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Industrial Electrical Engineering and Automation

Water Removal from Protective Glass

Max Guidotti

Michael Båth Halldén

Division of Industrial Electrical Engineering and Automation
Faculty of Engineering, Lund University

LUND UNIVERSITY FACULTY OF ENGINEERING

MASTER THESIS

Water Removal from Protective Glass

Authors:
Max Guidotti
Michael Båth Halldén

Examiner:
Johan Björnstedt, LTH

Supervisors:
Gunnar Lindstedt, LTH

Johan Kjörnsberg, Axis
John Åkesson, Axis
Oscar Strand, Axis

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Declaration of Authorship

We, **Max Guidotti** & **Michael Båth Halldén**, declare that this thesis titled, "Water Removal from Protective Glass" and the work presented in it are our own. We confirm that:

- This work was done wholly or mainly while in candidature for a Master's Degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where we have consulted the published work of others, this is always clearly attributed.
- Where we have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely our own work.
- We have acknowledged all main sources of help.
- We have contributed equally and all the work has been done by the both of us.

Signed: Date:

Max Guidotti

Signed: Date:

Michael Båth Halldén

"If you're not going to work efficiently, you might as well work eight hours a day"

Mix

Lund University Faculty of Engineering

Abstract

Faculty of Engineering LTH

Division of Industrial Electrical Engineering and Automation

Mechanical Engineering

Water Removal from Protective Glass

by Max Guidotti & Michael Båth Halldén

Today's network outdoor surveillance cameras face problems when water drops stick to the protective glass in front of the camera lens, thus significantly disturbing the image. This problem mainly occurs during heavy rain weather or when the camera is being cleaned with a hose. Solving this problem would greatly improve the performance and versatility of outdoor surveillance cameras.

The way this problem is solved today is by using wind shield wipers. The drawback with this solution is that the screen will get scratched over time, especially if the wipers accidentally operate on a dry protective glass.

To solve this problem, a systematic approach was used. After generating a wide spectrum of concepts, they were systematically tested and evaluated. Our mission was to find a solution that is reliable, energy efficient and implementable into existing products.

The final result of this project was a vibrating solution to the problem. By vibrating the protective glass at a specific frequency and amplitude, the water drops could successfully be removed. A prototype of the final solution was implemented into an already existing product which proves that the concept might be possible to include in future products.

The result of this project will be an attractive feature for network surveillance cameras. The results of this project have only been tested in camera applications, but have the potential of being implemented into other fields, such as car or home windows.

Preface and Acknowledgements

This thesis was written to fulfill the graduation requirements of the Mechanical Engineering program at the Faculty of Engineering within Lund University. The thesis was written between January and June 2017.

Thanks to *Johan Kjörnsberg*, our supervisor and coach. You helped us through all our electrical problems and were here to help us and teach us every day of our thesis work.

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Thanks to our supervisor and examiner at LTH, *Gunnar Lindstedt and Johan Björnstedt*, for helping us preparing for this master thesis, along the way and for all the feedback in the end.

We would also like to thank all the employees at Axis that have helped during the entire project.

Finally, but not least, we would to say a big thank you to Axis Communications. Working at Axis these past 20 weeks has been a pleasure, being a Master Thesis student at a company like Axis is truly a blessing.

We hope you enjoy your reading.

Max Guidotti & Michael Båth Halldén

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List of Abbreviations

PWM	**P**ulse **W**idth **M**odulation
PoE	**P**ower **o**ver **E**thernet
IR	**I**nfra**R**ed
DC	**D**irect **C**urrent
LTH	**L**unds **T**ekniska **H**ögskola
IP-Code	**I**nternational **P**rotection Marking
TBA	**T**o **B**e **A**nnounced

Dedicated to M6

Chapter 1

Introduction

1.1 Background

Cameras mounted outdoors are exposed to rain that sticks on the protective glass and affects the image quality in a negative way. Today there are different methods for removing rain; like manual cleaning, wipers etc. The reason for this master thesis was to examine if it is possible to remove water drops from the protective glass in any other way. This can be achieved by vibrating, rotating, heating, blowing on the glass etc.

One solution that is used today is the wind shield wiper. The problem with this solution is that it will end up scratching the protective glass over time. Especially when the wiper is accidentally activated on a dry surface.

1.2 Milestones & Objectives

This project was broken down into milestones. The main milestones of the project were

- Carrying out a thorough prestudy in order to gain as much knowledge as possible from previous progress in similar projects. This prestudy was carried out both internally at Axis and externally.
- Establishing desirable and necessary needs and properties for plausible solutions.
- Generating multiple different concepts for solving the problem without yet being constrained by limitations.
- Through systematic evaluations of the concepts choosing three main concepts to continue working with.
- Building simple prototypes of the three concepts and test them thoroughly by evaluating their respective ability to remove water from the protective glass.
- Deciding on the best concept and building a prototype that can both remove water and at the same time is resistant to water and dust.
- Building a final prototype which is controlled electronically.
- Assembling the final prototype into an existing or future product.

1.3 Delimitations

- The goal of the project was to build a functioning prototype to show that the final concept of cleaning a window from water drops works.
- The goal was not to build a fully functioning product, but rather a proof of concept.
- The prototype must not be completely resistant against water and dirt, but should be good enough so that the concept principles can be shown.
- The economical aspect was not taken into account, this means a concept was not rejected solely because of the fact that it was to expensive for mass production. This was a request from Axis in order to stimulate a wide range of concept ideas.
- Effects of long time wear was taken into account, but was not the main reason to reject a concept.
- Long term studies will have to be conducted internally after this project is done.

1.4 Scientific Basis for the Thesis

Martin Schmitt has published two papers regarding removing droplets using lamb waves. Lamb waves move on the top layer of the material, making the drops move down the glass. [1][2]

1.5 About LTH

The Faculty of Engineering, LTH, is a faculty of Lund University and has 9,600 enrolled students and 1,500 employees from all over the world. LTH has the responsibility for education and research in engineering, architecture and industrial design. [3]

1.6 About Axis

Axis was founded in 1984 in Lund, by Martin Gren, Mikael Karlsson and Keith Bloodworth. The first network camera was invented back in 1996 and today Axis is the market leader within this field. Before 1996 Axis mainly developed print servers and other technical products. Axis has grown a lot these last couple of years and their biggest market is the US. With 2,139 (2015) employees its a very innovative company with a lot of potential in the future.[4][5]

1.7 Project Plan

The project spanned over 20 weeks full time. The project started in the middle of January and was completed in the beginning of June. The project was carried out by two mechanical engineering students, both of whom are taking a masters degree in Mechanical Engineering specializing within Mechatronics.

1.8 Thesis Outline

Introduction In this chapter the reader is introduced to the projects Background, Milestones, Delimitations, Scientific Basis for the Thesis and the Project Plan.

Concept Development The process of developing the concept is described from the beginning to the end. The customer needs, knowledge of similar solutions and concept generation is presented in this chapter.

Concept Evaluation In this chapter the concepts are tested and evaluated.

Final Prototype The final prototype is built and tested and the final results are presented.

Discussion This chapter is about how this project should move forward and be further developed.

Chapter 2

Concept Development

2.1 Method

The method that is used for the prototype development is Ulrich & Eppingers product development method. This method is widely taught globally and is described in Ulrich & Eppingers book [6]. It consists of five main steps, *Identifying customer needs, Product Specifications, Concept Generation, Concept Selection & Concept Testing*. The concept development phase in this thesis will be based on said methodology, but with some modifications.

What differentiates the method used for this project compared to the orginal Ulrich & Eppinger plan:

- **Identifying customer needs** was not done by interviewing or sending out surveys to customers, these were given by Axis' product manager.
- **Product Specifications** was setup from the information that was given by Axis's product manager.
- **Concept Generation** was done in the same way that Ulrich & Eppinger suggested.
- **Concept Selection** was not done until after **Concept Testing**.

2.2 Limitations

For this master thesis the only limitations are electrical and mechanical.

2.2.1 Electrical Limitations

Axis uses ethernet[7] cables for communications from and to their cameras. This is also the cameras power source. The PoE standard, updated in 2009, can deliver 25 Watts to the camera which makes this a limited power source. The camera itself needs about 10-12 Watts and it is usually equipped with an IR-port that needs 1-2 Watts. During the winter the camera is cold and the rest of the power is used to heat the camera, to avoid getting frost on the glass. The IR and the heating can temporarily be shut down when extra power is needed. This means that the solution to this problem can use about 13-15 Watts for short periods of time.

2.2.2 Mechanical Limitations

Axis has IP codes on their cameras. Most Axis cameras have an IP68 classification. This means the camera can be submerged into water. However, the aim of this project is to find a solution that fulfills the IP66 classification. This means that the camera can be sprayed with a high pressure hose from a close distance. This is a situation that is more likely to happen in real world usage of this camera. The cameras are often mounted on walls, roof tops etc. This means that the camera cannot "be moved" too much, because the camera might end up dropping from the wall. Also if the camera is moving too much, it might cause unwanted sounds in the recording.

2.3 Definitions

Before moving forward, some concepts must be clarified and defined.

2.3.1 Protective Glass

The protective glass basically means the glass in front of the camera. The purpose of the protective glass is to protect the lens and camera house from dust, rain and mechanical impact, while at the same time being transparent. The protective glass in this thesis implies the glass, or in most cases see through plastic, covering the front of the camera house.

FIGURE 2.1: Image of a fixed box camera and corresponding protective glass.[8][9]

2.3.2 Cleaning Process

The cleaning process is the process of cleaning the protective glass from water. The main aim of the cleaning process is not to remove dirt, but mainly to remove water from the glass, for example after cleaning the camera with a hose. The cleaning process is started when water is detected, by either a sensor or a person. The cleaning process shouldn't be running permanently, only when the protective glass needs cleaning from water drops. The cleaning process should be automatically shut down.

2.4 Identifying Customer Needs

Before moving on to the Concept Generation section, the customer needs have to be clarified. By gathering, with interviews, as much information as possible from employees at Axis, a list of needs and their relative importance was produced. These are presented in Table 2.1 below.

TABLE 2.1: List of customer needs and their relative importance

No.	**Need**	**Imp.**
1	The water becomes removed	5
2	The solution is water proof	4
3	The cleaning process is energy efficient	4
4	The image quality is not permanently ruined	5
5	The image quality is not ruined during cleaning	3
6	The solution has low need of maintenance	4
7	The outer dimensions of the camera are altered as little as possible	3
8	The cleaning process needs no manual labor	5
9	The total weight of the product is low	4
10	The camera is not reoriented during cleaning process	5
11	The cleaning process is time efficient	3
12	The solution has low heat production during usage	2
13	The solution can be used in different cameras	2
14	The solution is functional in different climates and weathers	4
15	The cleaning process produces low noise	3
16	The solution is easy to manufacture	2
17	The solution is recyclable	2
18	The solution has low material usage	2

2.5 Product Specifications

After specifying the customer needs, the needs are translated into product specifications. Some needs are combined, and a few are omitted. These specifications are now the corner stones for the following product development phase of this thesis.

TABLE 2.2: List of product specifications needs and their relative importance

No.	Need	Imp.
1	The water becomes removed	5
2	The solution can endure external circumstances	4
3	The cleaning process is energy efficient	4
4	The image quality is maintained	4
5	The solution is maintenance free	4
6	The solution is small, light and flexible	3
7	The cleaning process is time efficient	3
8	The solution has low heat production during usage	2
9	The cleaning process produces low noise	3

The nine product specifications above must now be specified more accurately. This is done by quantifying each need into metrics. This is done in Table 2.3.

TABLE 2.3: List of customer needs and their relative importance

Metric No.	Need No.	Metric	Imp.	Units	Marginal values	Ideal values
1	1	Size of remaining water drops	5	mm	TBA	TBA
2	1	Number of remaining water drops	5	no.	TBA	TBA
3	2	Protection against water	4	IP class	IP65	IP66
4	2	Protection against dust	4	IP class	IP65	IP66
5	2	Operational temperatures	4	°C	-20 - +40	-40 - +60
6	3	Maximum power used	4	W	<13	<2
7	4	Image quality is maintained during cleaning process	3	subj.	Almost maintained	Totally maintained
8	4	Orientation of camera is fixed during cleaning process	5	yes/no	no	yes
9	4	Amount of mechanical wear on prot. glass	5	subj.	Little wear	No wear
10	5	The cleaning process is completely automatic	5	yes/no	yes	yes
11	5	Time between maintenance	4	Months	12	36
12	6	The outer dimensions of the camera are maintained	3	yes/no	no	yes
13	6	The total added weight of the product is low	4	g	<500	<250
14	7	The cleaning process is fast	3	s	<20	<5
15	8	The solution has low heat production during usage	2	yes/no	no	yes
16	9	The cleaning process is quiet	3	dB	<80	<65

About metric no. 1 & 2 in the table above, there are no chosen ideal or marginal values. The reason for this is that, this early in the project it hasn't been measured what size of water drops actually disturb the image or how many there are after rain etc.

2.6 Concept Generation

2.6.1 Clarify the problem

This step is about clarifying the situation, getting a general understanding of the main problem and breaking down the problem into smaller sub problems. This can be really beneficial when designing the prototypes since it is more simple to handle smaller problems compared with huge complex complications.

The main task is to remove water drops from the protective glass of the camera. The solution does not have to remove dirt, snow or other substances than water from the protective glass. The solution must be energy efficient and work automatically. The solution should not include a windshield wiper since a product with this solution is already developed at Axis.

2.6.2 Search Externally

This step is about finding solutions and information outside of the company, exploring patents, benchmarking other related products, consulting experts etc. For this step the Authors started by benchmarking other related products.

Clear view screen

There are a lot of products that today depend on keeping screens or mirrors clean. One example is the clear view screen, which is most commonly used on fishing ships. A picture of a Clear View Screen can be seen in Figure 2.2 below.

FIGURE 2.2: Clear View Screen

By rotating the glass the radial acceleration makes the water accelerate away from the center when it hits the screen. This method is also used for keeping a dentist's mirror [10] clean or even in a Hollywood camera [11]. This was an inspiration for the *Rotating Glass concepts* listed in *section 2.6.4*.

Disposable visors

There have been developments for visors in the motor cross industry, since the visors often get covered in dirt and water. The Authors found a patent that can solve this problem [12]. In Figure 2.3 below is a picture explaining the idea behind disposable visors.

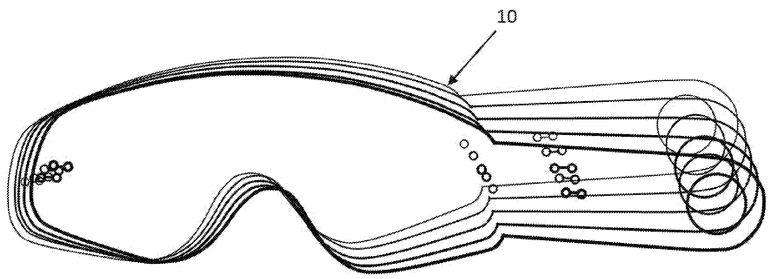

FIGURE 2.3: Disposable Visors [12]

The idea is very simple, when one visors gets dirty, the motor cross rider rips it off and continues the race without distractions.

Professors at LTH

A central problem with some of the solutions that have been discussed externally, for example the rotating glass, is that the protective glass has to move in order to remove the water. This would not be a large problem if it was not for the fact that the protective glass must also be water tight. The possibility of using watertight bearings was therefore discussed with a professor within Machine Elements, Lars Vedmar[13], at LTH. An interview with an electronics professor, Johan Björnstedt[14] gave insight into electromagnets and how big impact they can have on moving, rotating or vibrating the protective glass. By furthermore discussing resonances and vibrations with a Mechanics professor, Per Lidström[15] at LTH, information about how to move the protective glass was obtained. Understanding the resonance frequencies for the protective glass and different sizes of water drops had a huge impact on this project.

Ultrasound

Another idea that was investigated was ultrasound. Vibrating the glass very fast (>20 kHz), but with very small amplitude. These techniques have been researched by other companies before. For example, McLaren has tried to implement one technique of cleaning the front glass of their cars, using ultrasonic force field instead of using windshield wipers.[16] There are also other papers discussing using lamb waves for removing water drops from a surface.[1][2]

Coatings

After finding one of the leading producers of super hydrophobic coatings and learning how effective these coatings could be, further investigations in this area were carried out.[17] The findings from these investigations were that the coatings can be really effective, but they cannot be used on transparent surfaces since they tint the glass making it unusable in a camera application. In a Youtube video[18] showing the product in use, it can be noted that everything that is treated with The Ultra-Ever Dry® treatment has light or white color to hide the fact that the treatment stains or tints the treated surface.

2.6.3 Search Internally

The point of this step is to make sure that existing knowledge within the company or the team is used and not lost. Similar projects have been carried out earlier and the experience gained from earlier projects must be harvested. This was done by interviewing people who have prior experience in the product in question, or similar products. Another powerful tool in this stage of product development is brainstorming. Four helpful guidelines are explained by Ulrich & Eppinger [6]:

- **Suspend judgment** -During concept generation sessions, no criticism of concepts is allowed.
- **Generate many ideas** - The more ideas that are generated by the team, the more likely it is to fully explore all solutions and come up with new unique ways to solve the problem.
- **Be welcoming** - Welcome ideas that are seemingly infeasible. They will most likely stimulate the creation of other, more feasible ideas.
- **Be expressive** - Express all ideas graphically. Be sure to have all graphical equipment that is needed to express the different concept ideas.

After many interviews and discussions with employees at Axis, it became more clear what had been done so far. Most of the studies and prototypes that had been made were within vibration of the protective glass. These studies showed that the concept of vibrating the glass worked, but more investigation into the matter was necessary in order to implement the solution efficiently. The vibration in this case had been done using a magnet and a DC-motor, the concept is further explained in *section 2.6.4* under ***Motor with Magnet - V1.1***. For this concept the amplitude of the vibration depended on the frequency. Understanding how the amplitude and the frequency independently effects water drops on the protective glass was of great importance to finding the final concept.

Another concept that had previously been discussed and researched at Axis was the use of ultrasound. This was both explored internally on Axis, but also externally. See section 2.6.2.

Ultrasound

After talking to an Axis employee, Samir Helaoui, with knowledge withing the field of ultra sound, the same articles that were mentioned in *2.6.2 - Ultrasound* were brought up again. Even though it is important to remain open to all ideas in this early stage of the project, after some investigation it was decided that these theories would be to hard to implement into an Axis Camera during the 20 weeks that was given for this project. This is something that Helaoui agreed with.[19]

Vibration

Axis has done some tests using vibrations to remove water drops and the tests have been successful.[20] However, there are still parameters that need to be examined further, such as frequency, amplitude and direction of the vibrations (horizontal, vertical or oscillation).

Compressed Air

Using compressed air is something that Axis has been and still is investigating. The problem with using compressed air, is that in order to have a strong enough compressor to remove the water drops, the camera would consume more power than is available through PoE4. The solution for this is having an air tank acting as a buffer that could be pressurized with compressed air over time, thus lowering the peak power consumption. This would lead to many parts and quite a large air tank. Some of the benefits would be less wear on the protective glass and it is a solution that is relatively easy to water proof. In the cleaning process it would probably also be able to remove some of the dirt and dust, but this is just assumptions that have to be tested more thoroughly.

Coatings

After discussing with an Axis employee, Sven Svensson[21], about the discoveries regarding the coatings, it became more clear that it was not an easy solution to implement this for a camera solution. As mentioned in Section *2.6.2 - Search Externally*, the reason is that some of the coatings would stain the protective glass and other coating would wear out quickly and would have to be reapplied frequently. Svensson also mentioned the difference between hydrophilic and hydrophobic coatings. The hydrophilic coatings made the height of the waters drops smaller, as they tended to "smudge out" on the protective glass. Whereas the hydrophobic made the height of the water drops bigger. Svensson tested the two coatings, the hydrophilic helped the water drops run off the protective glass, while there were no significant differences using the hydrophobic coatings compared to not using coatings. The problem with hydrophilic coatings was that it would wear out quickly. It should be noted that neither of these coatings have been tested in combination with vibrations or any other water removal method.

