Automatic Gearshifting for Bicyles

Project Report

B127

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STUDENT REPORT

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Abstract:

Traffic congestion in larger cities is an everyday occurrence. This is due to multiple factors, one of these being that vehicles have to wait for bicycles to exit intersections before they can make right turns. To improve on these conditions the group behind this project has developed an automatic gear changing system, which costs less than 1000 DKK. With this system cyclists will be able to exit intersections at a better pace, which might improve traffic. To develop this product the group has analysed the target audience through interviews and questionnaires. From this, data components for the product has been chosen based on different factors. Afterwards a program was written for an Arduino to control the behavior of the hardware. The developed product serves as a "proof of concept", since it still misses certain parts or functionality that should be included if the product were to be implemented in real life.
From this it is concluded that it is possible to produce an automatic gear changing system for bicycles, which costs less than 1000 DKK.

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Abstract:

Trafikproblemer i større byer er hverdag for mange mennesker. Dette skyldes forskellige faktorer, og en af disse er, at køretøjer skal vente på cykelister, før de kan foretage højresving i lyskryds. For at forbedre disse forhold har gruppen bag dette projekt udviklet et automat gear til cykler, som koster under 1000kr. Med dette system kan cykelister komme fra lyskryds i et godt tempo, hvilket kan forbedre trafikken.
For at kunne udvikle et sådan, produkt har gruppen analyseret, hvem målgruppen er ved brug af interviews og spørgeskemaer. Der er hertil undersøgt, hvilke komponenter der ville være fordelagtige at benytte til produktet. Til det udformede hardware system er der skrevet kode, der ved hjælp af en Arduino styrer, hvordan produktet opfører sig.
Det endeligt udviklede produkt, fungerer som et "proof of concept", da det stadig mangler visse dele eller funktioner for, at kunne implementeres i virkeligheden.
Ud fra dette konkluderes det at der er riglig mulighed for at fremstille et automatgear, til under 1000kr for det samlede produkt.

Preface

This report is written by a group of 1st semester electronics and IT students at the university of Aalborg in the fall of 2016.

The general subject of the project is basic electronic systems, with the more specific subject of automatic gear shifting for bicycles. The project was created over a course of three months.

First of all we would like to thank our supervisor, Jan Hvolgaard Mikkelsen, for his insight and guidance. Additional we would like to thank: Aalborg university for providing the equipment and facilities necessary to complete the project, Vestbyen Cykelhandler for donating the bicycle and answering any technical questions we had, and Flemming Kristoffersen for helping finding and acquiring any special components.

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Chapter 1

Introduction

Every day thousands of people ride their bicycles in the streets, but not everyone remembers to shift their gears while riding. This was first observed during a morning commute to the University. To confirm this hypothopsis, more comprehensive observations were conducted. The detailed results of these can be found in appendix A. The observations were made on a normal workday, during rush hour, at a central traffic crossing in Aalborg. Every cyclist was counted when they stopped at a red light, then as the light turned green, it was counted how many people had to stand up or put their whole body weight into pedalling. Approximately one third of the people observed fell into this category, which means that this potentially could be a common problem. When people start out in a high gear at full stops, like at traffic lights or intersections, they slow down their own pace. This problem might also appear, when people do not choose a lower gear in situations such as ascending a hill or in headwind.

The problem of not shifting gears is causing people to be very inefficient as they may have to stand up on their pedals or at least pedal very hard. This inefficiency causes slower traffic and reduces the comfort of the cyclist, while also blocking the traffic for other bikers and left/right turning cars. Increasing the amount of cyclists in traffic who shift gear properly would have a positive effect on traffic in general. It would especially be helpful in crowded areas, like cities, because of the large amount of people commuting in such an area. Helping cyclists with shifting gears in a proper fashion would not only help themselves and cyclists behind them, but would also help motorized traffic. By making sure that bikes get across an intersection faster, the vehicles who have to turn right at the same intersection would also be able to do that faster, which in turn would speed up the rest of the traffic.

With these things in mind, a way to make cyclists shift gears more efficiently seems like a worthwhile investment as long as it targets a sizeable portion of the bike-riding commuters. Especially cyclists in cities should be targeted since that is where the heaviest

traffic congestion often occures.
There are of course many possible solutions to the problem of cyclists not shifting gears properly, but this report will focus on a solution that lies within the scope of electrical engineering, since the expertise of the authors lies within this field. As such, solutions like information campaigns, signs, or purely mechanical systems are ruled out from the start in favor of an electrical system that either makes the process of switching gears easier or automates it.

This report will from here on focus on documenting the creation of a product to solve the problem of efficiently switching gears. The initiating problem statement therefore becomes:

Can a product that helps bicyclists shift to the correct gear for a given situation be developed? If so, how should this be done?

In chapter 3 of this report, the problem field will be analysed to get a better understanding of exactly who, a possible solution should be targeted towards, along with the specifics of what kind of product should be developed. The first step in this process is to gather data and analyse it. To do this effectively one or more methods will have to be used to gather said data. The next chapter will therefore lay out the different methods used throughout the problem analysis and discuss how and why they have been chosen.

Chapter 2

Methodology

This chapter will cover the different methods that will be used throughout the problem analysis. This is done to give an insight into how the different methods are used in this project and why certain conclusions are drawn based on results from said methods.

2.1 Interview

Interviews are used to gather qualitative data on a subject through questions that an interviewee can answer as they see fit. Interviews can generally be categorized as either structured, semi-structured or unstructured. These will be briefly laid out in the following list[1]:

- **Structured Interview:** Structured interviews are preplanned down to every question. Every question is read aloud to the interviewee as they are written. Because of this there are no spontaneous questions in a structured interview and it cannot deviate from the plan based on answers given.
- **Semi-structured Interview:** Semi-structured interviews are used when the interviewer has some preplanned questions or topics they want to ask the interviewees about. The difference between a structured and semi-structured interview is that the semi-structured interview is not as rigid and can deviate from what has been planned to ask about topics that emerge during the interview.
- **Unstructured Interview:** The unstructured interview is where the interviewer sets the topic and lets a conversation unfold about it. It is a good approach to use if the interviewer wants to cut out their own preconceptions about the topic and wants to see what the interviewee finds to be the most important aspect of it.

In conjunction with this project a semi-structured interview has been conducted with two bikedealers as the interviewees in the city of Aalborg. This was done to see what they thought about automatic gear shifters for bicycles from the perspective of someone who would be able to sell such a device. The semi-structured interview was chosen based on the fact that the group had some questions that were necessary to get an answer to but at the same time wanted to get the bike shop employees' opinion on the subject without them being forced to only answer premade questions.

2.2 Questionnaire

Questionnaires are made up of a set of questions, usually these questions have a limited amount of answer options, thus simplifying the analysis of large data sets. Because of this questionnaires excel at gathering good amounts of quantitative data, as they can be sent out to a lot of people. However the rigid nature of questionnaires limits their value when what is needed is qualitative data. While it is possible to include options that let people write their own answers this somewhat ruins the intentions of a questionnaire. Questionnaires also run the risk of being too long or too complex which causes people to not pay attention to their answers or simply not answer at all. Another risk is that people do not identify with the given possible answers and therefore stop answering or fill out something that is not indicative of them/their behavior. These things mean that questionnaires can be rather difficult to actually make[1].

The group chose to opt for a questionnaire because it is a good tool for gathering good amounts of quantitative data. Even though questionnaires can be hard to properly make, there were no good alternatives that offered as good a benefit without the downside of potentially getting "bad data". Therefore the questionnaire was the best option for this project and the downsides of said method have been dampened trough thorough data analysis of the answers in section 3.2.

For this project a questionnaire with 15 questions was formed and sent out over social media to get as many answers as possible. The questions were about the gear shifting habits of people who use bicycles, as well as their interest in different solutions to help them with gear shifts. In the end around 270 people had answered the questionnaire which provided a decent sample size to analyse.

2.3 Literature Studies

Literature studies have been used to find pre-existing material on the subject of bicycle gearing. When choosing to base something off of empiric material it is important to be sceptical about it. Information like who wrote something and where it was published are examples of good questions to ask before choosing to cite something as a source.

It can be argued that by choosing certain material a form of interpretation of the subject is taking place. This will cause the report as a whole to assume a certain angle on the subject that would have been different had other people written it. However, as long as there is a good basis for taking the subject in a certain direction and as long as the report strives to be objective in its outlook this is acceptable and can actually help further studies on the subject by showing the good and bad of the angle of the paper.

2.4 Stakeholder Analysis

A stakeholder analysis is a way to find the different parties that could be interested in a given solution. This is generally done by brainstorming or seeking material that can show someone's interest in the subject. After finding the different parties these can be divided into groups based on aspects such as whether or not they should have a say in how the solution is developed, if it could be fiscally beneficial to target them, etc.

This kind of analysis is done in part to find out if there are people interested in a given solution, but also get a further understanding of who needs to be targeted or included in the development process to make the product successful.

The following chapter will use the described techniques to analyse the problem area, with the intention of narrowing it down to a solvable problem statement.

Chapter 3

Problem Analysis

This chapter will focus on analysing the different aspects of the problem area in hope of narrowing it down to a point where a problem statement can be made. With the resulting problem statement, a list of specifications for the final product can be made, which then leads on to actually making the product. In order to do this, section 3.2 will analyse the data given from the questionnaires and the interviews conducted. Afterwards, section 3.3 takes a look at already existing solutions within the problem area to give a better understanding of where a new product can be of value. Lastly in section 3.4, the different stakeholders will be identified so that the product can be tailored with these parties in mind.

3.1 Data collection

The data collection section will focus on what kind of questions that will be used through a survey for the problem. The questions from the questionnaire will be grouped and the thought behind them will be listed. The same thing will be done with a set of questions for an interview. This is all done to get a better insight on what people would say about the idea of a solution for gear shifting on bicycles.

3.1.1 Questionnaire

To quantify the need, want, and interest in a possible solution, a survey was created and distributed on social media. The survey includes three different solution proposals. Each of the proposals were carefully thought out as possible solutions to the problem of gear shifting. The proposals are:

- **A Fully Automatic Gearing System:**
  This would be the most complex and expensive solution of them all. However it is also the most powerful and user-friendly solution, as it would allow the cyclist to completely ignore the gearing aspect of a bicycle.

- **A System which Automatically Downshift at a Full Stop:**
  This solution is a less complex version of the fully automatic proposal, as the bicycle can be equipped with fewer sensors. On the other hand, this solution will not be as user-friendly, since the cyclist still has to use their gears manually while riding their bike.

- **A System which Recommends when to Shift Gear:**
  This is the most simple proposal, as there will not be a need for actuators to physically change the gears. In contrast to the other proposals, this solution will require the cyclist to perform all the gear shifting manually.

The questionnaire consists of 15 different questions, each with their own set of answer choices. The complete questionnaire can be found in appendix B. Following is a broad explanation for the inclusion of the various questions:

(Question numbers are derived from the survey in appendix B)

- **Question 1, 2:**
  These questions are regarding the respondents' age and gender. They were included in order to gather an overview of the demographics present in the survey.

- **Question 3, 4:**
  These questions attempt to gather information regarding the respondents' biking habits. This is useful for mapping what kind of users would be interested in the various systems (if any).

- **Question 5:**
  This question is used to determine which kind of gearing system is the most popular. This information can then potentially be used to determine which gearing system the solution should be designed for.

- **Question 6-9:**
  These inquire about the respondents' thoughts towards bicycle gearing, as well as their gearing habits. These questions will help quantify the need for the system.

- **Question 10-15:**
  These are asked to help figure out which of the three proposed systems generates the most interest.

3.1.2 Interview

In order to get a professional perspective on automatic gearing systems for bicycles, semi-structured interview sessions were held with two local bike shops around the Aalborg area. The questions that were asked during the interview were mostly preplanned, while some emerged during the interview.

List of questions that were asked under the interviews

- **What is more popular, internal or external gear?**
  It was asked in order to determine which type of gear is most popular among costumers. That way a professionals perspective can be used to determine which gearing type the product should be developed for.
- **Do you experience that people have trouble maintaining their bicycle's gears?**
  The question was asked in order to know, whether cyclists take care of their bicycles, since the developed product might sometimes need maintenance to run smoothly.
- **Do you sell a lot of extra equipment for bicycles? (such as bike computers)**
  This question aims to determine if bicycle shops sell extra equipments for bicycles and in this context, whether costumers are willing to buy this equipment. This information is useful to determine if there exits a market for the gear shifting product as extra equipment.
- **What is your opinion on automatic gearing for bicycles?**
  This question was asked in order to get a professional perspective on automatic gearing systems for bicycles.
- **Would you be interested in selling such a system? In that case, for what price?**
  The purpose of this question is to help figure out, if the bicycle shops are interested in selling this kind of a product, and what the optimal price range would be for such a product. This information is useful for setting up a budget before even starting the development of the product.
- **Do you have experience with similar products?**
  It was asked to figure out whether they had any knowledge about this kind of technology.
- **Any other comments?**
  This question was asked to find out whether they had any helpful advice.

-

3.2 Questionnaire Data Analysis

This section will first take the answers from the questionnaire. Here it will sort through the responses and analyse them. The section is meant for cleaning out the unnecessary data to make the analysis more clear. Following it will be transforming and modeling of this data into more manageable graphs. It will end in a conclusion of what the respondents' have answered and what the data analysis shows. The answers from the interviews will then be analysed briefly to show, what some of the bicycle dealers in Aalborg have to say about a product that can help people with changing gears. At the end of this section, a small conclusion of the data analysis will be presented.

3.2.1 Data Quality

Throughout the survey period, a total of 270 responses were collected. Unfortunately as with any anonymous and publicly available survey, it is likely that some of the responses were not answered truthfully. This will have to be taken into consideration during the analysis of the data. Since opinions can vary wildly from person to person, it is difficult to come up with a single and perfect method to sort the truthful from the non-truthful responses. Some non-truthful responses may seem to be legitimate, while some of the truthful responses can express extreme and/or rare views thus making them appear unrealistic and illegitimate. As it is important to not incorrectly label a truthful response as being illegitimate, only the most extreme and inconsistent responses have been removed from the response list. An example of such a response is shown in table 3.1:

Table 3.1: An example of a response which were evaluated to be illegitimate

Question:	Answer:
What is your gender?	Female
What is your age?	0-10
How often do you bike?	Never
How far do you on average bike per day?	Less than 1 km
Do you use hub gears or derailleurs	Hub gears?
How often do you think about changing gears?	Never
How often do you remember to downshift gears at a full stop?	Never
Do you find it tedious to shift gear?	Sometimes
How often do you feel confident about when to shift gears?	Never
How interested would you be in a bicycle which can shift gears automatically?	No Interest
How much (in DKK) would you be willing to pay for such a system?	1000+
How interested would you be in a bicycle which can recommend when to shift gears?	No Interest
How much (in DKK) would you be willing to pay for such a system?	1000+
How interested would you be in a bicycle which can automatically downshift at a full stop?	No Interest
How much (in DKK) would you be willing to pay for such a system?	1000+

The response shown in table 3.1 is suspicious for a number of reasons. First of all, the respondent has listed their age bracket as being from "0-10" and while this is not impossible, it would be quite rare for even a gifted 10 year old to find and answer a survey on their own. Second, and most importantly, the respondent states that she has no interest in any of the proposed systems, while at the same time being willing to pay over 1000 DKK for the product. This is quite an unconventional selection of answers, as it makes little sense for anyone to show no interest in a product, while at the same being willing to spend a large sum of money on it. Because of this consistent usage of extreme/rare answers, this response is deemed illegitimate, and consequently it will not be included in the data analysis. In total, six responses have been judged to be illegitimate, and have been removed from the data set, leaving us with a total of 264 responses. All of the illegitimate responses can be found in the original survey data in appendix C.

While interpreting the data, another important fact to keep in mind is that the demographic distribution of our survey responses, do not correlate well with Denmark's overall demographics, as evident by figure 3.1[2] and 3.2

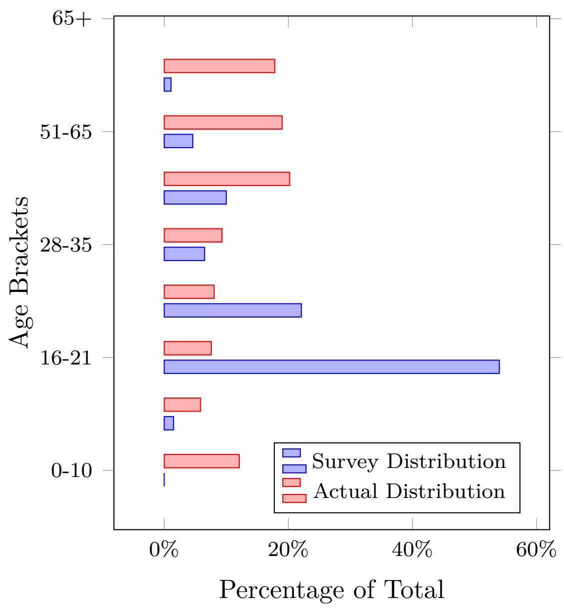

Figure 3.1: The real distribution of age brackets, versus that of the survey

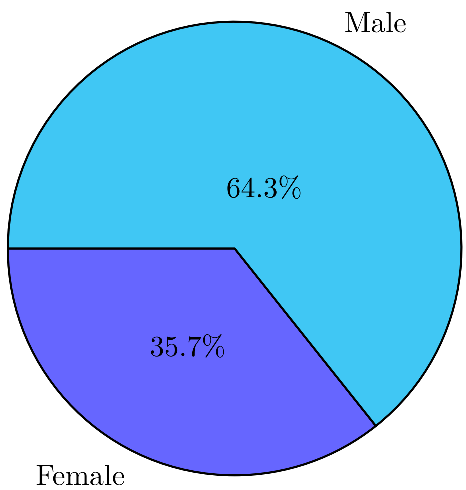

Figure 3.2: Gender distribution of survey results

3.2.2 Analysis of System Proposals

In the survey, people were asked to rate their interest in the three different system proposals - fully automatic gearing, automatic downshifting, and gear shift recommendations. Figure 3.3 shows how the respondents rated the three different proposals.

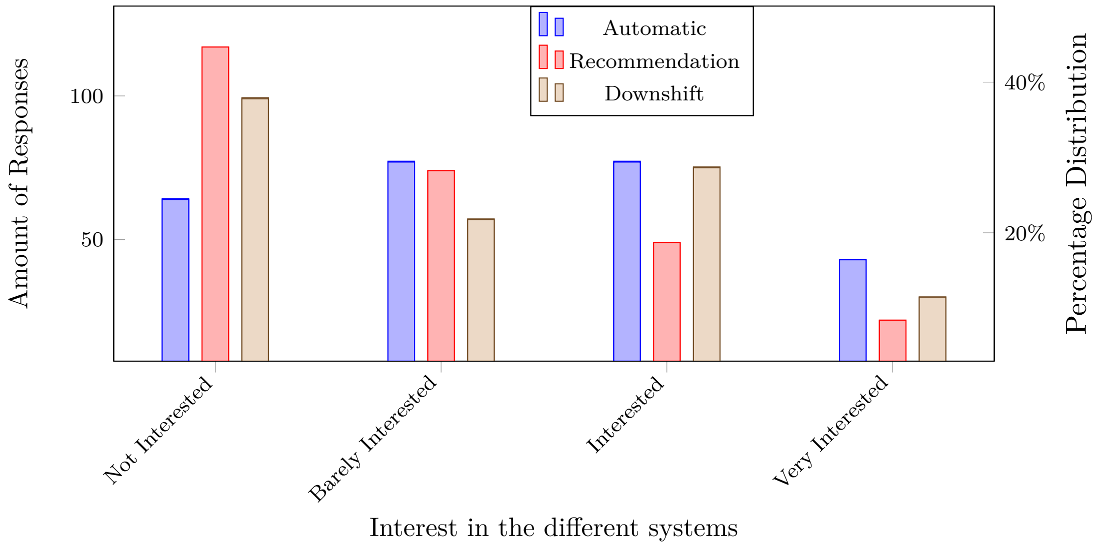

Figure 3.3: How the respondents rated their interest in the three proposals

The figure illustrates how the fully automatic and the automatic downshifting system gathered the most interest, with 46% and 40% of the respondents saying that they are 'Interested' or 'Very Interested' in the proposals respectively. In contrast only 27% show similar interest in the gear recommendation system. This low interest in the gear recommendation system essentially eliminates it as a viable solution. In another similar question, the respondents were asked to indicate how much they would be willing to pay for each of the three systems. Figure 3.4 shows how the responses are distributed:

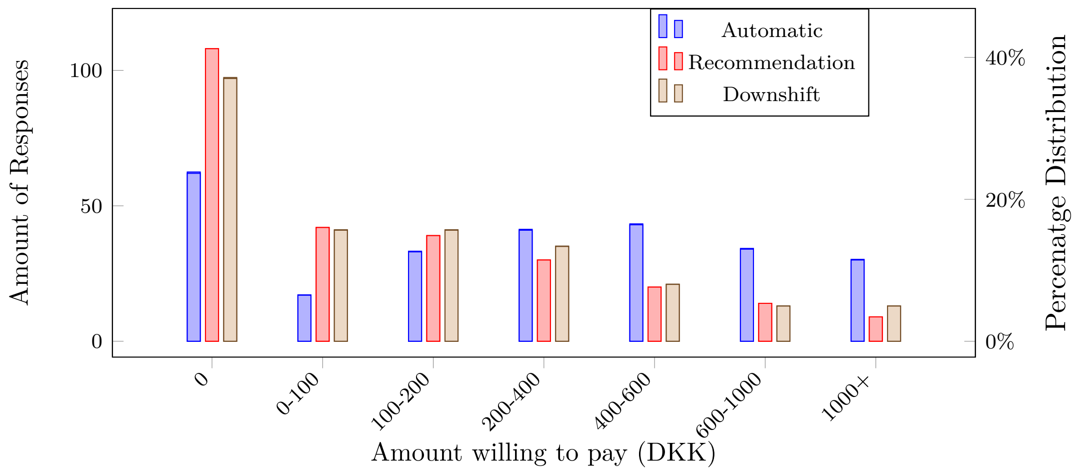

Figure 3.4: How much money (in DKK) individuals are willing to pay for the three different proposals

Both figure 3.3 and figure 3.4 exhibits how the respondents are willing to pay the most for the fully automatic system, while showing little interest to even pay for the gear recommendation system, thus reinforcing the idea that the gear recommendation system is not a viable solution. Disregarding the recommendation system going forward, the data further informs us that around 37% of the respondents would not be willing to pay for the downshifting gear system, whilst this is only the case for around 24% of the respondents for the fully automatic system.

Moreover the cumulative frequency distribution of the data shown in figure 3.4, presented in figure 3.5, further clarifies this point as it shows that in general there are fewer respondents who are willing to spend large amounts of money on the downshifting system, than on the fully automatic system.

