,67
50 km/h = 13,89 m/s	12,06	13,89	25,95
70 km/h = 19,44 m/s	23,62	19,44	43,06
80 km/h = 22,22 m/s	30,86	22,22	53,08
90 km/h = 25,00 m/s	39,06	25	64,06
100 km/h = 27,78 m/s	48,23	27,78	76,01
120 km/h = 33,33 m/s	69,43	33,33	102,76

Emergency stop with a deceleration of - 5 m/s² (wet road surface)			
Speed	**Braking distance In meters**	**Reaction time distance (1 second reaction time)**	**Stopping distance In meters**
10 km/h = 2,78 m/s	0,77	2,78	3,55
30 km/h = 8,33 m/s	6,94	8,33	15,27
50 km/h = 13,89 m/s	19,92	13,89	33,81
70 km/h = 19,44 m/s	37,79	19,44	57,23
80 km/h = 22,22 m/s	49,37	22,22	71,59
90 km/h = 25,00 m/s	62,5	25	87,5
100 km/h = 27,78 m/s	77,17	27,78	104,95
120 km/h = 33,33 m/s	111,09	33,33	144,42

Following distance: 2 and 3 seconds		
Speed	**2 seconds**	**3 seconds**
30 km/h = 8,33 m/s	16,67m	25m
50 km/h = 13,89 m/s	27,7m	41,67m
60 km/h = 16,67 m/s	33,3m	50
80 km/h = 22,22 m/s	44,4m	66,67m
100 km/h = 27,78 m/s	55,56m	83,3m
120 km/h = 33,33 m/s	66,67m	100m
130km/h = 36,11 m/s	72,2m	108,3m