2.6.4 Concepts

Rotating Glass

The rotating glass concepts were inspired by the investigations done during the *search externally* part of the product development process (*subsection 2.6.2*). The main problems that arise are how to make the glass rotate and how to keep it water tight.

The problem with rotating the glass is that it is difficult to have a center mounted shaft on the glass pane because of the camera that has to record video through the glass.

The main problem with making the solution water tight is that the friction must be very low in order to be able to rotate the glass under a strict power budget. To solve this problem, all concepts were built using a water proof ball bearing where the outer ring is attached to the camera house and the protective glass was placed in the inner ring of the ball bearing.

Different concepts for solving these problems were generated. They can be seen in the following sections.

Rotating Fork - RG1.1 The rotating fork concept solves the rotation problem by mounting a u-shaped fork on the inner ring of the ball bearing, making it possible for the motor and drive shaft to be located behind the camera, thus allowing the inner ring to rotate without disturbing the image quality. How the fork is attached to the ball bearing is not specified in the primary concept.

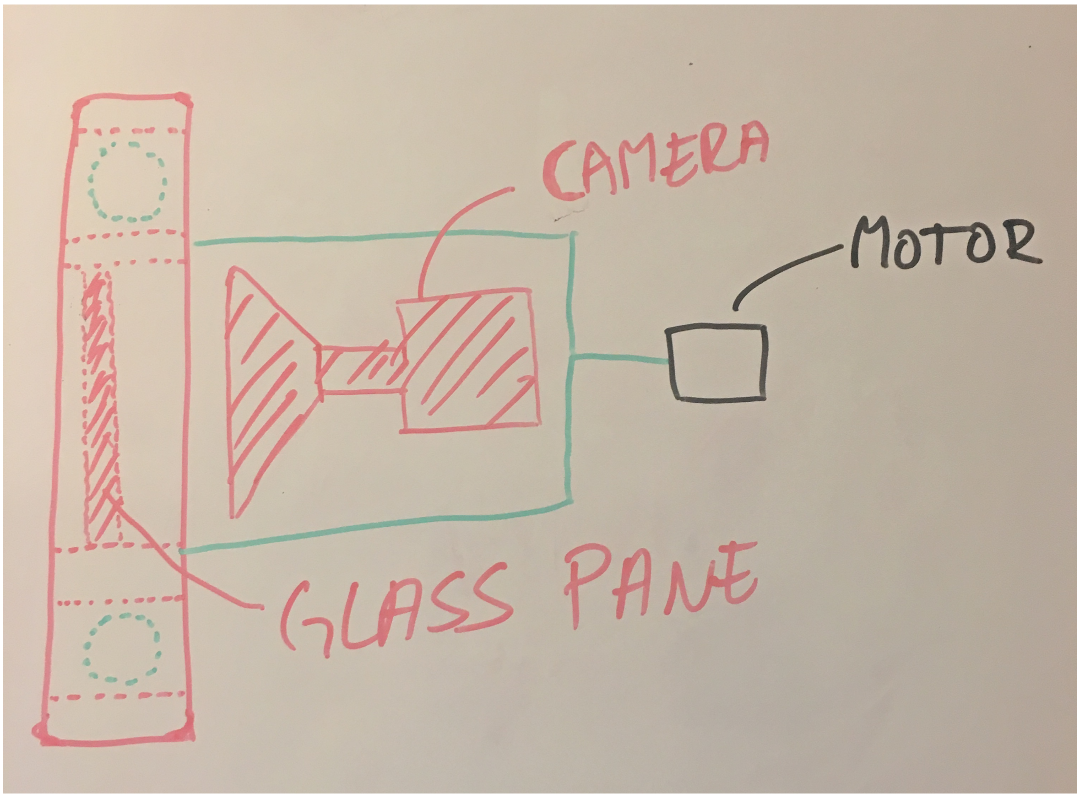

FIGURE 2.4: Sketch of concept RG1.1

Cogs - RG2.1 This concept uses cogs on the inner wheel and a small electrical motor to rotate the glass. This is done by fitting a cog wheel to the drive shaft of the small electrical motor that drives the inner ring of the ball bearing using the cogs attached on the ring.

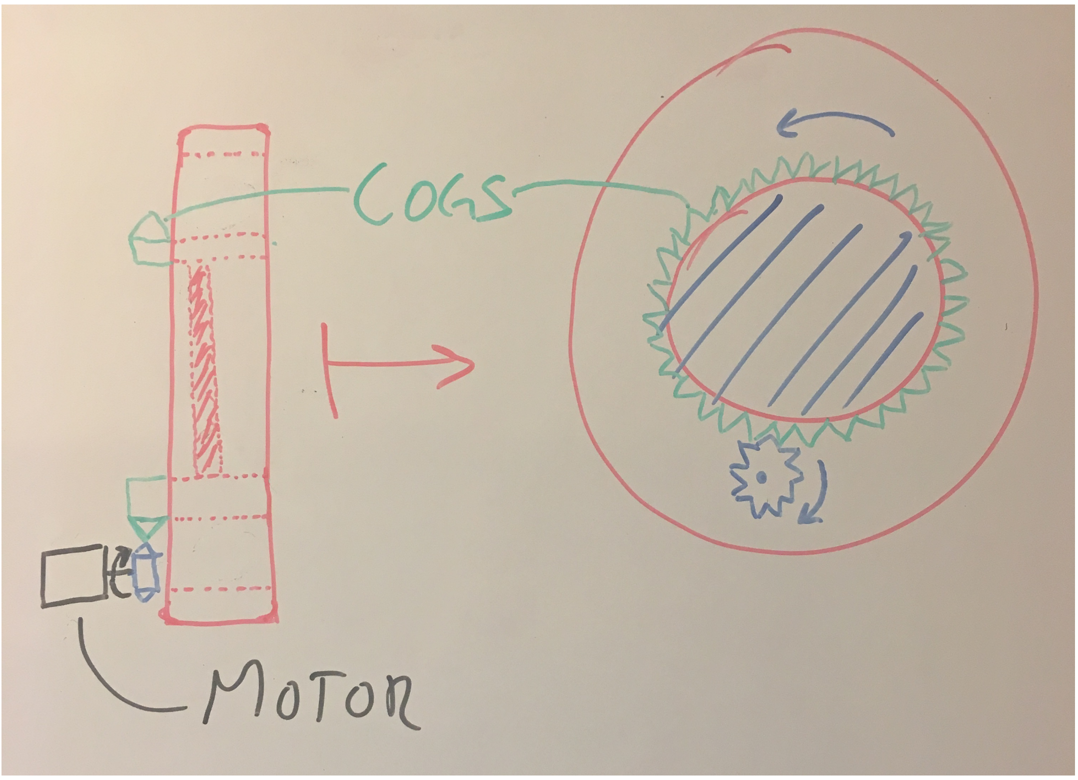

FIGURE 2.5: Sketch of concept RG2.1

Cogs with drive shaft - RG2.2 This concept is very similar to the *Cogs - RG2.1* concept above, but with one modification, the motor is now placed behind the camera and the power is transfered using a long drive shaft. This is for cameras that have a limited amount of space close to the glass, but have more space in the back of the camera house.

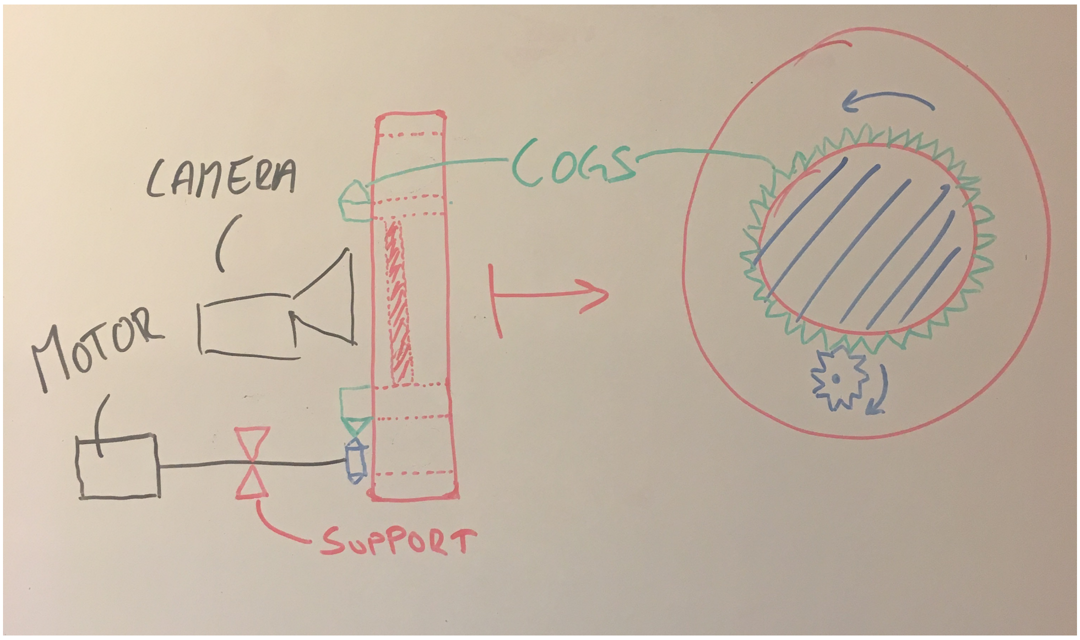

FIGURE 2.6: Sketch of concept RG2.2

Magnetic coils - RG3.1 This is a concept that is derived from the thought of not having space to place the motor. This concept transforms the ball bearing into an actual electrical motor. Instead of driving the inner ring of the ball bearing using an electrical motor, coils are installed into the ball bearing that work as a stator in an electrical motor and the inner ring becomes the rotor and starts to rotate. Basically replacing the inner shaft with a protective glass in Figure 2.8.

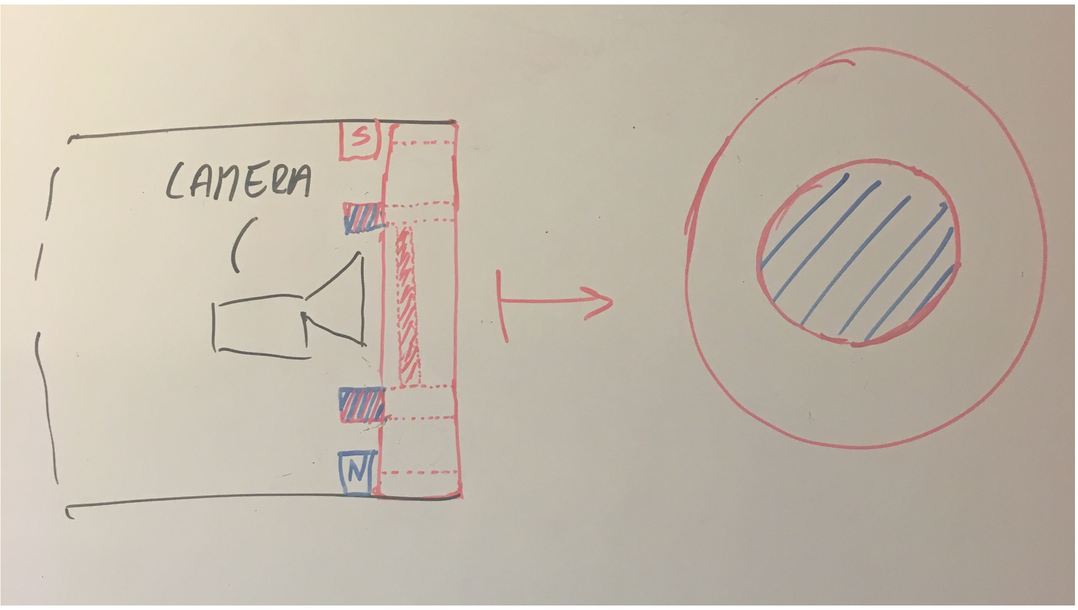

FIGURE 2.7: Sketch of concept RG3.1

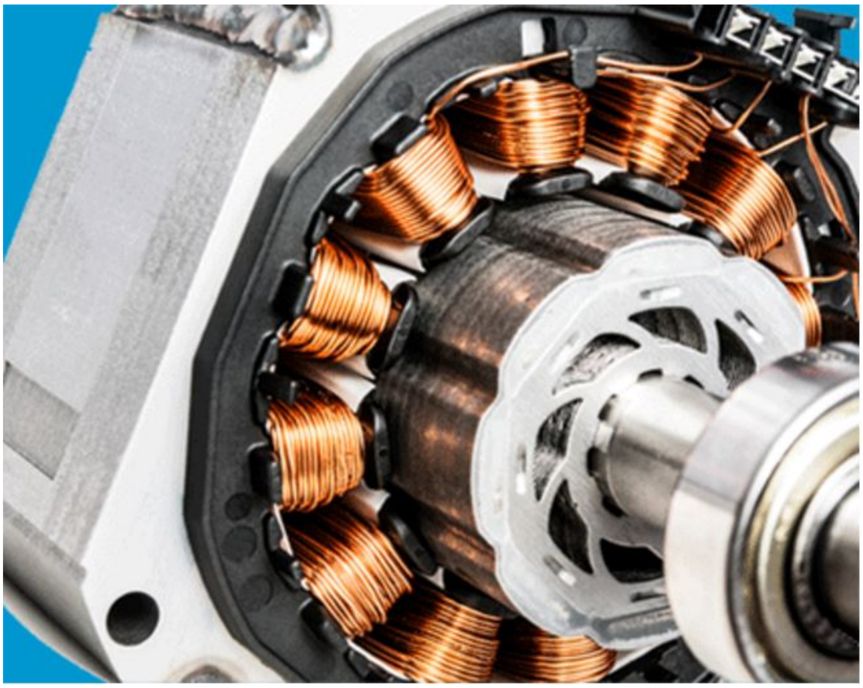

FIGURE 2.8: Image of an electrical motor

Vibration

The general idea of this main concept is vibrating the protective glass so that the water drops fall off. The main parts to investigate for the following concepts is how to keep it water tight, how to vibrate the glass and how the amplitude and the frequency are individually affecting the water drops.

Motor with Magnet - V1.1 The idea of this concept is having a rotating DC-Motor with an attached magnet. Also a magnet is attached to the protective glass. As the DC-motor rotates the magnets repel and attract each other, making the protective glass vibrate.

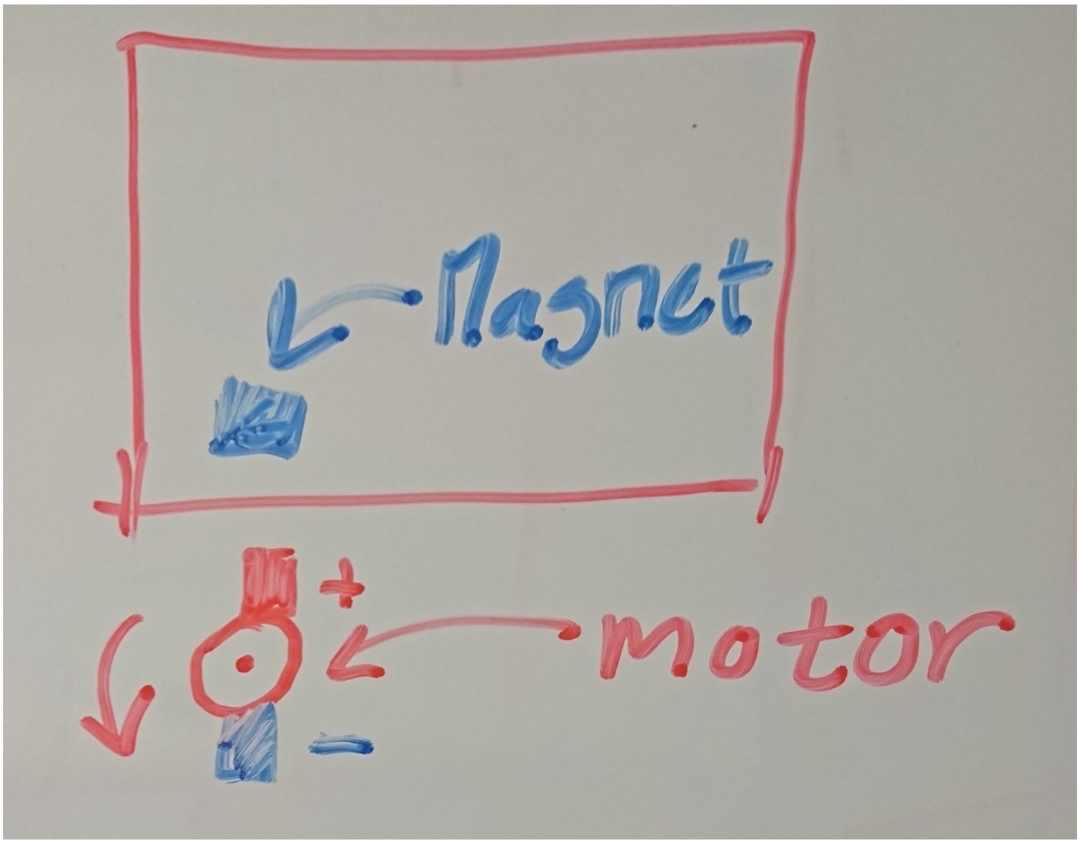

FIGURE 2.9: Sketch of Concept V1.1

Motor with Shaft V1.2 The idea of this concept is having a rotating DC-Motor with an attached crankshaft. The crankshaft is also attached to the protective glass with a connecting rod, whereas the motor rotates, the protective glass starts to vibrate

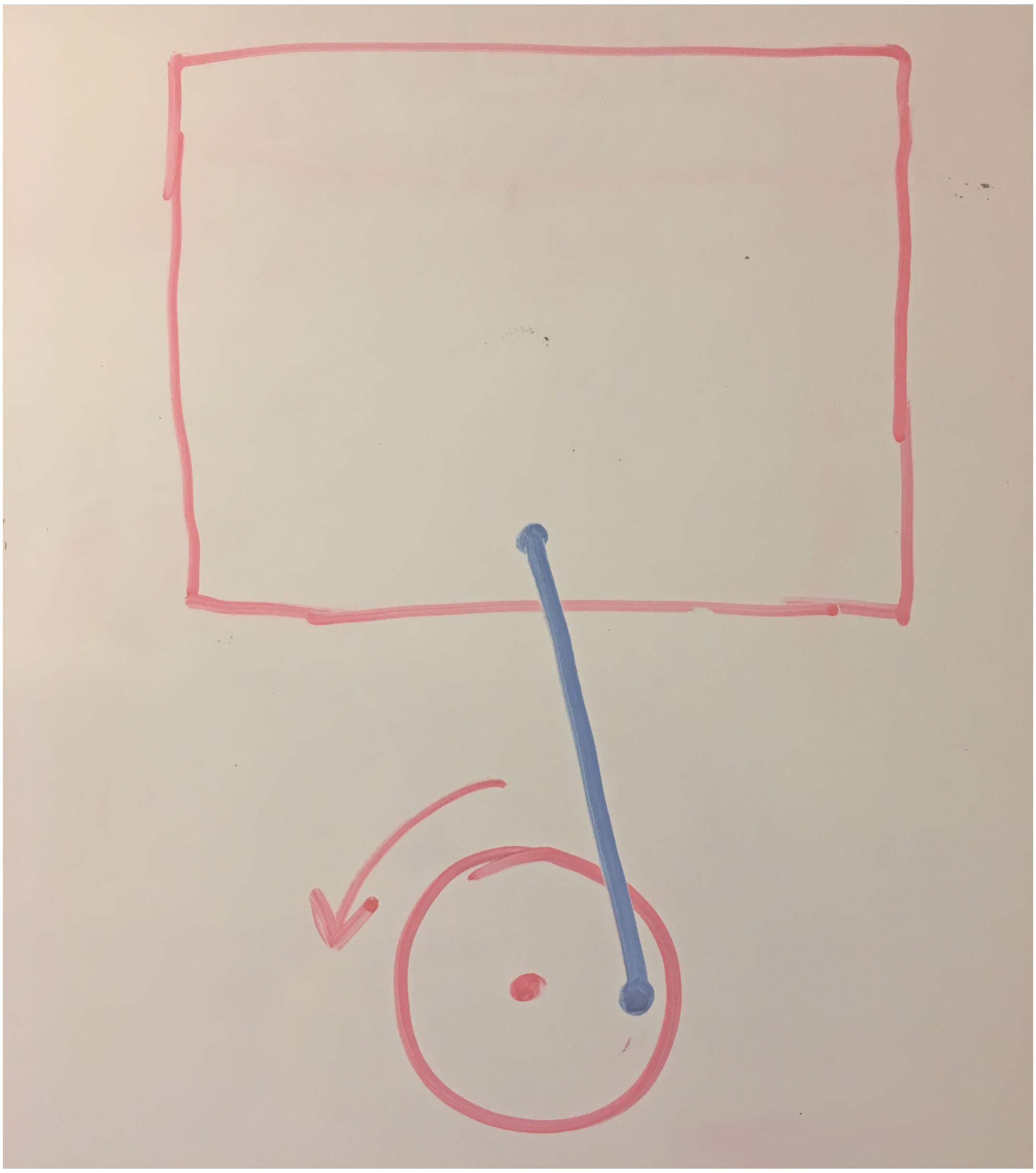

FIGURE 2.10: Sketch of Concept V1.2

Electromagnets as horseshoes V2.1 The idea of this concept is having two or four electromagnets around the protective glass. By giving them power with a certain algorithm, the protective can be vibrated in a chosen pattern. It can also be oscillated, which can be very interesting when removing the water drops.

