New Concepts for PTR Functionality in Fixed Domes

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MASTER THESIS

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Abstract

This report describes the design and development of new concepts for pan, tilt and rotate functionality in fixed domes at Axis Communications. The aim of the master's thesis was to generate a concept that are smaller and less expensive compared to the solutions today.

Remote pan, tilt and rotate is a unique feature which makes it possible to remotely control a camera during installation and redirection. At Axis this solution is called "remote PTR solution", which means that the camera can pan, tilt and rotate remotely.

Most of the information needed for the project was gathered at Axis during interviews and workshops. In parallel to the concept generation benchmarking, patent search and other research was made. The result from this showed that the combination of pan, tilt and rotate in fixed domes are not as common as only pan and tilt.

Due to the complexity of the problem it was divided into three sub problems. The first sub problem was to find a suitable electromechanical technology that enables movement. The most suitable electromechanical technology found was electrical motors. The next sub problem was to further investigate and evaluate different electrical motors. The most suitable electrical motors found was a stepper motor and a piezo motor. The final sub problem was to generate concepts with these motors.

After the concept generation a final concept was chosen. The final concept consists of three stepper motors and gear wheels of different types. The final concept was further developed and a CAD model was made. The proof of concept is a 3D printed model that shows that the pan, tilt and rotate functionality works. A financial analysis was made which shows that the concept is in fact less expensive compared to the solutions that exists today.

Keywords: *Product development, Axis Communications, Fixed Dome camera*

Sammanfattning

Denna rapport innehåller design och utveckling av nya koncept för panorering, lutning och rotation i fixed dome-kameror på Axis Communications. Syftet med masteruppsatsen var att skapa ett koncept som är mindre och billigare jämfört med de lösningar som finns idag.

Trådlös panorering, vinkling och rotation är en unik funktion som möjliggör trådlös installation och omdirigering av en kamera. På Axis kallas detta för ”trådlös PTR-funktionalitet”, vilket innebär att kameran kan panorera, vinklas och roteras på distans.

Huvuddelen av informationen som behövdes till projektet fanns på Axis och samlades in genom intervjuer och workshops. Parallellt med konceptgenerering gjordes undersökningar så som benchmarking och patentsökning. Resultatet från undersökningarna visade att kombinationen av panorering, vinkling och rotation i fixed dome-kameror inte är lika vanligt som endast panorering och vinkling.

Då problemet var komplex delades det upp i tre delar. Den första delen bestod av att hitta en lämplig elektromekanisk teknik som möjliggör rörelse. Den mest lämpliga elektromekaniska tekniken som hittades var elmotorer. Nästa del var att ytterligare undersöka och utvärdera olika elektriska motorer. De mest lämpliga elektriska motorerna som hittades var en stegmotor och en piezomotor. Slutligen genererades olika koncept med dessa motorer.

Efter att konceptgenerering slutförts valdes ett koncept. Det valda konceptet består av tre stegmotorer och kugghjul av olika typer. Konceptet vidareutvecklades och en CAD-modell gjordes. Proof-of-concept gjordes i form av en utskriven 3D modell. 3D-modellen visar att panorering, vinkling och rotation fungerar. En finansiell analys gjordes vilket visar att konceptet är mindre kostsamt jämfört med de lösningar som finns idag.

Nyckelord: Produktutveckling, Axis Communications, Fixed Dome-kamera

Preface

This report is a result of my Master's Thesis in Mechanical Engineering. The thesis has been conducted at the Division of Product Development at the Faculty of Engineering at Lund University in cooperation with Axis Communication.

I would like to thank my supervisor at Axis, Roger Jönsson, for believing in me and always answering my questions. I would also like to thank my supervisor at Lund University, Per-Erik Andersson, for his support during the project.

During the Master's Thesis several employees at Axis contributed with their expertise and time. First, I would like to thank Andrew Andersson for helping me building the test rig. Finally, I would like to thank all the employees at Axis who always answered all my questions and helped me at all times. A special thanks to Magnus Lundegård, Carl-Axel Alm, Charlotte Gunsjö, Samir Helaoui, David Bull, Johan Kjörnsberg and Nina Bergius.

Lund, February 2017

Rakel Hed

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1 Introduction

This chapter includes a short introduction to the thesis with information about the company, a background, a problem description, a list of limitations and an explanation of the structure of the report.

1.1 Background

Axis Communications AB (Axis) is Swedish-based company that is developing network video products. The first network camera was invented by Axis in 1996 and today their products can be found all over the world in public places such as retail chains, airports, trains and banks. [1]

Axis has developed a wide range of different fixed dome cameras and recently they launched the new camera model AXIS Q36, which is a very advanced model. One of the unique features with this fixed dome camera is that it can be remotely controlled during installation and when the camera needs to be redirected. At Axis this solution is called "remote PTR solution" where PTR is an abbreviation for pan, tilt and rotate, which means that the camera can pan, tilt and rotate remotely. The purpose for this functionality is to make it easier to install and redirect the camera and should not be mistaken for a PTZ camera that moves continuously. [2]

A natural step for Axis is to develop a new concept to enable a smaller remote PTR solution.

1.2 Problem Description & Goals

The problem description is to find a new cost effective electromechanical design to enable remote PTR functionality in a small fixed dome camera. The goal of the thesis is to develop new concepts for the remote PTR functionality in a fixed dome camera. The result will be presented in this report with a 3D model. If needed a prototype will be made as a proof of concept.

1.3 Limitations & Delimitations

The main limitation is the time period of only twenty weeks, which includes concept development, report writing and presentation. The focus will be on network cameras within the fixed dome segment. A concept will be developed to fit a specific camera but the idea is that the final concept with its technical solution also could be adapted to fit other camera models within Axis product range. Due to the complexity of the product it was decided to limit the project to cameras that are supposed to be mounted indoor on a wall or a ceiling. This decision was made because the requirements for outdoor cameras are considerably higher and will therefore be too advanced for the limited time period.

1.4 Structure of the Report

The report is divided into five main parts: methodology, background study, concept development, conclusion and discussion. References and appendices can be found in the end of the report.

2 Methodology

This chapter includes a description of the methodology used during the master's thesis. The chapter is divided into planning, scientific basis, background study and concept development.

2.1 Planning

Prior to the start of the master's thesis a project plan was made (see appendix A). The plan is that the master's thesis is going to have a duration of twenty weeks and the main part will be carried out at Axis. The result of the master's thesis will be shown during a presentation at the end of the time period.