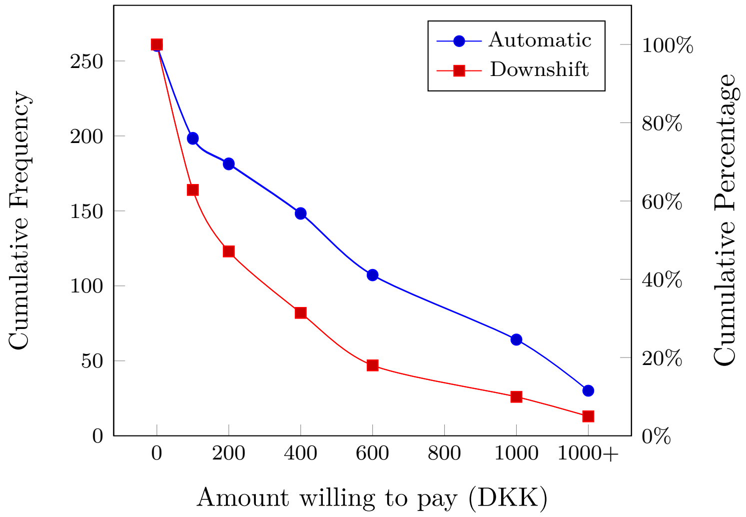

Figure 3.5: Cumulative frequency diagram of how much the respondents are willing to pay

Overall, the responses gathered from the survey clearly shows that the fully automatic system proposal gather the most interest, whilst simultaneously being the solution where respondents are prepared to pay the most. These new details establish that the fully automatic gear shifting system is the most sensible solution both as a business case and from a market adoption standpoint. Therefore, the automatic gear shifting system, is the chosen system that this project will attempt to create.

3.2.3 Analysis of Target Audience

In the survey, the respondents were also asked to answer a range of questions related to their biking habits, as well as their age and gender. This information is used to identify the potential target audience for the chosen solution. To identify the key audience, the first step is to divide the individual respondents into different groups. However, as there are nine different questions, each with multiple different answers, it would be difficult - if not impossible - to group all of these factors in any meaningful or organised fashion. So to make the analysis easier, the following areas will be independently grouped and analysed with respect to the groups expected price and interest in the solution: *Biking frequency, Distance* and *Gearing habits.*

Relationship between Biking Routines and Interest

To analyse what kind of bicycle users, e.g. power users who use their bikes constantly or casual users who rarely use their bikes, shows the most interest in the solution. The respondents are divided into groups based on their answers to the questions:

- How often do you bike? (Five possible answers)
- How far do you on average bike per day? (Six possible answers)

Each of the five possible answers to 'How often do you bike?' were divided into sub-groups based on the answer to 'How far do you on average bike per day?'. To ensure each of the groups are not left with too few respondents (thus creating a very large margin of error), the six possible answers for the question have been combined to form three groups:

- Respondents who bike less than 1 km, and those who bike 1-3 km
- Respondents who bike 3-5 km, and those who bike 5-10 km
- Respondents who bike 10-20 km, and those who bike more than 20 km

The combination of the five groups for 'How often do you bike?', and the three for 'How far do you on average bike per day?' leaves a total of 15 sub-groups.

In total 46% of the respondents said they were 'Interested' or 'Very Interested' in the solution. Figure 3.6 shows how much each of the 15 sub-groups contributed to the interest in the solution (both relatively and absolute):

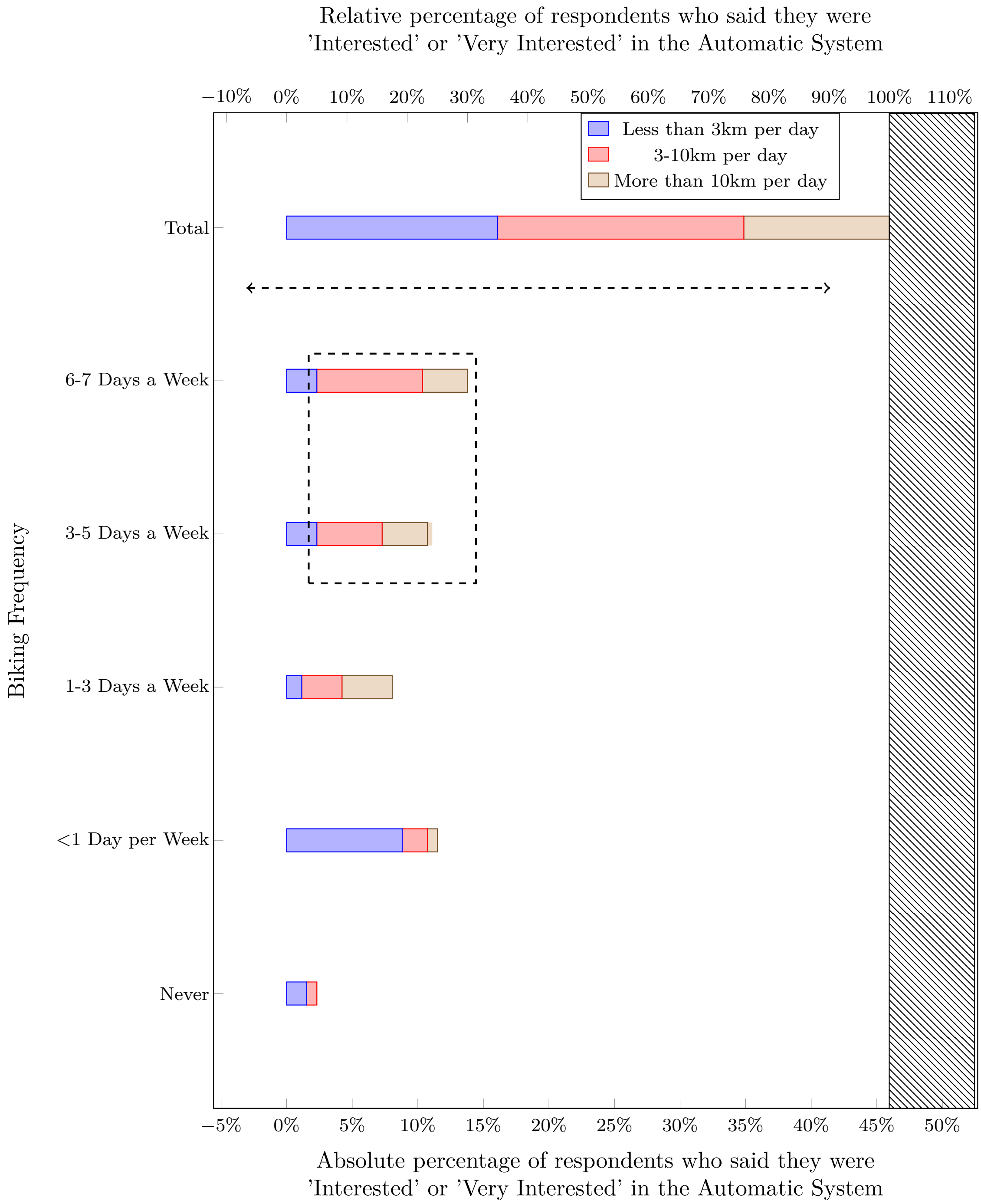

Figure 3.6: Comparison of how many each of the different bicycle users rated themselves as being 'Interested' or 'Very Interested' in the automatic system.

Figure 3.6 shows a range of important information regarding the questionnaire. First of all, when only focusing on the five groups based on biking frequency, all of the groups, with the exception of the ones who answered 'Never' to whether or not they used their bike, provided similar contributions towards the total percentage. While the difference between the '6-7 Days a Week' group's contribution of 13.8 absolute percentage points (APP) and the 7.3 APP of the '1-3 Days a Week' group might seem significant, due to the large margin of error caused by the relatively low amount of respondents in each group, it is reasonable to group these two groups together. These results indicate, that the interest in the solution is evenly distributed, and does not in any significant way correlate with the frequency someone bikes.

Changing focus, the previous propositions seem to also hold true for when the respondents are grouped into the three groups based on biking distance. The three groups, 'Less than 3km per day', '3-10km per day', and 'More than 10km per day' contributes each 16.1, 18.8, and 11.1 APP respectively towards the total. Similarly to when grouped by biking frequency, these values do not deviate enough from each other to find a correlation, other than that of a relatively evenly distributed interest across the three groups. However when zooming in to focus on the 15 sub-groups, certain patterns emerge. Within the '3-10km group', the respondents appear to show increasing interest in the solution as they are placed in higher biking frequency groups. On the other hand, the 'Less than 3km group' shows the majority of their interest being centered in the 'Less than 1 day per week' biking frequency, with the remainder of their interest being evenly distributed across the remaining frequency groups. The 'More than 10km per day' group has a very small part of their total interest located in 'less than one day per week' and 'Never', with the majority of their total interest distributed across the three groups in the 1-7 days a week range.

While the analysis may show few strong correlations between the different groups, the solution's goal, to help reduce bicycle traffic congestion, also has to be taken into consideration when searching for target audiences. Since people who bike the most and furthest cause more traffic compared to someone who rarely bikes. That is why it makes sense to remove the groups who rarely bike or who only bike short distances from the list of most important target audiences (note, these groups may still be viable target customers for the solution, however they are not the most important in trying to solve the proposed problem). It is decided to keep the groups who bike more than three days a week, and bike further than three km, the four remaining groups can be seen in figure 3.6 marked in the dashed square. While all of the remaining four groups are very important audiences, the two groups which bikes 3-10km per day are the most important, as they encompass the most people.

Analysis of Gear Shift Habits

The previous parts of the survey data analysis have primarily focused on finding people who would want to buy the proposed solution. In contrast, this final part of the analysis will attempt to figure out who actually needs the solution, by investigating the relationship between gear shifting habits of the various target audiences. Note that due to the large amount of questions (four) regarding the respondents biking habits, it is difficult to analyze them all in unison. Therefore it is decided to focus on the responses for the following question:

"How often do you remember to downshift gears at a full stop?"

It is considered the most important, since it ties directly into the original problem and informs about the need for a solution. Table 3.2 lays out the relationship between the respondents biking frequency and how often they believe they remember to downshift at a full stop.

Biking Frequency	Always %	Almost Always %	Sometimes %	Rarely %	Never %
6-7 days a week	32	26	19	6	17
3-5 days a week	41	26	12	8	14
1-3 days a week	48	21	17	10	4
<1 day per week	25	27	11	5	31
Never	7	7	7	7	71
Total	34	24	15	7	20

Table 3.2: Relationship between the respondents biking frequency and how often they remember to downshift at a full stop.

Specifically table 3.2 shows that, as one would expect, novice bike users tend to forget to downshift more often than the other groups. Similarly one would expect that the most experienced bicycling group ,'6-7 days a week', would also be the best at downshifting at stops. However this is not the case as that honor goes to the '1-3 days a week' group. In fact the '6-7 days' group is also behind the '3-5 days' group. While these results may be surprising, they continue to support the previous decision to focus on the groups with a higher biking frequency, as they show that there exists a need (albeit not as much as the novice users) for a solution, for the selected groups.

Finally table 3.3 contrasts table 3.2 by showing that the respondents who bike the furthest, are simultaneously the best at downshifting gears at full stops. Although this behaviour would be expected, it is surprising that the results deviate so much from the groups, sorted by frequency. The reasons behind this are currently unknown and it could be of interest to study the details behind this in a future study. Despite the data showing partially conflicting results, the focus on the four selected target audiences is still appropriate as they encompass a large amount of respondents, with a large portion of those having not only a need, but also a want for the solution.

Biking Distance	Always %	Almost Always %	Sometimes %	Rarely %	Never %
More than 20 Km	51	30	15	2	2
10-20 km	39	33	15	3	9
5-10 km	40	25	19	8	8
3-5 km	25	15	20	18	23
1-3 km	34	19	12	10	25
<1 km	12	26	6	0	56
Grand Total	34	24	15	7	20

Table 3.3: Relationship between the respondents biking distance and their ability to downshift at a full stop.

3.2.4 Reflection of Questionnaire Data Analysis

As stated, some of the responses have been removed, because they were judged to be illegitimate. The removed responses could in theory have been legitimate, and therefore it should be considered if removing them could have changed the conclusion of the survey. For this purpose figure 3.7 shows the original data compared to the sorted data in regards to what solutions people were interested in. Although most of the responses were suggesting that more people would pay more for all of the solutions, the final conclusion would not have changed.

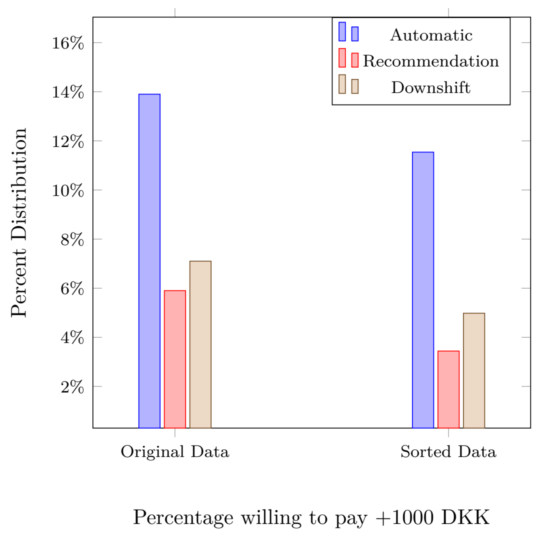

Figure 3.7: The percentage of the respondents who are willing to pay +1000 in the original and in the sorted data

Even though data from our questionnaire is not representing all ages, there is still enough data to make it clear that there is a market for a fully automatic gear shifting system in the lower price range.

3.2.5 Analysis of the Interviews

The first store interviewed was “Vestbyens cykelhandel”, where the popularity differences between external and internal gearing for bicycles were not apparent, since their customers usually bought the bicycle that suited them the best. People would also regularly come to the store for a service check, since they provided it for their customers. Another thing was that extra equipment for bicycles was a huge market and a big selling point for the store. The workers at this specific store also felt that automatic gearing system was a brilliant idea that unfortunately had a unsaturated market, since the price point for the already existing bicycles with automatic gearing was too expensive for the average consumer. They felt that somewhere around 1000 DKK would be the optimal price point for such a feature, but instead of it being extra equipment it should already be pre-installed on the bicycles. The employees at “Vestbyens cykelhandel” advised, that if this should be launched to the public it would be best to work together with a big name bicycle company such as Shimano. Finally, it was recommended that the system should be designed for internal hub gears, as opposed to external derailleurs, as they allow for the smoothest transition.

The second store interviewed was “Fri bikeShop Aalborg” where there were not any popularity differences between gear types either and it was not apparent whether people kept their bicycle in a good condition. They also felt that extra equipment for bicycles has a big market and automatic gearing for bicycle is a good idea that has potential to become something big if it was cheaper. They also made it clear that they believed that a product like this would have to be developed in cooperation with an established firm, such as Shimano, or else they feared that the consumer would not trust the integrity of the product.

3.2.6 Conclusion of the Data Analysis

From the data analysis consisting of surveys and interviews, it can be concluded that the public and bicycle shop owners are more interested in automatic gear shifting system for bicycles compared to the other two options presented. The data collected from the surveys shows that 24% of the respondents would be willing to pay more than 600 DKK for the automatic system. The bicycle shop owner from 'Vestbyen Cykelhandler" is even more optimistic and believes that a 1000 DKK price tag for the system is very reasonable, and could attract a lot of customers' attention. Furthermore, the survey showed that a total of 46% of the respondents were "Interested" or "Very Interested" in the system.

Overall, it can be concluded, that the fully automatic system is the solution that will be pursued throughout the project, as it is not only a viable solution for the proposed problem, but also generates the most public and commercial interest.

3.3 Existing Solutions

As stated in the conclusion to section 3.2, the chosen kind of solution to the problem is an automatic gear shifting system. The next step is to look for already existing solutions in this category and explore their advantages and disadvantages. This is done to figure out potential pitfalls before they are made and to see where the market is not saturated already so that the product made in conjunction with this report is not made instantly obsolete. Through Internet searches and interviews with bike sellers, it can be concluded that there are other alternatives solutions to the problem. This chapter will be used to lay out these solutions so that the proposed solution of this project does not have the same flaws and does not try to enter a saturated market. The section will focus exclusively on technological solutions (i.e through electrical and mechanical systems), as there does not appear to exist any non technological solutions.

3.3.1 Bioshift

Bioshift is a promising solution for automatic gear shifting system, which claims it can keep your bike in the most efficient gear at all times. Bioshift is a prototype by Baron Biosystems, but the idea behind the automatic gear shifting is from US research. The Bioshift, automatic gear shifting prototype has been developed in limited quantity to be tested by professional cyclists, but the product never came out to the market as a finished product for sale. The goal with such a gear shifting system is to increase the efficiency[3].

Technical Solution

The Biosystems solution is claiming to solve the problem for automatic gear shifting, since it can automatically determine which is the right gear for the situation and then it automatically shifts it to that gear. The way Bioshift works is that it collects data via sensors, processes the data, determines the right gear for the situation and finally shifts the gear with the help from the electronic shifting system. It is not as simple as it sounds. The Bioshift product should be clever enough to read your pedalling cadence across various intensity levels although it is challenging for the Bioshift to choose the right gear every time as the cadence is going to vary as you're riding. Besides it being an automatic gear shifting system, it also allows the user to shift the gear manually by overwriting the Bioshift system. Just like it sounds it is an advanced and a high end solution, which both solves the problem of changing gears and adds some new features[4].

3.3.2 NuVinci Harmony

One of the most promising solutions within automatic gear shifting systems for bikes is the NuVinci Harmony. It utilizes a continuously variable transmission (CVT), and is one of the few solutions that has any commercial success. It is a high-end solution and does not have a standalone kit, which means you have to buy it as an integrated part of an electric bicycle with prices starting at 15.000 DKK, NuVinci have however stated that a standalone-kit is on the way, and you can buy third party adaptations of the NuVinci Harmony on sites like e-bay.[5]

Technical Solution

The main feature of the NuVinci solution is the CVT which solves a lot of the problems that exist with automatic gears, such as the sudden movement of the pedals that can occur with standard gears when shifting, and the problem of changing gears while pedaling with internal gear hub, or not pedaling with derailleur gears. The CVT also allows an almost perfect gearing at any point. The battery problem is also solved by only offering the solution for electric bicycles. The shifting of the gears is done by a servo attached to the gear hub, and a cable leading to the shifting handle. They measure wheel speed and cadence at the gear hub as well. This is the optimal high end solution and was also similar to the group's initial idea. [6]

3.3.3 Conclusion

By considering the already available solutions it can be concluded that certain parts of the automatic bicycle gearing market are already covered. The optimal technical solution for automatic gearing is achieved by the NuVinci Harmony. However the low end of the market is by no means covered, and that is the market this project will aim to make a solution for. The next section will find the different stakeholders that could be interested in such a product.

3.4 Stakeholder Analysis

Since the previous section, 3.3, shows that a low end automatic gear shifting system for bicycles is what should be focused on, this section will find the different stakeholders that could be interested in such a product. A stakeholder Analysis is a way to identify the actors that are interested in a proposed solution to a problem. Therefore this section will be used for such an analysis to make sure that the data from the questionnaire will be used effectively. This way the solution can be tailored to the right people.

3.4.1 Identifying the Stakeholders

By brainstorming six different potential stakeholders who could have an interest in the product were found.

- **Common bicyclists:** Because an automatic gearshift will make gear shifting more smooth, lessen traffic congestion at intersections, and in general increase the comfort of riding a bike.
- **Bicycle Shops:** Because the sale of automatic gearshift can fill out a niche market.
- **Municipal and State governments:** Because they can be interested in supporting the automatic gearshift since it could lower traffic congestion in cities and make it more compelling to use a bicycle instead of a car.
- **Environmental organizations:** Mostly for the same reason as with the municipality and the government. People might pick the bicycle over the car.
- **Adult first-time bikers:** Because if someone never learned to ride a bike, they do not have to also think about gear shifting. Here the product could help the user by giving them one less thing to worry about.
- **Motorists:** Because it would lessen traffic congestion associated with bikes crossing the road.

3.4.2 The Development-Actors

Not only is it necessary to find the stakeholders, but it is also important to look into what kind of means the stakeholders have that might help the product. The government has the political power to make tax relief for bikes to help the environment. The cities can implement the idea on city-bikes to make the automatic gear shifting system a more publicly known solution. Lastly the bicycle dealers have the power to spread information about the product to the common cyclist and sell it. After looking into the brainstorm and the development-actors, it can be concluded that the first 3 stakeholders are the most important, since they got the most influence.

Now that the stakeholders have been identified the next step is to conclude on the problem analysis as a whole. This is done so that the data gathered can be used to make a problem statement that will guide the development of the actual product. This will therefore be done in the next section.

3.5 Problem Analysis Conclusion

To analyse the problem, different tools, such as questionnaires, interviews and observations, were used to understand peoples' opinions and behavior. A data analysis was made for the sake of getting an insight into peoples' different perspectives on the problem, which has led to the conclusion that around 42% of all people either forget or rarely shift gears when necessary, such as at a full stop. This is important since it makes it more difficult to pick up speed, which can lead to delays, or worse, traffic congestion. Three systems were proposed, and according to the data collected from the questionnaire, 46% showed interest in the fully automatic system which makes it the most wanted of the three proposed systems.

The data from the survey analysis shows that people are both interested and willing to pay up to about 1000 DKK for a product that can shift gears automatically. As mentioned in section 3.3, similar solutions have already been created to solve this problem, but the asking price is much higher than what many people are willing to pay.

With these points in mind, the following problem statement has been created:

Can an automatic gear shifting system for bicycles be created so that the final product costs no more than 1000 DKK? If so how should it be done and what should the requirements be?

The following chapter will lay out specifications for a final product so that it adheres to the problem statement and the rest of the points found throughout the problem analysis.

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Chapter 4

Product Specification

This chapter focuses on the initial-, technical-, and test specifications that the final product must adhere to. These specifications are critical as they will lay the foundation from which the product is built and designed on.

4.1 Initial Product Specifications

For the product to work as intended, some initial product specifications have been made. These specifications are a very important part of the project since they describe what the product should be able to do, allowing technical specifications to be made in such way that the intended idea for the product can be reached. The technical specifications are going to help evaluate whether the product is a success, failure, or something that requires more work. Furthermore the technical specifications are going to create the framework on which the product is going be built. This means that the initial product specifications does not have a direct impact on the final product, but are the building blocks for the technical specifications. The following list shows the initial specifications that has been made:

- The product should be able to downshift when the user is not pedalling, and has come to a stand still.
- The product should be able to shift gears when the user is pedalling.
- Max cost of the product can not exceed 1000 DKK.
- The product should be able to fit on a bicycle.
- The product should be able to shift gears based on the cadence of the user.

- The product should have a self contained power supply.

Now that the initial specifications have been listed an analysis of the technical specifications can begin. The initial specifications will guide the creation of the technical specifications and ensure that they remain relevant for the product.