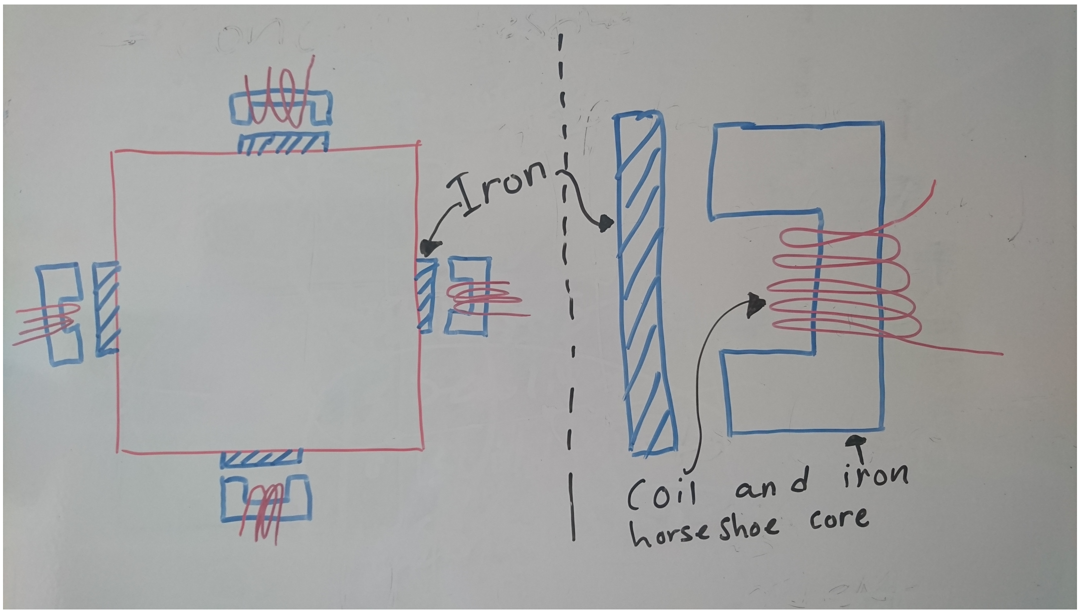

FIGURE 2.11: Sketch of Concept V2.1

Electromagnet as a Coil V2.2 This concepts is based on the idea of using coils and alternate current, for example 50 Hz. As can be seen in Figure 2.12 below, by alternating the current the electromagnets will change between positive and negative and this will make the protective glass vibrate because of the permanent magnets that are attached to it.

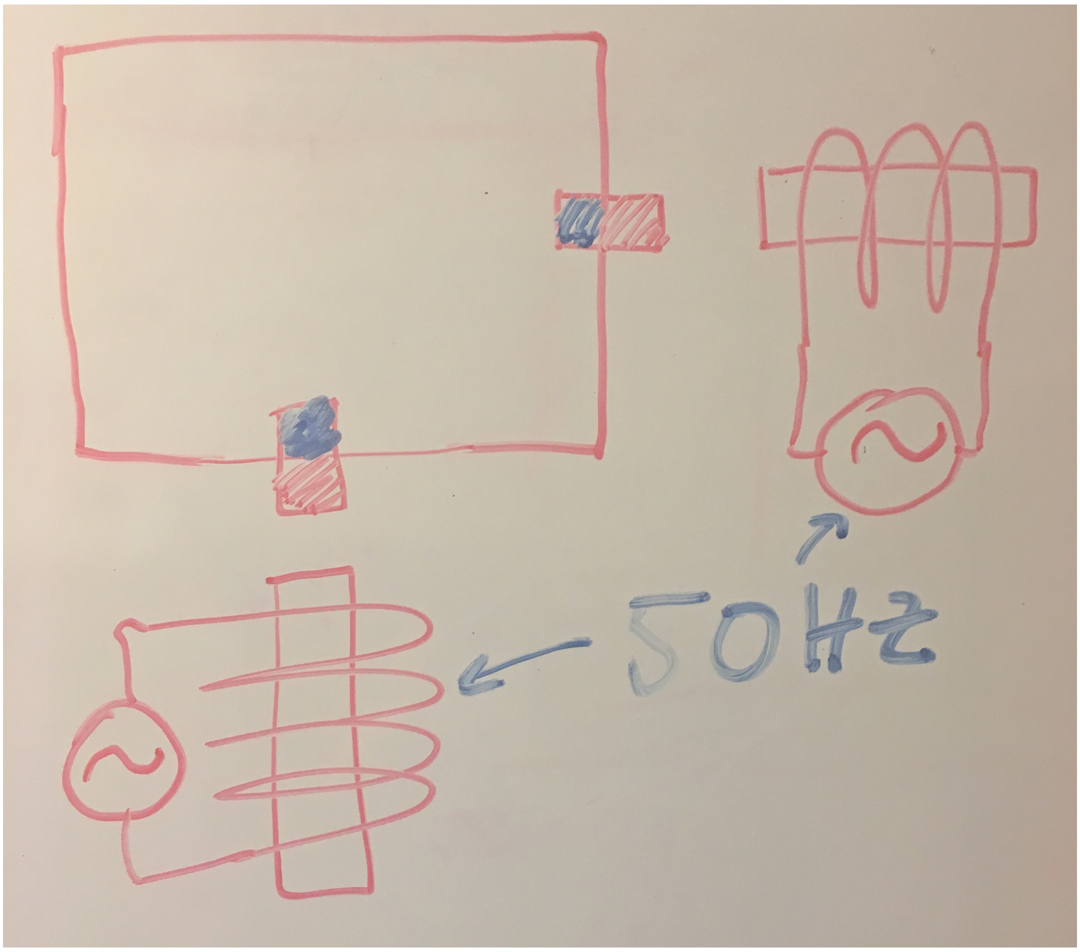

FIGURE 2.12: Sketch of Concept V2.2

Electromagnet as a Coil V2.3 This concept is similar to *Electromagnet as a Coil V2.2*, but instead of having permanent magnets on the protective glass there is one attached to the glass with a shaft. The magnet is surrounded by a coil that shifts polarity with alternating current, applying an alternating force on the permanent magnet. This will make the protective glass vibrate.

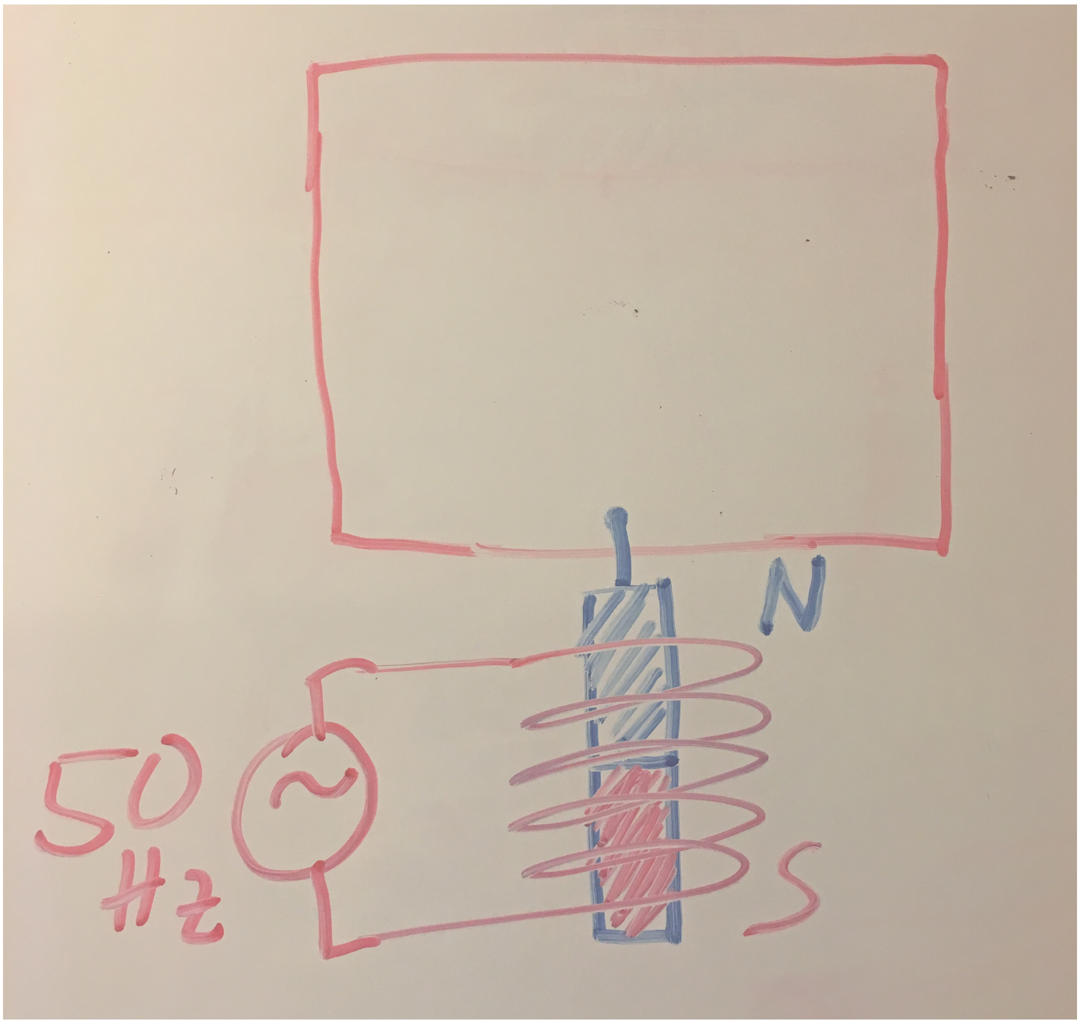

FIGURE 2.13: Sketch of Concept V2.3

Electromagnet as a horseshoe with Springs V2.4 What differentiates this concept compared to V2.1 is the two springs instead of using another electromagnet. The protective glass is pulled up by the springs and then pulled down by the electromagnet.

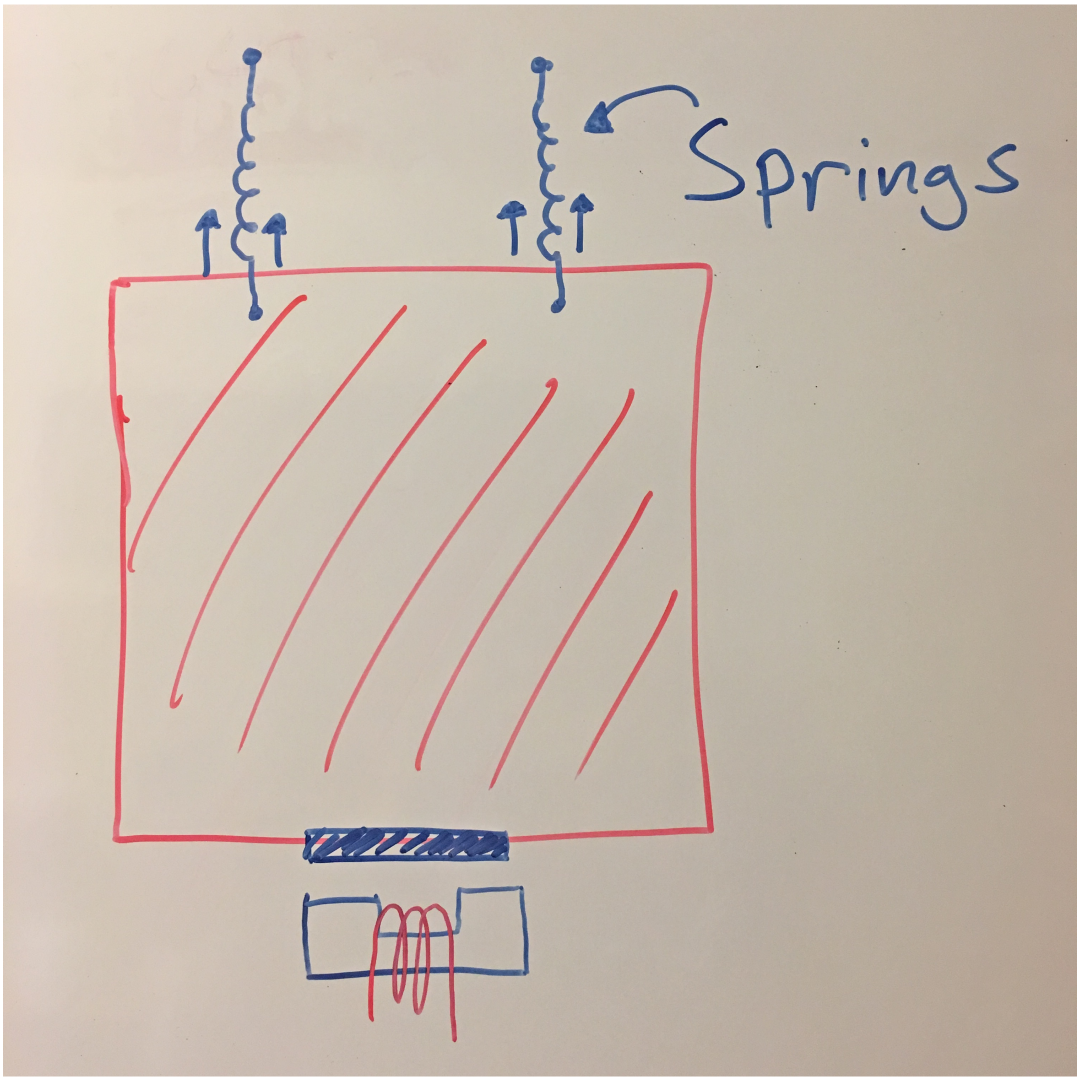

FIGURE 2.14: Sketch of Concept V2.4

Impulse

The basic idea of this concept is to push the protective glass upwards slowly and letting the springs pull the protective glass downwards, really fast, until it hits the rubber stops and the water drops fall downwards.

Mechanic Impulse I1.1 This concept is built on the idea of a camshaft, that pushes the protective glass upwards and finally the protective glass is pulled downwards, fast by the springs, until it hits the rubber stops. A sketch of the concept can be found below in Figure 2.15.

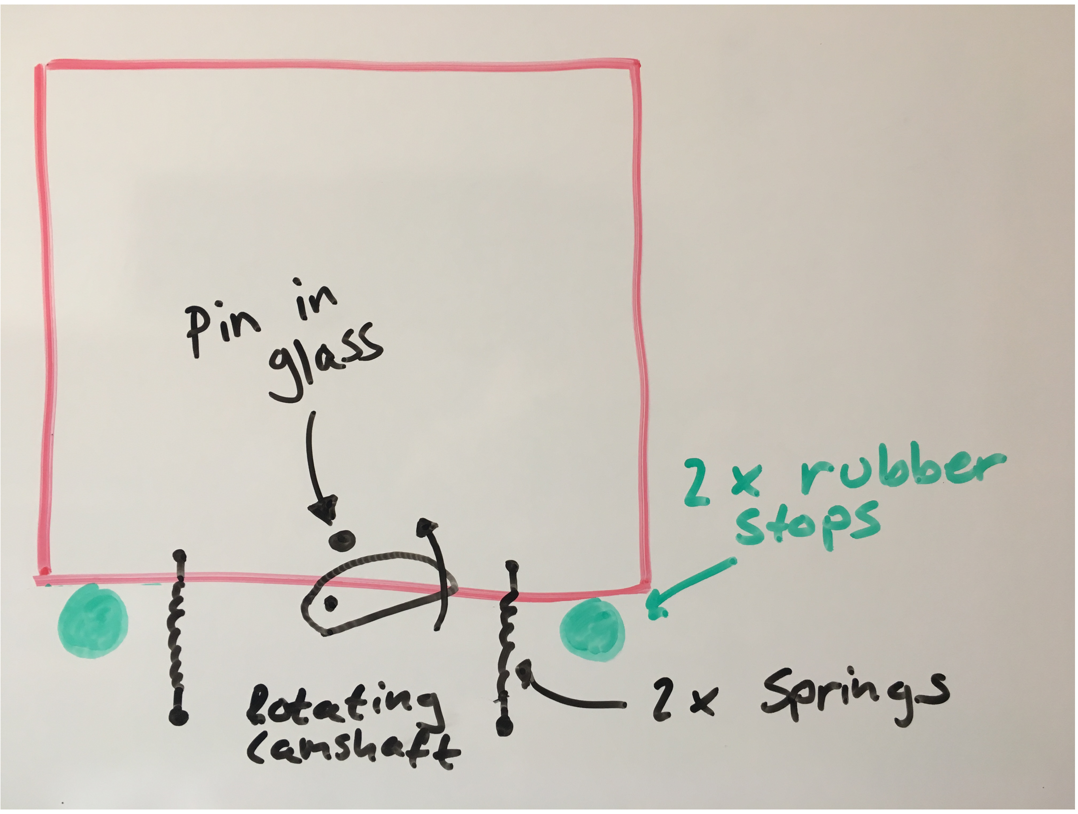

FIGURE 2.15: Sketch of Concept I1.1

Electromagnetic Impulse I1.2 This concept is built on the idea of an electromagnet and a small piece of steel on the top of the protective glass, that pulls the protective glass upwards slowly and then releases the force. Finally the protective glass is pulled downwards, fast by the springs, until it hits the rubber stops. A sketch of the concept can be found below in Figure 2.16.