Appendix III

Sides Distance Module / Speedometer Module

```
//based on code borrowed from https://electronics.stackexchange.com/questions/25278/how-to-connect-multiple-i2c-interface-devices-into-a-single-pin-a4-sda-and-a5 and http://www.instructables.com/id/Arduino-Bike-Speedometer/

#include <Wire.h>

#define NODE_ADDRESS 4

#define PAYLOAD_SIZE 3

#define reed A0//pin connected to read switch

float radius = 27;// tire radius (in inches)- CHANGE THIS FOR YOUR OWN BIKE

float spokes = 1;

int reedVal;

long timer = 0;

float kmu = 0.00;

float distance=0.00;

float circumference;


int maxReedCounter = 100;

int reedCounter;

byte nodePayload[PAYLOAD_SIZE];

long durationL, durationR;

long cmL, cmR;

int countDangerValueL, countDangerValueR;

int countSafeValueL, countSafeValueR;

int countBlankValueL, countBlankValueR;

int safeZone = 50;

const int pingPinL = 12;

const int echoPinL = 11;

const int pingPinR = 10;

const int echoPinR = 9;

int objectSpottedL, objectSpottedR;


void setup()

{
```

```
  Serial.begin(9600);


   reedCounter = maxReedCounter;
  circumference = (2*3.14*radius)/spokes;


  pinMode(reed, INPUT);
  cli();
  TCCR1A = 0;
  TCCR1B = 0;
  TCNT1  = 0;
  OCR1A = 1000;// = (1/1000) / ((1/(16*10^6))*8) - 1
  TCCR1B |= (1 << WGM12);
  TCCR1B |= (1 << CS11);
  TIMSK1 |= (1 << OCIE1A);
  sei();//allow interrupts
  //END TIMER SETUP
  pinMode(pingPinL, OUTPUT);
  pinMode(echoPinL, INPUT);
  pinMode(pingPinR, OUTPUT);
  pinMode(echoPinR, INPUT);
  Wire.begin(NODE_ADDRESS);  // Activate I2C network
  Wire.onRequest(requestEvent); // Request attention of master node
}
ISR(TIMER1_COMPA_vect) {//Interrupt at freq of 1kHz to measure reed switch
  reedVal = digitalRead(reed);//get val of A0
  if (reedVal){//if reed switch is closed
    if (reedCounter == 0){//min time between pulses has passed
      kmu = (91.44*float(circumference))/float(timer);//calculate kilometers per hour
      timer = 0;//reset timer
      reedCounter = maxReedCounter;//reset reedCounter
    }
    else{
      if (reedCounter > 0){//don't let reedCounter go negative
        reedCounter -= 1;//decrement reedCounter
```

```
      }
    }
  }
  else{//if reed switch is open
    if (reedCounter > 0){//don't let reedCounter go negative
      reedCounter -= 1;//decrement reedCounter
    }
  }
  if (timer > 2000){
    kmu = 0;//if no new pulses from reed switch- tire is still, set kmu to 0
  }
  else{
    timer += 1;//increment timer
  }

}

void displaykmu(){
  Serial.write(12);//clear
  Serial.write("Speed = ");
  Serial.write(13);//start a new line
  Serial.print(kmu);
  Serial.println(" KM/U ");
  //Serial.write("0.00 kmu ");
}



void loop()
{
  //displaykmu();
  Serial.println(objectSpottedL);
 // Serial.println(cmL);
  sendPingL();
  sendPingR();
```

```
  nodePayload[0] = objectSpottedL;

  nodePayload[1] = objectSpottedR;

  nodePayload[2] = kmu;


  if(kmu < 5 ){

    safeZone = 50;

  } else if(kmu > 5 && kmu < 10){

    safeZone = 100;

  } else if(kmu > 10){

    safeZone = 150;

  }

}

void requestEvent()

{

  Wire.write(nodePayload,PAYLOAD_SIZE);

//  Serial.print("Sensor value: ");  // for debugging purposes.

//  Serial.println(nodePayload[1]); // for debugging purposes.

}


long microsecondsToCentimeters(long microseconds) {

  // The speed of sound is 340 m/s or 29 microseconds per centimeter.

  // The ping travels out and back, so to find the distance of the

  // object we take half of the distance travelled.

  return microseconds / 29 / 2;

}


  bool sendPingL() {

  digitalWrite(pingPinL, LOW);

  delayMicroseconds(2);

  digitalWrite(pingPinL, HIGH);

  delayMicroseconds(5);

  digitalWrite(pingPinL, LOW);


  durationL = pulseIn(echoPinL, HIGH, 50000);
```

```
  cmL = microsecondsToCentimeters(durationL);

  if (cmL < safeZone && cmL != 0) {
    countDangerValueL++;
    countSafeValueL = 0;
    countBlankValueL = 0;
  } else if (cmL < 2500) {
    countSafeValueL++;
  } else {
    countBlankValueL++;
  }
  if (countSafeValueL > 3 || countBlankValueL > 5) {
    countSafeValueL = 0;
    countDangerValueL = 0;
    countBlankValueL = 0;
    objectSpottedL = false;
  }
  if (countDangerValueL > 5) {
    objectSpottedL = true;
  }
}
bool sendPingR() {
  digitalWrite(pingPinR, LOW);
  delayMicroseconds(2);
  digitalWrite(pingPinR, HIGH);
  delayMicroseconds(5);
  digitalWrite(pingPinR, LOW);

  durationR = pulseIn(echoPinR, HIGH, 50000);
  cmR = microsecondsToCentimeters(durationR);

  if (cmR < safeZone && cmR != 0) {
    countDangerValueR++;
    countSafeValueR = 0;
```

```
    countBlankValueR = 0;

  } else if (cmR < 2500) {

    countSafeValueR++;

  }


  if (countSafeValueR > 3 || countBlankValueR > 5) {

    countSafeValueR = 0;

    countDangerValueR = 0;

    countBlankValueR = 0;

    objectSpottedR = false;

  }

  if (countDangerValueR > 5) {

    objectSpottedR = true;


  }

}
```

Front and Rear Velocity Module

```
#include <Wire.h>

#define NODE_ADDRESS 2  // Change this unique address for each I2C slave node

#define PAYLOAD_SIZE 1 // Number of bytes  expected to be received by the master I2C node

byte nodePayload[PAYLOAD_SIZE];

const int radarPin = 8;

const int numReadings = 10;

int diffReadings = 10;

int readings[numReadings];      // the readings from the radar

int readIndex = 0;              // the index of the current reading

int previousReadIndex = 0;      // the index of the previous reading

int total = 0;                  // the running total

int average = 0;                // the average

unsigned long T1, T2, T;          // Periodendauer in us

double f;                 // Frequenz in MHz

int vcounter = 0;

int v;

void setup()

{

  Serial.begin(9600);

  Wire.begin(NODE_ADDRESS);  // Activate I2C network

  Wire.onRequest(requestEvent); // Request attention of master node

   Serial.println(3);

}


void loop()

{

  checkRadar();

  nodePayload[0] = average;

  Serial.println(average);

}

void requestEvent()

{

  Wire.write(nodePayload,PAYLOAD_SIZE);
```

```
}

int checkRadar() {

 while (digitalRead(radarPin));

 while (!digitalRead(radarPin));

  T1 = pulseIn(radarPin, HIGH);

  T2 = pulseIn(radarPin, LOW);

  T = T1 + T2;

  f = 1 / (double)T;       // f=1/T

  v = int((f * 1e6) / 44.0); // 24 GHz Radar

  total = total - readings[readIndex];

  readings[readIndex] = v;

  previousReadIndex = readIndex - 1;

  if(readings[readIndex] - readings[previousReadIndex] > diffReadings){

    readings[readIndex] = readings[previousReadIndex];

  }

  total = total + readings[readIndex];

  readIndex = readIndex + 1;

  if (readIndex >= numReadings) {

    readIndex = 0;

  }

  if(v == 0){

    vcounter++;

  } else {

    vcounter = 0;

  }

  average = total / numReadings;

   if(vcounter > 3){

    average = 0;

  }

}
```