4.2 Technical Specifications

To expand and clarify upon the details of the initial specifications, a list of technical specifications is required. Unlike the initial specifications, these specifications provide measurable requirements for the product. After and during the product development, the product will have to be tested, to ensure that it fulfills the technical specifications. Thus a set of testing specifications is created in conjunction with the technical specifications. The list of the technical specifications for the product is listed below:

1. The system should be able to shift one gear within one second.
2. The system should be able to automatically shift from gear one through seven.
3. The system should work up to a speed of 40 Km/h.
4. The system's internal battery should be able to power the bike for a minimum of 5 minutes.
5. The system should have a sensor measurement within a 10% margin of error.
6. The system should have a mean time between failure of minimum 1 hour.
7. While cycling, the user should be able to switch between automatic and manual gearing.
8. The system should stay operational through vibrations met on classified roads and light off-roading.
9. Max cost of the product can not exceed 1000 DKK

The specifications in the list before this paragraph make up the more technical specifications of the project. The next section will focus on creating test specifications that work in conjunction with the technical specifications to make sure that the specifications are quantifiable.

4.3 Test Specifications

Now that the technical specifications have been made clear in the previous section,4.2, this section will focus on making test specifications for each of these. These specifications are an explanation of how each of the corresponding technical specifications can be tested. The test specifications hereafter are mapped so that number one corresponds to the technical specification in the previous section of the same number.

1. This will be tested by taking the time with a stopwatch from the moment someone hits the button to change the gear until the stepper motor stops again.
2. This test will be done by turning the bicycle on its back to make sure the bike is not moving and then accelerate from a full stop (0 km/h) to a speed where the system shifts up to the 7th gear. It is impotent that the system enters and leaves every gear from one to seven.
3. This test will be performed by turning the bicycle over so the wheels are not touching the ground to make sure the bike is not moving. Then the pedals will be turned until the wheels reaches an RPM, which matches a speed of 40 km/h. The point of this test is to see if there are any flaws in the automatic system while the wheels are turning at a high angular velocity.
4. This test is done by measuring how long the system remains operational from the point of turning it on.
5. This is tested by turning the bike over to make sure the wheels do not touch the ground. Then we use an external sensor to measure the RPM at the same time the system does and compare the two results.
6. This test is done by keeping the bike going in automatic gear mode for an hour and biking around at different speeds to make sure the system are still shifting.
7. This will be tested by using the function to shift between the automatic and manual gearing while going at the speed of at least 10km/h.
8. This is tested by taking the bike for a ride over various surfaces and seeing if the system encounters failures or bugs.
9. This will tested by developing an automatically gearing system for a bicycle as cheap as possible. A solution that fulfill the requirements, but still not exceed 1000 DKK.

Since both initial, technical and test specifications have been created for the product the next chapter of the report will pick out the different hardware components needed to complete the task in a satisfactory manner. This is done to give a overall idea of how the

design of the product is going to unfold.
Due to the importance of the specifications they will be referred to periodically throughout the development process, so as to ensure that all of the specifications are fulfilled.

Chapter 5

System Design

This chapter will focus on the hardware that is at disposal and what is required to achieve the technical specifications listed in section 4.2.

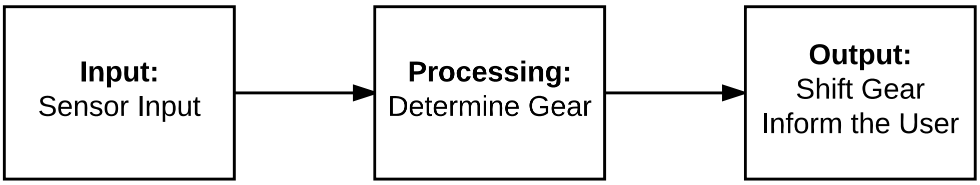

Figure 5.1: Input-output diagram of the system

A flow diagram has been made about the intention of the system, figure 5.1. This is done to make it clear what kind of hardware is needed to obtain the desired function. Figure 5.1 shows 3 boxes: input, processing, and output. Each one of these boxes are important to make sure that the system is functional as wanted. The description at the bottom of each box is a note telling what is thought about in relation to our system in this project. The first box called input is all about sensors. To make a system react to something you must first make sure it can detect the changes in the environment around it. The idea in this project is to have sensors to measure some information about the bicycle, which can be processed. The next box called processing focuses on processing the data that has been obtained through the input, and most importantly what to do next when the environment has been analysed. In this project this box would be about analysing the data from the bicycle and determine what gear is the most efficient for the current situation. The last box dealing with output focuses on doing an action with an actuator. In the bicycle system the action should be to shift the gear and inform the user with some kind of actuator.

All of these considerations are used to determine the following system design so that the right hardware can be chosen.

5.1 Bicycle

The basis for this project is the actual bicycle, as all of the hardware is mounted to the frame of it. Instead of buying a new bicycle, a used bicycle was donated from "Vestbyens cykelhandel" in Aalborg, which was one of the interviewed bicycle shops. This will allow the product to be implemented and tested on a real bicycle.

Figure 5.2: The original look of the used bicycle

The bicycle, shown in figure 5.2 [7] is unisex and has 28’ wheels. Most importantly the bicycle has a hub gear with seven internal gears. While this does not limit the project to using hub gears, since they can be replaced, it makes it more convenient to use them since time restrictions might not allow for changing the entire system. The gearing system will be discussed in section 5.2.5 to see the differences between the available options. The bike is also equipped with one handbrake to the front wheel and pedal brakes to the back wheel. In addition, the bicycle was also equipped with two bicycle baskets, one in the rear and one in the front. These baskets were concluded to not be of any use to the implementation of the automatic gear system. Therefore they were removed to have more space in the front and back of the bike. The bike was also equipped with front and back lights so it is ready and legal to drive around, and to test after dark.

The next section will discuss the different hardware parts that have to be implemented for the product to live up to the specifications in chapter 4.

5.2 Hardware Parts

This section focuses on what kind of parts that are needed for the system to be functional and whether it meets the requirements of the product specifications in chapter 4. By looking through valid hardware choices, the best possible solution have been chosen factoring in time, technical, and financial restrictions. The hardware is chosen based on the following needs:

- An output is needed to show certain information to the user.
- A number of sensors are needed to make sure the system knows when to activate the output and when the actuators are needed.
- The system needs to have a power source.
- The last and one of the more important of the hardware choices is gearing for the system, since there are a lot of different problems with the two different systems.

The following components are chosen to try and create the best possible prototype. This means that some of the chosen parts might not be suitable for a mass manufactured consumer product. Furthermore, due to time, technical, and financial constraints, certain parts will be out of reach for the creation of the prototype.

5.2.1 Output

The system should inform the user about the different gear changes it makes, as well as what gear it is currently on, so that the user can adjust their cycling or take manual control of the gears. It is important to consider exactly how this information is given to the user as well as making sure that it is understandable. Chances are that if the system does not deliver adequate information, the user will feel forced to bypass it or be annoyed. This section will therefore lay out different ways of outputting this information and its pros and cons. At the end, one of the different means of output (Or multiple in conjunction) will be chosen for the final product.
First of all, three categories of feedback will be layed out. These are: *haptic feedback, visual feedback* and *auditory feedback.*

- **Auditory Feedback** Auditory feedback relies on the sense of hearing and is also commonly seen in cellphones. Generally speaking, speakers are one of the most used medium for relaying auditory feedback.
- **Haptic Feedback:** Haptic feedback relies on the sense of touch. A common use of haptics is vibration in cellphones to indicate calls or messages.
- **Visual Feedback:** Visual feedback relies on the sense of vision and is very common in technology. E.g. A screen is a way of relaying information to a user via visual feedback.

Choice of Feedback Category

For this product auditory feedback is not ideal since the users will be on their bicycles in all kinds of settings. For an example, if the system used different sounds to indicate different things, the user might overhear them if they are in a crowded area with lots of ambient noise. On the other hand, if the users use headphones connected to the system on the bicycle it might work, but the wires from said headphones might cause problems if they dangle from the bicycle to the users ears. It might also be annoying for users who normally listen to music via headphones while cycling, since they would not be able to use their own headphones. If the system was linked to an application for smartphones it would be able to utilise headphones in a better way, but it would also mean that the user would have to download and set up a separate thing for the system to work properly, which some of the bikeshop owners warned against during the interviews 3.2.5. These faults mean that auditory feedback can be ruled out.

Haptic feedback could be used by putting vibrators in the handlebars to indicate that the system is gearing up or down. While this is better than auditory feedback it is important to make sure that the vibrations are easily distinguished from normally occurring vibrations from riding on something like an uneven surface. The vibrations also have to be powerful enough for the user to feel it through gloves used during cold weather. The vibrations made by the device also have to be easy to understand. For example, a long continuous vibration could mean that the system is gearing down, while a series of short vibrations could mean the opposite. Overall haptic feedback could be a good contestant for the choice of feedback method.

Visual feedback would definitely be a good way to relay information to a user of the system. A display on the handlebars of the bike could spell out if the system is going to change gears and could show the current gear as well. Another way to implement visual feedback could be to use blinking lights as indicators. With both forms of visual feedback it is important to make sure that the users attention is not taken completely off the road or that the lights/screen interfere with their ability to drive. If this can be factored into the solution, visual feedback could be a good way of relaying information to the user.

For this project, a combination of haptic and visual feedback has been chosen as this seems like an optimal solution for providing feedback to the user. The two components chosen for their respective category of feedback will be discussed in the following sections.

Visual Feedback Choice

For displaying the current gear, a 7-segment-LED-display will be used. It is chosen because of its low cost and low power consumption. For this project nothing else is expected from the LED display than showing the number of the current gear. It will be connected directly to the micro controller. With the LED - display, the user can always get a quick look at the current gear. The price for such a display is around 5 DKK [8]and therefore well within the budget of the product.

Haptic Feedback Choice

For haptic feedback, a small DC vibrator will be placed in the handle. When gears are being changed the vibrator will be turned on to inform the user that the gears are shifting. That way the user will always be notified, when the gear is shifted up or down and can observe the new number of the gear from the LED - display. The price for such a motor is around 5 DKK [9] and is therefore, like the display, within the budget of 1000 DKK total

5.2.2 Sensors

For the microcontroller to most efficiently calculate the appropriate gear, it should be fed an array of information on the state of the bike. The sensors should ideally be able to relay the following information regarding the state of the bicycle and its user:

- Input torque
- Wheel RPM
- Cadence

Sensors for gathering this data will be discussed in the following sections.

Input Torque:

A torque sensor has the ability to measure the instantaneous torque exercised by the cyclist. This would allow the product to change to the required gears almost instantaneously. Due to the existence of the electric bicycle market, there already exists a variety of easy-to-install and accurate torque sensors [10]. Unfortunately, even the cheapest of these sensors costs at least 450 DKK [11], thus making it's implementation into the project difficult to justify, as the sensor uses almost half of the maximum allocated budget. A cheaper, but less tested, and harder to implement method, would be to install deformation sensors, such as strain gauge sensors, next to the pedals [12]. While these systems may be cheap (10 DKK for two sensors [13]) They have their own set of problems. Since any of the sensors have to be installed next to the pedals, the sensor would be in constant motion, thus, making it impossible to connect the sensor to a micro controller using wires (as they would be cluttered together over time due to the rotational motion). Instead, a wireless solution would have to be used as a means of data transfer, and while this should be possible, it adds a lot of extra complexity to the solution. Due to these technical complexities, it is decided to maintain the design with low cost objective, and to try and built the product without a torque sensor.

Wheel Sensor:

A wheel sensor aims to measure the RPM of the wheel. For measuring the RPM, two options exist: Buy a premade wheel sensor or construct a custom sensor. Both options would be placed near one of the wheels, utilize magnets and reed switches (switches that are activated by magnetic fields) to measure the time between revolutions. The difference between the two options comes down to three points:

- **Price:** A premade wheel sensor is not very expensive and can be found online for as low as 35 DKK[14]. On the other hand, it is possible to buy a single reed switch for less than 1 DKK[15]. However, since the cost of a premade cadence sensor is only 3.5% of the total allocated budget, it is unlikely that price will be the deciding factor between the two options.
- **Flexibility and Adaptability:** Most modern premade wheel sensors are designed to work with a specific cyclocomputer model. This makes development difficult, as the received data would likely have to be reverse engineered to be understood. In contrast, a completely custom solution can be engineered to fit the solutions specific needs.
- **Ease of Implementation:** It is obvious that a premade solution would generally be the easiest to implement, as it would not be necessary to design, create, and implement custom circuits. But, as mentioned in the previous bullet, it is likely

that the premade cadence sensor would lack adequate documentation, thus creating new implementation challenges.

Due to the flexibility, it brings development a custom solution utilizing a reed sensor has been chosen for measuring the RPM of the wheels. It should be noted that a third option for measuring the RPM of the wheels exist: Measuring the change in voltage supplied by a hub dynamo. While this solution is not the most practical to implement, it does come with the advantage of being able to deliver power to the product while the cyclist pedals. However, due to time and technical limitations, this options was not pursued further.

Cadence:

A cadence sensor aims to measure the cadence, i.e the RPM of the crank. Similarly to the wheel sensor, the same two options for measuring cadence exists: Buy a premade cadence sensor or construct a custom sensor. However another, far simpler, option is also available. Instead of dedicating an entire sensor for measuring the cadence, it is possible to exclusively measure the wheel RPM, and then use that reading in combination with the gearing ratio to calculate the cadence. Due to its simplicity, this is going to be the option that will be used.

Reed Sensor

This section will focus on how the reed switch works and why it is chosen over the other solutions. There exits two types of reed sensors called *normally open* and *normally closed*. The focus will be on *normally open*, since it is the reed switch used in this project.

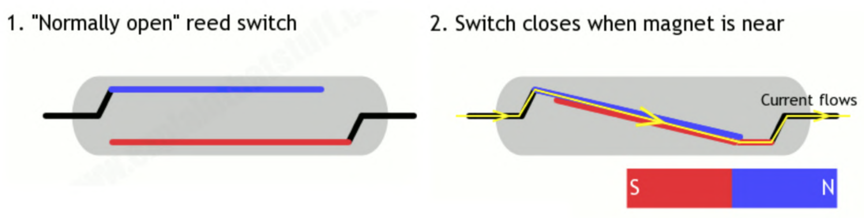

Figure 5.3: How a reed sensor works

As the figure 5.3 [16] shows, the reed sensor consists mainly of two contacts made of magnetic material (the two metal reeds inside the thin glass). One of them is north pole and the other one is south pole. When a magnet comes close to a reed switch, the contacts will be affected the opposite way, as shown on step 2 of figure 5.3. The magnet will attract one of the contacts and repel the other one. That way the contacts will close together and a connection will be created, where the current will flow through. Overall, the normally open reed switch will be off, unless a magnet comes close to the switch to turn it on. In this project the RPM will be measured, every time the reed switch comes close to the magnet on the wheel. The *normally open* reed switch is chosen over the other solutions 5.2.2 because it is simple, cheap and does not take up a lot of space.

5.2.3 Power Supply

For an electronic system to function, it needs a power supply. For the components used in this project, a power supply that can supply a direct current is required. The power in a consumer version of this project should be self sustained and the user should not ever have to think about it if possible. Such a solution could be achieved by attaching a dynamo and a rechargeable battery to the bike and connect it to the system. However, since the focus of this project is the automatic shifting system, it is not relevant to work on a dynamo system, as resources would have to be allocated away from the main focus of the project. Therefore it has been decided to use a battery pack to power the system.

5.2.4 Mechanical Actuator

The product will require some kind of mechanical actuator to shift the gears. Since the actuator needs to operate on a small scale and be relatively cheap it makes the most sense to utilize and electric actuator, such as a common DC motor or a stepper motor. Since precise movement is required to switch to the appropriate gear, it would make the most sense to use a high precision stepper motor. Furthermore, to reverse the rotational direction (thus downshifting) a driver is required.

For this project a stepper motor with a 1:5 gearing attached is used to shift the gears by pulling a steel wire on a standard city bike. However it is over-dimensioned to compensate for the pullback spring in the internal gearing. This size and strength would not be needed in a commercial product, since it could be made with a custom gearing hub with no spring. A smaller motor would be better in terms of cost and power consumption. The acquired motor is one of the more expensive parts as it costs around 200 DKK [17].

Stepper Motor

This section will focus on how stepper motors work in general. Stepper motors mainly consist of a rotor, which is a permanent magnetic rotating shaft, and the stator which are electromagnets surrounding the motor. Figure 5.4 [18] shows a complete rotation of a stepper motor in 5 steps.

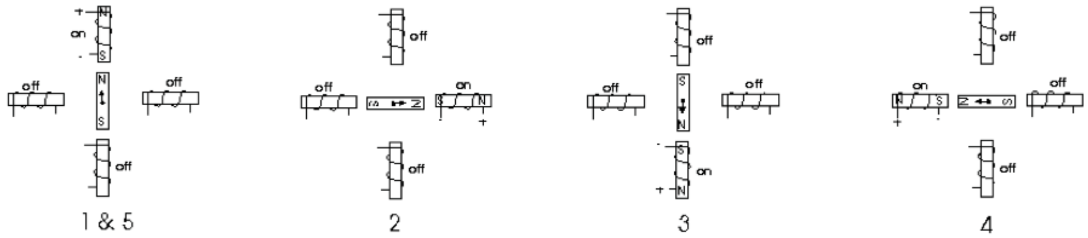

Figure 5.4: Diagram over a stepper motor

In step 1 the rotor is activating the upper electromagnet. The rotor will be moved clockwise when the upper electromagnet is deactivated and when the next electromagnet is activated as it is shown in step 2. The stepper will be moved 90 degrees clockwise until it reaches the active electromagnet. This process will be repeated the same way until it reaches the start position again (step 1). In the figure above a motor with 90 degrees resolution is used. This figure shows how a stepper motor works in general, but in reality a better motor is needed for most tasks. The resolution of the stepper motor can be doubled by a process also known as "half-stepping". With half-stepping two electromagnets can be activated at the same time, causing an equal attracting and that way the resolution will be doubled. [19]

Different types of stepper motors exist, where some require special motor drivers to work. For this project a 2 phase bipolar stepper motor is used, because it can be driven by normal motor drivers (further information on the motor control will be discussed in the next section). There are no further information or data sheet for this stepper motor, because it was the only stepper motor available and the serial number of the motor was pulled of. From the shape of the motor and through some Internet searches it has been found that the motor is a 2 phase bipolar motor with 2 groups of coils and 2 wires each. The phases can be activated with alternating the polarity and that way the motor will be turned with the help from the coils.

Motor Driver A4988

The motor driver used in this project is a A4988 driver, which makes it easy to operate a bipolar stepper motor. This driver allows for an output capacity up to 35 volt and +/- 2 ampere per coil and also features adjustable current limiting, and over current protection. This driver can be bougth for approximatly 9 DKK [20].

The driver has all in all 16 input ports "ENABLE, MS1, MS2, MS3, RESET, SLEEP,

STEP, DIR, VMOT, GND, 2B, 2A, 1A, 1B, VDD, GND" and each and every port has a different purpose. Different configurations of the inputs "MS1, MS2, MS3" allow the motor to take full, half, quarter, eight and sixteenth steps. The other ports such as "2B, 2A, 1A, 1B" are used to connect the stepper motor, while "VMOT" and "GND" are used for the power supply to the stepper motor. The ports "VDD" and "GND" are used to power the driver, which requires 3-5.5 V and "DIR" controls the direction the motor is running while "STEP" controls the amount of steps taken by the stepper motor. The last three ports "RESET, ENABlE and SLEEP" also have an effect on the motor. "RESET" sets the translator to a defined state while "ENABLE" switches on/off the all the outputs and lastly the "SLEEP" input effectively decreases the power consumption of the motor by setting it in sleep mode when it is not in use. [21]

5.2.5 Gearing

In general, two different types of bicycle gearing exist: Internal hub gears, and external derailleur gears. For the purpose of creating an automatic transmission, the gear hub has been chosen since it was the system present on the provided bicycle. However, even if the choice was present, the hub gear would be the superior gearing mechanism for the project as it can downshift while the users is not pedalling. This means that system will be able to shift to the first gear when the user reaches a complete stop.

Derailleurs have one distinct advantage over most hub gears: It is possible to shift gear while the cyclist is pedalling. While this is a very important feature for the project, the other advantage in favor of the hub gear is thought to be more important. It should be noted that certain modern hub gears also have the ability to shift gears while the cyclist is pedalling [22].

Picking hub gears, also falls in line with the information provided by "Vestbyens cykel-handel" during their interview (see section 3.2.5).

5.3 Hardware Platform

For this project an I/O device for the sensors and the actuators is needed. This section covers the thoughts and considerations that were made to choose the right platform for this project.

5.3.1 Requirements

For this project there are certain specifications to consider for the I/O unit:

- **Physical Size:** Since the device is going to be mounted on a bike, and it is inconvenient for it to be in the way of the user. That is why it should be as small as possible.
- **Power Consumption:** The device should consume as little power as possible. This means that the user has to think less about the battery and also means that there is a smaller requirement for battery in terms of its size
- **Experience:** It also has to be taken into consideration that there is a deadline, and that it might take too much time away from the rest of the project for the group to learn an unfamiliar platform.
- **Price:** Since the data in 3.2 shows that aiming at the lower price market is desirable, the device should be as cheap as possible for reduced material cost.

With these requirements in mind, different possible choices for the platform will be discussed in the following section. This will end in one of them being chosen for this product.

5.3.2 Single-Board Computer - SBC

As the name suggests a SBC is an entire computer with all its required components on a single circuit board. A SBC could be used for this project, but although it does meet the requirements, it also has unnecessary features, and uses an operating system, which will not be needed for this project. This would also simply be overhead that would result in a higher power consumption. Another problem is the cost, even though the cost has come down a lot recently, there are cheaper alternatives which will be covered next. Last but not least, the group would have to learn an entirely new platform.

5.3.3 Micro Controller Unit - MCU

A MCU is a computer on a single integrated circuit that includes a processor, memory, and has programmable I/O. The MCU exists in many forms, an example is the many kinds used on the Arduino like boards.

Arduino

An Arduino is one of the candidates that could be used as the micro controller to control the automatic gear shifting system. There are many different types of Arduinos such as the Arduino uno, nano, mini, zero etc [23]. with different sizes and specifications. An Arduino should be more than enough to control the other components like sensors and motors. As mentioned earlier the device should be as small as possible and should by no means be disturbing for the user. That's why it will be effective to use one of the small Arduino boards, since it satisfies all the demands.

The Arduino device will be used as the platform for this project. However it has been concluded that in a final version it would be better to use an even cheaper platform, since it doesn't need all the features of an Arduino board. One such solution could be to simply use the micro controller chip from the Arduino board alone, or another similar micro controller, in a custom circuit that meets the requirements of section 4.1 at the lowest possible price. For this project an Arduino Nano with an ATmega328 microcontroller is used. This unit can be acquired for about 20 DKK [24].

Now that all the hardware parts for the system has been chosen, the next step is to make choices regarding the software that is going to run on the Arduino.