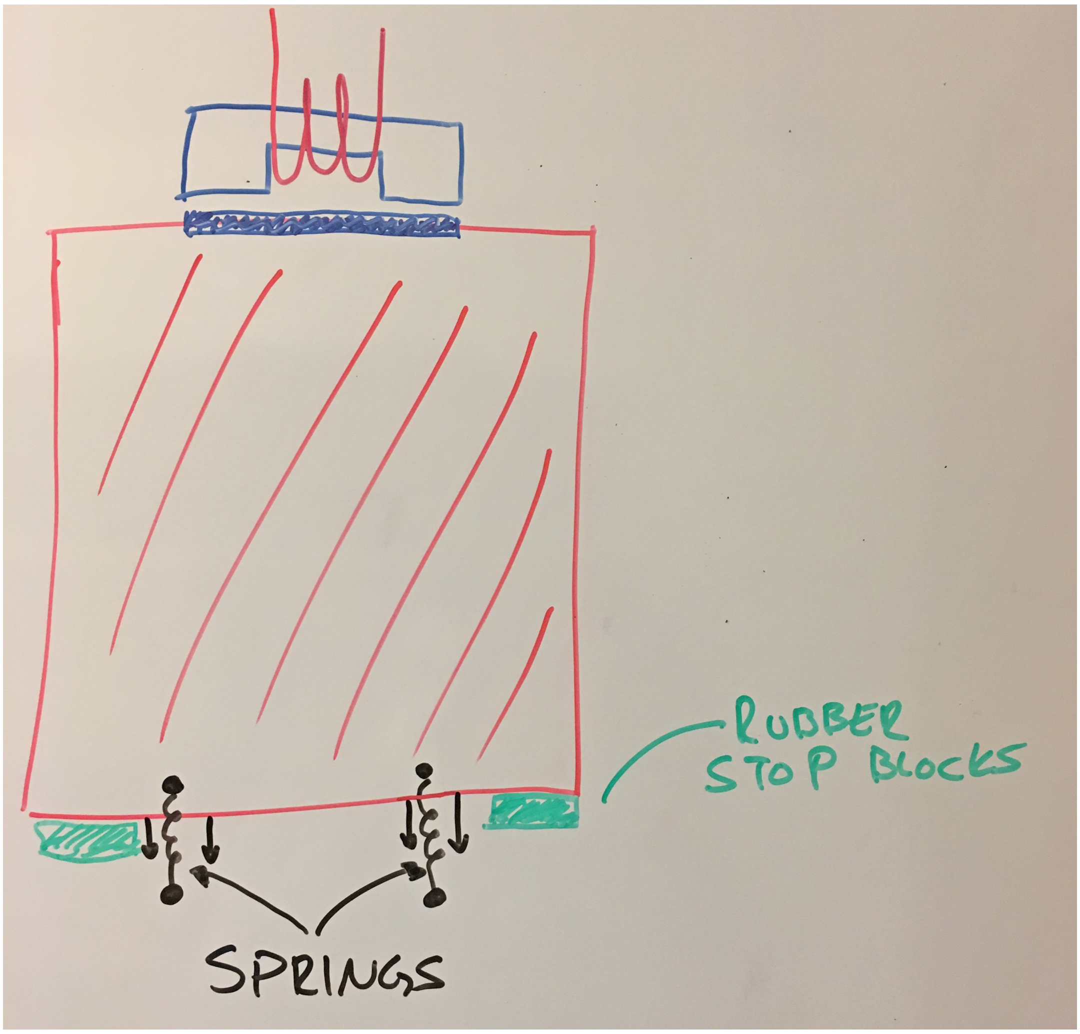

FIGURE 2.16: Sketch of Concept I1.2

Plastic Film

The idea of the plastic film was inspired by disposable visors that were mentioned in *subsection 2.6.2*. The idea is as simple as removing the most outer layer in front of the protective glass. From this idea two concepts were generated.

Cleaning Plastic Film PF1.1 With this concept there is a plastic film in front of the protective glass that rotates when the film is in the need of cleaning. The film goes through a simple "cleaning process" inside or outside the camera house. The cleaning process itself is not specified in this early stage of the concept development. A sketch of the concept can be found below in Figure 2.17.

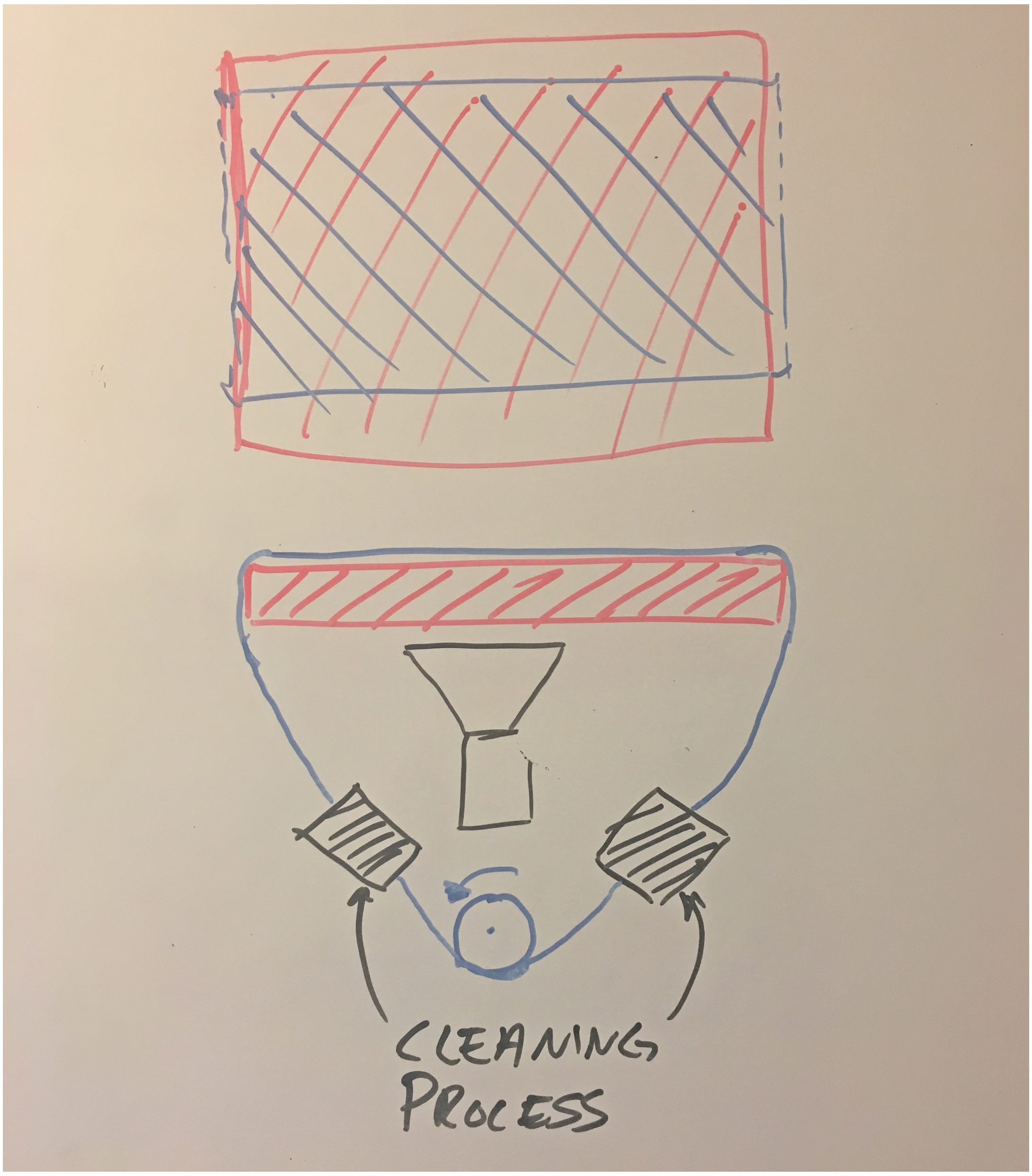

FIGURE 2.17: Sketch of Concept PF1.1

Cleaning Plastic Film PF1.2 This concept is quite similar to concept *Cleaning Plastic Film PF1.1*, but instead of having a plastic film going through a cleaning process there is a film dispenser on each side. The film dispenser needs to be changed when all the film is used. A sketch of the concept can be found below in Figure 2.18.

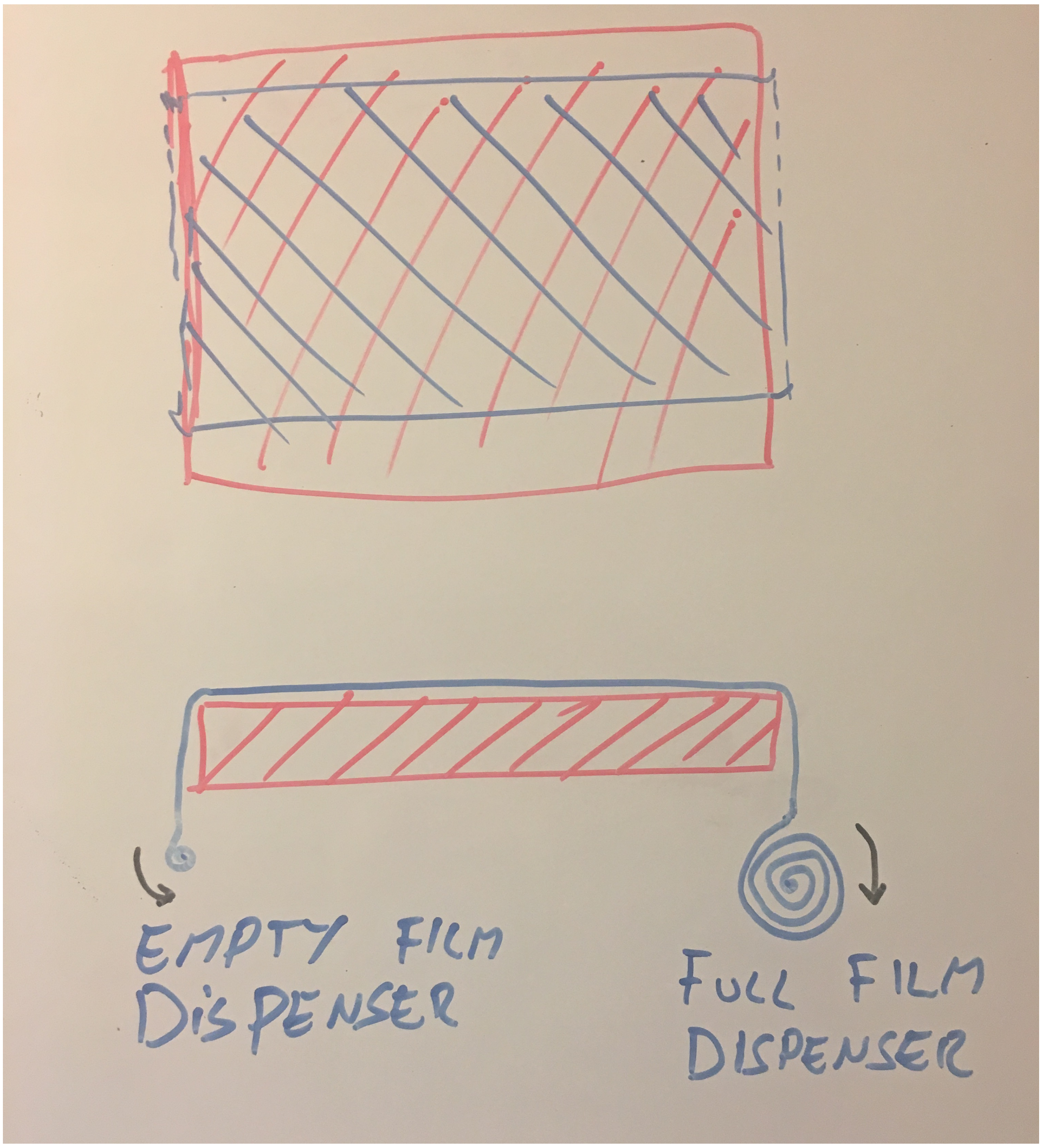

FIGURE 2.18: Sketch of Concept PF1.2

Compressed Air

Two concepts were generated with compressed air. The point of these concepts is to expose the water drops to streams of compressed air that effectively removes the water drops from the protective glass.

Compressed Air CA1.1 In this concept there is a compressor, an air tank and a valve behind the protective glass. On the top there is a nozzle that spreads the compressed air. The idea is to blow away the water drops from the protective glass. A sketch of the concept can be found below in Figure 2.19.

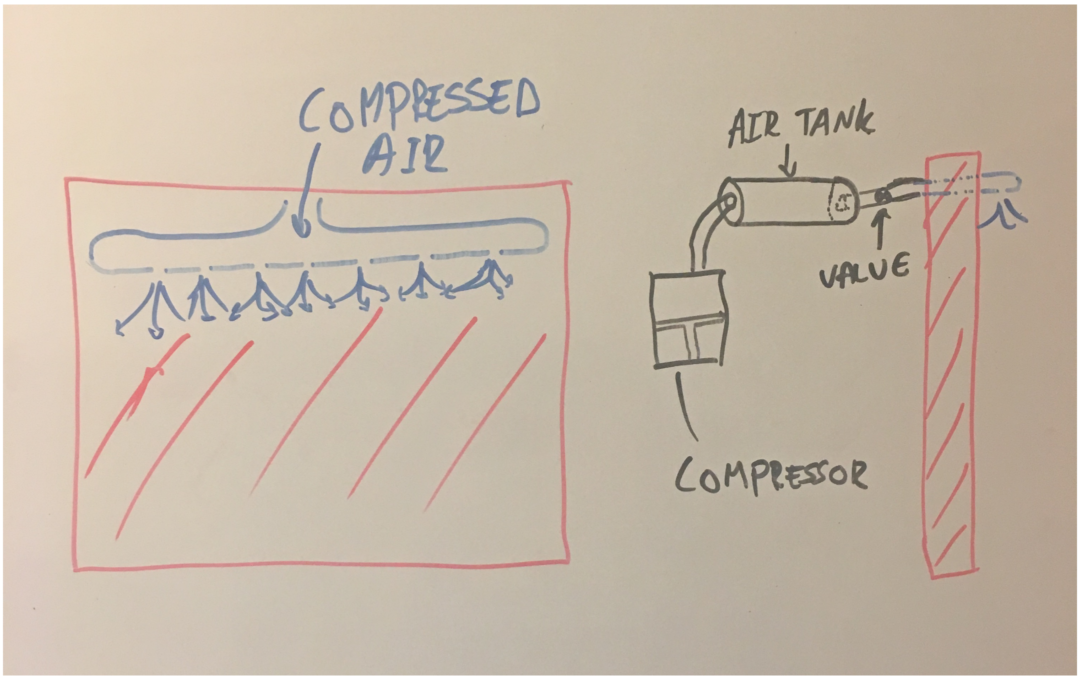

FIGURE 2.19: Sketch of Concept CA1.1

Compressed Air CA1.2 In this concept there is a compressor, an air tank and a valve behind the protective glass. There is a nozzle that spreads the compressed air. The idea is to blow away the water drops from the protective glass. What differentiates this concept from *Compressed Air CA1.1* is that the nozzle is attached to a pivoting shaft. This would work as a wind shield wiper, but with air instead of a conventional rubber wiper blade. A sketch of the concept can be found in Figure 2.20 below.

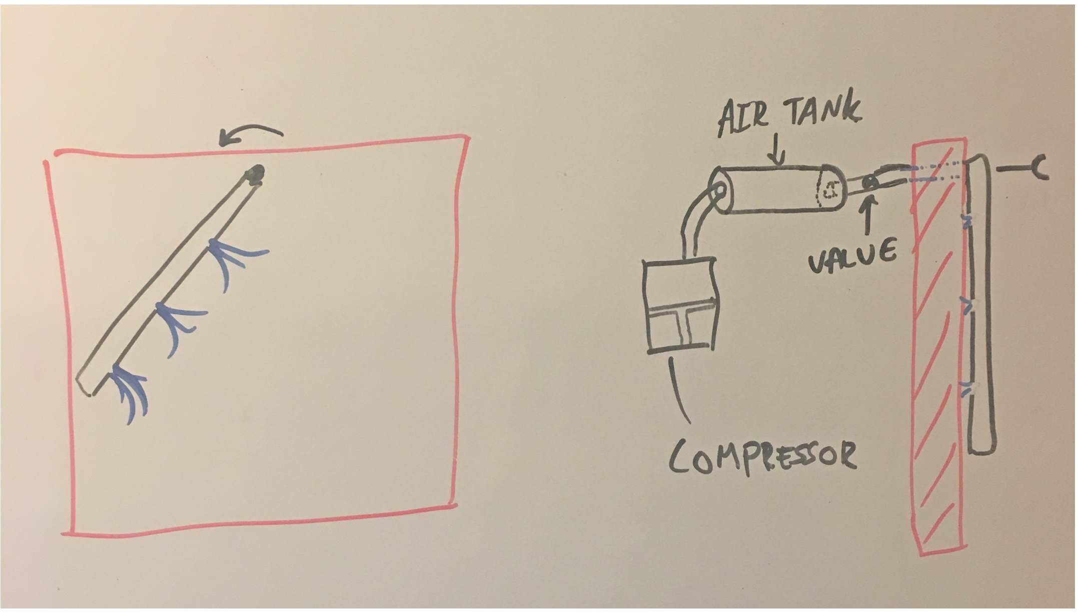

FIGURE 2.20: Sketch of Concept CA1.2

2.7 Concept Selection

With all the concepts generated, a selection of what concepts to move forward with needed to be done. The first part was deciding the main concept between; *Rotating Glass, Vibration, Impulse, Plastic Film and Compressed Air*. Since Axis Communications already had a department working on similar concepts to *Compressed Air CA1.1* and *Compressed Air CA1.2*, these were immediately removed. The Plastic Film concepts were discussed internally with supervisors at Axis Communications and were seen as concepts with too many problems to build a prototype of. Our supervisor also considered the concepts to be less sustainable compared to what was required of the product. This was something that was taken into account and agreed on. Therefore the project continued with three main concepts; *Rotating Glass, Vibration* and *Impulse*.

2.8 Further Evaluation

An important part of this project was the testing of the different concepts. After the concept selection, the three chosen main concepts were built into simple prototypes. The next chapter, *Concept Evaluation*, will give information regarding testing the concepts, how the tests were built and why they were built this way.

The grading of the three remaining concepts were based on the five criterion shown in Table 2.4 below.

TABLE 2.4: Table of the first concept screening

Metric/Concept	Vibration	Rotation	Impulse	Compressed air	Plastic film
Water removal	*Chosen for further testing*			*Removed*	
Energy consumption					
Sealing possibilities					
Image quality while cleaning					
Maintenance					
TOTAL	N/A	N/A	N/A	N/A	N/A

Chapter 3

Concept Evaluation

Before the testing phase there were mostly guesses and external/internal research that decided whether a concept would be interesting enough to be continued within the concept development.

Three main concepts were chosen, *Rotating Glass, Vibrations* and *Impulse*. The main idea of this part of the development was to truly understand each concept and how it affects water drops on the protective glass. The goal was to receive objective data regarding the concepts ability to clean the protective glass from water drops. Basically taking a completely clean picture behind the protective glass, then covering the protective glass with water drops, running one of the concepts and taking another picture behind the protective glass. Finally comparing these two pictures to receive data of the concept's ability to clean the protective glass from water drops.

The first step was to do a screening of the three concepts. This was an attempt to sort out concepts that did not work as good as intended or that used too much power before going forward into more thorough testing.

3.1 Testing Rotating Glass

The rig was modified for testing the concept *Rotating Glass* found in *section 2.6.4*.

3.1.1 Settings

The first setup was really simple and was only used for receiving data regarding the speed (rpm) that was necessary for removing the water from the protective glass. A picture for the first setup can be found below in Figure 3.1.