2.2 Scientific Basis

The scientific basis will consist of research articles, interviews and literature. One of the key references is going to be the book written by Ulrich and Eppinger (2008) "Product Design and Development" [3]. The interviews will be conducted at Axis with a selection of employees.

2.3 Background Study

The purpose of the background study is to understand the background of the problem and why there is a need solve it. The background study will consist of informal interviews with employees and documentation at Axis. The PTR solution for the camera model AXIS Q36 will not be investigated at this early stage to keep an open mind for other possible solutions.

2.4 Concept Development

The methodology for the concept development will follow Ulrich and Eppinger's product development method [3]. Due to the time limit of twenty weeks the focus is going to be on the concept development phase. Ulrich and Eppinger's method is a general product development method and therefore some modification will be made. The concept development phase is divided into different activities and in figure 2.1 the activities for this master's thesis are shown. Note that the figure is modified version of the figure in Ulrich and Eppinger's method [3]. Further descriptions of the different activities are given at the beginning of each chapter.

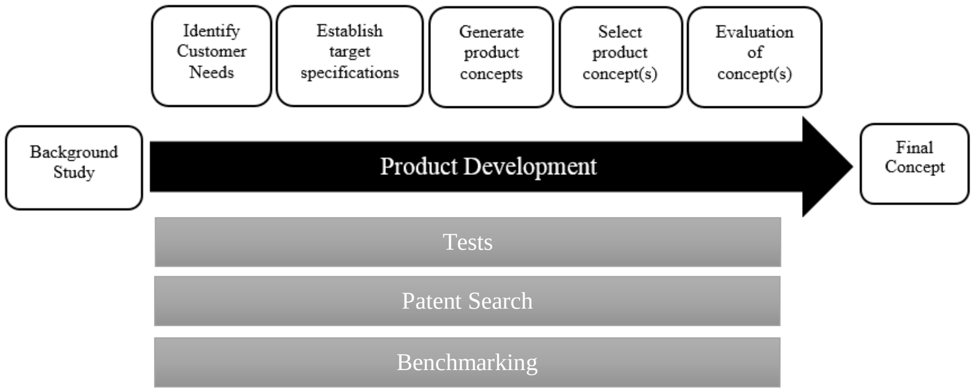

Figure 2.1 The different phases of this project.

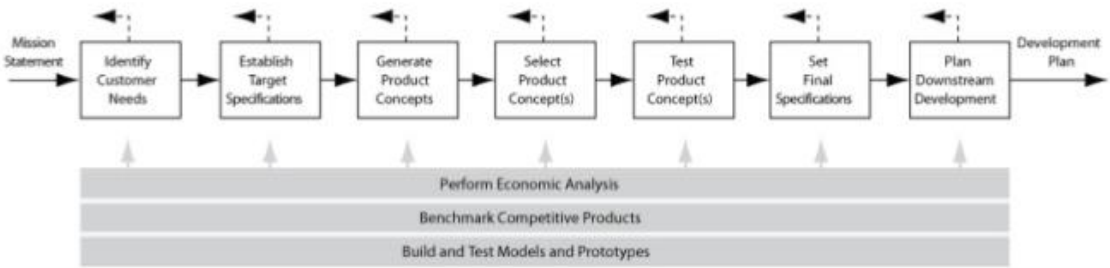

Figure 2.2 Ulrich and Eppinger's concept development phases.

3 Background Study

This chapter includes description of the current camera design and other relevant technical information that is needed to understand the background of the problem.

3.1 The Camera

The aim of the thesis is to find a new electromechanical design to enable a miniature and cost effective design for remote PTR functionality in a fixed dome camera. To do so, the generated concepts will be implemented on one of the smallest fixed dome cameras in Axis product range. The choice of camera model is less important because of the fact that the electromechanical design should be scalable to fit all small fixed dome cameras within Axis product range.

In this project, the generated concepts should be applicable on the fixed mini dome AXIS M3044-V Network Camera. The camera has a 3-axis angle adjustment and it is one of the cameras in the Axis M30 series. The camera is ideal for indoor surveillance applications in retail and logistics centers. As seen in figure 3.1 the camera is protected by a dome consisting of a white solid cover (1) and a translucent part (2), these parts will later on be referred as the “shell” of the camera. In figure 3.2 the shell is separated from the rest of the camera. [4]

Figure 3.1 AXIS M3044-V Network Camera.

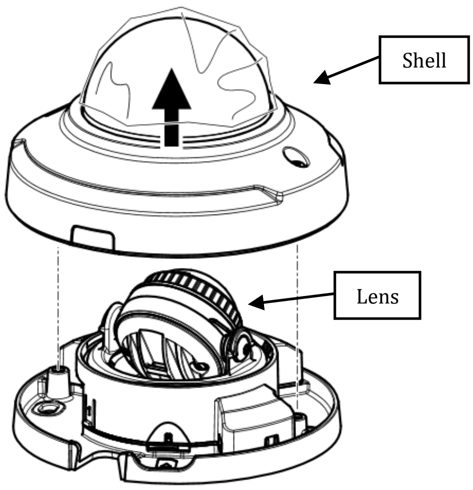

Figure 3.2 The camera with the shell separated.

The remote PTR functionality should be able to fit inside the shell of the camera. If this is found not to be possible the height, 56 mm, could be adjusted about 10 mm but the diameter needs to be 101 mm [5]. The reason for this is that it has to fit existing camera accessories. The dimensions of the camera model are shown in figure 3.3.

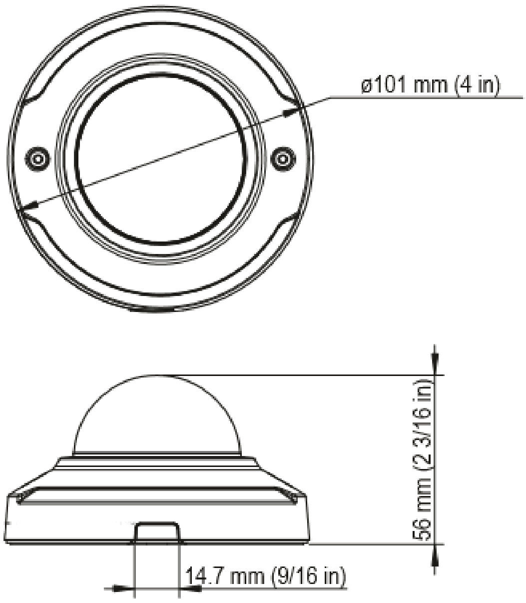

Figure 3.3 Dimensions of the camera model.