5.4 Choosing the Programming Language

For the purpose of this project, the programming language should be compatible with the Arduino hardware since this was chosen as the platform for the system to run on in section 5.3. There are a few possible options. The c programming language is one of the default language for the Arduino [25]. It is therefore very well documented and does not limit the capabilities of the hardware. There is also a huge community, and many places to seek help regarding potential problems. In addition the Arduino programming language is associated with the "programming" lectures, which gives the group more experience of how the Arduino programming language is used. Overall, Arduino is very easy to pick up and use, since it is basically like c programming. Thus the Arduino version of c programming will be the programming language used for the prototype.

5.5 An Illustration of design

It has been determined in all of chapter 5 what the system should include when looking at the specifications 4.2, to be able to shift into the optimal gear. This information can be used to make figure 5.1 more essential to the system that is being built.

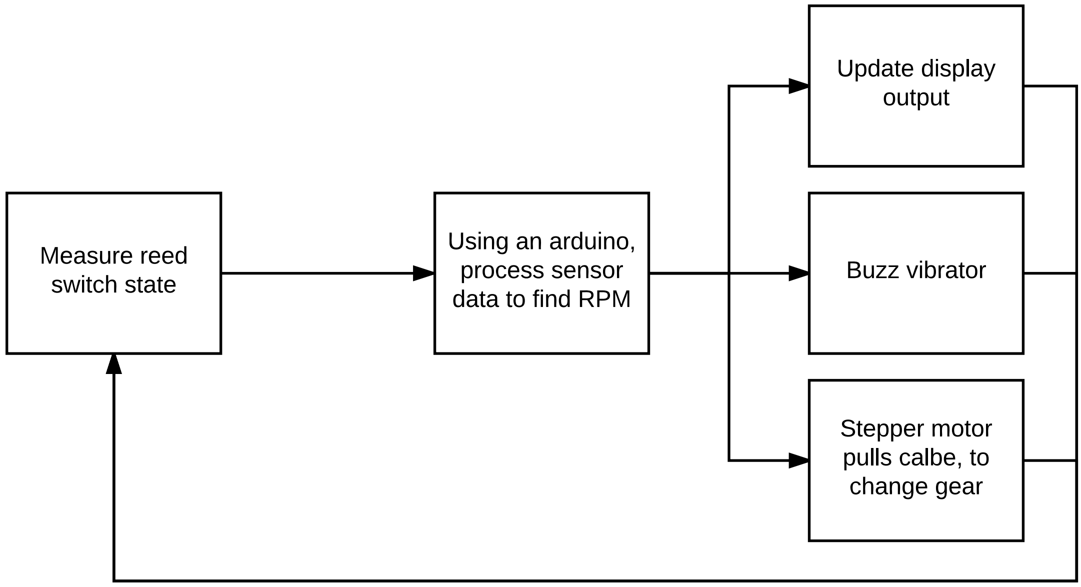

Figure 5.5: Basic flow diagram showing how the automatic gear system should work

In figure 5.5 the first box is sensor measurement, coming from an input sensor, which is the reed switch. This data is then processed trough an Arduino. From the processed data the most efficient gear is calculated through the Arduino programming. In the end, the system uses the stepper motor to change the gear to the optimal gear and informs the user trough a visual and haptic feedback in the form of a display and a DC vibrator. This flow is then repeated endlessly.

Now that the a design for the system have been made it is possible to go further into the implementation of the hardware. The next chapter will go into not only the hardware, but also the software implementation of the product.

Chapter 6

Implementation

For this project it is required to create a physical electronic product where the technical design is a crucial part for the construction of the system. Throughout chapter 3 different studies were conducted in order to figure out which product this project was going to focus on. At the same time chapter 4, focuses both on the different functional and technical specifications for the product and chapter 5 is about the hardware components necessary in order to build the product. So by combining what was learned throughout these three chapters this chapter will focus on the different circuit designs and the implementation of the components and software necessary for the product to function properly.

Since the product consists of electronic components, the circuit design started with breadboard builds and later moved on to be soldered on to PCB prototype matrix boards. The different components are then finally connected to the Arduino.

6.1 Hardware

The hardware section will focus on how the system is built up from each little wire to the motor, which is controlling the gear. This is mostly done trough the use of diagrams to get a better visual information.

6.1.1 Initial Prototype

Since the exact purpose, nature, and framework surrounding the solution has been described in the previous chapters, it is possible to design and construct an initial prototype. Using the components described in chapter 5, figure 6.1 shows the pictorial diagram created for the initial prototype. The prototype was set up on a simple breadboard, as it is a flexible development platform, which allows for quick circuit construction. This also makes it easier to deal with problems while debugging the circuit.

The goal of the prototype is to prove that all of the selected components could successfully be connected to an Arduino, but more importantly that all of the components operated as expected - both as individual components and as one system. In both of these areas the prototype was a success. One shortcoming, however, is that the components of the prototype were all not attached to an actual bicycle. While this setup allowed for a great deal of modularity in the circuit, it made it difficult to test how the individual components would behave, when attached to a bicycle. Thus tests were carried out, to make sure that each sub-circuit behaved as intended.

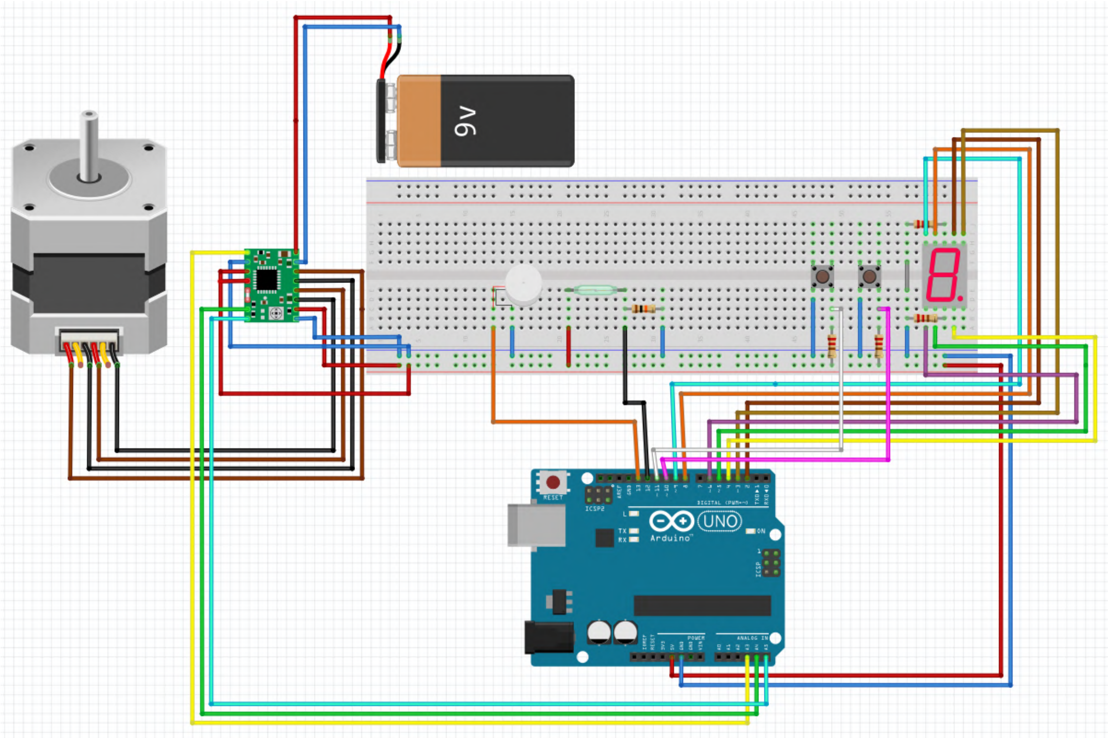

Figure 6.1: Pictorial diagram of the initial prototype

6.1.2 Hardware Implementation

This sections is accompanied by schematics located in Appendix E.

After the initial prototype design was built on a breadboard, the system was divided into multiple segments and then connected to an Arduino. This increases modularity and allows the parts of the product to be tested and built separately, thus simplifying the assembling, testing, and debugging of the hardware.

1. **The Arduino and the Stepper Motor Driver**, are both critical components in the system, as all communication between the other hardware components are relayed through them. The Arduino and driver module is built on a PCB matrix board, as shown in figure 6.2, and it contains the pins necessary to connect to the other hardware segments.

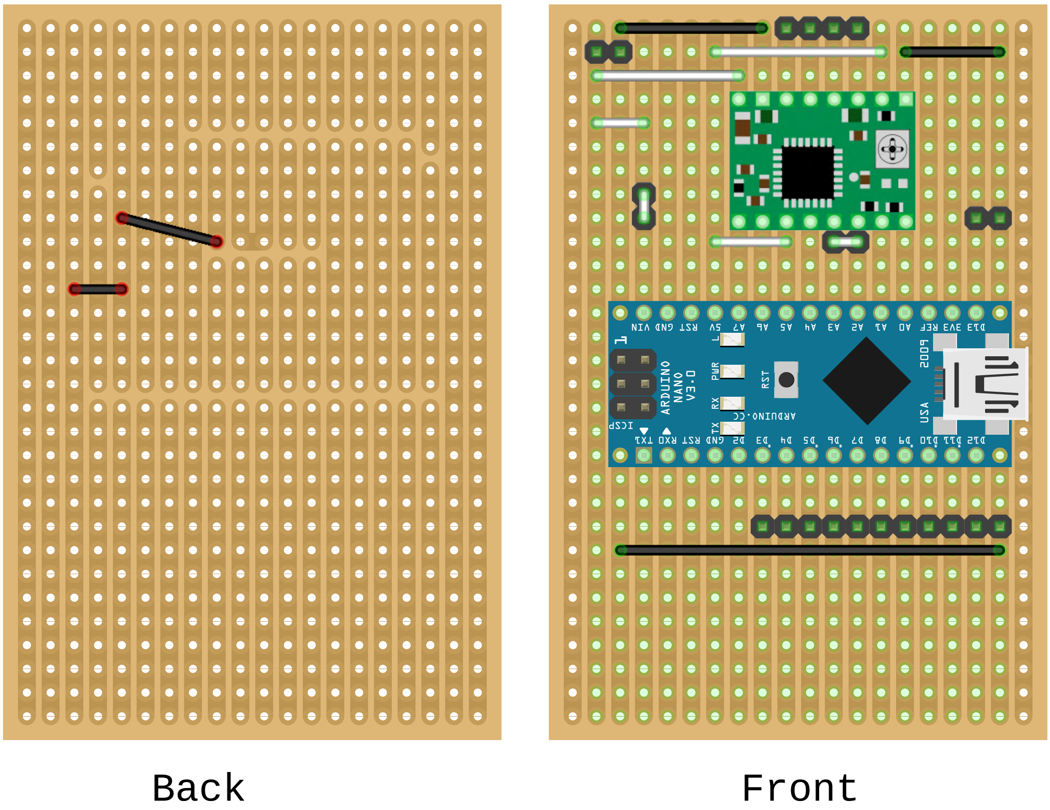

Figure 6.2: Pictorial diagram of the Arduino + Driver module

2. **The Display Segment**, shown in figure 6.3, is the module containing the 7-segment display. The module has 11 pins, where the ground pin, pin '1', is attached via two 220Ω resistors to the two ground pins of the display. The 3,4, 6-11 pins control the eight segments and are connected to output pins on the Arduino. Pins 2 and 5 are not in use. Like the Arduino and driver module, the display segment is built on a PCB.

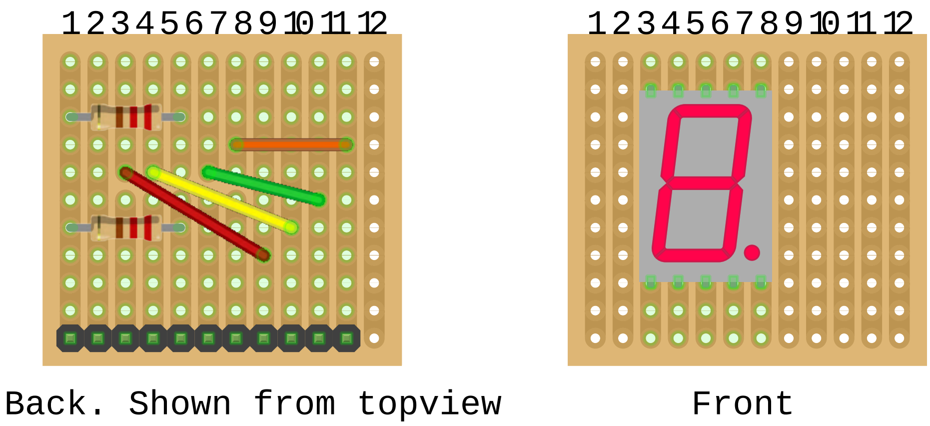

Figure 6.3: Pictorial diagram of the display module

3. **The Button Module**, shown in figure 6.4, is also a segment made on a PCB matrix board. The module has two buttons and four pins. The buttons are connected to pin '1' and '3' respectively. These pins are then in turn connected to two input pins on the Arduino (the pins take advantage of the Arduino's internal pull up resistors). Both of the buttons are connected to common ground through 220Ω resistors. The last pin is unused, but was implemented in case it become desirable to connect 5 volts to the buttons.

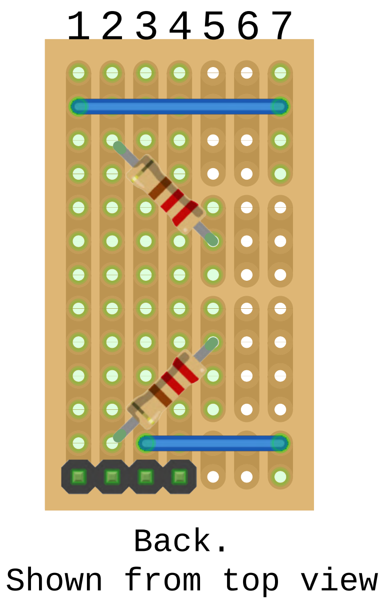

Figure 6.4: Pictorial diagram of the button module

4. **The Vibration Motor** is placed in the handles of the bicycle, and it is connected directly to the Arduino.

5. **The Reed Switch** is a fragile piece of equipment, therefore it is placed inside a plastic container. The switch is placed near the rear wheel, and it is connected to the Arduino through wires running along the frame of the bicycle. The reed switch uses a pull down resistor to normalize input reading (this is not supplied by the Arduino, as it only supplies internal pull up resistors).

6. **The Stepper Motor** is attached to the rack of the bicycle. It uses a shield, as shown in figure 6.5, to protect and contain the gearing cable. The stepper motor is connected to the driver by running the four required cables along the frame, to the driver/Arduino module.

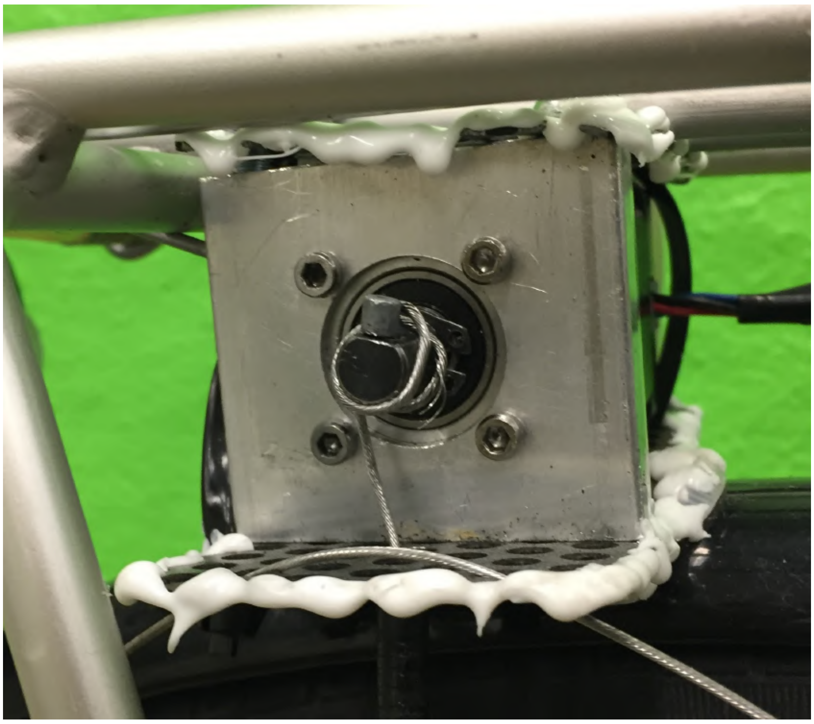

Figure 6.5: The stepper motor

7. **Seven AA Alkaline Batteries** are used to power the electronics. Each battery supplies 1.5 volts, resulting in a total of 10.5 volts, and they are located on the handle bars of the bicycle. Even though it is only necessary to have 9 volts in order to run the system properly. It was decided to use an extra battery as an insurance since the stepper motor might not run properly under stress. Another reason is because of the fact that batteries undergo voltage drops. This would be a problem if the system is only supplied with 9 volts, and it could lead the stepper motor to run insufficiently, thus rendering the product useless.

All of the segments listed above are connect to form one unified circuit. These connections are illustrated as a pictorial diagram in figure 6.6. In addition, the complete circuit is shown in detail, in the included schematics in appendix E.

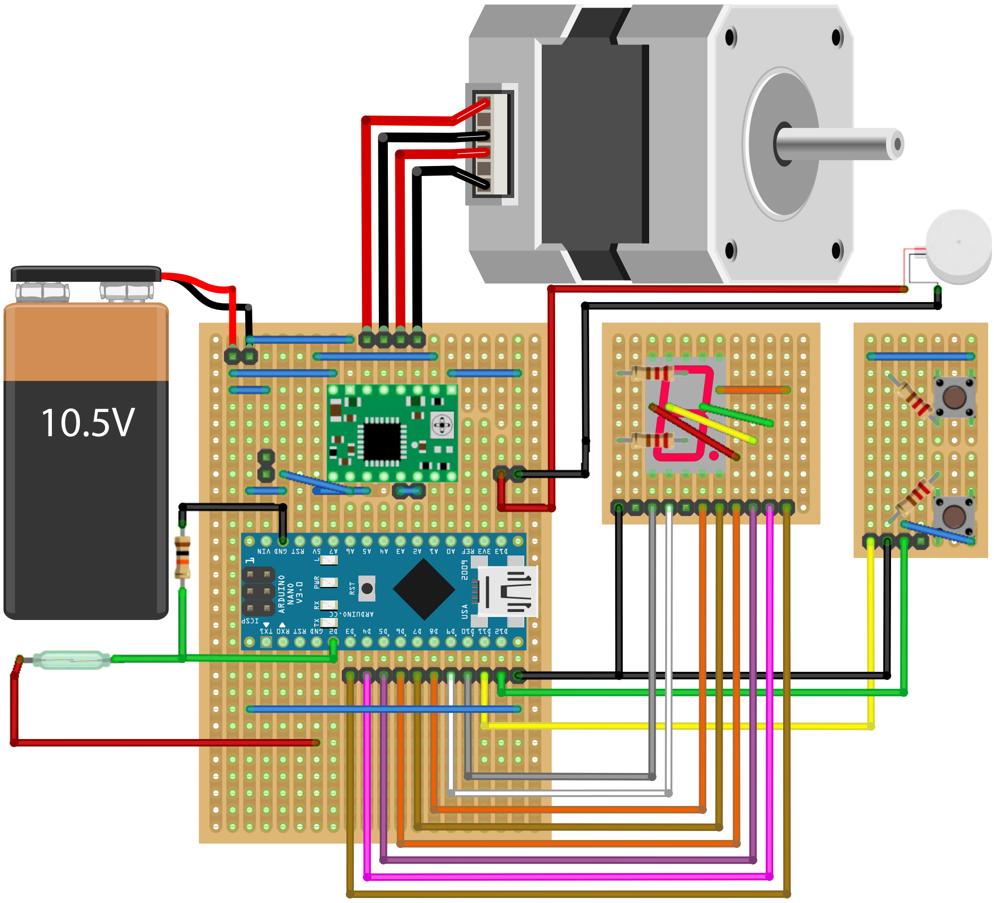

Figure 6.6: Pictorial diagram of the complete circuit

All of the hardware parts used in the circuit are placed on the frame of the bicycle. A visual presentation of each segment is shown in figure 6.7. The numbers on the figure refers to the list shown earlier in this section. The modular parts are mounted on wooden plates, which are fastened with zip-ties in the front of the bicycle. The display (2) and buttons (3) are both placed on the handlebar while the Arduino and motor driver (1) sit in front of the bicycle handlebar. Next to the buttons the vibrator is placed (4), which is hidden under the bicycle handlebar grips. The stepper motor is mounted under the rear rack (6) while the reed switch is fitted next to the center of the rear wheel (5).The power supply (7) is placed in front of the handlebars.

Figure 6.7: Component placement were the numbers refer to the corresponding values in the list in section 6.1.2.

6.2 Software

This section will go in-depth with the software programmed into the Arduino which can be found in Appendix D. An overview of the logic of the software is expressed through the flowchart found in appendix F. The chart shows the overall program flow, and the code examples shown throughout this section further describes parts of the logic shown in the chart. Since most of the actual code is not particularly advanced there will not be spent a huge amount of time explaining each individual function in it. Instead, a few selected functions or code-snippets will be explained to give an understanding of the thought behind them.

6.2.1 Setup

There is a setup branch in the default Arduino programming code. The setup is done once, when the system is turned on. This is where the pins are assigned, the calculations on the desired RPMs are done and the last state of the system is loaded.

6.2.2 The Main Loop

When the setup is done, the software enters a infinite loop that contains all the logic. The software design is based on this loop that iterates through a series of update functions. The flow of the software can be seen in figure F.1. All functions are designed to never let the program wait. This is to make sure that it reads the reed sensor pin often enough to not miss a change in input. This is important, because the main input of the system is the reed switch, which is on for very short durations. It is essential for the system that no change of state of the reed sensor is missed, or at the most 2 in 5 with the error filter.