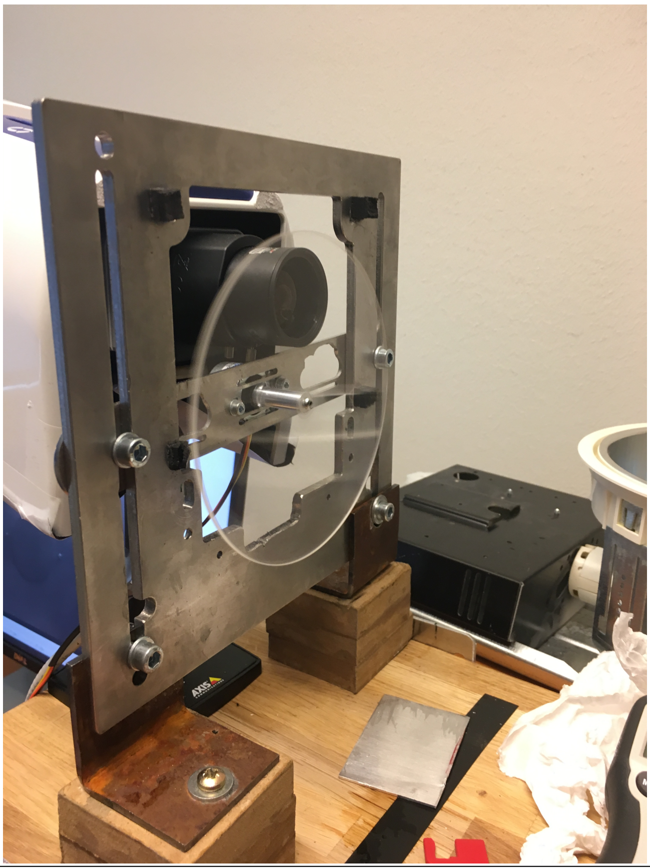

FIGURE 3.1: The first test rig for the concept rotating glass

The second setup was a little bit more complex. It was designed to understand how the speed and the needed power were effected by each other, while still keeping the rotating glass water proof. This setup was inspired by concept *Cogs - RG2.1* found in *section 2.6.4*. A ball bearing was attached with its outer ring to a steel frame. The protective glass was attached to the inner ring of the ball bearing. A cogwheel was attached on the back of the inner ring and driven by a smaller cogwheel that was connected to a stepper motor. A picture of the front and the back of the setup can be found in Figure 3.2.

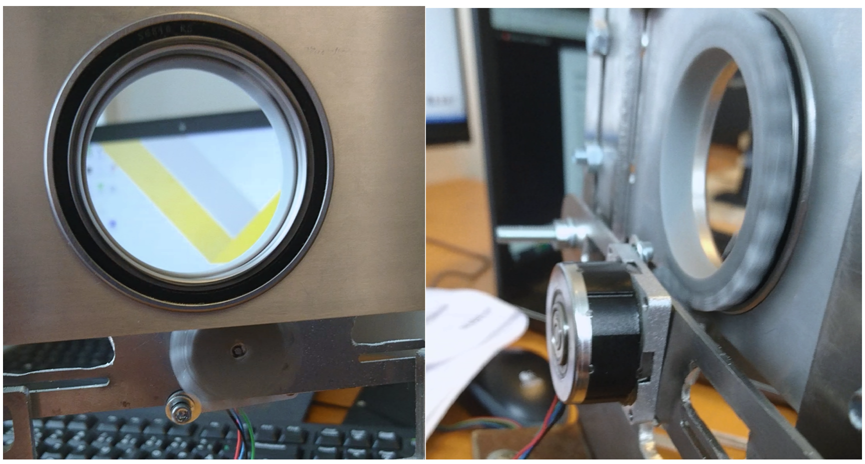

FIGURE 3.2: The second test rig for the concept rotating glass

3.1.2 Problems

With the first setup there were no particular problems, but as mentioned earlier it was a simple setup. The second setup had to much friction in the ball bearing. The ball bearing was of the type "Rubber Sealed", meaning that it was sealed for moisture and water drops. This was necessary for the final prototype, but generated to much friction and the protective glass wasn't able to reach the needed speed. Even with this type of ball bearing it would have been difficult to fully seal the ball bearing and for the final prototype a radial shaft seal would also be needed.

3.1.3 Results

The first setup indicated that the needed speed was around 1000 rpm for removing the water drops. With a speed of 1500 rpm the protective glass was perfectly clean. The second setup showed that this was not possible with a Rubber Sealed ball bearing, because there was too much friction. The stepper motor that was available, was only able to run the protective glass at a speed of 600-700 rpm until it started to stall. When a stronger DC-motor was introduced, the protective glass could be accelerated to 1500 rpm. The power needed to run the ball bearing at this speed was about 15 W. With the limitations of this product development, this concept would unfortunately not be possible. The concept is possible though, with more power delivered to the camera.

3.2 Testing Impulse

The rig was modified for testing the concept *Impulse* found in *section 2.6.4*.

3.2.1 Settings

The test rig was built of a protective glass pane suspended by elastic rubber mounts. A screw was mounted at the bottom of the glass. A motor was attached to the test rig underneath the glass and on the motor shaft a camshaft was attached. The camshaft lifts the glass pane upwards, and after about $\frac{1}{2}$ revolution of the camshaft, the glass pane is pulled down by two loaded springs. The glass stops abruptly by two rubber stops to produce a high impulse.

The test was conducted by letting the motor shaft rotate at 1 Hz and lifting the glass 2 mm up before rapidly letting it go down and collide with the rubber stops. The test went on for 10 seconds.

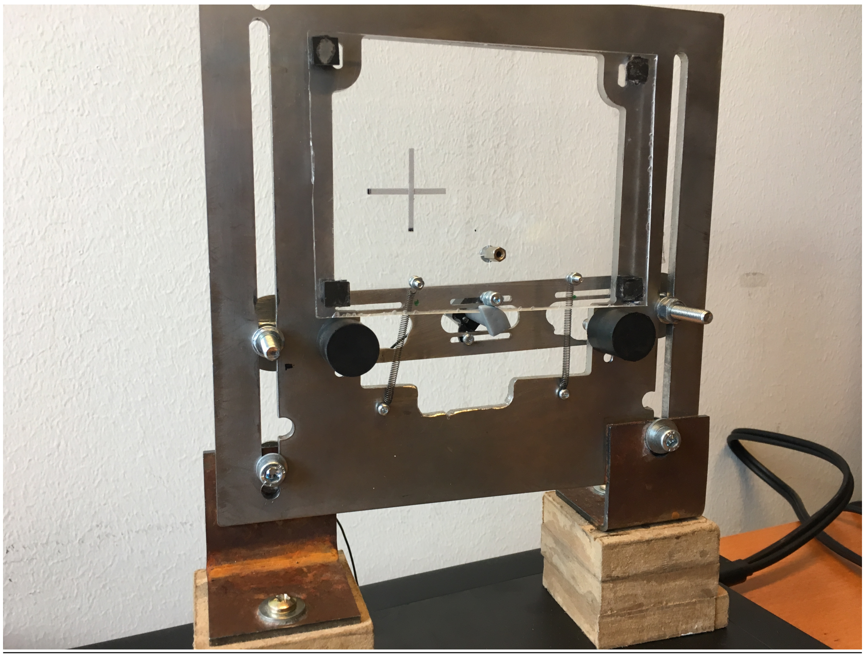

FIGURE 3.3: The test rig for the concept impulse

3.2.2 Problems

It turned out to be difficult to acquire enough impulse without having to increase the amplitude too much. By using stiffer springs, the downward force was increased, but this introduced problems with mechanical stability for the motor and drive shaft which limited the possible amplitude. To succeed with this design, a large amplitude and a high downward force was required. Unfortunately this was not possible to achieve, given the limitations of the project.

Due to the high torque needed to overcome the springs and to lift the glass, the motor had to operate with a gearbox with high gearing ratio. Our motor had a ratio of 1:280 which produced a large torque, but with a greatly reduced speed. To be able to reach higher frequencies, a stronger motor is required.

3.2.3 Results

The results of the impulse tests were disappointing. The water drops hardly moved on the protective glass and it was difficult to compare the results to the vibration tests. This concept turned out to be harder than anticipated to succeed with. Due to the high forces and torques generated from the springs, large deflections of the motor shaft and motor bracket were experienced. To be able to test this concept more thoroughly, more time and resources is needed.

3.3 Testing Vibrations

The test rig was modified for testing vibrations, the setup was inspired by concept *Motor with Shaft V1.2* found in *section 2.6.4*.

3.3.1 Settings

The protective glass was attached in the same way as in *Testing Impulse*, but the springs and rubber stops were removed and replaced by a shaft and wheel. This made it possible to change frequency and amplitude. For this first screening a fixed frequency of 50Hz and an amplitude of 1.5 mm was used.

3.3.2 Problems

There were no major problems with this solution.

3.3.3 Results

The results of the vibration screening tests were that the performance of the water removal was good. The drops started to move as intended. The power usage was low (5-10 W). This concept had potential to actually succeed in removing the water with low power consumption. To further investigate and optimize the vibration concepts, further tests had to be performed. These are explained in Section *3.5 - Optimizing vibrations* below.

3.4 Evaluation of concept screening

In Table 3.1 below are the results from the screening of the concepts. The different metrics were scored from 1 to 3 accordingly:

- **Water removal** - This metric was subjectively evaluated by looking at the protective glass after the cleaning process.
- **Energy consumption** - This metric was measured during the cleaning process.
- **Sealing possibilities** - This metric was subjectively determined.
- **Image quality while cleaning** - This metric was subjectively evaluated by looking at the footage from the network camera during the cleaning process.
- **Maintenance** - This metric was not measured since it is too early in the process to determine.

TABLE 3.1: Final evaluation of concepts. The concepts are graded from 1 to 3 points, where 1 is worst and 3 is best.

Metric/Concept	Vibration	Rotation	Impulse	Compressed air	Plastic film
Water removal	2	3	1	*Removed*	*Removed*
Energy consumption	2	1	3	*Removed*	*Removed*
Sealing possibilities	3	1	2	*Removed*	*Removed*
Image quality while cleaning	2	3	2	*Removed*	*Removed*
Maintenance	?	?	?	*Removed*	*Removed*
TOTAL	**9**	**8**	**8**	**N/A**	**N/A**

The vibration concept was chosen as the main concept to continue with. To be able to optimize this concept, a series of tests had to be performed. These are explained more thoroughly in *Section 3.5 - Optimizing vibrations* below.

3.5 Optimizing vibrations

3.5.1 Setting up the test

Setting up the test required some iterative thinking and simple tests were performed along the way until the test rig was finally set up. Some of the solutions were impossible to use due to light reflections or other mechanical obstacles such as DC-motors where the speed varied with temperature. This made it necessary to iteratively build the test rig and perform pre-tests along the way until a usable solution was found.

In this section the building of the rig, evaluation of results, test conditions and test procedure are explained.

3.5.2 Building the rig

Before the testing of the different settings could begin, a standardized test rig had to be built. This was to ensure the quality of the tests. The most important feature of the test rig was to build a test environment that was as similar as possible between all the performed tests.

It was important to make the test rig modular to be able to test more than one set of settings (amplitude, frequency & distance) on the same rig. This was partly to minimize the time and resources spent on building multiple test rigs, but mainly to achieve as comparable results as possible. This meant the rig had to be customizable enough to allow different tests to be performed on the same rig, but at the same time fixed enough so that the results of the different tests were comparable.

A test rig was built on a thick and sturdy wooden platform on which the camera was mounted securely with three screws. To be able to have a clean and uniform background for the camera to focus on, a metal screen was attached to the end of the wooden platform. This meant the camera and screen were now mounted at a distance of 470 mm to each other, this was necessary when comparing different tests. See Figure 3.4.

One of the criterion of the test rig was to be able to film the vibration prototype with a high speed camera to determine the amplitude of the test. This was achieved by creating a hole in the back screen of the test rig where the lens of the high speed camera could fit. The use of the high speed camera is further explained in the following sections. For the color and texture of the back screen, three different concepts were tested and evaluated. Eventually a matte black color was chosen. The choice of background is further explained in *subsection 3.5.5 - Evaluating the results*.

The actual concept module was then placed in front of the camera lens at a fixed distance of 10 mm. This is a standard distance which is used in a wide range of Axis products.

To simulate rain drops on the protective glass, a spray flask was used. To be able to get as exact conditions as possible between different tests, a small platform was built for the flask. This ensured that the flask was at the same height and distance to the screen in all tests. The platform was built in a way that the flask could be placed at two different distances to the protective glass. This is because the size of the drops differs depending on the distance between the screen and the flask. This is explained in more in *subsection 3.5.4 - Conditions*.

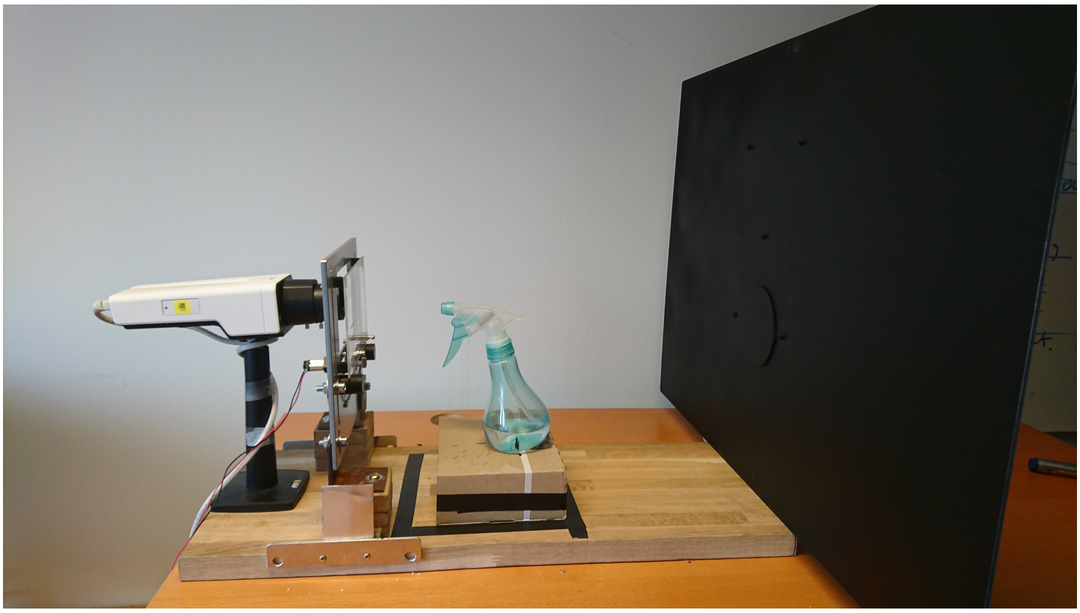

FIGURE 3.4: The test rig

3.5.3 Test procedure

To receive as objective data as possible, the test procedure had to be as standardized as possible. Test data was received from 16 different test cases. Each test case used different amplitudes and frequencies. Each case started by measuring the distance from the camera lens to the protective glass (10 mm). Then a clean picture was taken of the protective glass. A water spray flask was used to cover the protective glass in water drops, the protective glass was always sprayed once and from a fixed distance. Then the prototype ran for 10 seconds and finally a picture was taken of the protective glass. The protective glass was wiped completely clean and the procedure was repeated four more times.

After this, the distance between the spray flask and the protective glass was changed and another five pictures were taken. Why each test case needed pictures with the spray flask at different distances is further explained in *subsection 3.5.4 - Conditions*.

3.5.4 Conditions

The test conditions were important during the testing phase. Since the pictures that were taken were compared to each other, the lighting should be the same at all times. This was achieved by always taking a new clean picture before taking five pictures of that specific test.

A small temporary camera house was built. The inside of the camera house was covered in light-absorbing fabric, this was built in order to remove reflections on the protective glass and was necessary in order to achieve similarity between the tests.

Covering the protective glass with water drops was done with a water spray flask at two distances. The far distance was 80mm and the near distance was 50 mm. This was important because the different distances gave different sizes of water drops. The 80 mm distance gave smaller water drops compared to the 50 mm distance.

3.5.5 Evaluating the results

The next step was to evaluate the results from the test. For each test case there was a clean picture and five pictures where water was sprayed from 80 mm and then cleaned by vibrations. Also a clean picture and five other pictures with water sprayed from 50 mm were taken. Evaluating how much the five pictures differentiated from the clean picture was difficult, but necessary in order to evaluate metric 1 & 2 in *Table 2.3 - List of customer needs and their relative importance*. During the rig building process three different backgrounds were tested; one matte black, one with a white and black grid and one with a black velvet fabric.

The first idea was to measure the water drops with a caliper, but this didn't give any information regarding what water drops that actually interfered in the picture. The next idea was to use a grid as a background and count the number of squares that were covered in water drops for each test. Both of these ideas would have been time consuming and less objective compared with the third idea. Finally a Matlab-code was written to compare to two pictures and it was easiest to distinguish the water drops with the matte black background, therefore this background was chosen. The code used built in functions in Matlab to compare the images pixel for pixel. This resulted in a result between 0 (perfectly clean picture) and about 1800 (totally contaminated picture). The Matlab-code was run for each test picture and compared them to the clean picture taken for that specific case. Because of the objectivity and simplicity in using a Matlab-code to evaluate the results, metric no. 1 & 2 in *Table 2.3* were combined and changed into *Matlab score*.

Below are some images of how the same situation looks from three different camera angles, and also the Matlab score for each image.

The top image shows a picture of the camera from the outside. The second image is a picture taken of the exact same situation, but with the actual camera inside the camera house looking out. The third picture is generated by the Matlab algorithm. This is actually the *difference* between the current picture and a completely clean picture. This means that if a picture is completely clean, the Matlab will generate a totally black image, and the more water drops that are left on the protective glass after cleaning, the more drops will be visible in the picture generated by the Matlab algorithm.

The images below show four examples of how the outcome from a test could look like, combined with the actual score generated from the Matlab code.

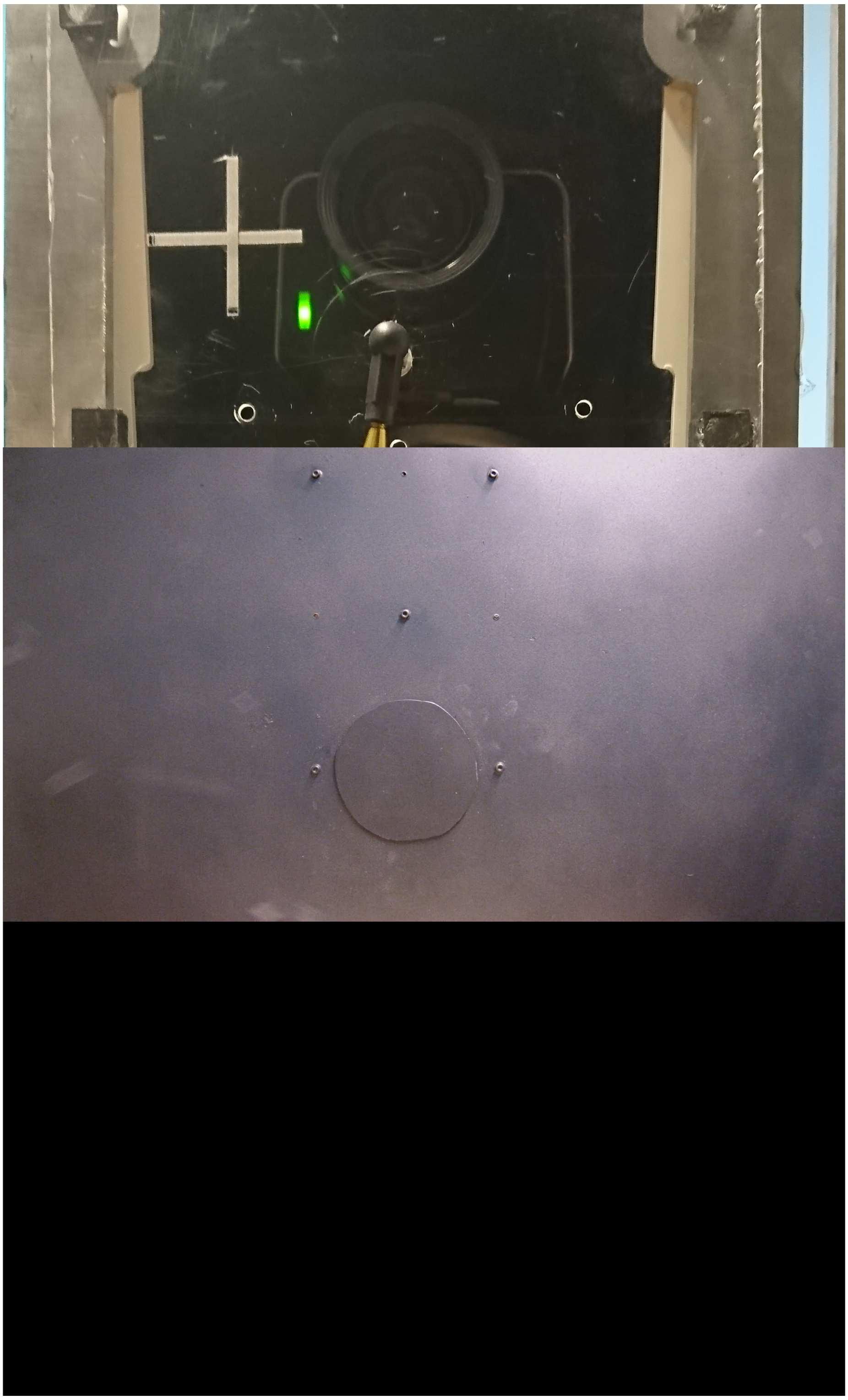

FIGURE 3.5: Image of a completely clean screen taken from in front of (top) and behind (middle) the protective glass, and a Matlab-generated image (bottom) of the difference between the image above and a completely clean image. **Matlab score = 0**.