3.2 Pan, Tilt & Rotate Functionality

Due to the nature of the master's thesis the current solution for the PTR functionality is interesting to examine. In the current solution the lens inside the camera is moved manually during installation and redirection. Pan is the rotation of the lens and the mounting device, tilt is the movement of the lens up/down and rotate is the rotation of the lens to make the picture aligned. Figure 3.4 shows how these movements are done with the current manual solution. Figure 3.5 shows the coordinate system for the different axis.

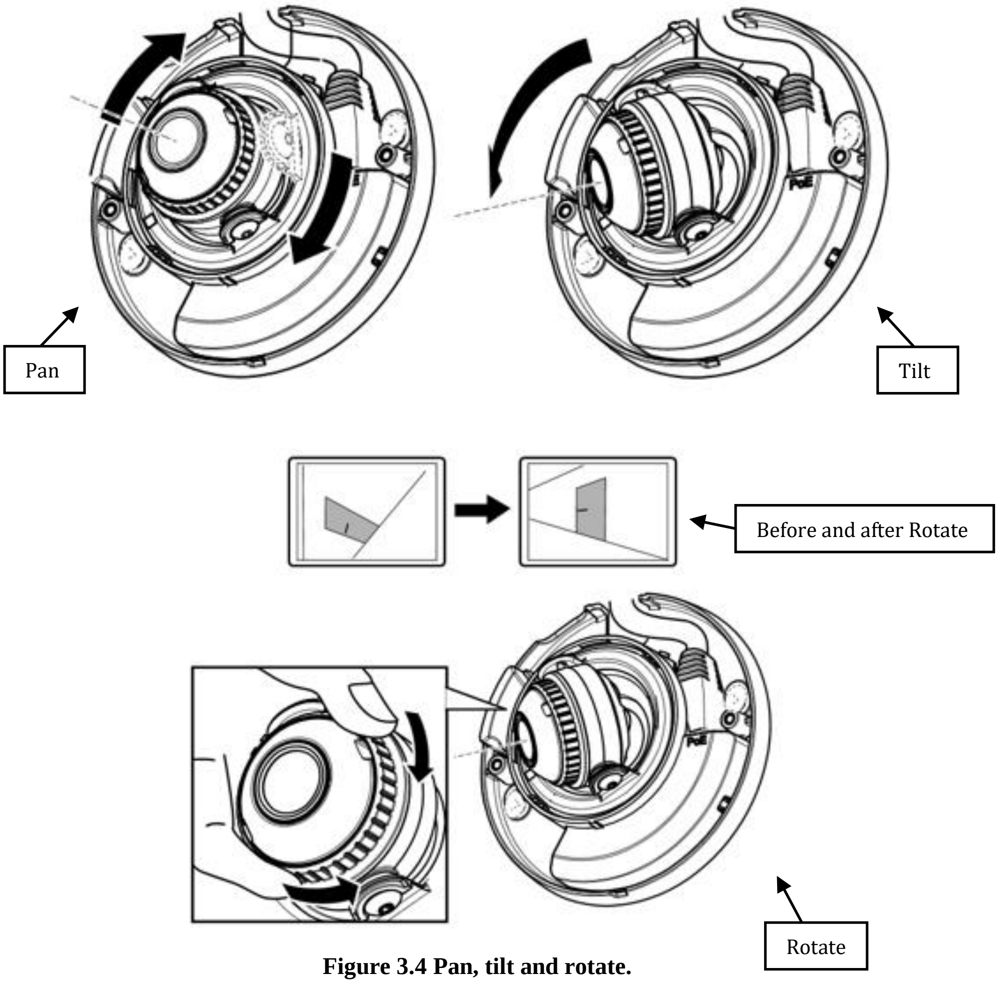

Figure 3.4 Pan, tilt and rotate.

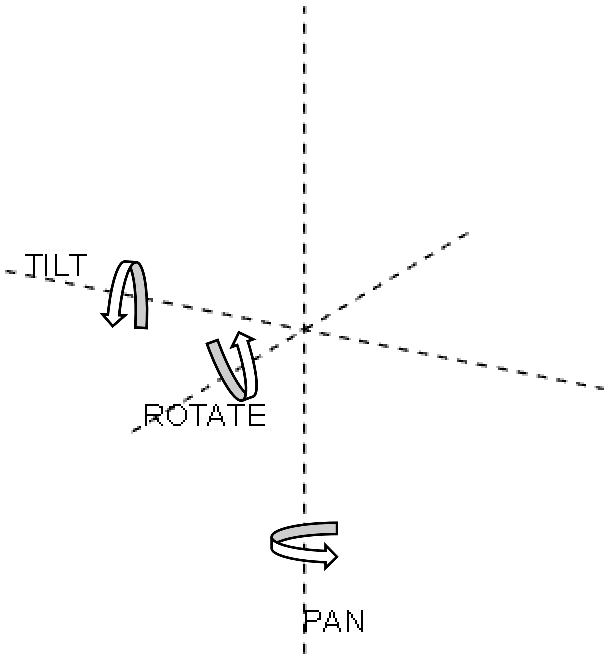

Figure 3.5 Axis for pan, tilt and rotate.

3.2.1 **Friction**

In the current design two wave springs are used to create extra friction. The added friction is there to make sure that the camera is steadily in position after installation and redirection as well as making the feeling of the manual movements more robust. This is a vital part of the design for a fixed dome and it is important that it is in fact fixed at all times.

Although, when designing a product where parts are moving, friction is often one of the biggest challenges. Therefore, this has to be taken under consideration during the concept development. Most likely a tradeoff between friction and fixations will have to be made.

4 Specifications

The first activity in the product development process is the identification of customer needs followed by establishment of target specifications.

4.1 Background

Identifying customer needs is an important part of the product development process. The purpose of this is to ensure that the product is in fact focused on the customer needs and to identify hidden needs. Furthermore, it develops a common understanding of the customer needs between the participants in the project, in this case the student and the company. [3]

The goal with identifying the customer needs is to obtain a basis for the target specifications. Since Axis already has substantiated specifications for their cameras, the extensive work according to Ulrich and Eppinger's method will not be performed. The purpose of this part is only to gather the customer needs that are not already stated in the specifications for Axis cameras. These customer needs will complement the already existing specifications.