6.2.3 Detecting Change of Input

The software is looping through the main loop multiple times every second. However, certain functions should only be called at a certain event such as the reed switch or a button turning on. The inputs are all measured as a digital input, thus the state can either be *HIGH* or *LOW*. To register a change, the code compares the current measurement to the previous measurements, which is then saved as a static variable at the end of the function for the next comparison. This way it is used when detecting a button is pressed and then released. This way of checking the change of state has been used multiple times in *checkButtons()* seen in figure 6.8.

```
1
2  void checkButtons() {
3    // Variables to check if there is a change in state of the buttons
4    static bool lastUpB;
5    static bool lastDownB;
6    static bool lastBothB;
7    static bool bothHasBeenPressed = false;
8    static long lastButtonAction = millis();
9    // Read button sates
10    //states are inverted because pull up resistors are used
11   bool upB = !digitalRead(UP_BUTTON);
12   bool downB = !digitalRead(DOWN_BUTTON);
13   bool bothB = upB && downB;// true if both buttons are pressed
14   //Checking what buttons are pressed
15   if ((lastButtonAction + 50) < millis()) {//Added delay for debouncing
16     if (bothHasBeenPressed) { // check for both buttons to be liftet after they have both been
          pressed
17       bothHasBeenPressed = (upB || downB);
18     } else if (bothB) {//Toggle the autogear if both buttons are pressed and save that both
          buttons has been pressed
19       bothHasBeenPressed = true;
20       toggleAuto();
21     } else if (!upB && lastUpB) { //button is not pressed but was last check, shift gear up
22       shiftGearUp();
23     } else if (!downB && lastDownB) {//button is not pressed but was last check, shift gear down
24       shiftGearDown();
25     }
26     //saving values for next check
27     lastUpB = upB;
28     lastDownB = downB;
29     lastBothB = bothB;
30     lastButtonAction = millis();//Used for debouncing logic
31   }
32 }
```

Figure 6.8: Example of reading the button input (found in line 237 of the source code)

The lines 3 to 6 contains static variables that is used to save the previous state of the buttons, these variables are saved at the end of the function in lines 27 to 29. On lines 11 to 13 the buttons are read. On line 15, a reading delay has been added to avoid bouncing. On line 16, it is checked whether both buttons already has been pressed. At line 17 it is waiting for both buttons to be released. Line 19 and 20 is called when both buttons has just been pressed and it toggles the automatic shifting. Lines 21 to 24, the code is checking if one of the buttons has been released, and if so it shift up or down accordingly.

6.2.4 Calculating RPM and Cadence

Since this product is aiming to optimize the pedaling efficiency by automatically shifting gears based on the cadence, this part of the program is rather important. Since the reed sensor is measuring the RPM of the wheel, the cadence will have to be calculated based on the gearing, both in the gear hub and between the front and the rear cogwheels. The calculation is as follows:

$$\text{RPM} = \frac{\text{Cadence}}{\frac{\text{Pedal cogwheel teeth}}{\text{Gear hub cogwheel teeth}} \times \text{Gearing ratio}}$$

Figure 6.9: Equation for calculating the RPM

As mentioned, each gear is saved as the desired RPMs in an array called *rpmForGears* for each gear.

The code in figure 6.10 is used for the measuring and calculating the RPM.

```
1 void updateRPM() {
2   long currentMillis = millis(); // To compare time of reading
3   static long lastOn;// To compare time of last reading
4 
5   bool reed = digitalRead(REED_SWITCH); // The current reading
6   static bool lastRead; // To compare state of last reading
7 
8   if (reed && reed != lastRead) { // Called when a magnet pass
9     float calcedRpm = (60000 / (currentMillis - lastOn)) / MAGNETS; //Calculate rpm
10 
11    rpms[rpmReadingIndex] = calcedRpm; // the calculated RPM is inserted into buffer array
12    rpmReadingIndex++;
13    if (rpmReadingIndex > rpmsSize)
14      rpmReadingIndex = 0;
15    lastOn = currentMillis;
16 
17  }
18  else if ((lastOn + FULL_STOP_TIME) < currentMillis) // called if no magnets passed in FULL_STOP_TIME ms
19  {
20    // If the wheel has not been turning for FULL_STOP_TIME ms it is assumed that the bike is at a full stop
21    for (int i = 0; i < rpmsSize ; i++) { // Set entire array to 0
22      rpms[i] = 0;
23    }
24    lastOn = currentMillis;
25  }
26  lastRead = reed;
27 }
```

Figure 6.10: Code snippet that is used to measure RPM (found in line 161 of the source code)

At line 2, the time is saved in a variable to use the same time troughout the function. At line 3, a static variable is used for saving the time of the last time the reed switch changed from off to on. At line 5, it saves the current reading on the reed switch. At line 6, a static variable is used to compare the state of the previous reading. At line 8, it checks if the reed switch has turned from off to on and if it has not it will go to line 18 and check whether *FULL_STOP_TIME* milliseconds has passed since last magnet. If it has it will assume that the bike is at full stop and will change the entire buffer array to 0s. At line 9 it calculates the RPM based on the time since the last magnet passed and how many magnets that is attached. At lines 11 to 14 it saves the Calculated RPM at the next spot in the buffer array. Then at line 15 or 24 it saves the saved time for the next comparison as *lastOn*. And finally it also saves the reed switch state for the next comparison at line 26.

6.2.5 Automatically deciding which gear to use

As the desired RPM has been calculated and the current RPM is being calculated and saved in *rpmForGears*, an algorithm has to decide which gear to shift to. The algorithm seen in figure 6.11 first finds the gear that matches the current RPM by, in lines 2 to 10, looping through *rpmForGears*. Then at line 13 to 14, it checks if the gear it just estimated is less than the current gear. Then it also uses the function *isXCloserThanY(float in, float x, float y)* to check whether the current or the matching gear (variable *i*) is closer to the current RPM. This assures that once it has shifted up a gear, the RPM has to be even lower to downshift, which is to make sure that the RPM is not on the edge of the gear intervals and fluctuate between the gears.

```
1  void updateGear() {
2    rpm = getRpm();
3    int i = 1;
4    while (i < NUM_GEAR) {//Check which gear it requires to match the rpm
5      if (rpm > rpmForGears[i-1]) {
6        i++;
7      } else {
8        break;
9      }
10   }
11
12    // this assures that once it has shifted a gear up, the rpm has to fall even lower to
          downshift, this is to make sure that the rpm is not on the edge of the two values and
          fluctuate between the gears
13   if (i > targetGear || i < targetGear && isXCloserThanY(rpm, rpmForGears[i-1],
         rpmForGears[targetGear-1])) {
14     targetGear = i;
15   }
16 }
```

Figure 6.11: An example of how preprocessing code was used for debugging (found in line 215 of the source code)

6.2.6 Debugging using Preprocessing Code

Debugging has been used to make sure the system was doing as expected. Most of the debugging was done by making the Arduino send some data through the connected usb at certain points in the code. However in the final code there should not be any debugging code. For this purpose preprocessing code was used as seen in figure 6.12.

```
1 #define debug// uncomment for debugging
2 ...
3
4 #ifdef debug// Compile this if debugging
5 ...
6 Serial.write( value); //For an example: Send some value to the console
7 ...
8 #else // Compile this if not debugging
9 ...
10 // Some other code if needed
11 ...
12 #endif
```

Figure 6.12: An example of how preprocessing code was used for debugging

At line 1, a variable *debug* is defined. At line 4, it checks whether *debug* is defined, if it is, it will compile as it shows in between line 4 and up til line 8. If *debug* is not defined it will compile the code from line 8 to 12. This was an effective way to ensure that none of the debugging code would be compiled in a final version of the software.

Now the final implementation of the product is complete, the next step is to test the functionality of the completed solution. Using the testing specifications from section 4.3, the following chapter will present the results of the tests the solution went through.

Chapter 7

Tests

After the completion of the product, it was put through a series of tests based on the testing specifications from section 4.3. This was done to ensure that it fulfills all of the technical specifications from 4.2. This chapter will describe the results from the performed tests.

Test 1 - Timing Gear Shifts

This test had to do with checking how long it takes for the product to shift one gear. It was first performed as described in section 4.3. However, in addition to using a stopwatch for recording the time, code was created to record the time between the stepper motor being activated and deactivated. This approach was used as it provides more accurate readings than that of a humanly activated stop watch.

The test results from timing it with a stopwatch, gave an average time of a gear shift of about 0.8 seconds. This is within the requested one second, but as stated above the test was also performed with debug code since it was assumed that the margin of error for a test with stopwatch would be too high.

The test results from the code was printed to the console of the Arduino IDE and ten measurements were then made by pushing a button to shift a gear ten times. The average result of these tests showed that it takes around 0.72 seconds for the system to change one gear. This means that the product fulfills the first technical specification.

Test 2 - Automatic Gear Shifting

This test was done to examine whether or not the bicycle could automatically switch between every single gear available. It was performed as described in section 4.3 and was measured by turning the pedals of the bike, while holding the back wheel up to ensure that the bike was standing still. A person then slowly accelerated the back wheel to make sure the bike actually entered every single gear. The motor successfully changed to each gear at the intended interval and the display showed the desired gear. When the test was repeated, the same results were obtained. Thus the product fulfills the second technical specification.

Test 3 - Speed Test

The aim of test number 3 was to make sure the solution continued to operate at high speeds. As described in 4.3 the bicycle had to reach a simulated speed of 40 km/h. The test was performed as it was intended by lifting the back wheel and then turning the wheel until the sensor reached an RPM that matched the speed of 40 km/h. The test was performed two times and the system reached a speed of 56 km/h, which is a significantly higher speed compared to the target of 40 km/h. Even though the wheels were spun to match a speed of 56 km/h, nothing went wrong and the product could still switch gears - both automatically and manually. This means that the third technical specification is fulfilled.

Test 4 - Battery Life

Test number 4 was not performed explicitly. The technical specification was assumed to be met since the system has been turned on for a significantly longer period of time than 5 minutes to perform the other tests as well as through normal operation of the bicycle. This means that the fourth technical specification is fulfilled.

Test 5 - Measurement Accuracy

This test was performed by using a photo-contact tachometer and applying a reflective piece of tape to the back wheel of the bike. The pedals were then turned at around 30kmph while the bike's back wheel was held off the ground. The highest recorded RPM on the photo-contact tachometer was then compared to the highest RPM that the Arduino calculated on the same run.
The Arduino calculated a top RPM of 241 while the photo-contact tachometer measured a top RPM of 238. This means that there is a 1% difference between the measured RPM and the calculated RPM at a fairly high speed. This difference will of course vary when measurement uncertainty is taken into account, but even with an uncertainty of plus 5% the results still lie within the wanted 10% margin of error specified in the technical specification. This test therefore comfortably proves that the product adheres to the fifth technical specification.

Test 6 - Endurance Test

This test was almost performed as described in 4.3. The one difference was that instead of actually taking the bicycle out and riding it, the bicycle was in a room with its back wheel lifted. Since the bicycle was not being ridden in the city where you naturally have to stop at traffic light, stops were made once in a while to see if the system would shift down. As an endurance test, the system continued to work as planned, and it did not show any sign of system malfunctions. However, the reed switch kept on occasionally provided inconstant readings. Despite these inconsistencies, the system continued to work as intended since it requires 2 or 3 error readings in a row for it to change to a wrong gear. However, during the test the cause of these inconsistencies was discovered, and un the last 10 minutes of the test the reed switch was changed from using a 3.5 volt output to a 5 volt output. This successfully eliminated the errors.

Since the test was only focused on endurance of the system and making sure nothing out of the ordinary would happen when the system was being used for a long time without a brake, means the test was successful. The errors the reed switch returned were already there before the test, that means it was not because of the extended use of the system. The product therefore fulfills the sixth technical specification.

Test 7 - Switching Modes

Test number 7 was performed while the back wheel of the bicycle was lifted. Then as described in 4.3, the function to shift between the automatic and manual gearing was tested while going 20km/h. It could easily change between the two settings within the time span of a second. The seventh technical specification is therefore fulfilled.

Test 8 - Off-Road Test

This test was not performed as mentioned in 4.3. Instead the test was performed inside with the back wheel lifted, while one person lifted and dropped the steering wheel up and down to simulate an off-road ride. The reason for it to be the front wheel that was shaken, is that all of the components are in the front and this is therefore the place where the system could take most damage. The automatic gearing worked without any errors and the components remained in their places without taking any damage. With this test the eighth technical specification is fulfilled.

Test 9 - Max Cost 1000 DKK

While this specification is not directly testable, it is possible to estimate the cost of the product by combining the estimated components cost as well as labor costs. However, since the completed product is only a proof of concept, it is difficult to estimate what the labor cost would be for a consumer ready product. Because of these uncertainties regarding how a completed consumer product would differ from the product in its current state, the cost estimates of the product have to be very basic and they primarily consider the components cost of the proof of concept. Table 7.1 lists the price of the various components. It is based on the prices mentioned in section 5.2.

Table 7.1: Component cost

Component	Cost (DKK)
Arduino Nano	20
Stepper Motor	200
Motor Driver	9
7 Segment Display	5
Vibration Motor	5
Reed Switch	1
Miscellaneous	50
Total:	290

As shown in table 7.1, the total component cost is not expected to rise above 300 DKK. This price is well within the set specification, and allows for up to 700 DKK, per unit, to be allocated to the various other manufacturing expenditures. It should be noted that if the product was ever manufactured, the component prices would most likely drop due to economics of scale.

Chapter 8

Conclusion

In chapter 1 of this report, a problem was identified, and the following initial problem statement was created:

Can a product that helps bicyclists shift to the correct gear for a given situation be developed? If so how should this be done? And what should the requirements be?

Following in chapter 3 was a detailed analysis of the proposed problem. This analysis helped to create a more defined problem statement:

Can an automatic gear shifting system for bicycles be created so that the final product costs no more than 1000 DKK? If so how should it be done and what should the requirements be?

To help clarify the exact nature of this problem, a list of technical specifications were created in section 4.2.

Throughout this report, an approach for solving the problem above has been documented. The resultant product is a proof of concept, with many of it's components being attached using wood, glue, and cable ties. However, despite this unpolished appearance, the completed product manages to fulfill all of the specifications, with certain aspects of the product even exceeding the set expectations. Thus it can be concluded, that it is possible to create an effective automatic gear changing system for bicycles costing less than 1000 DKK.

Chapter 9

Discussion

During this project the goal was to make a functioning product. However the scope of the project was limited since it was created by students with limited resources, a three month deadline, and a focus electrical engineering. First of all the project has to be relevant for the curriculum. Thus the project had to use a micro controller, some sensor input and some actuators. Therefore solutions such as purely mechanical designs or campaigns were not options. The biggest challenged faced was limited equipment. Although additional equipment could have been ordered, it was not at disposal when it was needed. Due to time constraints, the equipment that was available, had to be used. Despite these limitations, it has been considered what would have been done without these limiting factors. This chapter will discuss what could have been done if there had been no such constraints as well as what impact a final product could have on society.

9.1 Further Development

In this section further development of the product is discussed. The proposals are based on the assumption that the product should go from being a proof of concept to an actual product for consumers. In the following subsections different hardware choices for the prototype are considered and alternatives to these are laid out. Other features that have not yet been implemented will also be discussed.

9.1.1 Power Source

The power source for the prototype product is, as stated in section 6.1.2, a series of batteries to produce an output voltage of 10.5. This does not allow for the system to run for very long and therefore hampers the potential of the product. In further versions of the product a dynamo could be implemented on one of the wheels which would allow for the system to charge itself while the user is riding their bike. This coupled with a small power source to make sure the system also functions when the user starts from a full stop would be an excellent solution to the power problem. This is of course provided that a dynamo could reliably deliver enough power for the system. A dynamo might also serve to replace the currently implemented reed switch for reading the RPM of the wheels since the system could get that data from said dynamo. This would of course require some signal processing and therefore a bit more computer power, but since the currently implemented Arduino's processor shows no signs of being to slow, this should not be a problem if it were to be implemented efficiently. As stated in section 5.2.3 a dynamo was not chosen for the prototype due to time restrictions but it is recommended that others who wish to further develop this product look into such a solution.

9.1.2 Weather Resistance

Since the product is attached to a bicycle and used outside, it would be a good idea to make sure that it can withstand the elements. Things like rain and cold should not damage the system. Because the developed prototype is a proof of concept the durability of the system was not of high priority and therefore it cannot withstand much of anything. Therefore if the product is ever developed into a consumer product, it will be necessary to further the development of the products' weather resistivity

9.1.3 Design of the Product

Since the product is still a prototype, design has not really been considered as a high priority. Although if the product have to be sold to customers the design choices should be reconsidered since it could have an effect on the peoples opinion of the product, and therefore in extension also its success/adoption rate.

9.1.4 Microprocessor

A final product might not want to use a full Arduino board, but rather just a micro-processing chip since it would save space. The chip could also be specially designed to suit the needs of the product which could make implementation of the other parts easier.

9.1.5 More Sensors

A later iteration of the product could make use of more sensors to measure things like torque on the pedals of the bike or the cadence of the user. This information might make for smoother gear changes for the automatic gear since it could factor in more things into the parameters for such changes. However further research should be conducted to figure out if this is viable/desirable

9.1.6 Cycling Computer

A 7-segment-LED-display is used on the current/prototype product. This display can only show a single digit, and in the current iteration of the product this is used to represents the current gear. The product could be more informative if the display could additional information such as current RPM, battery percentage, automatic gear changing enable/disable indicator etc. That way the user can always get a overview of the current status of the bicycle. In further versions of this product a larger LCD - display could be implemented to show such information.

9.1.7 Gear Cable

The gear cable used for the prototype is showing noticeable wear and tears from the short time it has been in use. This is due to the cable not being intended to be wrapped around a stepper motor. In future iterations of the product, it might be to its advantage to use a custom made cable that is made to withstand such treatment or to come up with an alternative method for changing gears.

9.1.8 Using a Linear Actuator

If the product were to be further developed with the same core parts another type of stepper motor called a linear actuator might be useful. This kind of motor does not turn round itself but rather pushes and pulls a rod meaning that such a motor could pull on the gear cable. This would be useful since the cable would not be put under the same amount of strain that it would normally suffer from being coiled up around a small metal rod. A linear actuator would therefore be a much better fit for this type of execution of the core concept, but due to time restraints it was not available for this project.

9.1.9 Opportunity for a different number of gears

Since a single bicycle with seven hub gears was provided, the finished product was made to fit this type of gear. In future versions, the product should be compatible with bicycles with different numbers of gears. This addition should not be too complicated to implement, as it should onle require a few changes to the code.

9.1.10 Printed Circuit Board(PCB)

In the proof of concept the components of the product are soldered onto prototype PCB matrix boards. Initially there were aspirations to develop the final iteration of the product on PCB. Unfortunately this was not possible due to time constraints. Due to its compactness, professionalism, and ease of manufacture, future versions of the product should aim to use PCB's.

9.1.11 Interrupts for Reading Sensor

In this project the software is based on the Atmega328 processor being able to complete the main loop fast enough to measure the magnets before they pass the sensor. This means that the program should take less time to loop than the time it takes for a magnet to pass the reed switch to consistently measure the magnets passing. After the end of the product development, a new, superior method has been discovered – interrupts. Interrupts would simplify the software by allowing the program to simply call a function each time there is a change in state at some of the pins of the micro controller. If this product was to be further developed, it would be preferable to implement interrupts since, they do not rely on a reading frequency and would therefore help to ensure consistency while being able to run more advanced and time consuming functions that otherwise stall the reading on the reed switch.

9.1.12 Manually Adjusting the Target Cadence

Even though there is a range of cadence's which is most efficient, different persons can have different preferences. Thus it would be a desirable feature to be able to adjust the target cadence. This would ensure that anyone could use the product in their preferred way. This could even be expanded by adding a option to set the speed or cadence for each gear individually if so desired. To be successful among users, this feature would require the user interface to be expanded

9.2 Tests

Most of the tests conducted on the product, as seen in chapter 7, were simulated. For example test 8 was not done by riding the bike on an uneven surface but was rather done by simulating shaking. The same goes for the tests where max speed was measured. The bike was not ridden at the intended speeds during the tests, but rather the wheels were spun to simulate them.

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Appendix A

Observations

During the observation, 339 cyclist were accounted for. Of these, 243 (72%) people were believed to be in an appropriate gear when accelerating from a standstill. Meanwhile 96 (28%) people were in thought to be in to high of a gear. Figure A.1 helps illustrate the distribution:

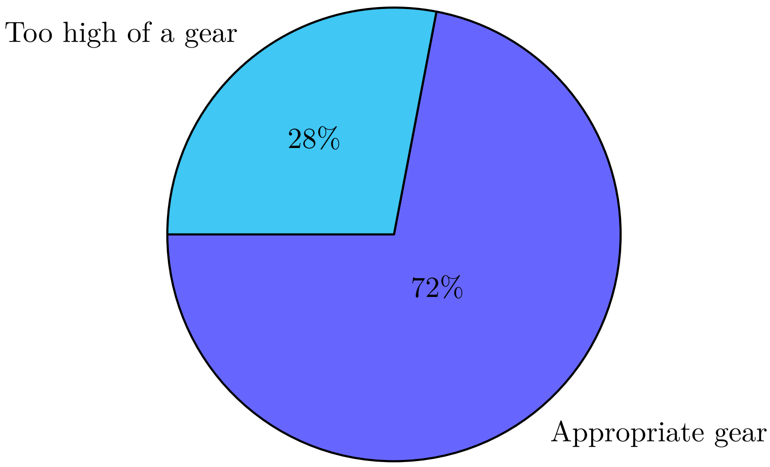


Figure A.1: Distribution of cyclists who were believed to be in to high of a gear when accelerating from a standstill versus those who were in an appropriate gear.

Appendix B

Original Survey

Table B.1: The survey and the possible answers

#	Question:	Answer Options:
1	What is your gender?	• Male • Female
2	What is your age?	• 0-10 • 11-15 • 15-21 • 22-27 • 28-35 • 36-50 • 50-65 • 65+

3	How often do you bike?	• 5-7 days a week • 3-5 days a week • 1-3 days a week • <1 days a week • <1 days a month • Never
4	How far do you on average bike per day?	• More than 20 km • 10-20km • 5-10 km • 3-5 km • 1-3 km • Less than 1 Km
5	Do you use hub gears or derailleurs	• Derailleurs • Hub Gears • Other
6	How often do you think about changing gears?	• Always • Almost Always • Sometimes • Rarely • Never

7	How often do you remember to downshift gears at a full stop?	• Always • Almost Always • Sometimes • Rarely • Never
8	Do you find it tedious to shift gear?	• Yes • No • Sometimes
9	How often do you feel confident about when to shift gears?	• Always • Almost Always • Sometimes • Rarely • Never
10	How interested would you be in a bicycle which can shift gears automatically?	• Very Interested • Interested • A Little Interested • No Interest

11	How much (in DKK) would you be willing to pay for such a system?	• 0 • 0-100 • 100-200 • 200-400 • 400-600 • 600-1000 • 1000+
12	How interested would you be in a bicycle which can recommend when to shift gears?	• Very Interested • Interested • A Little Interested • No Interest
13	How much (in DKK) would you be willing to pay for such a system?	• 0 • 0-100 • 100-200 • 200-400 • 400-600 • 600-1000 • 1000+

14	How interested would you be in a bicycle which can automatically downshift at a full stop?	• Very Interested • Interested • A Little Interested • No Interest
15	How much (in DKK) would you be willing to pay for such a system?	• 0 • 0-100 • 100-200 • 200-400 • 400-600 • 600-1000 • 1000+

Appendix C

Survey Responses

In the table below, the red entries represents the sorted responses.