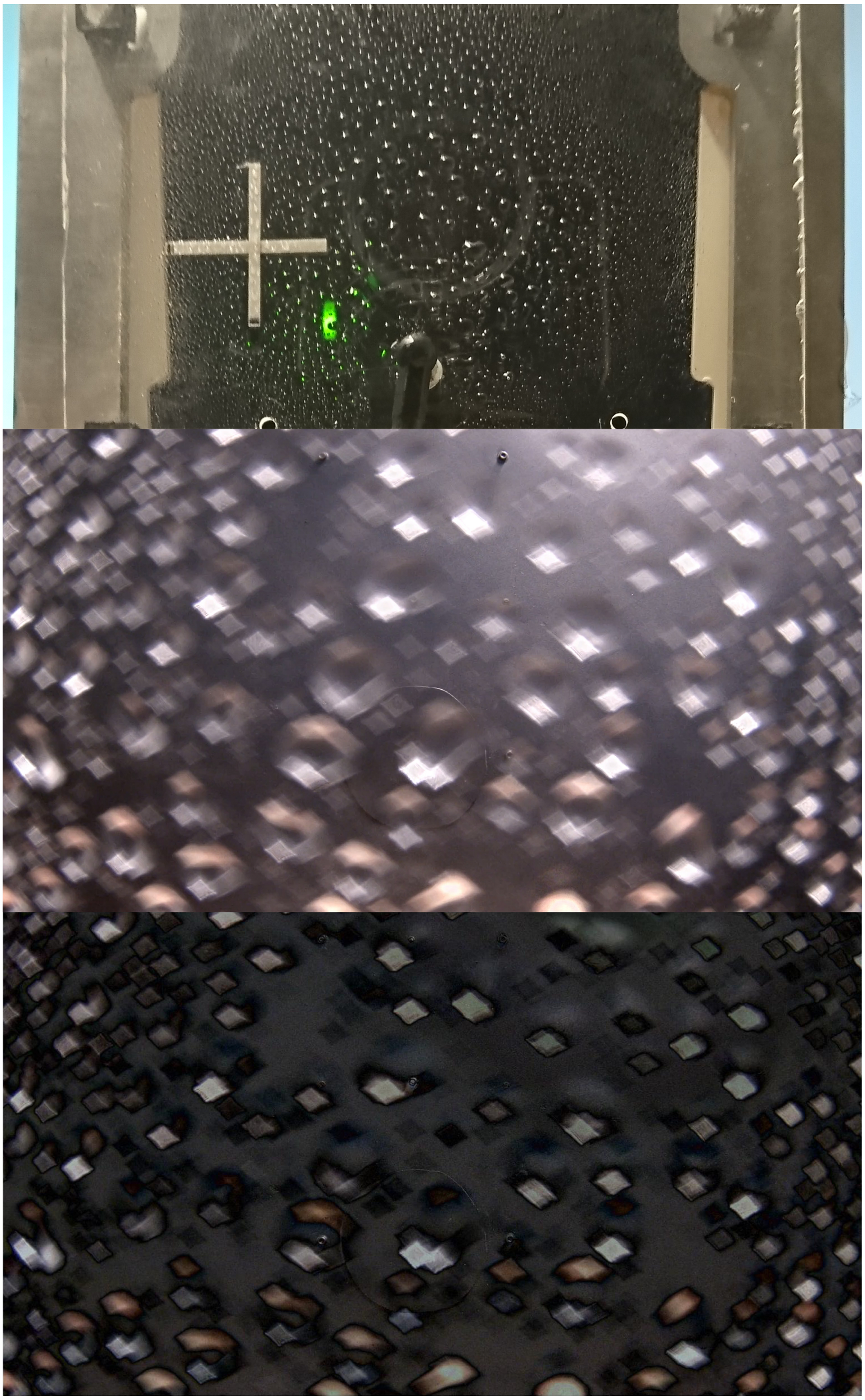

FIGURE 3.6: Image of a sprayed down screen taken from in front of (top) and behind (middle) the protective glass, and a Matlab-generated image (bottom) of the difference between the image above and a completely clean image. **Matlab score = 1747**.

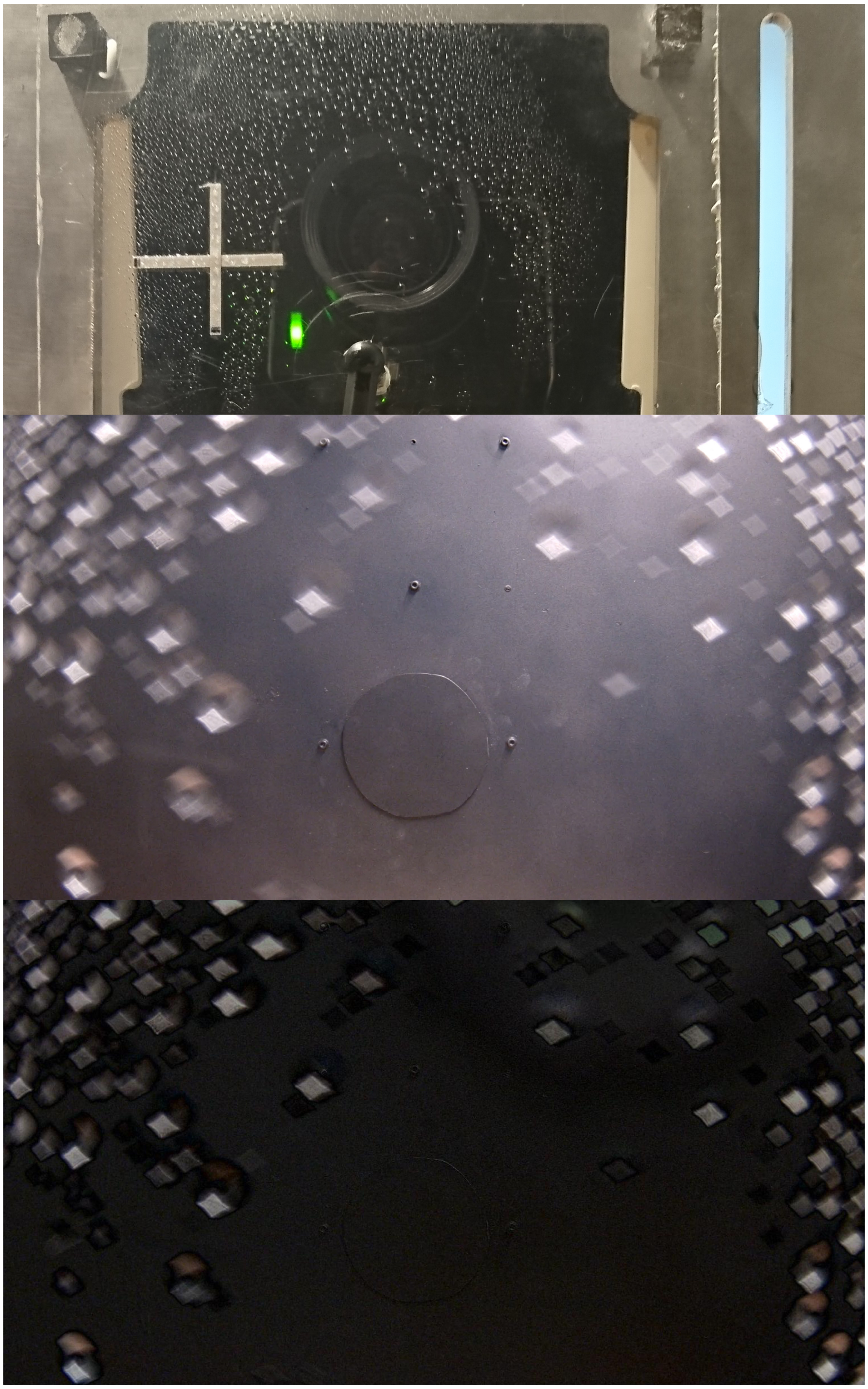

FIGURE 3.7: Image of a sprayed screen after vibration at 40 Hz taken from in front of (top) and behind (middle) the protective glass, and a Matlab-generated image (bottom) of the difference between the image above and a completely clean image. **Matlab score = 784**.

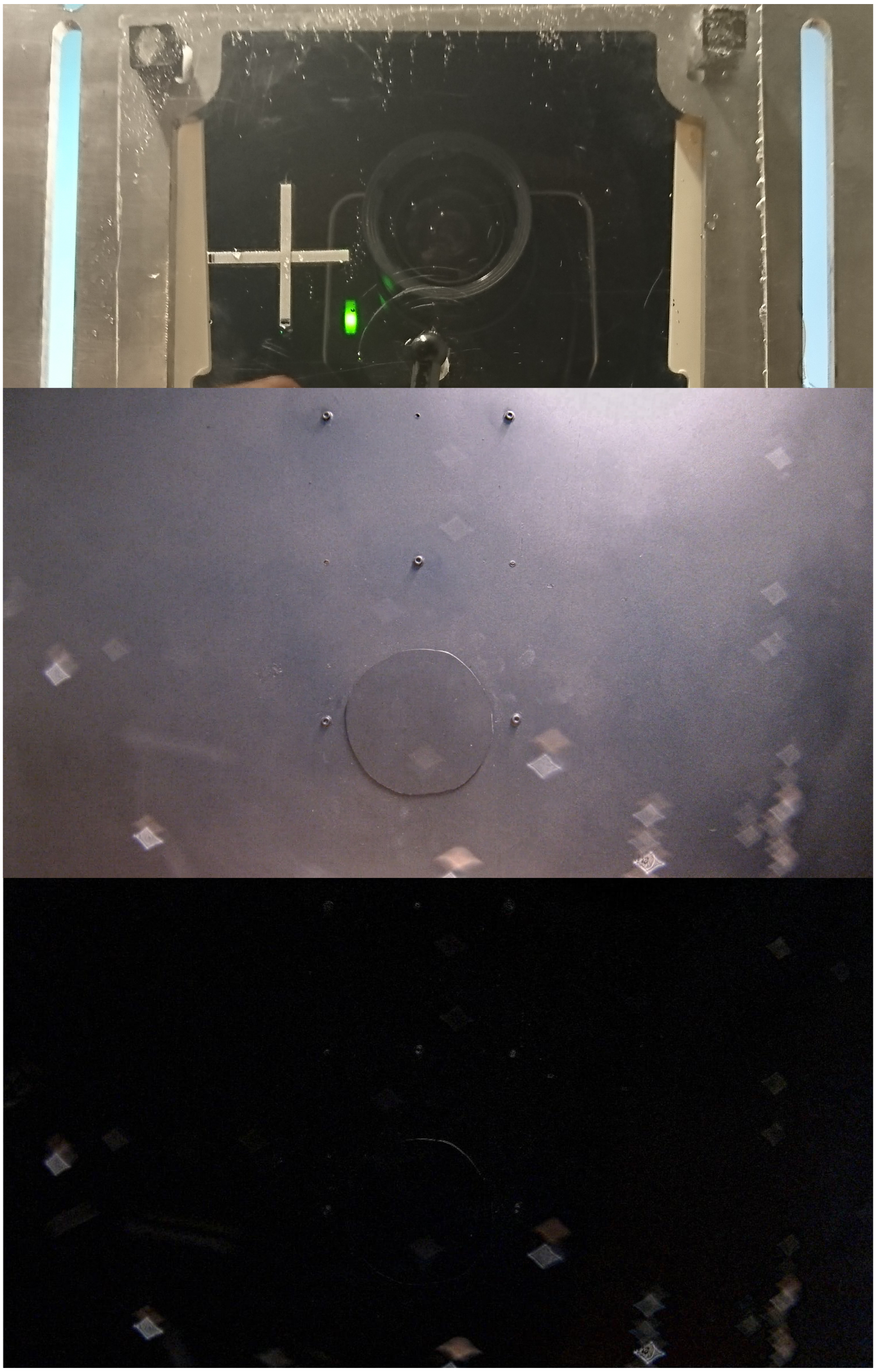

FIGURE 3.8: Image of a sprayed screen after vibration at 60Hz taken from in front of (top) and behind (middle) the protective glass, and a Matlab-generated image (bottom) of the difference between the image above and a completely clean image. **Matlab score = 84**.

3.5.6 Settings

For each new test case, the amplitude needed to be measured. This was accomplished by using a high-speed camera and a cross on the protective glass. By knowing the real size of the cross and measuring the size and the amplitude of the cross on the screen, the real amplitude could be calculated. A picture taken with the high-speed camera can be found below, in Figure 3.9.

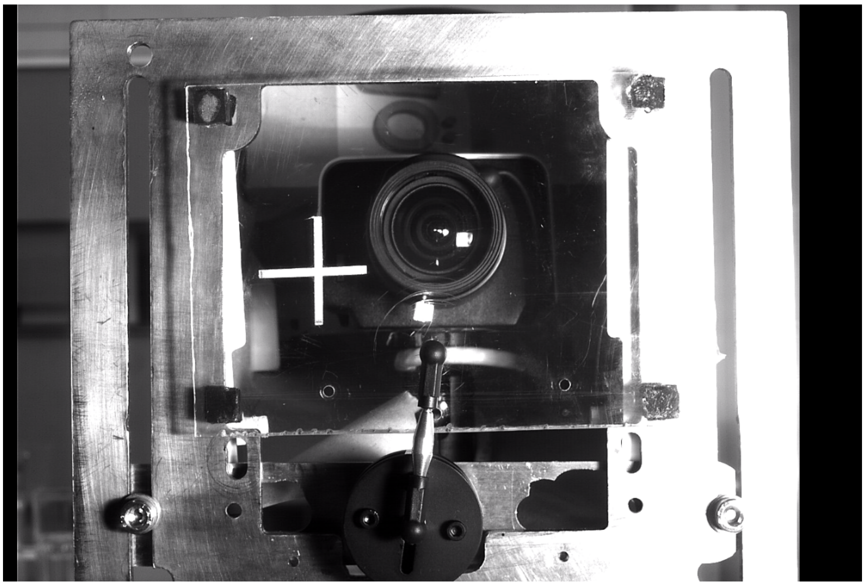

FIGURE 3.9: Cross on the protective glass from high-speed camera's perspective

The goal was to receive results from the frequencies 30, 40, 50 and 60 Hz for each of the amplitudes 1, 2 and 3 mm.

As a final stage when testing the vibrations, a horizontal and an oscillation test were conducted. So instead of having the protective glass vibrating up and down, the glass vibrated side to side or in the oscillation case the glass vibrated in a circular motion.

3.5.7 Problems

Even though the wheel connected to the shaft had the ability to change the amplitude, it was difficult to obtain a perfect amplitude. Also, because of the small instabilities in the rig, the amplitude increased with increased frequency. Therefore, the only way to measure the amplitude at a given frequency correctly was by starting the vibration and measuring the amplitude at the same time as the vibration was running. This was done using a high speed camera.

The solution with the high-speed camera was very accurate, but it must be noted that it was measured by a human being thus introducing the risk that the amplitude was measured incorrectly. Even though this would only affect the measured amplitude marginally, it is still important to keep in mind when reviewing the results.

3.5.8 Results

The results of the vibrations showed that the frequency of the vibrations had a large impact on the result, while the amplitude had less impact. According to the results in Figure 3.10, it seems like the amplitude has to be over about 1 mm for the vibrations to affect the water drops significantly. After this amplitude, however, the amplitude does not affect the score significantly.

In all figures below, the vertical axis is the score of the test. A lower score means a better result where 0 is perfect.

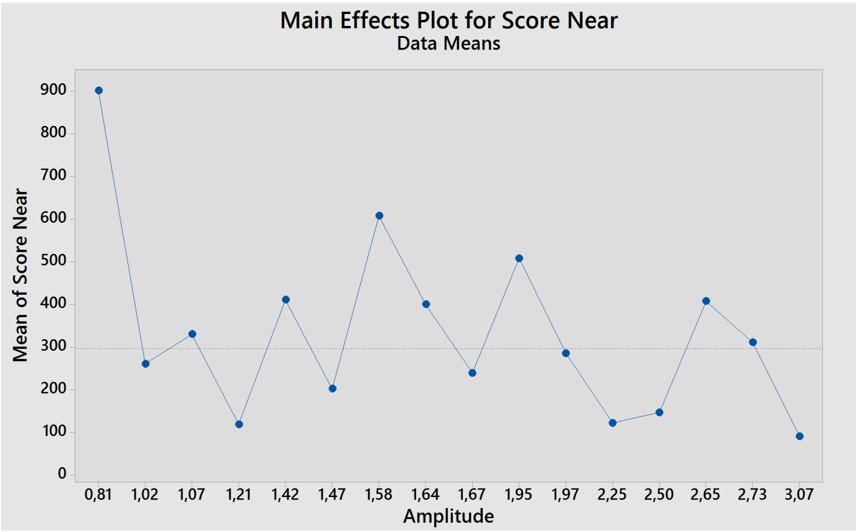

FIGURE 3.10: Plot showing different amplitudes effect on the score

The results of the frequency tests in Figure 3.11 below show that a higher frequency clearly produces a lower (better) score.

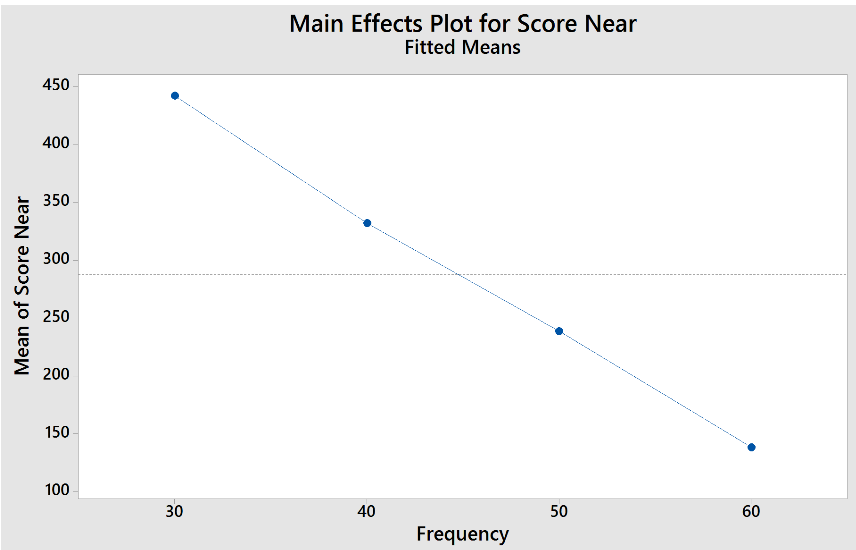

FIGURE 3.11: Plot showing different frequencies effect on the score

Even though it seems that an even higher frequency would produce an even better result, it turned out that it was problematic mechanically to produce frequencies higher than 60 Hz while still maintaining a desired amplitude. After screening the results and taking into account motor power consumption and mechanical wear, 60 Hz and just above 1 mm was chosen as optimal settings for the vibration.