4.2 Customers

When looking into possible customers, three customers were identified:

- The end customer
- The installer
- Axis Communications

The three customers have different needs but all needs must be taken under consideration during the identification of customer needs. A typical end customer for a small fixed dome camera is a retail store or a shopping mall and the installer will most likely be a certified camera installer. Axis Communications is the company that have asked for a new concept and therefore are their business needs important customer needs to consider during the concept generation.

The collected raw data from Axis was based on informal interviews with employees that had been involved in the AXIS Q36 project. This decision was based on the fact that they had interesting thoughts and reflections from the previous AXIS Q36 project. More information from the interviews can be found in Appendix B. To gain an understanding of the customer needs from the certified camera installers and the end customer information was gathered from the global product manager [6]. This decision was based on the fact that she is the one that communicate with the end customers and knows what they need. The information obtained from conversations with her gave a lot of insight when it comes to customer needs.

4.3 Target Specifications

The purpose of the target specifications is to describe the goals with the product. The specifications shall contain a measurable quantity and a desired value. The target specifications are based on the customer needs. [3]

All camera models that have been developed at Axis have a document named Product Requirement Specification. In this document there is a list of requirements for the specific camera model. To make sure that the camera models live up to Axis standards all models have to pass certain certifications tests and standards. From these documents the requirements, tests and standards relevant for this project was gathered and summarized into table 4.1.

Table 4.1 List of Product Requirements Specifications.

Product Requirement Specifications	
1.	Camera angle adjustments: Pan: ±180°, Tilt: ±90° and Rotate: ±95°
2.	By default the picture shall be correct rotated for camera mounted in/on wall
3.	No loss of function within the temperature range of 0°C to + 45°
4.	Possible to store the product in the temperature range of -40°C to +70°C
5.	No loss of function within the humidity range of 15% to 85% RH (non-condensing)
6.	Efficient and discreet cable solution
7.	It shall be possible to mount the product on wall/ceiling
8.	Pass Axis certification test and standards

Based on the specifications above and the customer needs the target specifications for this project can be found in table 4.2. Three stars shows that the need is of the utmost importance and one star shows that the need is desired. The weight factors was established by the writer of the thesis based on the information gained from the informal interviews. The final list of target specifications will be used as a reference during the concept generation to make sure that the product is in fact focused on the customers and their needs.

Table 4.2 Final List of Specifications.

Final List of Customer Needs & Target Specifications		
Pan, tilt and rotate functionality	***Weight***	***Unit***
1. Pan, tilt and rotate remotely (pan: ±180°, tilt: ±90°, rotate: ±95°)	***	°
2. Withstand redirection approximately once a month (200 cycles)	**	Cycles
3. Should not be possible to hacking the camera from the outside	***	Subj.
4. The camera can be fixated without help of the PTR functionality	**	Subj.
5. Function during the cameras lifecycle (minimum 3 years)	*	Years
6. Reasonable time for the full cycle of movements (maximum 2 min)	*	min
7. It shall be possible to mount the product on wall/ceiling	***	Subj.
8. Reasonable cost	***	SEK
Environment		
9. No loss of function within the temperature range of 0°C to + 45°C	**	°C
10. Possible to store the product in the temperature range of -40°C to +70°C	**	°C
11. No loss of function within the humidity range of 15% to 85% RH (non-condensing)	*	%
Measurement		
12. Maximum diameter: 101 mm	**	mm
13. Interval for height: 56 – 66 mm	**	mm
14. Efficient and discreet cable solution	*	Subj.
Other		
15. Pass Axis certification test and standards	***	n/a
16. Easy to install (10 min)	**	h
17. Ease of manufacture (20 min)	*	h

5 Benchmarking, Patents & Tests

This chapter includes benchmarking, patent search and tests. All these parts of the concept development are carried out in parallel to the other parts.

5.1 Background

The choice of products for the benchmarking was based on the research conducted in the different phases of the concept generation. The aim of the benchmarking was to find products that could pan, tilt and rotate as well as investigate if any of Axis competitors had developed similar products. When realizing that most of the products only could pan and tilt these products were also included in the benchmarking. When looking at other products it was interesting to see how the movement was created as well as the overall design. To gain inspiration for a cost efficient concept some low-priced cameras were also investigated. The information was gathered both internally and externally and the findings were compiled into a table 5.1. The pictures and figures from the benchmarking can be found in Appendix C. During the patent search the focus was on patents with pan, tilt and rotate mechanisms. At this stage it was interesting to see which technologies that enabled the movement as well as how the transmission was designed. The choice to perform tests was made to learn more about the pan, tilt and rotate movements. The idea was that the results from the test would give insights for the final solution.

5.2 Benchmarking

During the benchmarking eight different interesting cameras were found. In table 5.1-2 important information regarding the cameras are summarized. The information that could not be obtained is marked with not applicable (N/A).

Table 5.1 Basic information.

Model name	***Company***	***Price***	***Weight***	***Size (mm)***	***Indoor/ Outdoor***
Q3615-VE	Axis [7]	$ 1349	2.3 kg	Ø 198 x 166	Outdoor
Q3617-VE	Axis [7]	$ 1549	2.3 kg	Ø 198 x 166	Outdoor
VB-H651V	Canon [8]	$ 1.172	0.89 kg	Ø 150 x 129	Indoor
VB-H651VE	Canon [8]	$ 1.591	1.71 kg	Ø 180 x 135	Outdoor
EyeSeeCam	Robot Eye [9]	N/A	0.10 kg	44 x 44 x 200	Indoor
M3S	Baby monitor [10]	$ 200	0.45 kg	22 x 16 x 14	Indoor
B97A	ACTi [11]	$ 1398	1.3 kg	Ø 153 x 116	Outdoor
IPC-A15	Dahua [12]	$ 224	220 g	94 x 94 x 94	Indoor

Table 5.2 PTR functionality.

Model name	***Technology***	***Pan***	***Tilt***	***Rotate***	***Gears***
Q3615-VE	Servo gearbox motors	370°	±81	±110	Worm and gear wheels
Q3617-VE	Servo gearbox motors	370°	±81	±110	Worm and gear wheels
VB-H651V	Stepper motors	±175° 20.1°/s	±75° 21.7°/s	±175° 40.0°/s	Worm and gear wheels
VB-H651VE	Stepper motors	±175 20.1°/s	±75 21.7°/s	±175 40.0°/s	Worm and gear wheels
EyeSeeCam	Ultrasonic piezo motors	±30°	±30°	±30°	No gears needed
M3S	Stepper motors	N/A	N/A	N/A	Direct transmission
B97A	Stepper motors	±175°	0-180°	N/A	Three gear wheels / motor
IPC-A15	Stepper motors	0°-355° 100°/s	0°-90° 100°/s	N/A	Worm and gear wheels

Both Axis and Canon has developed two camera models each with remote PTR functionality. As seen in the specifications all four models are bigger than the camera used in this project. When it comes to the technologies all benchmarked products uses some kind of motor to create the movement. The solution ACTi and Canon are using in their camera models is interesting. They use three gearwheels per motor to create high gear ratio. The usage of several gear wheels takes up quite a lot of space, but could still be an interesting solution for this project. The EyeSeeCam is a compact and high dynamic camera developed for a robot eye. The mechanical design is based on a parallel kinematic system with ultrasonic piezo motors. This solution is interesting as well, although it might not be the most cost efficient option.