What Is your Gender?	What is your age?	How often do you bike?	How far do you on average bike per day?	Do you use a gear hub or derailleur	How often do you think about shifting gear?	How often do you remember to downshift gears at a full stop?	Do you find it tedious to shift gear?	How often do you feel confident about when to shift gears?	Interest in Automatic gearing for bicycle	How much (in DKK) would you be willing to pay for such a system? (1)	How interested would you be in a bicycle which can recommend when to shift gears?	How much (in DKK) would you be willing to pay for such a system? (2)	How interested would you be in a bicycle which can automatically downshift at a full stop?	How much (in DKK) would you be willing to pay for such a system? (3)
Female	0-10	Never	Less than 1 km	h	Never	Never	Sometimes	Never	Not at all interested	1000+	Not at all interested	1000+	Not at all interested	1000+
Male	11-15	3-5 days a week	More than 20 Km	Derailleur	Always	Always	No	Always	Barely interested	1000+	Interested	1000+	Barely interested	1000+
Male	11-15	3-5 days a week	More than 20 Km	Derailleur	Almost Always	Almost Always	No	Always	Very Interested	600-1000	Barely interested	100-200	Interested	200-400
Male	11-15	3-5 days a week	1-3 km	Derailleur	Always	Almost Always	Yes	Always	Very Interested	200-400	Not at all interested	0	Very Interested	200-400
Male	11-15	Less than one day per week	1-3 km	Don't Know	Rarely	Rarely	Sometimes	Rarely	Very Interested	1000+	Interested	400-600	Interested	400-600
Male	11-15	3-5 days a week	More than 20 Km	Derailleur	Almost Always	Almost Always	No	Almost Always	Barely interested	600-1000	Barely interested	400-600	Barely interested	400-600
Male	15-21	Never	3-5 km	Derailleur	Sometimes	Rarely	Sometimes	Sometimes	Interested	200-400	Interested	0-100	Barely interested	100-200
Male	15-21	Never	3-5 km	Don't Know	Sometimes	Sometimes	Sometimes	Almost Always	Very Interested	200-400	Interested	100-200	Interested	0-100
Male	15-21	Less than one day per week	1-3 km	Derailleur	Sometimes	Rarely	Yes	Sometimes	Very Interested	400-600	Interested	200-400	Interested	200-400

Male	15-21	6-7 days a week	5-10 km	Derailleur	Sometimes	Almost Always	Sometimes	Almost Always	Barely interested	400-600	Interested	200-400	Barely interested	200-400
Male	15-21	1-3 days a week	1-3 km	Gear Hub	Sometimes	Rarely	Sometimes	Sometimes	Interested	200-400	Interested	100-200	Interested	100-200
Male	15-21	Never							Very Interested	400-600	Not at all interested	0	Very Interested	200-400
Male	15-21	3-5 days a week	5-10 km	Derailleur	Always	Almost Always	No	Always	Barely interested	600-1000	Barely interested	600-1000	Barely interested	600-1000
Male	15-21	Less than one day per week	Less than 1 km	Gear Hub	Almost Always	Sometimes	No	Sometimes	Barely interested	400-600	Interested	100-200	Very Interested	100-200
Male	15-21	1-3 days a week	1-3 km	Don't Know	Rarely	Always	No	Always	Barely interested	100-200	Barely interested	0-100	Interested	0-100
Male	15-21	Less than one day per week	1-3 km	Gear Hub	Sometimes	Always	Sometimes	Almost Always	Interested	400-600	Barely interested	100-200	Interested	200-400
Male	15-21	6-7 days a week	5-10 km	Gear Hub	Almost Always	Almost Always	No	Almost Always	Barely interested	200-400	Interested	200-400	Very Interested	200-400
Male	15-21	3-5 days a week	5-10 km	Gear Hub	Almost Always	Rarely	No	Sometimes	Interested	0-100	Barely interested	0-100	Barely interested	0-100
Male	15-21	6-7 days a week	10-20 km	Derailleur	Almost Always	Rarely	Sometimes	Sometimes	Interested	200-400	Barely interested	100-200	Interested	400-600
Female	15-21	1-3 days a week	3-5 km	Gear Hub	Always	Always	No	Always	Interested	100-200	Not at all interested	0	Barely interested	0-100
Male	15-21	3-5 days a week	5-10 km	Don't Know	Sometimes	Sometimes	No	Rarely	Very Interested	100-200	Not at all interested	0-100	Interested	0-100
Male	15-21	6-7 days a week	1-3 km	Derailleur	Always	Sometimes	No	Always	Barely interested	100-200	Not at all interested	0-100	Barely interested	0-100
Female	15-21	3-5 days a week	10-20 km	Gear Hub	Almost Always	Almost Always	Sometimes	Sometimes	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	15-21	6-7 days a week	1-3 km	Derailleur	Always	Always	No	Always	Barely interested	100-200	Not at all interested	0	Barely interested	0
Male	15-21	3-5 days a week	5-10 km	Gear Hub	Almost Always	Always	No	Always	Not at all interested	100-200	Barely interested	100-200	Barely interested	100-200
Female	15-21	Less than one day per week	5-10 km	Don't Know	Rarely	Never	No	Sometimes	Interested	200-400	Barely interested	0-100	Interested	200-400
Female	15-21	3-5 days a week	1-3 km	Derailleur	Sometimes	Almost Always	No	Always	Barely interested	400-600	Not at all interested	0-100	Interested	200-400
Female	15-21	Less than one day per week	Less than 1 km	Don't Know	Rarely	Never	Sometimes	Sometimes	Barely interested	600-1000	Not at all interested	0-100	Barely interested	100-200
Male	15-21	3-5 days a week	5-10 km	Derailleur	Always	Always	No	Always	Not at all interested	0	Not at all interested	0	Very Interested	400-600
Male	15-21	Never	Less than 1 km	Don't Know	Rarely	Never	No	Never	Not at all interested	0	Barely interested	0	Not at all interested	0
Male	15-21	6-7 days a week	3-5 km	Gear Hub	Always	Almost Always	No	Always	Barely interested	0-100	Barely interested	0	Interested	100-200
Male	15-21	Less than one day per week	Less than 1 km	Don't Know	Sometimes	Never	Sometimes	Sometimes	Not at all interested	0-100	Not at all interested	0-100	Not at all interested	0-100
Male	15-21	1-3 days a week	5-10 km	Don't Know	Sometimes	Almost Always	No	Almost Always	Barely interested	100-200	Barely interested	0-100	Barely interested	0-100
Male	15-21	1-3 days a week	10-20 km	Derailleur	Always	Always	Sometimes	Almost Always	Barely interested	0-100	Barely interested	0-100	Barely interested	1000+
Female	15-21	6-7 days a week	5-10 km	Gear Hub	Always	Almost Always	No	Always	Barely interested	200-400	Not at all interested	0	Very Interested	200-400
Female	15-21	Less than one day per week	5-10 km	Derailleur	Almost Always	Never	No	Almost Always	Barely interested	0-100	Barely interested	100-200	Barely interested	100-200
Female	15-21	3-5 days a week	1-3 km	Derailleur	Always	Always	No	Always	Barely interested	0-100	Barely interested	0-100	Interested	100-200

Male	15-21	6-7 days a week	1-3 km	Gear Hub	Sometimes	Rarely	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Female	15-21	6-7 days a week	1-3 km	Don't Know	Rarely	Never	Sometimes	Almost Always	Interested	100-200	Interested	200-400	Barely interested	0
Male	15-21	Never	Less than 1 km	Derailleur	Sometimes	Almost Always	Sometimes	Almost Always	Interested	400-600	Very Interested	200-400	Very Interested	400-600
Male	15-21	3-5 days a week	1-3 km	Derailleur	Sometimes	Almost Always	Sometimes	Almost Always	Not at all interested	0	Not at all interested	0-100	Not at all interested	0-100
Male	15-21	6-7 days a week	1-3 km	Derailleur	Always	Always	No	Always	Barely interested	100-200	Barely interested	100-200	Interested	100-200
Male	15-21	3-5 days a week	3-5 km	Gear Hub	Always	Always	No	Almost Always	Interested	0-100	Barely interested	0-100	Barely interested	0-100
Female	15-21	3-5 days a week	3-5 km	Derailleur	Never	Rarely	Yes	Never	Interested		Barely interested	200-400	Barely interested	200-400
Female	15-21	3-5 days a week	5-10 km	Don't Know	Almost Always	Sometimes	No	Almost Always	Very Interested	600-1000	Interested	200-400	Interested	200-400
Male	15-21	6-7 days a week	5-10 km	Derailleur	Always	Always	No	Always	Interested	200-400	Not at all interested	0	Not at all interested	0
Female	15-21	3-5 days a week	3-5 km	Gear Hub	Almost Always	Sometimes	No	Almost Always	Not at all interested	100-200	Not at all interested	0	Not at all interested	0
Female	15-21	3-5 days a week	10-20 km	Derailleur	Sometimes	Never	No	Rarely	Barely interested	0	Barely interested	0-100	Barely interested	0-100
Male	15-21	Less than one day per week	5-10 km	Gear Hub	Never	Always	Sometimes	Sometimes	Barely interested	600-1000	Not at all interested	0-100	Interested	200-400
Male	15-21	Less than one day per week	1-3 km	Derailleur	Rarely	Never	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	15-21	6-7 days a week	1-3 km	Gear Hub	Sometimes	Always	No	Always	Barely interested	0	Not at all interested	0	Barely interested	0
Female	15-21	6-7 days a week	10-20 km	Don't Know	Sometimes	Almost Always	No	Almost Always	Not at all interested	0	Barely interested	0-100	Barely interested	0-100
Female	15-21	6-7 days a week	1-3 km	Derailleur	Always	Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Female	15-21	Less than one day per week	3-5 km	Derailleur	Always	Never	No	Sometimes	Not at all interested	200-400	Barely interested	200-400	Interested	200-400
Male	15-21	Less than one day per week	1-3 km	Don't Know	Sometimes	Never	Sometimes	Rarely	Interested	400-600	Barely interested	100-200	Interested	200-400
Female	15-21	6-7 days a week	3-5 km	Gear Hub	Rarely	Never	No	Sometimes	Interested	100-200	Not at all interested	0	Barely interested	0-100
Male	15-21	Less than one day per week	1-3 km	Derailleur	Always	Always	Sometimes	Almost Always	Very Interested	600-1000	Interested	600-1000	Barely interested	600-1000
Female	15-21	Less than one day per week	Less than 1 km	Don't Know	Never	Almost Always	No	Almost Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	15-21	3-5 days a week	Less than 1 km	Don't Know	Sometimes	Never	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	15-21	Less than one day per week	3-5 km	Derailleur	Sometimes	Rarely	No	Sometimes	Very Interested	400-600	Barely interested	0-100	Barely interested	100-200
Male	15-21	3-5 days a week	1-3 km	Gear Hub	Rarely	Rarely	Sometimes	Almost Always	Barely interested	200-400	Not at all interested	0	Not at all interested	0
Male	15-21	6-7 days a week	10-20 km	Don't Know	Almost Always	Always	No	Always	Barely interested	200-400	Barely interested	200-400	Barely interested	100-200
Female	15-21	1-3 days a week	3-5 km	Gear Hub	Sometimes	Rarely	No	Sometimes	Interested	400-600	Not at all interested	0	Barely interested	400-600
Female	15-21	1-3 days a week	1-3 km	Don't Know	Almost Always	Sometimes	No	Sometimes	Very Interested	400-600	Interested	100-200	Interested	100-200

Male	15-21	Less than one day per week	1-3 km	Gear Hub	Sometimes	Never	Yes	Almost Always	Interested	200-400	Very Interested	0-100	Very Interested	100-200
Female	15-21	6-7 days a week	1-3 km	Gear Hub	Sometimes	Never	Sometimes	Sometimes	Very Interested	100-200	Barely interested	0-100	Very Interested	0-100
Female	15-21	3-5 days a week	1-3 km	Don’t Know	Sometimes	Almost Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	15-21	3-5 days a week	1-3 km	Derailleur	Sometimes	Always	Yes	Always	Barely interested	600-1000	Not at all interested	0	Interested	600-1000
Female	15-21	Less than one day per week	Less than 1 km	Derailleur	Rarely	Almost Always	Sometimes	Sometimes	Interested	200-400	Not at all interested	0	Interested	200-400
Female	15-21	6-7 days a week	3-5 km	Gear Hub	Sometimes	Almost Always	No	Almost Always	Interested	200-400	Interested	100-200	Interested	200-400
Female	15-21	Less than one day per week	Less than 1 km	Don’t Know	Rarely	Never	Sometimes	Rarely	Interested	600-1000	Interested	600-1000	Barely interested	400-600
Male	15-21	Less than one day per week	1-3 km	Gear Hub	Sometimes	Never	Yes	Almost Always	Interested	200-400	Very Interested	0-100	Very Interested	100-200
Male	15-21	Less than one day per week	1-3 km	Gear Hub	Sometimes	Never	Yes	Almost Always	Interested	200-400	Very Interested	0-100	Very Interested	100-200
Male	15-21	Less than one day per week	1-3 km	Gear Hub	Sometimes	Never	Yes	Almost Always	Interested	200-400	Very Interested	0-100	Very Interested	100-200
Female	15-21	6-7 days a week	5-10 km	Gear Hub	Almost Always	Sometimes	Sometimes	Almost Always	Very Interested	100-200	Very Interested	200-400	Interested	100-200
Male	15-21	3-5 days a week	More than 20 Km	Derailleur	Sometimes	Always	Sometimes	Always	Interested	1000+	Interested	1000+	Interested	1000+
Female	15-21	1-3 days a week	3-5 km	Gear Hub	Always	Sometimes	No	Sometimes	Barely interested	400-600	Barely interested	100-200	Barely interested	100-200
Female	15-21	3-5 days a week	1-3 km	Gear Hub	Always	Always	No	Almost Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	15-21	6-7 days a week	10-20 km	Gear Hub	Rarely	Always	No	Always	Barely interested	100-200	Barely interested	0	Barely interested	0-100
Male	15-21	Less than one day per week	Less than 1 km	Don’t Know	Sometimes	Almost Always	No	Almost Always	Very Interested	400-600	Not at all interested	0	Not at all interested	0
Male	15-21	3-5 days a week	More than 20 Km	Derailleur	Almost Always	Always	Yes	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Female	15-21	6-7 days a week	1-3 km	Don’t Know	Rarely	Sometimes	No	Almost Always	Very Interested	200-400	Very Interested	200-400	Very Interested	200-400
Male	15-21	6-7 days a week	10-20 km	Fixie bike	Never	Never	No	Never	Not at all interested	0	Not at all interested	0	Not at all interested	0
Female	15-21	Less than one day per week	Less than 1 km	Don’t Know	Almost Always	Sometimes	Sometimes	Sometimes	Not at all interested	200-400	Interested	100-200	Not at all interested	0
Female	15-21	3-5 days a week	1-3 km	Don’t Know	Sometimes	Never	No	Always	Interested	200-400	Barely interested	0-100	Not at all interested	0-100
Male	15-21	Less than one day per week	10-20 km	Derailleur	Never	Always	No	Always	Not at all interested	0	Very Interested	400-600	Not at all interested	0
Male	15-21	Less than one day per week	1-3 km	Gear Hub	Sometimes	Always	No	Almost Always	Barely interested	200-400	Barely interested	200-400	Barely interested	200-400
Female	15-21	6-7 days a week	5-10 km	Gear Hub	Always	Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Female	15-21	6-7 days a week	5-10 km	Gear Hub	Always	Always	Sometimes	Sometimes	Very Interested	400-600	Very Interested	400-600	Not at all interested	0
Female	15-21	6-7 days a week	3-5 km	Derailleur	Rarely	Rarely	No	Almost Always	Barely interested	0-100	Not at all interested	0	Barely interested	0

Male	15-21	Less than one day per week	Less than 1 km	Derailleur	Almost Always	Almost Always	Sometimes	Almost Always	Interested	600-1000	Interested	600-1000	Interested	600-1000
Male	15-21	6-7 days a week	10-20 km	Gear Hub	Rarely	Sometimes	No	Almost Always	Barely interested	200-400	Barely interested	200-400	Barely interested	0-100
Male	15-21	6-7 days a week	10-20 km	Gear Hub	Always	Always	No	Always	Not at all interested	0-100	Not at all interested	0-100	Barely interested	0-100
Male	15-21	6-7 days a week	5-10 km	Derailleur	Almost Always	Sometimes	No	Almost Always	Interested	1000+	Not at all interested	0	Barely interested	1000+
Male	15-21	Less than one day per week	1-3 km	Gear Hub	Always	Always	Sometimes	Almost Always	Very Interested	1000+	Barely interested	400-600	Interested	600-1000
Male	15-21	Less than one day per week	Less than 1 km	Gear Hub	Always	Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	15-21	3-5 days a week	More than 20 Km	Derailleur	Almost Always	Never	Sometimes	Always	Barely interested	1000+	Barely interested	1000+	Interested	1000+
Male	15-21	6-7 days a week	5-10 km	Gear Hub	Rarely	Sometimes	No	Almost Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	15-21	1-3 days a week	3-5 km	Don't Know	Almost Always	Sometimes	No	Almost Always	Interested	200-400	Barely interested	200-400	Interested	100-200
Male	15-21	3-5 days a week	3-5 km	Don't Know	Always	Rarely	Sometimes	Always	Very Interested	600-1000	Not at all interested	0-100	Very Interested	100-200
Male	15-21	1-3 days a week	5-10 km	Derailleur	Always	Always	No	Always	Very Interested	400-600	Interested	400-600	Interested	400-600
Male	15-21	6-7 days a week	3-5 km	Derailleur	Almost Always	Never	No	Almost Always	Not at all interested	200-400	Barely interested	100-200	Not at all interested	0-100
Male	15-21	3-5 days a week	1-3 km	Derailleur	Almost Always	Sometimes	Yes	Almost Always	Barely interested	100-200	Barely interested	100-200	Barely interested	100-200
Female	15-21	3-5 days a week	3-5 km	Gear Hub	Rarely	Never	No	Sometimes	Interested	1000+	Barely interested	1000+	Interested	1000+
Male	15-21	3-5 days a week	More than 20 Km	Don't Know	Almost Always	Almost Always	No	Almost Always	Barely interested	100-200	Barely interested	100-200	Barely interested	100-200
Female	15-21	1-3 days a week	5-10 km	Don't Know	Always	Always	Sometimes	Always	Barely interested	0	Not at all interested	0	Interested	0-100
Female	15-21	1-3 days a week	1-3 km	Don't Know	Almost Always	Sometimes	No	Almost Always	Barely interested	200-400	Not at all interested	0	Not at all interested	0
Male	15-21	6-7 days a week	3-5 km	Don't Know	Almost Always	Sometimes	Sometimes	Almost Always	Interested	400-600	Interested	400-600	Very Interested	400-600
Female	15-21	1-3 days a week	1-3 km	Derailleur	Sometimes	Rarely	Sometimes	Almost Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Female	15-21	Less than one day per week	3-5 km	Don't Know	Always	Never	No	Always	Barely interested		Not at all interested	0	Not at all interested	0
Male	15-21	Less than one day per week	3-5 km	Don't Know	Sometimes	Almost Always	No	Almost Always	Barely interested	200-400	Barely interested	100-200	Not at all interested	0
Female	15-21	6-7 days a week	5-10 km	Gear Hub	Almost Always	Rarely	Yes	Almost Always	Barely interested	100-200	Barely interested	0-100	Not at all interested	0
Male	15-21	1-3 days a week	More than 20 Km	Derailleur	Always	Sometimes	No	Almost Always	Barely interested	600-1000	Barely interested	100-200	Barely interested	200-400
Female	15-21	1-3 days a week	Less than 1 km	Don't Know	Almost Always	Never	No	Always	Barely interested	100-200	Not at all interested	0	Not at all interested	0
Male	15-21	6-7 days a week	5-10 km	Derailleur	Almost Always	Almost Always	No	Always	Very Interested	200-400	Barely interested	100-200	Not at all interested	0-100
Female	15-21	6-7 days a week	1-3 km	Gear Hub	Always	Never	Sometimes	Almost Always	Barely interested	0-100	Barely interested	0-100	Interested	0-100
Male	15-21	3-5 days a week	5-10 km	Derailleur	Always	Sometimes	No	Always	Interested	100-200	Interested	100-200	Interested	100-200
Female	15-21	Less than one day per week	1-3 km	Don't Know	Rarely	Almost Always	No	Sometimes	Not at all interested	400-600	Not at all interested	200-400	Not at all interested	0

Female	15-21	6-7 days a week	5-10 km	Don't Know	Almost Always	Always	No	Always	Interested	0-100	Interested	0-100	Very Interested	0-100
Female	15-21	Never	Less than 1 km	Don't Know	Never	Never	Yes	Never	Barely interested	0-100	Not at all interested	0	Not at all interested	0
Female	15-21	3-5 days a week	1-3 km	Derailleur	Always	Always	No	Always	Interested	400-600	Not at all interested	0	Barely interested	0-100
Female	15-21	6-7 days a week	5-10 km	Don't Know	Almost Always	Always	No	Always	Interested	0-100	Interested	0-100	Very Interested	0-100
Male	15-21	6-7 days a week	1-3 km	Gear Hub	Rarely	Always	No	Always	Barely interested	600-1000	Not at all interested	0	Not at all interested	0
Male	15-21	3-5 days a week	10-20 km	begge dele	Always	Always	Sometimes	Almost Always	Interested	1000+	Interested	1000+	Interested	1000+
Female	15-21	3-5 days a week	3-5 km	Gear Hub	Sometimes	Never	Sometimes	Always	Interested	200-400	Not at all interested	0	Not at all interested	0
Female	15-21	3-5 days a week	1-3 km	Don't Know	Sometimes	Never	No	Always	Interested	200-400	Barely interested	0-100	Not at all interested	0-100
Male	15-21	Less than one day per week	More than 20 Km	Derailleur	Always	Sometimes	No	Always	Very Interested	600-1000	Barely interested	100-200	Interested	100-200
Female	15-21	Less than one day per week	Less than 1 km	Derailleur	Sometimes	Never	No	Sometimes	Interested	400-600	Very Interested	400-600	Interested	100-200
Male	15-21	Never	Less than 1 km	Don't Know	Never	Never	Yes	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Female	15-21	1-3 days a week	5-10 km	Don't Know	Always	Always	Sometimes	Always	Barely interested	0	Not at all interested	0	Interested	0-100
Female	15-21	1-3 days a week	5-10 km	Don't Know	Always	Always	Sometimes	Always	Barely interested	0	Not at all interested	0	Interested	0-100
Female	15-21	1-3 days a week	5-10 km	Don't Know	Always	Always	Sometimes	Always	Barely interested	0	Not at all interested	0	Interested	0-100
Female	15-21	Less than one day per week	10-20 km	Gear Hub	Almost Always	Sometimes	No	Sometimes	Barely interested	100-200	Not at all interested	0	Not at all interested	0
Female	15-21	6-7 days a week	5-10 km	Don't Know	Never	Never	No	Never	Very Interested	1000+	Not at all interested	0	Not at all interested	0
Male	15-21	1-3 days a week	5-10 km	Derailleur	Always	Rarely	Yes	Sometimes	Very Interested	600-1000	Barely interested	100-200	Interested	400-600
Female	15-21	6-7 days a week	10-20 km	Don't Know	Almost Always	Almost Always	No	Always	Interested	600-1000	Not at all interested	0	Not at all interested	0
Female	15-21	6-7 days a week	3-5 km	Gear Hub	Almost Always	Sometimes	No	Always	Barely interested	400-600	Barely interested	100-200	Barely interested	200-400
Male	15-21	6-7 days a week	3-5 km	Derailleur	Almost Always	Never	Sometimes	Almost Always	Very Interested	1000+	Interested	600-1000	Interested	400-600
Male	15-21	Less than one day per week	1-3 km	Gear Hub	Always	Almost Always	Sometimes	Almost Always	Very Interested	1000+	Not at all interested	0	Interested	600-1000
Female	15-21	1-3 days a week	1-3 km	Don't Know	Sometimes	Always	No	Always	Barely interested	400-600	Not at all interested	0	Barely interested	200-400
Male	15-21	3-5 days a week	More than 20 Km	Derailleur	Never	Almost Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	15-21	6-7 days a week	10-20 km	Derailleur	Always	Always	No	Always	Not at all interested	0	Barely interested	200-400	Not at all interested	0
Female	15-21	3-5 days a week	5-10 km	Don't Know	Rarely	Sometimes	No	Almost Always	Barely interested	100-200	Barely interested	0-100	Interested	0-100
Female	15-21	6-7 days a week	3-5 km	Don't Know	Almost Always	Sometimes	Sometimes	Almost Always	Interested	200-400	Interested	100-200	Not at all interested	0
Male	15-21	3-5 days a week	5-10 km	Gear Hub	Rarely	Sometimes	No	Almost Always	Barely interested	100-200	Not at all interested	0	Interested	0-100
Male	15-21	3-5 days a week	3-5 km	Derailleur	Almost Always	Almost Always	No	Almost Always	Barely interested	200-400	Barely interested	200-400	Interested	100-200
Male	15-21	Less than one day per week	More than 20 Km	Derailleur	Rarely	Always	No	Almost Always	Barely interested	400-600	Not at all interested	200-400	Not at all interested	100-200