All tests were performed on drops sprayed from a near and a far distance. The near distance produced fewer but larger drops while the far distance produced more but smaller drops. The results in Figure 3.12 show that the large drops were easier to remove than the small drops. This is partly because the larger drops are easier to affect with the vibrations that are used in these tests, and partly because the large drops bump into other drops on the way down the glass, thus making smaller drops disappear as well.

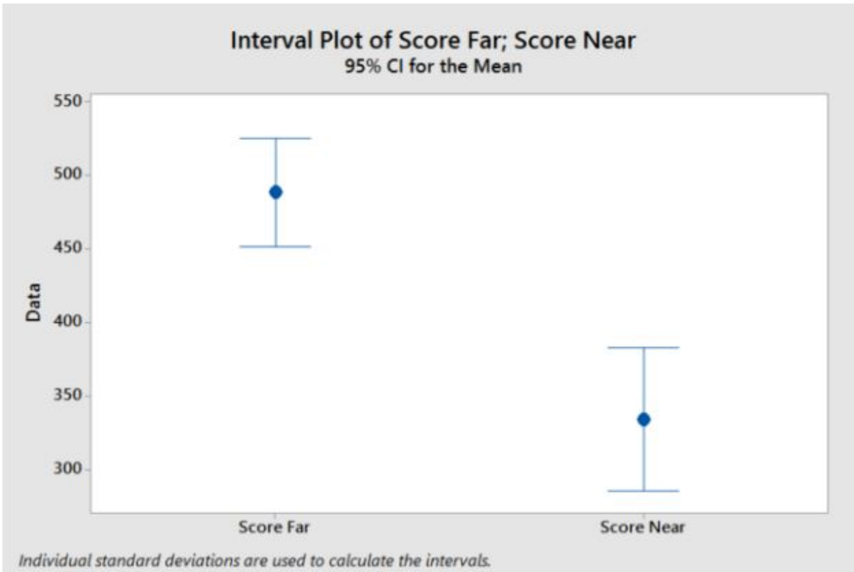

FIGURE 3.12: Score depending on distance of applied water drops. (Near - fewer but larger drops. Far - more but smaller drops)

After the optimal vibration settings were found, tests were performed to investigate the difference between vibration horizontally, vertically and by moving the glass in an oscillating way. The results show that the vertical vibration is the most efficient way of clearing the protective glass from water drops.

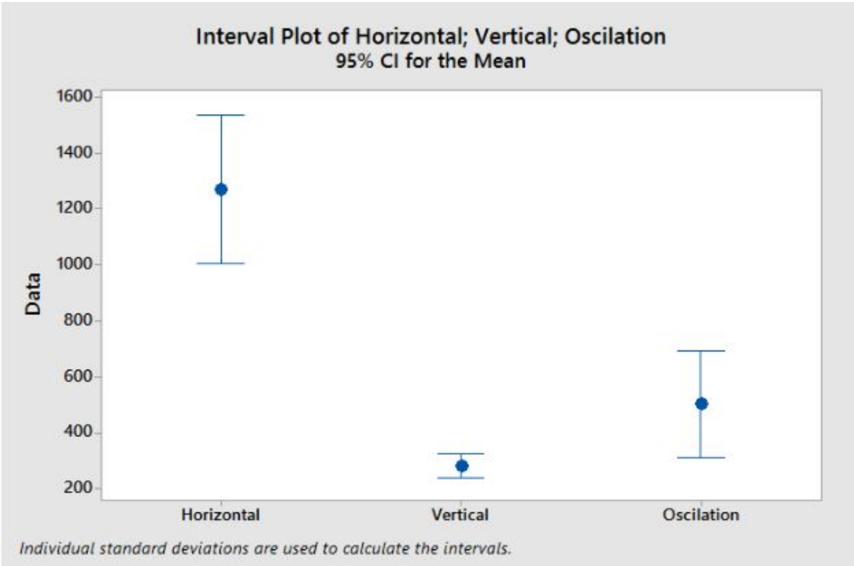

FIGURE 3.13: Difference in results between horizontal vibration, vertical vibration and oscillation

Chapter 4

Final Prototype

This chapter is about how the final prototype was built. What has been decided so far, what problems were left to solve before a final prototype could be assembled, how the prototype was built and finally the results from the prototype.

4.1 Progress so far

So far, the final main concept was chosen. The water was removed by vibrating the protective glass. A fully functioning prototype of the concept was built and tested thoroughly in a test rig. According to the test results from the test rig, the protective glass should be vibrated vertically at a frequency of 60 Hz and at an amplitude just above 1 mm.

There were still some problems that needed to be addressed, including how to integrate the final concept into an existing product, how to seal the product from water and dirt, while still maintaining the ability to vibrate the glass. Additionally, *how* to vibrate the glass had to be chosen. There are different ways of vibrating the glass, for instance by using electromagnets, a motor with a no-contact magnet or to drive the vibrations with a physical shaft. After this, the correct motor or electromagnet must be chosen and lastly electronic control of the chosen solution must be implemented.

4.2 Building the prototype

4.2.1 Sealing

For the prototype a gasket was needed, which could not be too stiff but still not too loose. This is because the prototype needed to be completely sealed, preferably with a IP-class[22] of IP66, and still the protective glass has to be able to move. Ordering custom made gaskets is quite expensive and takes a lot of time, fortunately there were a few gaskets at Axis that could be tested. It was important to keep in mind that the glass would be vibrated vertically when choosing the gasket.

Among the tested ones were the one shown in Figure 4.1 below.

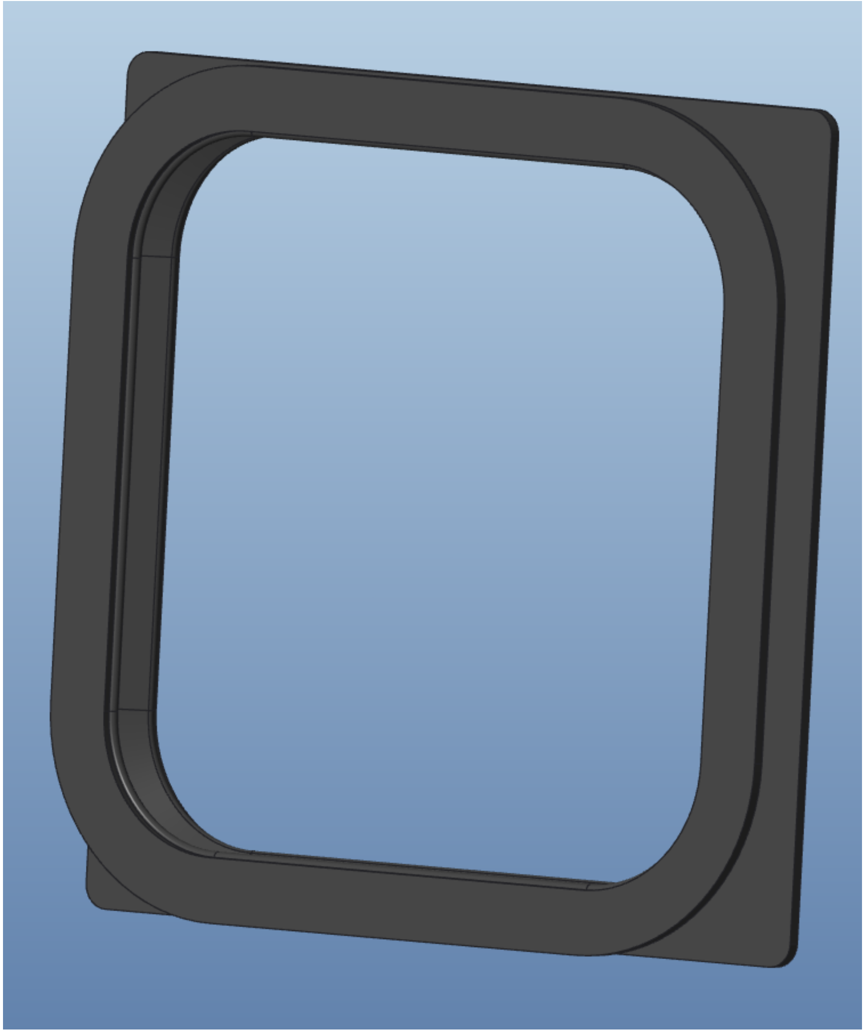

FIGURE 4.1: Tested Gasket

The problem with the gasket in Figure 4.1 is the way it "wants" to move. As can be seen in the picture, the gasket helps the protective glass move inwards and outwards instead of vertically. This is why this gasket was not chosen.

A picture of the the chosen gasket can be found in Figure 4.2 below.

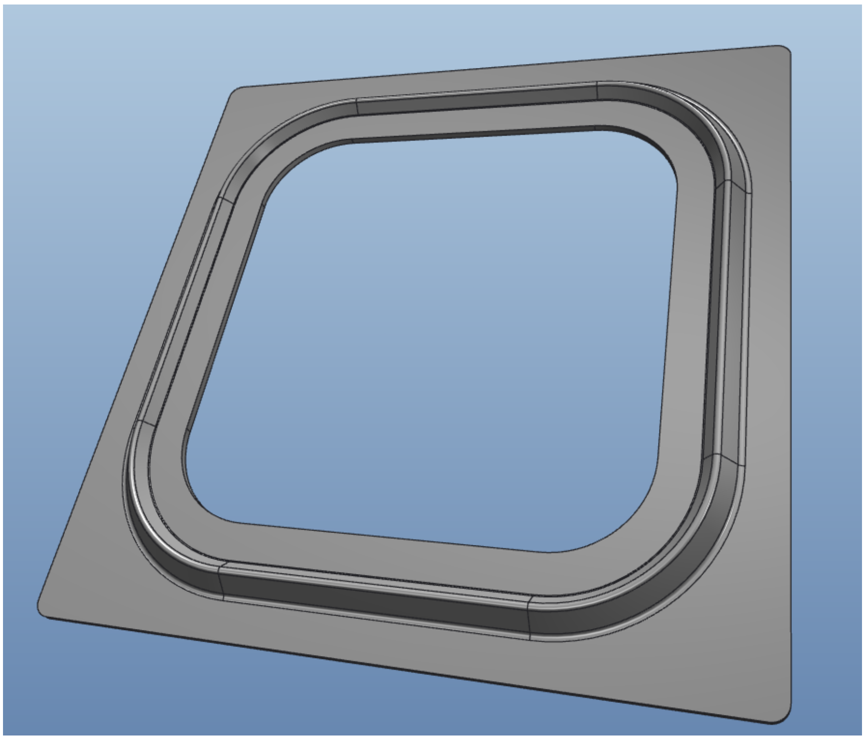

FIGURE 4.2: Chosen Gasket

This gasket is not perfect, but it worked for the final prototype and was able to show a proof of concept. In further development of this project a more optimized gasket should be designed in order to decrease the power usage and wear.

4.2.2 Vibration method

So far the protective glass was vibrated using a shaft connected to a rotating wheel. This was developed to create flexibility with the prototype and so could be easily modified. A picture of the previous setup can be found in Figure 4.3

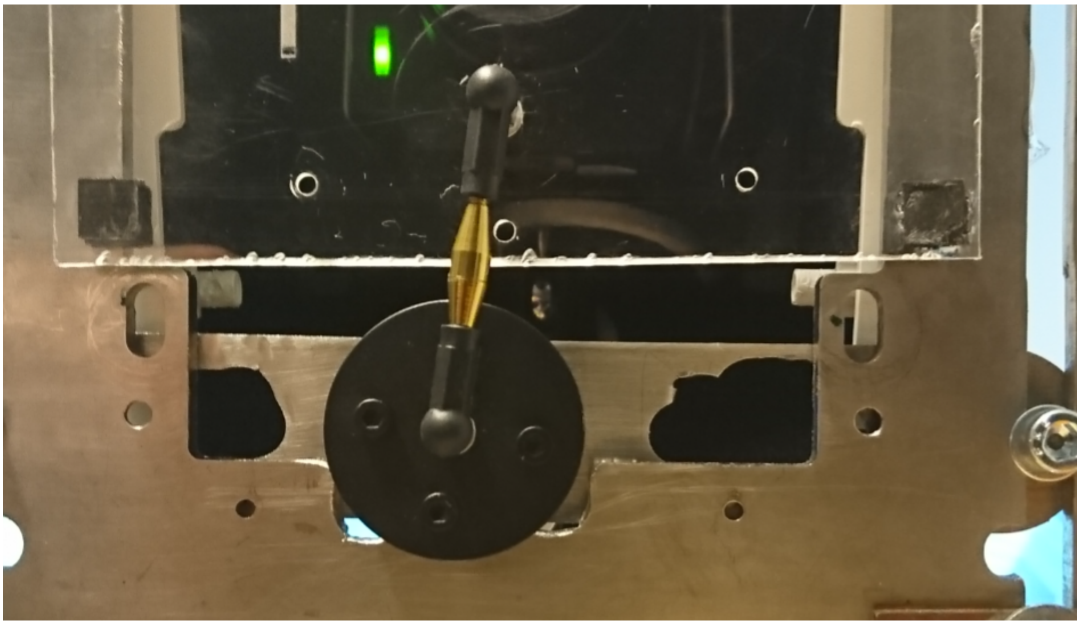

FIGURE 4.3: Previous vibration technique

This setup was benefitial for all the testing of amplitudes and frequencies, but it needed to be more minimalistic. There was a lot of discussion regarding how to vibrate the protective glass. As can be found in *section 2.6.4 Vibration*, a lot of different concepts were generated before even testing to vibrate the protective glass. Including using electromagnets, permanent magnet on a motor, springs etc. The reason for choosing to stay with a regular motor was the simplicity of developing the technique.

Before using electromagnets, a lot of studies would have to be done to properly understand the physics behind the electromagnets and achieve the performance that was desired. Also when discussing this with employees at Axis, it was mentioned that it had been tested before and even though a small amplitude was desired this might be hard to achieve. As can be seen from Equation 4.1, the needed power for an electromagnet is increased with the length between the magnet and the target squared.

$$F = \frac{\mu^2 N^2 I^2 A}{2\mu_2 L^2} \tag{4.1}$$

Using a permanent magnet on a motor, as was discussed in *Motor with Magnet - V1.1*, had been tested before. The problem with using a concept like this one is that the permanent magnet would get stuck while the motor wasn't running and this would result in difficulties in starting the motor. Also this would result in oscillation, something that wasn't desired.

The chosen method for vibrating the protective glass was a crankshaft connected to a motor with a corresponding track glued to the protective glass. On the top of the shaft there is a small pin, that is not centered on the shaft, this is what makes the glass vibrate. A picture of the shaft and track can be found below in Figure 4.4.

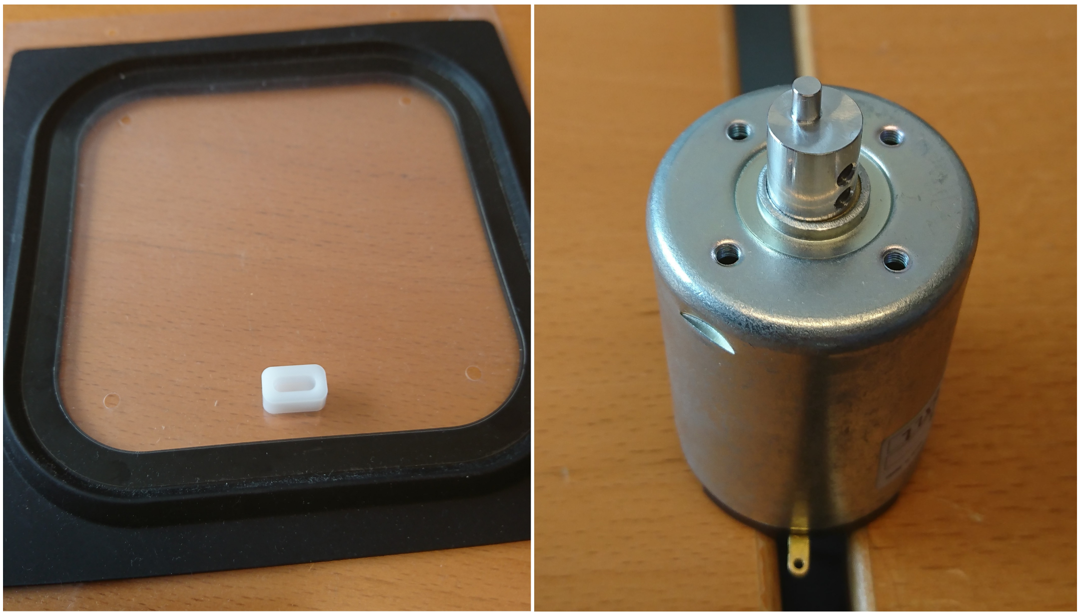

FIGURE 4.4: Picture of the motor shaft and corresponding track glued to the protective glass

4.2.3 Choosing motor

What motor to use was hard to decide on. During the previous tests a stepper motor was used to be able to accurately control the speed and acceleration of the motor in order obtain as fair and objective results as possible. For the final prototype it was decided that a DC-motor would be better because of the relatively high rotational speed needed and because the need for absolute accuracy in rotational speed is quite low. A few motors were tested before it was decided that a large DC motor would be used. The motor is a little over dimensioned for the prototype, and this is further discussed in *5.3.3 - Motor*.

4.2.4 Integration into existing product

After deciding which technique to use for vibrating the glass and after that choosing a suitable motor, the next step was to integrate the solution into an existing product. The product that was chosen was a large camera house which has plenty of room for extra equipment such as our motor and controllers. The front of the camera is also big enough to fit the gasket that was previously chosen. In order to assemble the gasket with as little use of adhesives as possible, the gasket was pressed together between an inner and an outer wall of the camera. This design allows the gasket to be fixated with only small amounts of adhesives.

4.2.5 Electronic Control

The last step of the final prototype was to control it electronically. In order to obtain speeds of 60 Hz with a DC motor, the speed had to be monitored and the voltage controlled. To monitor the speed a hall sensor[23] and a magnet were used. The magnet was attached to the back end of the motor shaft and the sensor was placed near the magnet and shaft. The hall sensor outputs a signal every time the magnet passes by the sensor. This particular hall sensor gives six pulses per revolution and this was accurate enough to control the motor at the desired speeds.

The sensor values were sent to an Arduino®[24] board where they were processed through a PID-Controller[25] and a PWM-signal was outputted to a H-bridge[26] that controls the voltage to the motor. The PID-regulator was tuned to prioritize a stable control that works well in all situations, at the cost control speed. The D-part of the regulator was set quite low, and so was the P-part. The I-part does most of the work, but has quite a strict anti-windup function. The code for the Arduino can be found in Appendix *A.2 - Arduino Code*.

To be able to hook up the Arduino, H-bridge, hall sensor and motor with each other, custom made wires had to be made. Different combinations of wires were soldered together, put into connectors and then put into shrink tubing[27]. This made the process of setting up the rig much easier than if every wire had to be connected individually.