5.3 Patents

Eleven different interesting patents were found during the patent search. In table 5.3 the result from the patent search is summarized when it comes to the technology and transmission used as well as PTR functionality or only PT functionality.

Table 5.3 Result from the patent search.

Patent	***Technology***	***PTR***	***Transmission***
Dome shaped camera with simplified construction positioning. [13]	Stepping motor	PT	Gears/rollers/belts and pulleys/chains
Camera head with pan, roll and tilt movement. [14]	Electric DC motor	PTR	Gears or sprockets
Fourth axis camera support system and method. [15]	Motor	PT	Drive gears
Camera having a slip ring and pan-tilt mechanism. [16]	Motor	PT	Tooth spur gear pinion
Two degree of freedom camera mount. [17]	Servomotor	PT	Linkages and knobs
Direct drive electric motor apparatus incorporating slip ring assembly. [18]	Stepping motor	PTR	Gears/rollers/belts and pulleys/chains
Miniaturized turret-mounted camera assembly. [19]	Servomotor	PT	Follow gears and feedback gears
Pan/tilt camera system. [20]	Stepping motor	PT	Pan: Toothed belt Tilt: Worm wheel and worm shaft
Pan/tilt apparatus and camera equipped with the same. [21]	Motor	PT	Gears
Miniature low cost pan/tilt magnetic actuation for portable and stationary video cameras. [22]	Pan: motor Tilt: magnetic field + mirror	PT	Spindle gear
Drive mechanism for surveillance camera pan and tilt. [23]	Motor	PT	Gears, worm drives, idler wheels

As seen in the table most of the patents found only has pan and tilt and not rotate. From the patent search some interesting ideas was found which contributed to the concept generation. The two patents that were found with full PTR functionality are further described below.

5.3.1 **Camera head with pan, roll and tilt movement**

This patent describes a remote control camera head with a first and a second roll fork attached to the pan frame. The head can provide movements in three axes. The camera head (20) is connected to a pan frame (22) with a pan motor (34) and the camera head (20) can rotate around the pan axis (14). To create the roll movement, along the roll axis (16), roll tracks (44) are attached at the inner edges of the roll arms (42). The motor for the roll movement (66) drives gears along the tracks and the roll frame can move ±30 degrees. To create the tilt movement a motor (50) is attached to the left side arm (64). The tilt motor (50) makes the camera rotate along the tilt axis (18). [14]

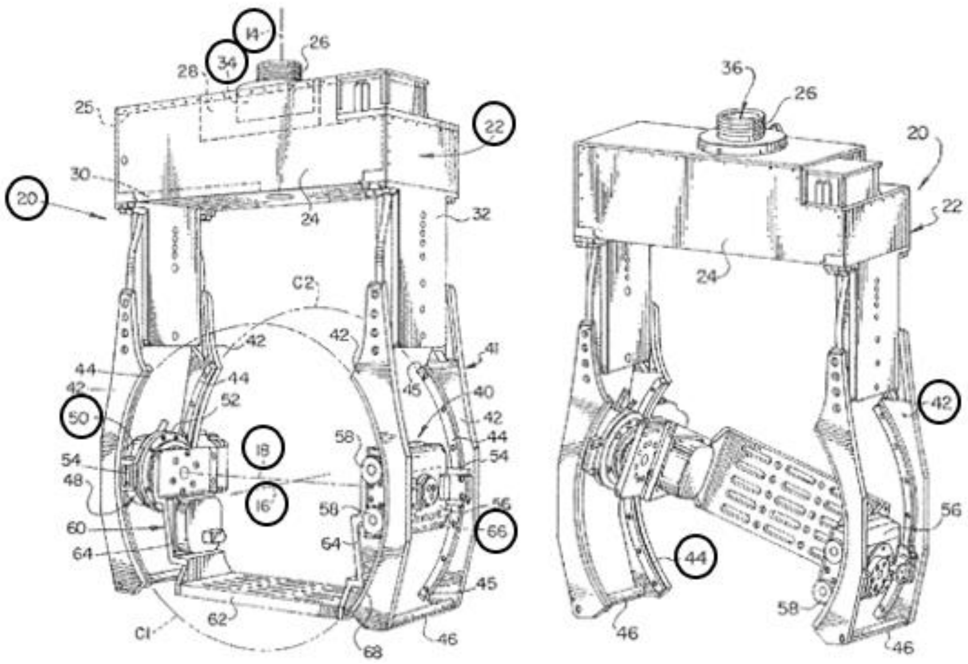

Figure 5.1 Camera head with pan, roll and tilt movement.

5.3.2 **Direct drive electric motor apparatus incorporating slip ring assembly**

This patent describes an apparatus with electrical motors for positioning a camera or a robot arm in three axes. A pan motor (2) is fixed to the base plate (4), which makes the rotation around the horizontal axis. A tilt motor (10) is fixed to the bracket (7) and the camera (12). The tilt motor makes the camera rotate along the vertical axis. In the figure to the right a robot arm (20) with a motor (25) creates the rotary movement. [18]