Female	15-21	6-7 days a week	1-3 km	Don't Know	Almost Always	Never	No	Almost Always	Interested	100-200	Very Interested	100-200	Interested	0-100
Female	15-21	6-7 days a week	3-5 km	Gear Hub	Almost Always	Sometimes	No	Always	Interested	100-200	Interested	0-100	Interested	0-100
Male	22-27	6-7 days a week	10-20 km	Gear Hub	Always	Always	No	Almost Always	Interested	1000+	Interested	600-1000	Interested	1000+
Male	22-27	6-7 days a week	5-10 km	Derailleur	Always	Always	No	Always	Barely interested	200-400	Not at all interested	0	Barely interested	100-200
Male	22-27	Never	Less than 1 km	Don't Know	Never	Never	No	Never	Interested	600-1000	Interested	600-1000	Not at all interested	0
Male	22-27	3-5 days a week	1-3 km	Derailleur	Rarely	Almost Always	No	Always	Barely interested	100-200	Not at all interested	100-200	Barely interested	100-200
Male	22-27	6-7 days a week	1-3 km	Derailleur	Almost Always	Always	No	Almost Always	Barely interested	400-600	Interested	200-400	Interested	0-100
Male	22-27	3-5 days a week	5-10 km	Begge	Rarely	Always	No	Always	Not at all interested	0	Barely interested	0-100	Not at all interested	0
Male	22-27	6-7 days a week	5-10 km	Gear Hub	Always	Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	22-27	3-5 days a week	5-10 km	Gear Hub	Sometimes	Always	Sometimes	Always	Very Interested	400-600	Interested	100-200	Barely interested	0-100
Male	22-27	6-7 days a week	10-20 km	Gear Hub	Always	Sometimes	Sometimes	Almost Always	Very Interested	400-600	Interested	200-400	Interested	200-400
Male	22-27	6-7 days a week	10-20 km	Derailleur	Never	Sometimes	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	22-27	1-3 days a week	1-3 km	Don't Know	Rarely	Never	Sometimes	Sometimes	Interested	400-600	Barely interested	200-400	Interested	400-600
Male	22-27	3-5 days a week	5-10 km	Gear Hub	Sometimes	Almost Always	No	Always	Interested	400-600	Interested	200-400	Interested	100-200
Female	22-27	6-7 days a week	10-20 km	Gear Hub	Almost Always	Almost Always	No	Almost Always	Very Interested	400-600	Barely interested	0-100	Interested	200-400
Female	22-27	1-3 days a week	10-20 km	Gear Hub	Almost Always	Almost Always	Sometimes	Almost Always	Very Interested	600-1000	Very Interested	400-600	Interested	100-200
Male	22-27	3-5 days a week	3-5 km	Derailleur	Always	Always	Sometimes	Always	Barely interested	0	Not at all interested	0	Not at all interested	0
Male	22-27	Less than one day per week	Less than 1 km	Derailleur	Almost Always	Almost Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	22-27	3-5 days a week	1-3 km	Derailleur	Almost Always	Always	No	Always	Interested	400-600	Not at all interested	0	Barely interested	0
Male	22-27	1-3 days a week	10-20 km	Derailleur	Almost Always	Almost Always	No	Always	Barely interested	0	Barely interested	0-100	Interested	100-200
Female	22-27	6-7 days a week	1-3 km	Don't Know	Almost Always	Sometimes	Sometimes	Almost Always	Interested	400-600	Barely interested	200-400	Interested	400-600
Male	22-27	6-7 days a week	5-10 km	Fixie!	Never	Never	No	Almost Always	Not at all interested	100-200	Very Interested	200-400	Not at all interested	0
Female	22-27	Never	Less than 1 km	Don't Know	Never	Never	No	Never	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	22-27	Less than one day per week	3-5 km	Gear Hub	Always	Always	Sometimes	Almost Always	Interested	400-600	Not at all interested	0	Interested	100-200
Female	22-27	3-5 days a week	1-3 km	Don't Know	Almost Always	Sometimes	Sometimes	Almost Always	Interested	200-400	Interested	100-200	Interested	100-200
Male	22-27	6-7 days a week	3-5 km	Derailleur	Rarely	Almost Always	Sometimes	Almost Always	Barely interested	1000+	Interested	100-200	Very Interested	100-200
Female	22-27	Less than one day per week	Less than 1 km	Gear Hub	Always	Almost Always	No	Almost Always	Interested	600-1000	Barely interested	0	Barely interested	100-200
Female	22-27	Less than one day per week	Less than 1 km	Don't Know	Rarely	Never	Sometimes	Almost Always	Interested	200-400	Not at all interested	0	Not at all interested	0
Male	22-27	3-5 days a week	10-20 km	Derailleur	Almost Always	Almost Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0

Male	22-27	6-7 days a week	1-3 km	Derailleur	Almost Always	Almost Always	No	Almost Always	Interested	200-400	Barely interested	100-200	Not at all interested	0
Male	22-27	6-7 days a week	3-5 km	Begge	Almost Always	Always	No	Always	Interested	400-600	Barely interested	0	Barely interested	0
Male	22-27	6-7 days a week	More than 20 Km	Derailleur	Always	Always	No	Always	Not at all interested	0	Not at all interested	0	Interested	200-400
Male	22-27	3-5 days a week	1-3 km	Gear Hub	Never	Always	No	Always	Barely interested	0-100	Not at all interested	0	Not at all interested	0
Male	22-27	1-3 days a week	3-5 km	Derailleur	Always	Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	22-27	1-3 days a week	More than 20 Km	Derailleur	Rarely	Almost Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	22-27	3-5 days a week	5-10 km	Gear Hub	Rarely	Always	No	Always	Very Interested	200-400	Interested	200-400	Very Interested	200-400
Female	22-27	Never	Less than 1 km	Cykler ikke	Always	Never		Never						
Female	22-27	1-3 days a week	10-20 km	Don't Know	Always	Almost Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	22-27	6-7 days a week	More than 20 Km	Derailleur og fastnav	Sometimes	Almost Always	No	Almost Always	Barely interested	1000+	Not at all interested	0	Barely interested	1000+
Male	22-27	6-7 days a week	10-20 km	Gear Hub	Never	Always	No	Always	Interested	100-200	Not at all interested	0	Not at all interested	0
Female	22-27	3-5 days a week	10-20 km	Gear Hub	Always	Almost Always	No	Always	Interested	400-600	Not at all interested	0	Interested	200-400
Female	22-27	6-7 days a week	5-10 km	Gear Hub	Always	Almost Always	No	Always	Very Interested	600-1000	Interested	400-600	Interested	200-400
Female	22-27	1-3 days a week	5-10 km	Derailleur	Rarely	Rarely	Yes	Always	Interested	600-1000	Very Interested	400-600	Interested	400-600
Male	22-27	Less than one day per week	1-3 km	Gear Hub	Sometimes	Never	No	Almost Always	Very Interested	100-200	Interested	100-200	Interested	100-200
Male	22-27	6-7 days a week	More than 20 Km	Derailleur	Always	Almost Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Female	22-27	6-7 days a week	5-10 km	Derailleur	Always	Almost Always	Sometimes	Almost Always	Interested	200-400	Not at all interested	0	Barely interested	0-100
Male	22-27	3-5 days a week	3-5 km	Derailleur	Always	Always	Sometimes	Always	Barely interested	0	Not at all interested	0	Not at all interested	0
Female	22-27	3-5 days a week	Less than 1 km	Don't Know	Rarely	Never	No	Sometimes	Barely interested	100-200	Barely interested	100-200	Not at all interested	0
Male	22-27	Never	Less than 1 km	Cykler ikke	Never	Never	No	Never	Very Interested	400-600	Barely interested	400-600	Very Interested	400-600
Female	22-27	3-5 days a week	Less than 1 km	Don't Know	Rarely	Never	No	Sometimes	Barely interested	100-200	Barely interested	100-200	Not at all interested	0
Male	22-27	Less than one day per week	1-3 km	Gear Hub	Sometimes	Almost Always	No	Almost Always	Barely interested	200-400	Not at all interested	0	Barely interested	200-400
Male	22-27	Never	Less than 1 km	Jeg cykler ikke	Never	Never	No	Sometimes	Not at all interested	100-200	Barely interested	100-200	Not at all interested	100-200
Male	22-27	3-5 days a week	More than 20 Km	Derailleur	Rarely	Always	No	Always	Barely interested	1000+	Not at all interested	0	Not at all interested	0
Male	22-27	6-7 days a week	1-3 km	Don't Know	Never	Never	Yes	Always	Barely interested	0-100	Not at all interested	0-100	Barely interested	0-100
Male	22-27	Less than one day per week	1-3 km	Don't Know	Never	Almost Always	No	Sometimes	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	22-27	1-3 days a week	1-3 km	Gear Hub	Almost Always	Always	No	Always	Barely interested	400-600	Barely interested	200-400	Not at all interested	0
Male	22-27	1-3 days a week	3-5 km	Gear Hub	Always	Always	No	Always	Very Interested	400-600	Not at all interested	0	Very Interested	400-600
Female	22-27	Less than one day per week	Less than 1 km	Derailleur	Always	Almost Always	No	Sometimes	Interested	600-1000	Barely interested	100-200	Not at all interested	0

Male	22-27	6-7 days a week	10-20 km	Derailleur	Never	Never	No	Always	Very Interested	400-600	Not at all interested	0	Interested	100-200
Male	22-27	6-7 days a week	5-10 km	Gear Hub	Sometimes	Almost Always	No	Always	Interested	100-200	Not at all interested	0	Not at all interested	0
Male	28-35	Less than one day per week	Less than 1 km	Derailleur	Sometimes	Almost Always	No	Almost Always	Interested	1000+	Not at all interested	0-100	Barely interested	100-200
Female	28-35	Less than one day per week	More than 20 Km	Don't Know	Rarely	Never	No	Sometimes	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	28-35	1-3 days a week	More than 20 Km	Derailleur	Rarely	Almost Always	No	Almost Always	Interested	600-1000	Interested	600-1000	Interested	600-1000
Male	28-35	6-7 days a week	5-10 km	Derailleur	Sometimes	Sometimes	No	Always	Interested	1000+	Not at all interested	0	Interested	1000+
Female	28-35	6-7 days a week	3-5 km	Derailleur	Sometimes	Never	No	Rarely	Barely interested	0-100	Barely interested	0-100	Not at all interested	0
Male	28-35	Less than one day per week	More than 20 Km	Derailleur	Sometimes	Sometimes	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	28-35	3-5 days a week	More than 20 Km	Derailleur	Rarely	Always	No	Always	Not at all interested	1000+	Not at all interested	1000+	Not at all interested	1000+
Male	28-35	1-3 days a week	More than 20 Km	Derailleur	Sometimes	Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	28-35	3-5 days a week	3-5 km	Derailleur	Sometimes	Never	No	Almost Always	Barely interested	600-1000	Barely interested	100-200	Not at all interested	0
Female	28-35	1-3 days a week	10-20 km	Derailleur	Sometimes	Almost Always	No	Almost Always		1000+	Barely interested	0	Barely interested	0
Female	28-35	1-3 days a week	More than 20 Km	Derailleur	Always	Almost Always	Yes	Almost Always	Interested	1000+	Interested	400-600	Interested	600-1000
Male	28-35	3-5 days a week	More than 20 Km	Derailleur	Rarely	Rarely	No	Almost Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Female	28-35	Less than one day per week	1-3 km	Gear Hub	Sometimes	Always	Sometimes	Always	Interested	600-1000	Barely interested	400-600	Very Interested	400-600
Female	28-35	6-7 days a week	3-5 km	Gear Hub	Always	Always	No	Almost Always	Not at all interested	0	Very Interested	600-1000	Not at all interested	0
Female	28-35	1-3 days a week	More than 20 Km	Derailleur	Never	Always	No	Almost Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	28-35	1-3 days a week	More than 20 Km	Derailleur	Sometimes	Almost Always	No	Almost Always	Interested	400-600	Barely interested	200-400	Very Interested	400-600
Male	28-35	3-5 days a week	10-20 km	Singlespeed	Never	Always	No	Always	Barely interested	1000+	Not at all interested	0	Barely interested	400-600
Male	28-35	1-3 days a week	More than 20 Km	Derailleur	Sometimes	Always	Sometimes	Always	Barely interested	1000+	Interested	400-600	Not at all interested	0
Female	36-50	Less than one day per week	3-5 km	Gear Hub	Always	Always	No	Always	Very Interested	600-1000	Very Interested	600-1000		
Male	36-50	3-5 days a week	More than 20 Km	Derailleur	Almost Always	Always	No	Always	Interested	200-400	Interested	200-400	Interested	200-400
Male	36-50	6-7 days a week	More than 20 Km	Derailleur	Always	Almost Always	No	Always	Barely interested	600-1000	Barely interested	100-200	Not at all interested	0
Male	36-50	6-7 days a week	More than 20 Km	Derailleur	Almost Always	Almost Always	No	Almost Always	Barely interested	600-1000	Barely interested	600-1000	Barely interested	600-1000
Male	36-50	1-3 days a week	More than 20 Km	Derailleur	Almost Always	Sometimes	No	Almost Always	Barely interested	600-1000	Interested	1000+	Barely interested	200-400
Female	36-50	6-7 days a week	10-20 km	Derailleur	Never	Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	36-50	Less than one day per week	More than 20 Km	Derailleur	Always		No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	36-50	6-7 days a week	5-10 km	Derailleur	Rarely	Almost Always	Sometimes	Always	Barely interested	1000+	Barely interested	1000+	Barely interested	1000+

Male	36-50	3-5 days a week	5-10 km	Gear Hub	Sometimes	Almost Always	No	Almost Always	Very Interested	600-1000	Interested	600-1000	Interested	600-1000
Female	36-50	6-7 days a week	5-10 km	Derailleur	Sometimes	Almost Always	No	Always	Interested	1000+	Interested	400-600	Barely interested	0-100
Male	36-50	6-7 days a week	More than 20 Km	Både-og	Sometimes	Sometimes	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	36-50	6-7 days a week	More than 20 Km	Derailleur	Never	Always	No	Always	Barely interested	1000+	Not at all interested	0	Not at all interested	0
Female	36-50	Never	Less than 1 km	Gear Hub	Never	Never	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	36-50	1-3 days a week	More than 20 Km	Derailleur	Always	Always	No	Always	Interested	1000+	Barely interested	100-200	Barely interested	0-100
Male	36-50	3-5 days a week	More than 20 Km	Derailleur	Almost Always	Always	No	Almost Always	Interested	1000+	Interested	400-600	Barely interested	200-400
Male	36-50	6-7 days a week	More than 20 Km	Derailleur	Rarely	Almost Always	No	Always	Interested	1000+	Interested	1000+	Interested	1000+
Male	36-50	3-5 days a week	More than 20 Km	Derailleur	Sometimes	Always	No	Always	Interested	1000+	Not at all interested	0	Not at all interested	0
Male	36-50	6-7 days a week	10-20 km	Gear Hub	Always	Always	No	Always	Very Interested	1000+	Not at all interested	0	Very Interested	1000+
Male	36-50	1-3 days a week	More than 20 Km	Derailleur	Always	Always	No	Always	Barely interested	1000+	Interested	1000+	Not at all interested	0
Male	36-50	1-3 days a week	More than 20 Km	Derailleur	Sometimes	Sometimes	No	Always	Not at all interested	0-100	Not at all interested	0-100	Not at all interested	0-100
Male	36-50	3-5 days a week	More than 20 Km	Derailleur	Almost Always	Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	36-50	1-3 days a week	More than 20 Km	Derailleur	Always	Sometimes	No	Always	Interested	400-600	Not at all interested	0	Not at all interested	0
Male	36-50	Less than one day per week	Less than 1 km	Derailleur	Rarely	Always	No	Always	Barely interested	600-1000	Barely interested	400-600	Barely interested	200-400
Male	36-50	3-5 days a week	More than 20 Km	Derailleur	Almost Always	Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	36-50	1-3 days a week	10-20 km	Derailleur	Always	Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	36-50	Less than one day per week	3-5 km	Gear Hub	Never	Almost Always	Yes	Always	Interested	200-400	Interested	200-400	Interested	200-400
Male	36-50	1-3 days a week	5-10 km	Derailleur	Almost Always	Always	No	Almost Always	Very Interested	400-600	Very Interested	400-600	Very Interested	400-600
Female	36-50	3-5 days a week	10-20 km	Derailleur	Sometimes	Almost Always	Sometimes	Almost Always	Interested	600-1000	Interested	600-1000	Interested	100-200
Male	36-50	1-3 days a week	More than 20 Km	Derailleur	Always	Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	50-65	1-3 days a week	More than 20 Km	Derailleur	Always	Always	No	Always	Barely interested	1000+	Not at all interested	0	Not at all interested	0
Male	50-65	1-3 days a week	More than 20 Km	Derailleur	Sometimes	Almost Always	No	Always	Barely interested	100-200	Very Interested	1000+	Interested	1000+
Male	50-65	Less than one day per week	Less than 1 km	Gear Hub	Almost Always	Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	50-65	1-3 days a week	More than 20 Km	Derailleur	Always	Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Female	50-65	Less than one day per week	10-20 km	Derailleur	Almost Always	Sometimes	Sometimes	Almost Always	Barely interested	400-600	Barely interested	200-400	Interested	400-600
Male	50-65	3-5 days a week	More than 20 Km	Derailleur	Almost Always	Always	Sometimes	Almost Always	Very Interested	600-1000	Very Interested	600-1000	Very Interested	600-1000
Male	50-65	Less than one day per week	1-3 km	Gear Hub	Almost Always	Almost Always	Yes	Sometimes	Very Interested	400-600	Very Interested	0-100	Very Interested	0-100
Male	50-65	1-3 days a week	More than 20 Km	Derailleur	Always	Always	No	Rarely	Interested	1000+	Very Interested	1000+	Very Interested	1000+

Male	50-65	1-3 days a week	More than 20 Km	Derailleur	Rarely	Always	No	Almost Always	Very Interested	1000+	Very Interested	1000+	Very Interested	1000+
Male	50-65	Less than one day per week	More than 20 Km	Derailleur	Almost Always	Always	Sometimes	Always	Interested	600-1000	Interested	400-600	Interested	600-1000
Male	50-65	3-5 days a week	More than 20 Km	Derailleur	Rarely	Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Male	50-65	3-5 days a week	More than 20 Km	Derailleur	Almost Always	Always	No	Always	Interested	1000+	Barely interested	1000+	Interested	600-1000
Female	65+	6-7 days a week	3-5 km	Gear Hub	Always	Rarely	Yes	Sometimes	Very Interested	400-600	Barely interested	0-100	Very Interested	200-400
Female	65+	6-7 days a week	More than 20 Km	Halv halv	Always	Never	No	Never	Not at all interested	1000+	Not at all interested	1000+	Not at all interested	1000+
Female	65+	Never	Less than 1 km	Shimano DI2	Rarely	Always	No	Always	Not at all interested	0	Not at all interested	0	Not at all interested	0
Female	65+	Never	Less than 1 km	Don't Know	Never	Never	No	Never	Not at all interested	0	Not at all interested	0	Not at all interested	0