Processing Module

```
// based on code borrowed from http://www.instructables.com/id/Stereo-Audio-with-Arduino/

#include <Wire.h>

#define PAYLOAD_SIZE 1 #define NODE_MAX 4

#define START_NODE 2

#define outputSelector 8

#define CS 9

#define WR 10

int arrayData[PAYLOAD_SIZE];

int radarvalueF;

int radarvalueR;

int average;

int average2;

int dangerValueR = 0;

int dangerValueF = 0;


byte sine[] = {127, 134, 142, 150, 158, 166, 173, 181, 188, 195, 201, 207, 213, 219, 224, 229,
234, 238, 241, 245, 247, 250, 251, 252, 253, 254, 253, 252, 251, 250, 247, 245, 241, 238, 234,
229, 224, 219, 213, 207, 201, 195, 188, 181, 173, 166, 158, 150, 142, 134, 127, 119, 111, 103,
95, 87, 80, 72, 65, 58, 52, 46, 40, 34, 29, 24, 19, 15, 12, 8, 6, 3, 2, 1, 0, 0, 0, 1, 2, 3,
6, 8, 12, 15, 19, 24, 29, 34, 40, 46, 52, 58, 65, 72, 80, 87, 95, 103, 111, 119,};

byte index = 0;

bool channel = 0;


int val = 0;

int kmu = 0;

bool objectSpottedL, objectSpottedR;


void setup()

{

  Serial.begin(9600);


   for (byte i=0;i<8;i++){

    pinMode(i, OUTPUT);
```

```
  }

  pinMode(outputSelector,OUTPUT);
  pinMode(CS,OUTPUT);
  pinMode(WR,OUTPUT);

  Wire.begin();
}


void loop()
{

   Wire.requestFrom(2, 3);
  if(Wire.available() == 3){
  for (int i = 0; i < 3; i++){
    arrayData[i] = Wire.read();
  }
    objectSpottedL = arrayData[0];
    objectSpottedR = arrayData[1];
    kmu = arrayData[2];
  }

  Wire.requestFrom(4, PAYLOAD_SIZE);
  if(Wire.available() == PAYLOAD_SIZE){
    radarvalueF = Wire.read();
    average = radarvalueF;

   if(average > 7){
   dangerValueF = 100;
  } else if(dangerValueF < -1000) {
    dangerValueF = -1;
  } else {
```

```
    dangerValueF--;
   }
   }

   Wire.requestFrom(3, PAYLOAD_SIZE);
   if(Wire.available() == PAYLOAD_SIZE){

     radarvalueR = Wire.read();
     average2 = radarvalueR;

    if(average2 > 5){
    dangerValueR = 100;
   } else if(dangerValueR < -1000) {
     dangerValueR = -1;
   } else {
    dangerValueR--;
   }
   }
   ledFunction();
      Serial.print(dangerValueR);
    Serial.print("/");
    Serial.print(radarvalueR);
    Serial.print("/");
     Serial.print(dangerValueF);
    Serial.print("/");
    Serial.print(radarvalueF);
     Serial.print("/");
      Serial.print(objectSpottedL);
       Serial.print("/");
        Serial.print(objectSpottedR);
     Serial.print("/");
     Serial.println(kmu);
}
```

```
void makeNoiseRight(){
digitalWrite(outputSelector,HIGH);//select DACA
makeNoise();
}

void makeNoiseLeft(){
 digitalWrite(outputSelector,LOW);//select DACA
 makeNoise();
}

void makeNoiseBoth(){
  if(channel){
  digitalWrite(outputSelector,LOW);//select DACA
  } else {
    digitalWrite(outputSelector,HIGH);//select DACA
  }
  makeNoise();
  channel ^= 1;
}

void makeNoise(){
digitalWrite(WR,HIGH);//hold outputs- so new DAC data does not get sent out until we are ready
   PORTD = sine[index];//send sine to digital pins 0-7

    index++;//increment index value by one
    if (index==100){//reset index if it reaches 100
      index=0;
    }
  digitalWrite(WR,LOW);//enable output again
  index = 0;
}

void ledFunction() {
```

```
  if (objectSpottedL) {
    makeNoiseLeft();
  }
  else
  if (objectSpottedR) {
    makeNoiseRight();
  }
  else if (dangerValueF > 0 || dangerValueR > 0){
   makeNoiseBoth();
  } else
  {
    digitalWrite(WR,HIGH);

  }
}
```