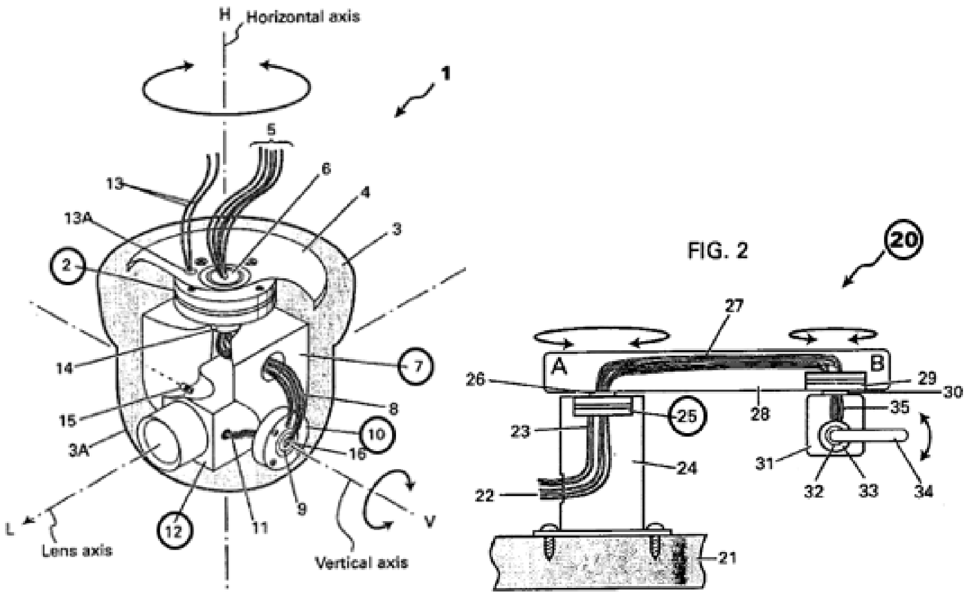

Figure 5.2 Direct drive electric motor apparatus incorporating slip ring assembly.

5.4 Test Rig

Before the concept generation a test rig was set up to test how much torque that is needed when using motors together with gear wheels. Because of simplicity it was decided that the test rig only tests the pan and the tilt movements. It was assumed that the motors would be able to make the rotational movement if they manage the pan and tilt movements.

The design of the test rig was made by the writer of the thesis at Axis own workshop. The overall design was made of bent sheet metal. When designing the test rig the gear wheels needed to be placed accurate to simulate how the motors and gear wheels would behave in a real product. Therefore, the center distance between the gear wheels was calculated.

To calculate the center distance (a) the teeth number (N), the pitch diameter (D_p) and the outer diameter (D_o) must be known. See equation 5.1 and 5.2 below [31].

$$a = \frac{D_{p1} + D_{p2}}{2} \tag{5.1}$$

$$D_p = \frac{D_o \times N}{N + 2} \tag{5.2}$$

Table 5.4 Values for the gear wheels in the test rig

Gear wheel	***Teeth Number (N)***	***Outer diameter (D_o)***
Pinion – Tilt	10	11,5 mm
Gear wheel – Tilt	30	31, 5 mm
Pinion – Pan	20	21,5 mm
Gear wheel – Pan	50	51,5 mm

Using equation 5.1 and 5.2 and the values in table 5.4 the calculations gave a center distance of 35 mm for pan and 20 mm for tilt.

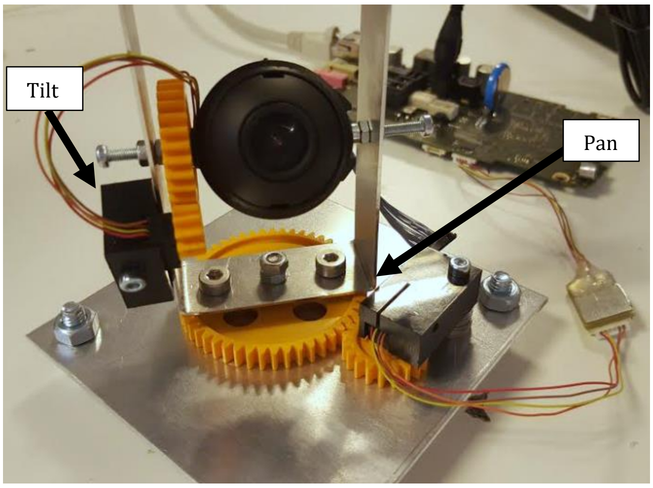

Figure 5.3 The test rig.

To calculate how much torque that is needed the gear ratio must be known. The gear ratio is calculated by dividing the number of teeth on the driven gear with the number of teeth of the drive gear (the pinion). See equation 5.3 below.

$$Gear - ratio = \frac{N_{driven}}{N_{drive}} \tag{5.3}$$

The tests in the test rig showed that the torque needed for pan is at least 0.025 Nm and the torque needed for tilt is at least 0.015 Nm. Rotate was not tested in the test rig but it was assumed that the torque needed for rotate is between 0.015 Nm and 0.025 Nm. More details and other test results can be found in chapter 8.

6 Problem Decomposition

This chapter includes the problem decomposition.

6.1 Background

The aim of the thesis is to find a new electromechanical design to enable a cost effective remote PTR functionality in a small fixed dome camera. To develop such concept a decision was made to divide the problem into sub problems.

Problem decomposition is a way to divide the problem into simpler sub problems. When dividing the problem into sub problems it is important to describe the sub problems in a way that does not imply on a specific technological working principle. The problem decomposition will result in a list of sub problems to be solved in a focused way. [3]

6.2 Sub Problems

It was decided that the following sub problems needs to be handled in the order that they are written in.

1. Find a suitable electromechanical technology that enables the movement.
2. Further investigation and evaluation of the chosen electromechanical technology.
3. Generate the complete concept based on the result from previous sub problems.

7 The First Sub Problem

This chapter includes the selection of electromechanical technology. Before the actual selection the method is described as well as the background and the identified challenges. In the end of the chapter an electromechanical technology is chosen with the use of a concept classification tree.

7.1 Method

To find a suitable electromechanical technology information was gathered internally and externally. The research was based on sources outside Axis and informal conversations within Axis was carried out throughout the process. A concept classification tree was used to divide possible solutions into several branches, which was evaluated and compared before some of the branches could be dismissed [3].

7.2 Background

To create the PTR movements there is a need of some kind of actuator that supplies motion. This is a critical part of the final design and therefore it needs to be carefully selected. The choice to use a classifications tree was based on the thought that some of the less promising technologies could be removed early in the process.

7.3 Identified Challenges

One of the challenges was to find a technology that is efficient when it comes to size and force. Another challenge was that it is important that the technology itself does not disturb the technology inside the camera.