4.3 Final results

4.3.1 The prototype

The final prototype was successfully built into an existing product. Since this was just a proof of concept, some components were removed from the camera house, leaving only the actual camera and the logic for the vibration in the camera house. This meant there was plenty of space in the camera house. The Arduino board and the H-bridge were attached to the roof of the camera house in the rear part of the house. This was to make as much space as possible for the camera.

In Figure 4.5 and 4.6 below, the final prototype can be seen.

FIGURE 4.5: External picture of the final prototype

From the front of the final prototype, the camera and the vibrating mechanism can be seen. Aside from this, there are almost no visual differences between this prototype and the original product without the vibrating window glass. Looking inside the camera house, some differences can be seen. In this actual prototype, most of the components in the camera house were removed, in order to fit the vibration mechanism. The only thing left was the actual camera, the motor that drives the vibration and the logic for the motor. This can be seen in Figure 4.6.

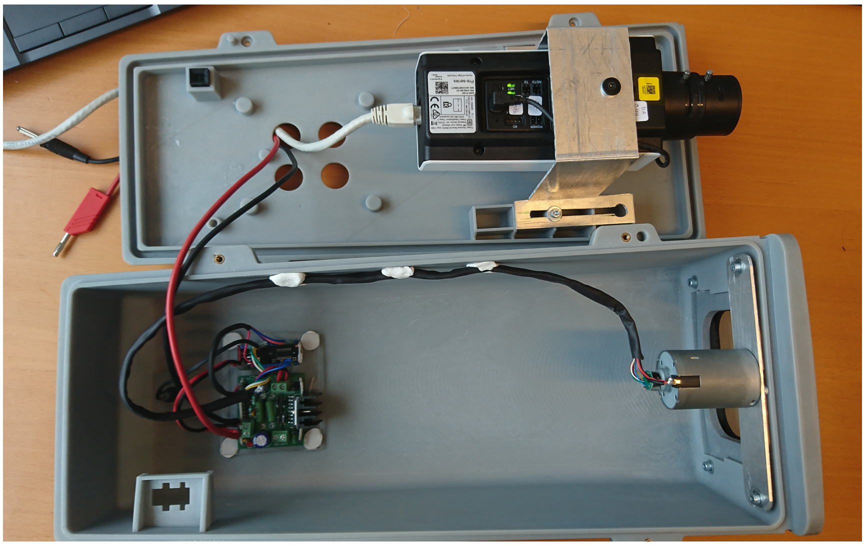

FIGURE 4.6: Picture of the inside of the final prototype

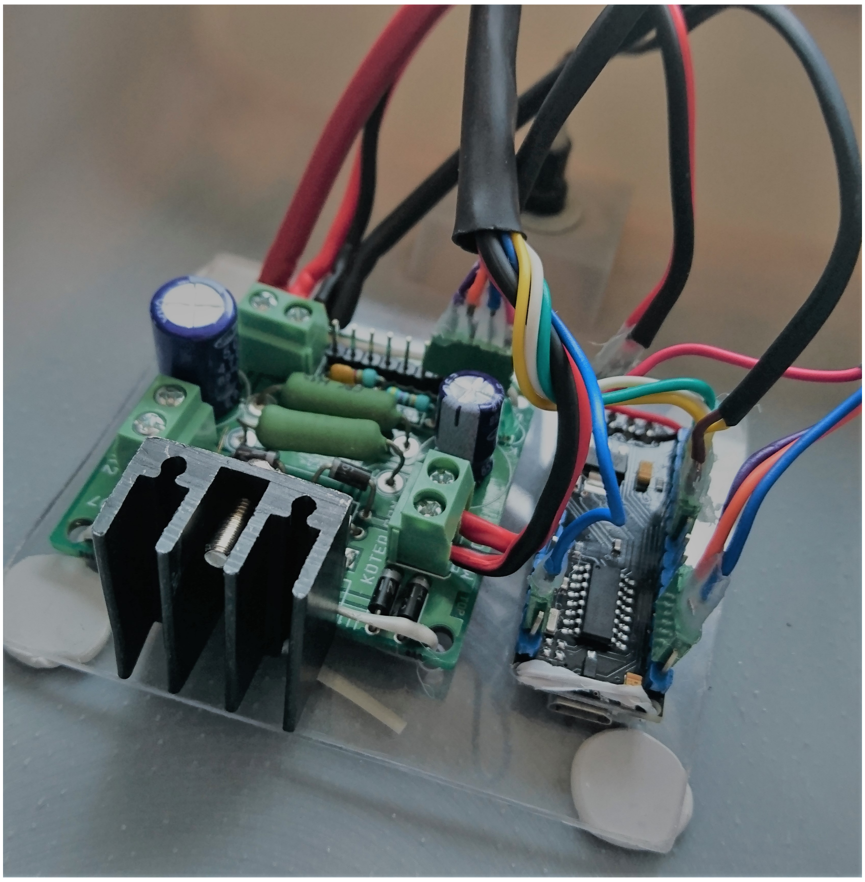

FIGURE 4.7: Picture of the Arduino and the H-bridge

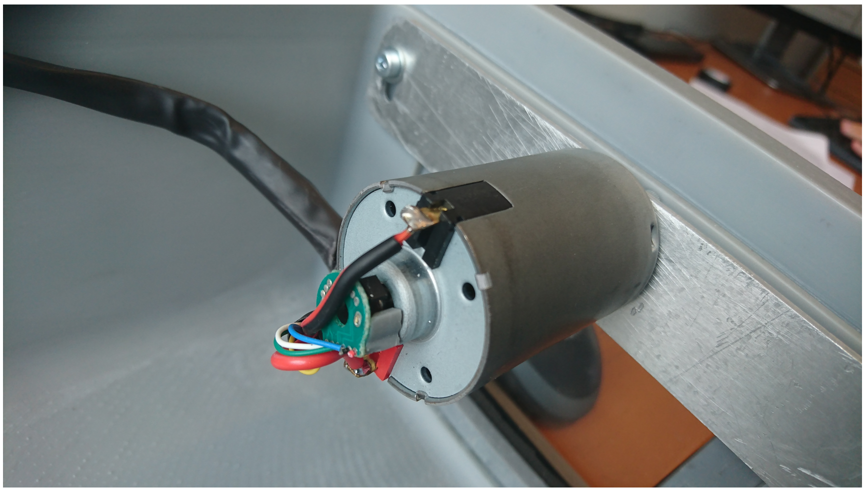

FIGURE 4.8: Picture of the Hall sensor, assembled on the DC-motor

4.3.2 Performance

The final test of the prototype was performed at 60 Hz with an amplitude of 1.35 mm. In order to be comparable with prior tests, the final test was performed in the exact same way as all prior tests (see section 3).

Noise level

After assembling the protective glass to the camera house and running the cleaning procedure, a disturbing noise was produced by the vibrations. When measuring the noise, it was at 79 dB. This was too loud, and was fixed by attaching a piece of rubber gasket material around the protective glass. This made the glass vibrate more quietly, but at the cost of some water removal performance. The glass became cleaner when vibrating without the rubber gasket, but with the gasket the noise level was reduced to 69 dB, which is a large reduction. Since the glass became clean either way, it was decided that the rubber gasket should be kept on the final prototype. The only risk with the gasket is that the cleaning process might have to be run for a little longer to acquire the same results as without the gasket, but these differences are only marginal.

The noise measurements were carried out using a dB-meter and measuring at a distance of 20 cm from the protective glass of the camera. The average noise level from one entire cleaning process (10 seconds) was noted.

Cleaning performance

The cleaning performance of the final prototype was impressive. With an average score of 72 for water drops sprayed from a near distance (large drops) and 54 for water drops sprayed from a far distance (small drops), these results surpassed the predicted results.

The cleaning process was programmed to take 10 seconds, and after this time almost all visible drops were successfully removed.

The image quality was practically unaffected during the cleaning process (see Figure 4.9 below).

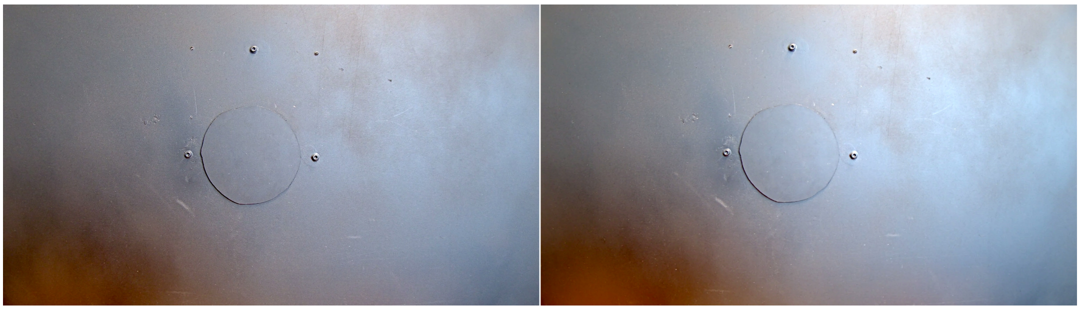

FIGURE 4.9: Picture of the camera image without the cleaning process running (left) and with the cleaning process running(right)

Power usage

To run the entire setup, a voltage of 13.7 V and a current of 0.43 A was needed. This would equal a total of 5.9 Watts in electricity consumption. This could probably be lowered in an actual product, by integrating the control system and h-bridge with the already existing electronics in the product. Also, as is discussed in *Section 5.3.3 - Motor*, the motor can be changed for lower electricity consumption.

Comparing results to customer needs

In table 4.1 below, a list of customer needs is shown. This is the same table as Table 2.3 in section *2.4 - Identifying Customer Needs*, with the modification of metric No. 1 that is now *Matlab score* instead of measuring size and number of drops. This table is also extended with the real test results from the final testing of the prototype.

TABLE 4.1: List of customer needs and their relative importance

Metric No.	**Metric**	**Imp.**	**Units**	**Marginal values**	**Ideal values**	**Result**
1	Matlab-Score (lower is better)	5	-	<200	<100	54 (far) 72 (near)
2	Protection against water	4	IP class	IP65	IP66	Not measured
3	Protection against dust	4	IP class	IP65	IP66	Not measured
4	Operational temperatures	4	°C	-20 - +40	-40 - +60	Not measured
5	Maximum power used	4	W	<13	<2	5.9
6	Image quality is maintained during cleaning process	3	subj.	Almost maintained	Totally maintained	Totally maintained
7	Orientation of camera is fixed during cleaning process	5	yes/no	yes	yes	yes
8	Amount of mechanical wear on prot. glass	5	subj.	Little wear	No wear	No wear
9	The cleaning process is completely automatic	5	yes/no	no	yes	yes
10	Time between maintenance	4	Months	12	36	Not measured
11	The outer dimensions of the camera are maintained	3	yes/no	no	yes	yes
12	The total added weight of the product is low	4	g	<500	<250	270
13	The cleaning process is fast	3	s	<20	<5	10s
14	The solution has low heat production during usage	2	yes/no	no	yes	yes
15	The cleaning process is quiet	3	dB	<80	<65	69

Chapter 5

Discussion & Conclusion

5.1 Conclusion

Looking at the milestones and objectives in Chapter 1, this would state that this project has been successful.

- A thorough prestudy was carried out in order to gain as much knowledge as possible from previous progress in similar projects. This prestudy was carried out both internally at Axis and externally.
- Desirable and necessary needs and properties were established for plausible solutions.
- Multiple different concepts were generated for solving the problem without yet being constrained by limitations.
- Thorough systematic evaluations were done of the concepts and finally three main concepts were chosen to continue working with.
- Simple prototypes of the three concepts were built and tested thoroughly by evaluating their respective ability to remove water from the protective glass.
- The best concept was chosen and a prototype was built that can both remove water and at the same time is resistant to water and dust.
- The final prototype was controlled electronically.
- The final prototype was assembled into an existing or future product.

There were however, a few metrics in Table 4.1 that states as 'Not Measured, this is unfortunately due to lack of time and resources.

The final prototype ended up cleaning the protective glass using vibrations. The vibrations were created by using a 12 volts DC-motor with a shaft and a decentralized pin moving in a track, glued to the protective glass. The track was necessary to obtain strictly vertical vibrations. The amplitude of the vibrations was set to 1.35 mm and the frequency was set to 60 Hz. The frequency was controlled by controlling the rotational speed of the DC-motor using a hall sensor, an H-bridge and a PID-controller. The protective glass was mounted on a gasket and the gasket was held in place by pressing it together between a metal and a plastic plate. No coatings were used on the protective glass.

5.2 Discussion

There are a few considerations though that might have effected the results of this master thesis.

When testing the rotation and impulse concepts, they were not tested using the same systematic method as for the vibration concept. Since the method for optimizing vibrations was more objective, it would have been good to have the same tests for rotation and impulse. However, rotation was removed because it required to much power. The impulse concept was removed from subjective studies stating that it did not work nearly as good as vibrations, this could have been proved using the same method as used for optimizing vibrations.

During the tests for optimizing vibrations, most things were standardized. However, making exactly the same size of the water drops with the spray flask would have been impossible. The light might have changed during tests, which would have made Matlab interpret the results differently. For example, some water drops might have been more or less highlighted in the picture with more or less light.

5.3 Further Development

5.3.1 Coatings

Something that was clear during the testing period and while building different prototypes, was that the protective glass had an effect on the result. With a newer and more clean glass, the water drops would fall off more easily. During the tests of the projects the glass was frequently cleaned with degreasers, to receive the most fair result for all the tests. Even though there are no measured result for how big of an impact the protective glass actually has on the result, this is definitely something that effects how easily the water drops fall off.

In *2.6.2 - Search Externally* different coatings are discussed, this is something that Axis has to look into. As mentioned in *Search Externally* there are various aspects to have in mind, the coating needs to last for long periods of time, not stain or discolor the protective glass etc. The difference between hydrophilic and hydrophobic coatings is mentioned in *2.6.3 - Search Internally* and even though, it is stated that hydrophobic coatings did not have an impact on the water drops, this has not been tested in combination with this newly developed prototype. Therefore this is something that Axis most definitely has to look into.

5.3.2 Gasket

The chosen gasket for this project was something that Axis had already ordered. Ordering a customized gasket is quite expensive and time consuming, therefore it was decided not to order or create anything specially customized for this project. The chosen gasket can be found as Figure *4.2* on page *53*.

The gasket works for proving the concept, but it can definitely be optimized. Analyzing the gasket used in the final prototype, it is noticeable that the protective glass can be moved in all directions. This is totally unnecessary since the protective glass only vibrates vertically. The bellows are the same on every side and since the protective glass only moves in one direction, this is not the best solution. For moving the protective glass vertically, the bellows above and below the glass are perfect. The bellows to the right and left, on the other hand, can be changed. As they are formed now, they create a resistance to the applied force from the motor.

Instead of using the already formed gasket, the left and right side can take inspiration from an accordion (found in the Figure 5.1 below).

FIGURE 5.1: Accordion

5.3.3 Motor

As mentioned in section *4.2.3 - Choosing motor* in *Chapter 4*, the motor that was chosen for the final prototype was quite over dimensioned. The reason for this was to be able to test different amplitudes and frequencies (once again), without encountering any problems due to lack of motor power. When the motor was chosen it was also dimensioned to suffice the previous method for vibrating the protective glass, which was inspired by the concept *2.6.4 - Motor with Shaft V1.2* found in *Chapter 2*. If Axis decides to develop this concept into a product, they can definitely scale down the motor.

5.3.4 Vibration Method

If Axis decides to develop the concept of vibrating the protective glass further, something that can be looked into are different methods of vibrating. There are a lot of different concepts discussed in *Chapter 2*. The reason for choosing a motor and a shaft, is the simplicity of it. A simple way of vibrating was chosen because of the time limit, since most of the time was used for finding a perfect frequency and amplitude once the concept of vibrating the protective glass was chosen.

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Appendix A

Code Appendix

A.1 Matlab Code

```
close all;
clear all;
X1 = imread('1.jpg');
X2 = imread('2.jpg');
X3 = imread('3.jpg');
X4 = imread('4.jpg');
X5 = imread('5.jpg');
Y1 = imread('Clean.jpg');

YX1 = imabsdiff(Y1,X1);
YX2 = imabsdiff(Y1,X2);
YX3 = imabsdiff(Y1,X3);
YX4 = imabsdiff(Y1,X4);
YX5 = imabsdiff(Y1,X5);

figure
imshow(YX1,[])
figure
imshow(YX2,[])
figure
imshow(YX3,[])
figure
imshow(YX4,[])
figure
imshow(YX5,[])

err1 = immse(Y1,X1);
err2 = immse(Y1,X2);
err3 = immse(Y1,X3);
err4 = immse(Y1,X4);
err5 = immse(Y1,X5);

error = [err1, err2, err3, err4, err5]

mean = mean(error)
stdev = std(error)
CV = stdev/mean
```

A.2 Arduino Code

```
const byte interruptPin = 2;
const byte buttonPin = 3;
int enablePin = 9;
int PinA = 10;
int PinB = 11;
double targetRPM = 3600;
const double K = 0.08;
const double I = 0.064;
const double D = 0.016;
const double milli = 50.0;
volatile double count = 0;

double hz = 0;
volatile double rpm = 0;

unsigned long last;

const int NBR_OF_TURNS = 4;
double pwm = 0;

volatile unsigned long lastTrigger = 0;
volatile boolean activated = false;

double errorSum = 0;
double prevError = 0;

void setup() {
  pinMode(interruptPin, INPUT_PULLUP);
  pinMode(buttonPin, INPUT_PULLUP);
  Serial.begin(9600);
  attachInterrupt(digitalPinToInterrupt(interruptPin), trigger,
      CHANGE);
  attachInterrupt(digitalPinToInterrupt(buttonPin), test, HIGH);


  pinMode(enablePin, OUTPUT);
  digitalWrite(enablePin, HIGH);
  analogWrite(enablePin, 0);

  pinMode(PinA, OUTPUT);
  digitalWrite(PinA, HIGH);

  pinMode(PinB, OUTPUT);
  digitalWrite(PinB, LOW);

  pinMode(4,OUTPUT);
  digitalWrite(4, LOW);
}

void loop() {
  if (Serial.available() > 0)
  {
    targetRPM = Serial.parseInt();
  }
```

```
  if (activated) {
    if (millis() - last > 500) {
      rpm = 0;
    }
    control();
    if (millis() - lastTrigger > 10000) {
      analogWrite(enablePin, 0);
      activated = false;
    }
  }
  delay(1);
}

void trigger() {
  if (count == 6 * NBR_OF_TURNS) {
    long elapsed = millis() - last;
    last = millis();
    hz = 1000.0 * NBR_OF_TURNS / elapsed;
    rpm = hz * 60;
    count = 1;
  }
  else {
    count++;
  }

}
void test() {
  lastTrigger = millis();
  activated = true;
}

void control() {
  double error = targetRPM - rpm;
  errorSum += error;
  antiWindup();
  double kValue = K * error;
  double iValue = I * errorSum;
  double dValue = D * (error - prevError);
  prevError = error;

  pwm = kValue + iValue + dValue;
  if (pwm > 255) {
    pwm = 255;
  }
  if (pwm < 0) {
    pwm = 0;
  }
  analogWrite(enablePin, (int)(pwm + 0.5));

  Serial.print(rpm);
  Serial.print(" ");
  Serial.print(targetRPM);
  Serial.print(" ");
  Serial.print(pwm);
  Serial.print(" ");
  Serial.print(kValue);
  Serial.print(" ");
```

```
  Serial.print(iValue);
  Serial.print(" ");
  Serial.println(dValue);
}
void antiWindup() {
  if (errorSum * I > 250) {
    errorSum = 250 / I;
  }
  if (errorSum * I < 0) {
    errorSum = 0;
  }
}
```