Appendix IV

Name: Ruben

1. Orientation test: Please fill out the direction you think the "danger" is coming from.

No.	Left	Right	Front/rear
1			X
2			X
3	X		
4		X	
5	X		
6		X	
7			X
8		X	
9	X		
10			X

2. Running test: Please fill out the following questions about the five running tests.

No.	Did you brake in time?	Did you hear sound in time?
1	yes	yes
2	yes	yes
3	no	no
4	yes	no
5	yes	yes

3. Questionnaire: Please fill out whether or not you agree with the following statements.

1 = fully disagree
2 = disagree
3 = neutral
4 = agree
5 = fully agree

No.	Statement	1	2	3	4	5
1	I like the idea of having a system that assists me in monitoring the surroundings.					X
2	The system can help prevent hazardous situations.				X	
3	The system is intuitive.				X	
4	The system is easy to use.			X		
5	The system would enhance my awareness of surrounding traffic.				X	
6	The system did not distract me.				X	
7	Auditory feedback is more logical than tactile or visual feedback for this system.				X	
8	The auditory feedback was loud and clear.				X	
9	The distinction between left and right was clear.				X	
10	There was a logical connection between the feedback and the surroundings.				X	

Name: Dimitris

1. **Orientation test: Please fill out the direction you think the "danger" is coming from.**

No.	Left	Right	Front/rear
1			X
2			X
3	X		
4		X	
5	X		
6		X	
7			X
8		X	
9	X		
10			X

2. **Running test: Please fill out the following questions about the five running tests.**

No.	Did you brake in time?	Did you hear sound in time?
1	yes	yes
2	no	no
3	yes	yes
4	yes	yes
5	no	no

3. **Questionnaire: Please fill out whether or not you agree with the following statements.**

1 = fully disagree
2 = disagree
3 = neutral
4 = agree
5 = fully agree

No.	Statement	1	2	3	4	5
1	I like the idea of having a system that assists me in monitoring the surroundings.				X	
2	The system can help prevent hazardous situations.			X		
3	The system is intuitive.				X	
4	The system is easy to use.			X		
5	The system would enhance my awareness of surrounding traffic.			X		
6	The system did not distract me.				X	
7	Auditory feedback is more logical than tactile or visual feedback for this system.				X	
8	The auditory feedback was loud and clear.			X		
9	The distinction between left and right was clear.				X	
10	There was a logical connection between the feedback and the surroundings.			X		

Name: Nadine

1. **Orientation test: Please fill out the direction you think the "danger" is coming from.**

No.	Left	Right	Front/rear
1			✓
2			✓
3	✓		
4		✓	
5	✓		
6		✓	
7			✓
8		✓	
9	✓		
10			✓

2. **Running test: Please fill out the following questions about the five running tests.**

No.	Did you brake in time?	Did you hear sound in time?
1	No	Yes
2	yes	yes
3	yes	yes
4	Yes	No
5	yes	yes

3. **Questionnaire: Please fill out whether or not you agree with the following statements.**

1 = fully disagree

2 = disagree

3 = neutral

4 = agree

5 = fully agree

No.	Statement	1	2	3	4	5
1	I like the idea of having a system that assists me in monitoring the surroundings.				✓	
2	The system can help prevent hazardous situations.					✓
3	The system is intuitive.				✓	
4	The system is easy to use.				✓	
5	The system would enhance my awareness of surrounding traffic.				✓	
6	The system did not distract me.				✓	
7	Auditory feedback is more logical than tactile or visual feedback for this system.			✓		
8	The auditory feedback was loud and clear.				✓	
9	The distinction between left and right was clear.				✓	
10	There was a logical connection between the feedback and the surroundings.			✓		

Appendix V

Component	Type	Link
Arduino	Uno R3	https://www.arduino.cc/
Radar	IPM-165	http://shop.weidmann-elektronik.de/index.php?page=product&info=8
Ultrasonic sensor	HC-SR04	https://www.sparkfun.com/products/13959
DAC	TLC7528-CN	http://www.ti.com/lit/ds/symlink/tlc7528.pdf
Bluetooth transmitter	LogiLink BT0024	http://www.logilink.org/showproduct/BT0024.htm