7.4 Concept Classification Tree

During the research four main technologies were found that could create movement. The following technologies were found:

- pneumatic
- hydraulic
- motors
- magnetism

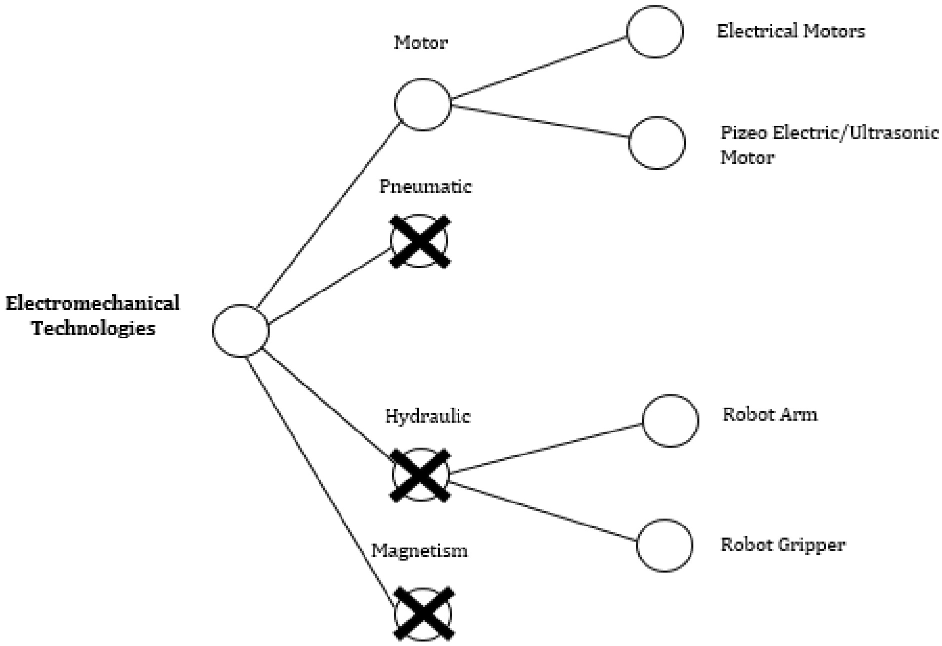

Figure 7.1 Concept Classification Tree.

7.5 Result

When analyzing the concept classifications tree, three technologies could be dismissed. Magnetism was dismissed because it could disturb the electronics in the camera and it could easily be manipulated from the outside. Pneumatics was dismissed due to the fact that it needs a source of compressed air and it is difficult to control. Hydraulic actuators have some benefits when it comes to torque and nonlinear dynamics and it is a technology that is commonly used in the industry

[24]. The biggest drawback with hydraulic actuators is that they need a complex and external power supply system [25], which most likely will not fit inside the camera device. Another drawback with hydraulic systems is that they have a complicated mechanical design [26], which makes it difficult to control them compared to electrical motors. The conclusion was that hydraulics and pneumatics solutions are not as suitable as electrical motor because the size of the overall system will not fit inside the shell of the camera. Furthermore, none of the products found during the benchmark or patent search were based on magnetism, hydraulics or pneumatics. Therefore, the conclusion was that the electromechanical technology that is best suited for the task is motors.

Now the first sub problem "Find a suitable electromechanical technology that enables the movement" is finished. The next step is "Further investigation of the chosen electromechanical technology". The chosen electromechanical technology was motors, therefore the next step was to investigate which kind of motor types that would be best suited for application.

8 The Second Sub Problem

This chapter includes the selection of motor type. In this chapter the method is described as well as the background and the identified challenges. This is followed by research and concept development. In the end of the chapter a motor type is chosen with the use of a concept screening matrix.

8.1 Method

To find a suitable motor type information was gathered externally. Some of the research conducted during the first sub problem could be reused but more information regarding different motor types was collected. For this part a concept screening matrix was used. The purpose of a concept screening matrix was to narrow down the concepts in an easy and efficient way. [3]

8.2 Background

During the concept generation of motor types it was assumed that the friction would be less than in the original camera design. Therefore, it also included motors that otherwise would be too weak. Different motor types were investigated to see how and if the specific motor type is suitable for the application. The selection of motor types was based on the benchmarking, the patent search and discussions with employees at Axis. Furthermore, the selection was based on the results from the tests which showed that the torque needs to be at least 0.025 Nm for pan and 0.015 Nm for tilt.

8.3 Identified Challenges

It is already known that there will be a limited amount of space for the motors. The friction is also a challenge due to the fact that it creates a need for stronger motors which often are larger compared to less stronger motors.

8.4 Concept Generation – Motor Types

To create the PTR movements there is a need of three motors, one for each rotation axis.

8.4.1 Concept A – Servo Motors

A servo motor has an integrated gearing set, which makes the torque higher. A servo motor comes with a control circuit and a position sensor. When the motor has found the correct position it will hold that position until the force is higher than the torque. The motor is controlled with PWM signals, which is complicated compared to controlling a stepper motor. The advantage with a servo motor is that they are fast. The drawback is that they are difficult to control but on the other hand Axis already have knowledge of how to control it. [27]

8.4.2 Concept B – DC Motors

A DC motor is similar to a servo motor when it comes to the specifications interesting for this project, but without the benefit of an integrated gearing set, a control circuit and a position sensor. Therefore, a DC motor can only be turned on or off. The drawback with a DC motors is that they are difficult to control and as a result it is challenging to create an accurate positioning. [27]

8.4.3 Concept C – Stepper Motors

A DC motor and a servo motor uses continuous rotation and a stepper motor rotates using steps. The integrated steps make it easy to control it, although it needs an external control circuit. Compared to the servo motor and DC motor a stepper motor is quite slow. [27]

8.4.4 Concept D – Spherical Motor

A spherical motor is a way to create movement in three dimensions with less moving parts. A spherical motor consist of a stator and a rotor and the symmetry of the pole arrangement is different in the stator and the rotor. Therefore, the torque is created by energizing the stator, which then creates a movement of the rotor. The rotor of a spherical motor is hollow sphere with permanents magnets inside of the sphere. [28]

When using a spherical motor only one motor is needed to create the PTR movement. The benefit with a spherical motor is that it does not need any extra components. Compared to the servo motor, DC motor and stepper motor the drawback with the spherical motor is that Axis have none experience and it is a technology that are still under development.

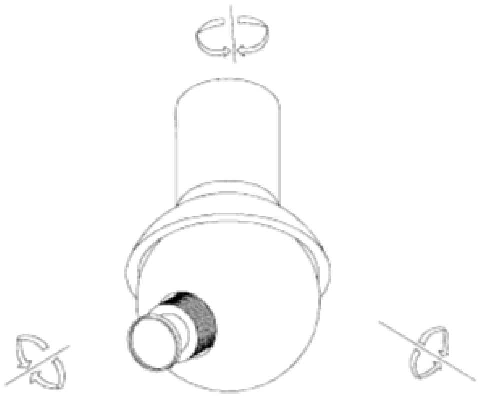

Figure 8.1 Spherical Stepper motor.