Appendix D

Source code

```
//Defines made for ease of reading the code
#include <EEPROM.h>
#define debug// uncomment for debugging
#define NANO// uncomment for NANO
//===================Physical constants===================
#define PEDAL_GEAR_TEETH 38.0 //Number of teeth on the cogs attatched to the pedals
#define REAR_GEAR_TEETH 18.0//Number of teeth on the cogs attatched to the gearring
#define STEPS_PER_GEAR 771//Steps to change one gear
#define MAGNETS 2
#define NUM_GEAR 7 //Number of gears on the bike
//=====================Pins===========================

#ifdef NANO // ---PINS FOR NANO------------------------------
//       ________SEGMENTS PINS_________
#define SEG_A 4 //For displaying segment "a" on the display
#define SEG_B 3 //For displaying segment "b" on the display
#define SEG_C 8 //For displaying segment "c" on the display
#define SEG_D 9 //For displaying segment "d" on the display
#define SEG_E 10 //For displaying segment "e" on the display
#define SEG_F 5 //For displaying segment "f" on the display
#define SEG_G 6 //For displaying segment "g" on the display
#define SEG_COM 8//ground should not be used for output
#define SEG_DOT 7
//       ________OTHER PINS_____________
#define VIB_MOTOR 13 //For accessing the vibration motor pin
#define UP_BUTTON 11 //For accessing the button to shift to higher gear's pin
#define DOWN_BUTTON 12 //For accessing the button to shift to lower gear's pin
#define REED_SWITCH 2 //For accessing the pin for the read switch.
#define MOTOR_DIRECTION A0//For setting the direction of the motor.
#define MOTOR_ENABLE A7 //For enabling the motor
#define MOTOR_STEP A1//For making the motor turn

#else// ---------PINS FOR UNO-------------------------------
//       ________SEGMENTS PINS_________
#define SEG_A 4 //For displaying segment "a" on the display
#define SEG_B 5 //For displaying segment "b" on the display
#define SEG_C 9 //For displaying segment "c" on the display
#define SEG_D 7 //For displaying segment "d" on the display
#define SEG_E 6 //For displaying segment "e" on the display
#define SEG_F 3 //For displaying segment "f" on the display
```

```
#define SEG_G 2 //For displaying segment "g" on the display
#define SEG_COM 8//ground should not be used for output
#define SEG_DOT 10
//       ________OTHER PINS____________
#define VIB_MOTOR A5 //For accessing the vibration motor pin
#define UP_BUTTON 11 //For accessing the button to shift to higher gear's pin
#define DOWN_BUTTON 12 //For accessing the button to shift to lower gear's pin
#define REED_SWITCH 13 //For accessing the pin for the read switch.
#define MOTOR_DIRECTION A0//For setting the direction of the motor.
#define MOTOR_ENABLE A2 //For enabling the motor
#define MOTOR_STEP A1//For making the motor turn
#endif
//==================CONSTANTS====================
#define SAVE_ADDR_CURRENT_GEAR 10 // Memory address for saving the current gear
#define DEAD_STOP_TIME 2000 // How long to wait for the bicylcle to be at a full stop
#define TARGET_CADANCE 50

//Global variables used to control the flow of the program in other functions
int stepperIndex = 0; //The current step for the stepper motor
float rpmForGears[7] = {0, 31, 62, 93, 124, 155, 186}; //estimated rpm for gears

float rpm; // The rpm of the back wheel
int rounds; // Times that a magnet has passed
byte targetGear = 1; // The gear that the stepper motor should shift towards


bool autoGear = false; // Should auto shift be on
bool shouldVibrate = false; // Variable used to turn on vibration moter
float wheelToPedalRpm = PEDAL_GEAR_TEETH / REAR_GEAR_TEETH; // Multiiply by this value to calculate cadance

float gearRatio[7] =   {0.632, 0.741, 0.843, 0.989, 1.145, 1.335, 1.545}; // Gear ratio for each gear

float gearStep[6] =           {0.173, 0.138, 0.173, 0.158, 0.166, 0.158}; // Step between gears
float gearStepCumulative[7] = {0, 0.173, 0.311, 0.484, 0.642, 0.798, 0.966}; // Steps to reach each gear

int rpmsSize = 5;
int rpms[5] = {0, 0, 0, 0, 0}; // Buffer for rpm readings
int rpmReadingIndex = 0;


#ifdef debug
long startShifting;
long endShifting;
#endif

float cadanceToRpm (int gear) { // Used to calulate rpm from cadence

  return wheelToPedalRpm * gearRatio[gear];
}
void setup() {

  for (int i = 0; i < NUM_GEAR; i++) {

    rpmForGears[i] = TARGET_CADANCE * cadanceToRpm(i);
  }

#ifdef debug
  Serial.begin(250000); // Serial should only be open for debugging
  Serial.println(wheelToPedalRpm);
```

```
  Serial.println(NUM_GEAR);
  Serial.println(wheelToPedalRpm);
  Serial.print("gear rpm array{");
  for (int i = 0; i < 7; i++) {
    Serial.print(rpmForGears[i]);
  }
  Serial.println("}");
#endif


  //Setup of pins used for the display
  pinMode(SEG_A, OUTPUT);
  pinMode(SEG_B, OUTPUT);
  pinMode(SEG_C, OUTPUT);
  pinMode(SEG_D, OUTPUT);
  pinMode(SEG_E, OUTPUT);
  pinMode(SEG_F, OUTPUT);
  pinMode(SEG_G, OUTPUT);
  pinMode(SEG_DOT, OUTPUT);


  //Setup of the pin used for the read switch.
  pinMode(REED_SWITCH, INPUT);

  //Setup of pins used for the buttons
  pinMode(DOWN_BUTTON, INPUT_PULLUP);
  pinMode(UP_BUTTON, INPUT_PULLUP);

  //Setup of the pin used for the vibration motor
  pinMode(VIB_MOTOR, OUTPUT);

  //Setup of pins used for the stepper motor
  pinMode(MOTOR_ENABLE, OUTPUT);
  pinMode(MOTOR_STEP, OUTPUT);
  pinMode(MOTOR_DIRECTION, OUTPUT);
  digitalWrite(MOTOR_ENABLE, LOW); // Motor is on if LOW

  readFromMemory(); // Load the last state recorded

}


//======================LOOP================================
void loop() {// MAIN LOOP

  updateRPM();

  if (autoGear) updateGear();

  checkButtons();

  updateStep();

  updateVibrate();

  updateDisplay();
}


//======================UPDATES================================

void updateRPM() {
```

```
  // To compare time of reading
  static long lastMeasurement;
  long currentMillis = millis();
  static long lastOn;
  // To compare last reading
  bool reed = digitalRead(REED_SWITCH);
  static bool lastRead;

  if (reed && reed != lastRead) { // Called when a magnet pass
    float calcedRpm = (60000 / (currentMillis - lastOn)) / MAGNETS; //Calculate rpm

#ifdef debug
    Serial.print("calculated rpm: ");
    Serial.println(calcedRpm);
    Serial.print("time since last: ");
    Serial.println(currentMillis - lastOn);
#endif

    rpms[rpmReadingIndex] = calcedRpm;
    rpmReadingIndex++;
    if (rpmReadingIndex > rpmsSize)
      rpmReadingIndex = 0;
    lastOn = currentMillis;
    rounds++;
#ifdef debug
    Serial.print("nr Rounds: ");
    Serial.println(rounds);
#endif
  }
  else if ((lastOn + DEAD_STOP_TIME) < currentMillis) // called if no magnets passed in DEAD_STOP_TIME
  {
#ifdef debug
    //Serial.println("rpm 0");
#endif
    for (int i = 0; i < rpmsSize ; i++) {
      rpms[i] = 0; // Set entire array to 0
    }
    lastOn = currentMillis;
  }


#ifdef debug
  if (reed && reed != lastRead) {
    Serial.print("RPM: ");
    Serial.println(getRpm());

    Serial.print("kmph: ");
    Serial.println((rpm * 3.14 * 0.71 * 60) / 1000);
  }
#endif
  lastRead = reed;
}

void updateGear() {
  rpm = getRpm();
  int i = 1;
  while (i < NUM_GEAR) {//Check which gear it requires to match the rpm
    if (rpm > rpmForGears[i - 1]) {
      i++;
    } else {
      break;
```

```
    }
  }

  // this assures that once it has shifted a gear up, the rpm has to fall even lower to downshift, this is to make sure that the rpm is not on the edge of the two values and fluctuate between the gears
  if (i > targetGear || i < targetGear && isXCloserThanY(rpm, rpmForGears[i - 1], rpmForGears[targetGear - 1])) {
    targetGear = i;
  }
}

boolean isXCloserThanY(float in, float x, float y) {
  return (in - x) * (in - x) < (in - y) * (in - y); //comparing the diffrences squared instead of abolute value to save computing time
}

// BUTTON INPUT
void checkButtons() {
  // Variables to check if there is a change in state of the buttons
  static bool lastUpB;
  static bool lastDownB;
  static bool lastBothB;
  static bool bothHasBeenPressed = false;
  static long lastButtonAction = millis();
  // Read button sates
  //states are inverted because pull up resistors are used
  bool upB = !digitalRead(UP_BUTTON);
  bool downB = !digitalRead(DOWN_BUTTON);
  bool bothB = upB && downB;// true if both buttons are pressed
  //Checking what buttons are pressed
  if ((lastButtonAction + 50) < millis()) {//Added delay for debouncing
    if (bothHasBeenPressed) { // check for both buttons to be liftet after they have both been pressed
      bothHasBeenPressed = (upB || downB);
    } else if (bothB) {//Toggle the autogear if both buttons are pressed and save that both buttons has been pressed
      bothHasBeenPressed = true;
      toggleAuto();
    } else if (!upB && lastUpB) { //button is not pressed but was last check, shift gear up
      shiftGearUp();
    } else if (!downB && lastDownB) {//button is not pressed but was last check, shift gear down
      shiftGearDown();
    }
    //saving values for next check
    lastUpB = upB;
    lastDownB = downB;
    lastBothB = bothB;
    lastButtonAction = millis();//Used for debouncing logic
  }
}

//Function for making the stepper motor turn
void updateStep() {
  shouldVibrate = true;
  static bool calibrated = true;
  if ( stepperIndex < STEPS_PER_GEAR * targetGear) { //Step up one step if current gear is bellow target
    stepOnce(HIGH);
    stepperIndex++;
    calibrated = false;
```

```
  } else if ( stepperIndex > STEPS_PER_GEAR * targetGear) { //Step down one step if current gear
      is above target
    stepOnce(LOW);
    stepperIndex--;
    calibrated = false;
  } else { //Do this if it is the right gear
    digitalWrite(MOTOR_ENABLE, LOW);
    // currentGear = targetGear;
    shouldVibrate = false;


    if (!autoGear && !calibrated) {
      if ( targetGear == NUM_GEAR) {// This is for tightning the gearing cable if needed, it will
          turn the stepper moter pass the maximum stepper index
        debugMotorTurn(500, true);
        debugMotorTurn(40, false);
      }
      calibrated = true;
      writeToMemory();
#ifdef debug
      stopChanging();
#endif
    }
  }
}

void updateDisplay() {
  displayDigit(targetGear);
}

void updateVibrate() {// Turn on vibrator if shouldVibrate
  digitalWrite(VIB_MOTOR, shouldVibrate);
}
// ============================== FUNCTIONS ==============================

//Function for making the system gear up by one gear
void shiftGearUp() {
  startChanging();
  if (targetGear < NUM_GEAR)
    targetGear++;

#ifdef debug
  Serial.print("Gear: up ");
  Serial.println(targetGear);
#endif

}

//Function for making the system gear down by one gear
void shiftGearDown() {
  startChanging();
  if (targetGear > 1)
    targetGear--;

#ifdef debug
  Serial.print("Gear: down ");
  Serial.println(targetGear);
#endif

}

void stepOnce(bool dir) { // Steps once in 'dir' direction, takes about 0.0008 seconds
```

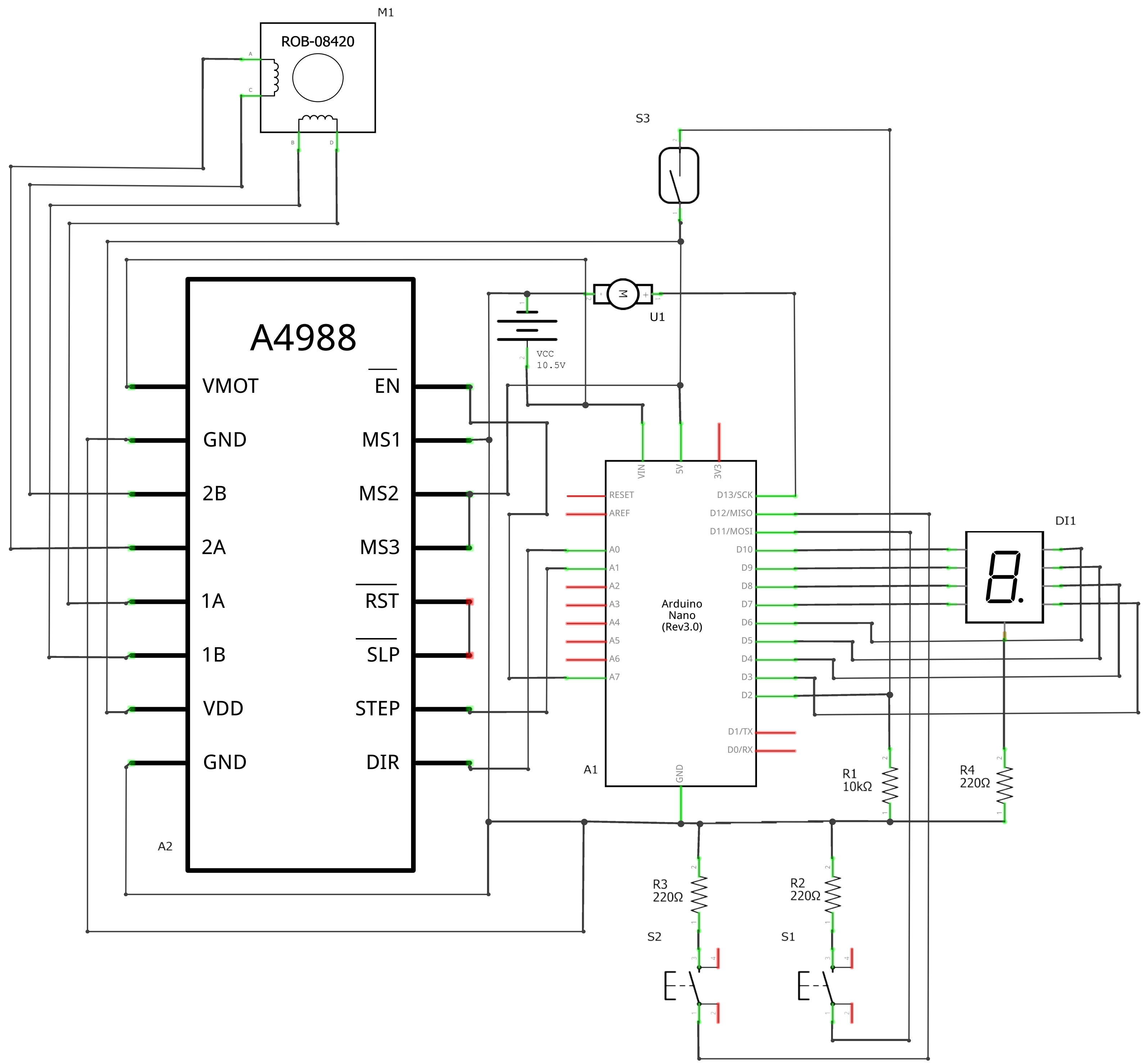
```
  digitalWrite(MOTOR_ENABLE, LOW);
  digitalWrite(MOTOR_DIRECTION, !dir);
  digitalWrite(MOTOR_STEP, HIGH);
  delayMicroseconds(400);
  digitalWrite(MOTOR_STEP, LOW);
  delayMicroseconds(400);
}

void writeToMemory() {// Save current target gear to the persistent memory
  EEPROM.write(SAVE_ADDR_CURRENT_GEAR, targetGear);
}

void readFromMemory() {// Load from persistent memory
  targetGear = EEPROM.read(SAVE_ADDR_CURRENT_GEAR);
  stepperIndex = STEPS_PER_GEAR * targetGear;
}


float getRpm() {// Method for getting current rpm
  return median(rpmsSize, rpms);
}

float mean(int m, int a[]) { // Return the mean value for the array a
  int sum = 0, i;
  for (i = 0; i < m; i++)
    sum += a[i];
  return ((float)sum / m);
}

float median(int n, int x[]) { // return the median value for the array x
  float temp;
  int i, j;
  // the following two loops sort the array x in ascending order
  for (i = 0; i < n - 1; i++) {
    for (j = i + 1; j < n; j++) {
      if (x[j] < x[i]) {
        // swap elements
        temp = x[i];
        x[i] = x[j];
        x[j] = temp;
      }
    }
  }
  if (n % 2 == 0) {
    // if there is an even number of elements, return mean of the two elements in the middle
    return ((x[n / 2] + x[n / 2 - 1]) / 2.0);
  } else {
    // else return the element in the middle
    return x[n / 2];
  }
}

void toggleAuto() {// Toggle the Autogear

  autoGear = !autoGear;
  digitalWrite(SEG_DOT, autoGear);
#ifdef debug
  Serial.print("Auto gear: ");
  Serial.println(autoGear);
#endif
}

```

```

//Function for turning off all segments of the display
void turnOffDisplay()
{
  digitalWrite(SEG_A, LOW);
  digitalWrite(SEG_B, LOW);
  digitalWrite(SEG_C, LOW);
  digitalWrite(SEG_D, LOW);
  digitalWrite(SEG_E, LOW);
  digitalWrite(SEG_F, LOW);
  digitalWrite(SEG_G, LOW);
}

//Function for lighting up the different segments of the display to show specific numbers
void displayDigit(int digit)
{
  turnOffDisplay();
  //Conditions for displaying segment a
  if (digit != 1 && digit != 4)
    digitalWrite(SEG_A, HIGH);

  //Conditions for displaying segment b
  if (digit != 5 && digit != 6)
    digitalWrite(SEG_B, HIGH);

  //Conditions for displaying segment c
  if (digit != 2)
    digitalWrite(SEG_C, HIGH);

  //Conditions for displaying segment d
  if (digit != 1 && digit != 4 && digit != 7)
    digitalWrite(SEG_D , HIGH);

  //Conditions for displaying segment e
  if (digit == 2 || digit == 6 || digit == 8 || digit == 0)
    digitalWrite(SEG_E, HIGH);

  //Conditions for displaying segment f
  if (digit != 1 && digit != 2 && digit != 3 && digit != 7)
    digitalWrite(SEG_F, HIGH);
  if (digit != 0 && digit != 1 && digit != 7)
    digitalWrite(SEG_G, HIGH);
}
// OTHER FUNCTIONS
// ======================= Debug functions =======================
#ifdef debug
void loopDisplay() {
  for (int n = 2; n < 10; n++) {

    pinMode(n, OUTPUT);
  }
  /* digitalWrite(currentGear, HIGH);
    for (int n = 2; n < 10; n++) {
      if (n != currentGear)
        digitalWrite(n, LOW);
    }
  */
  for (int i = 2; i < 10; i++) {
    digitalWrite(i, HIGH);
    for (int n = 2; n < 10; n++) {
      if (n != i)
        digitalWrite(n, LOW);
```

```
    }
    delay(1000);
  }
}
//

void startChanging() { // For testing
  startShifting = millis();

}


void stopChanging() { // For testing
  endShifting = millis();
  Serial.print("end shifting: ");
  Serial.println(endShifting - startShifting);
}


void debugMotorTurn(int steps, bool dir) {
  for (int i = 0; i < steps; i++) {
    digitalWrite(MOTOR_ENABLE, LOW);
    digitalWrite(MOTOR_DIRECTION, !dir);
    digitalWrite(MOTOR_STEP, HIGH);
    delayMicroseconds(400);
    digitalWrite(MOTOR_STEP, LOW);
    delayMicroseconds(400);
  }


}
#else
void debugMotorTurn(int steps, bool dir) {
  for (int i = 0; i < steps; i++) {
    digitalWrite(MOTOR_ENABLE, LOW);
    digitalWrite(MOTOR_DIRECTION, !dir);
    digitalWrite(MOTOR_STEP, HIGH);
    delayMicroseconds(400);
    digitalWrite(MOTOR_STEP, LOW);
    delayMicroseconds(400);
  }
}
#endif
```

Appendix E

Schematics



Reference	Component
R1	10k Ω ±1%,0.25W
R2	220 Ω ±1%,0.25W
R3	220 Ω ±1%,0.25W
R4	220 Ω ±1%,0.25W
S1	Push-button
S2	Push-button
S3	Normally open Reed Switch
A1	Arduino Nano
A2	Pololu A4988
VCC	10.5 V DC Power Supply
M1	Bipolar Stepper Motor
U1	Vibration Motor
DI1	Seven Segment Display

Figure E.1: Wiring diagram of the complete circuit

Appendix F

Flow Diagram of software

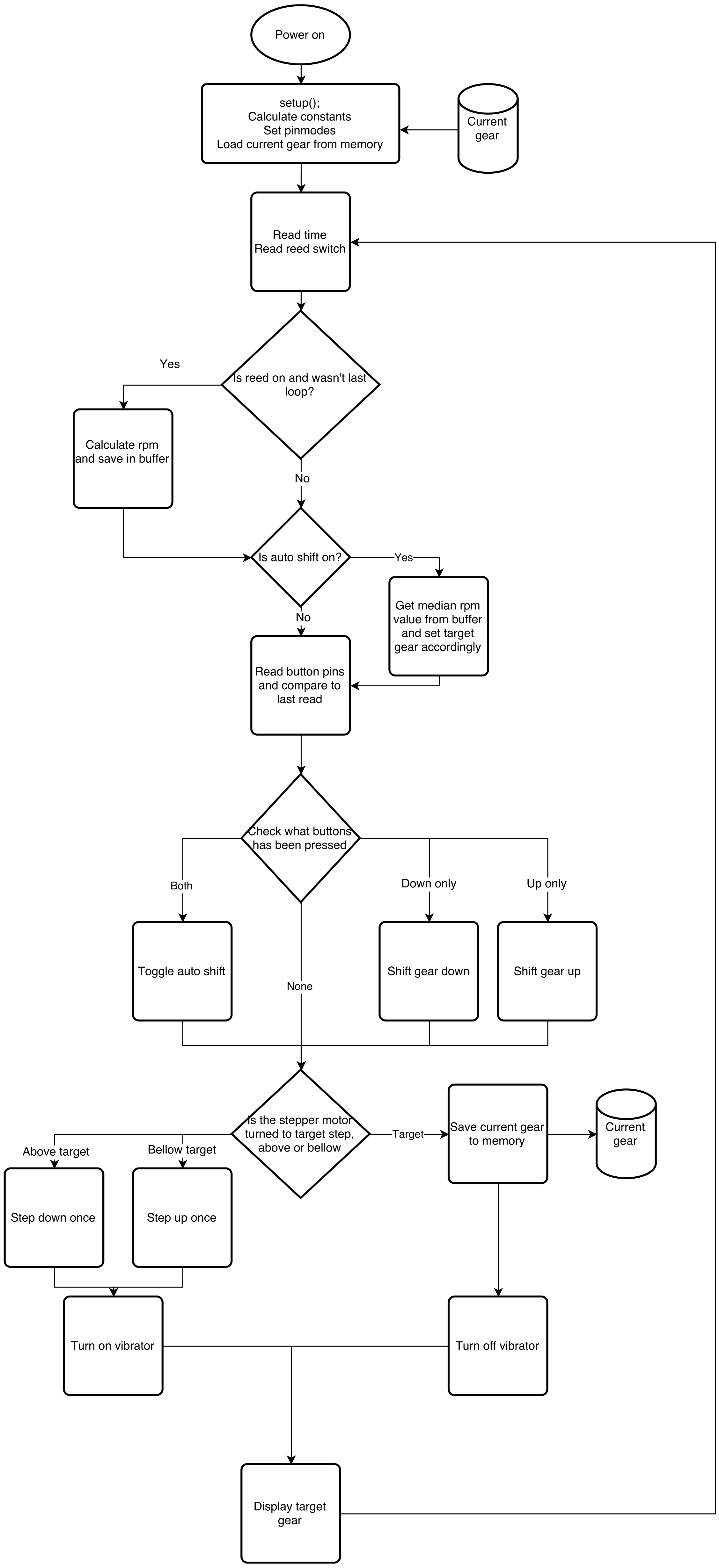


Figure F.1: Flow diagram of the software