8.4.5 Concept E – Piezo Motors

The technology of a piezo motor consists of a rotor and a stator. The reverse piezoelectric effect converts electric power into mechanical energy created from vibrations. [29] The piezo electric motor is expensive compared to a servo motor, a DC motor and a stepper motor. The torque gain from a piezo motor is strong compared to the size of the motor, a quality that would be useful in this project.

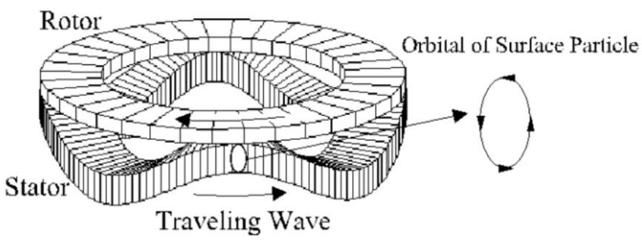

Figure 8.2 Piezo Electric Technology.

8.5 Concept Selection

The method used to select motor type was concept screening [3]. The selection criteria were based on the customer needs and target specifications. Although, they were modified to fit the selection of motor type. Servo motor (concept A) were used in the AXIS Q36 camera and will therefore be the reference concept. To determine the concepts rates in comparison to the reference concept they received either a plus (+), a zero (0) or a minus (-). If a concept receive a plus it means that it is better than the reference concept, if it receives a zero it means that is it the same as the reference concept and a minus means that it is worse than the reference concept.

Table 8.1 Concept Screening Matrix.

	Concepts				
Selection Criteria	***A - Servo (Reference)***	***B - DC Motor***	***C - Stepper***	***D-Spherical***	***E - Piezo***
Controllability	0	-	+	-	0
Speed	0	0	-	0	+
Positioning	0	-	0	-	+
Torque	0	0	0	0	-
Size	0	0	+	0	+
Prize	0	0	0	-	-
Sum +'s	0	0	2	0	3
Sum 0's	6	4	3	3	1
Sum –'s	0	2	1	3	2
Net Score	0	-2	1	-3	1
Rank	3	4	2	5	1
Continue	No	No	Yes	No	Yes

The DC motor is quite similar to the reference concept but the fact that it difficult to control and has less accurate positioning was the reason why it was decided that it will not be continued. The stepper motor is also quite similar to the reference concept. It is easier to control and more size efficient but it is not as fast as the reference concept. The spherical motor is both expensive and has worse controllability characteristics compared to the reference concept. The piezo motor has some advantages and disadvantages compared to the reference concept. Even though the price will be an important aspect when selecting the final concept it was decided that the piezo motor could still be an interesting option.

8.6 Further Investigation

In this part the goal was to find a stepper motor and a piezo motor within the size and torque limits. After research and workshops with experiences mechanical developers at Axis [30] a promising stepper motor was found. The motor found is a micro geared stepper motor from Seiko with model number X0565. Three companies that manufacture piezo motors was found: PiezoMotor, PI Ceramic and PCB Motors, all of them develops and manufacture piezo motors with controllers. PiezoMotor is a Swedish company in Uppsala, PCB Motor is Danish company and PI Ceramic is located in Germany. Based on the fact that Axis already had a contact at PCB Motor one of the PCB Motors was selected for further investigation.

The torque gained from a motor is usually coherent with the size of the motor. This means that there it is a tradeoff between size and torque. In this project it is important that the torque is high enough to move the camera along the three axis but it is also important that the motor is not unnecessarily strong due to the limited amount of space available. Therefore, the Seiko X0565 and the PCB Motor are further investigated and tested in the following sections.

8.6.1 **Seiko X0565**

The Seiko Geared Motor X0565 has an integrated gearing set and a pinion. The choice of motor was based on the fact that it creates high torque compared to its size. More information about the motor can be found in table 8.2. To see if the motor is in fact strong enough a test was conducted on the test rig. The drawing of the motor can be found in Appendix D. The information about the motor was gathered at Axis.

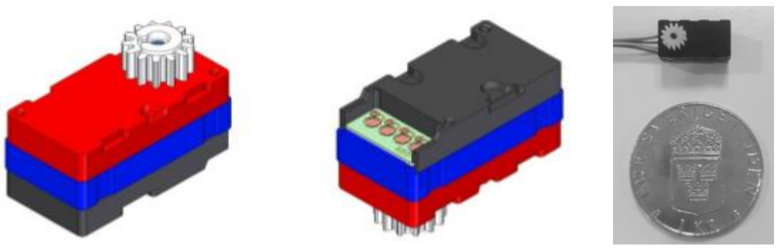

Figure 8.3 Seiko X0565.

Table 8.2 Specifications – Seiko X0565.

Motor	
Type	Stepping motor
Size	13.3 × 7 × 6.3 mm
Weight	0.9 g
Torque	0.006 Nm
Positioning	0.41°
Prize	$ 2
Temperature range	-10°C to +50°C

Pinion	
Tooth form	Involute
Pressure angle	20°
Module	0.3
Number of teeth	13
Pitch diameter	Ø 3.9 mm
Outside diameter	Ø 4.5 mm

8.6.2 **PCB Motor**

PCB Motor was contacted through a conference call with the owner Henrik Mogens Stæhr-Olsen (9 November). During the meeting the overall mechanical design as well as the performance, reliability and cost of the motors were discussed. The conclusion was that the motor will cost approximately $15 each if Axis buys high quantities and Henrik thought that the torque and speed of the PCB Motor will be sufficient for the application.

The information gained was promising but also a disappointment. The PCB Motors piezo motors appeared to be quite expensive and require an advanced mechanical design.

Table 8.3 Specifications for the PCB Motor.

Model	***PCBMotor***
Type	Piezo motor
Size	Ø12, 24 x 6 mm
Torque	0.025 Nm
Speed	1.3 rps
Prize	$ 15
Temperature	-20°C to +50°C

To test the piezo motors a start kit was bought from PCB Motor. The start kit consists of a motor (Ø30 mm) with a stator, a rotor and driver electronics. The start kit was be powered with a standard USB Mini B cable. There was no need for any software to control it, instead it was powered by shorting two pins.

Figure 8.4 PCB Motor start kit.

8.6.3 Test Results

When testing the Seiko X0565 gears were used to simulate how it would work in a real product. The gear ratio in combination with the torque from the motor created a total torque of 0.018 Nm for tilt and 0.03 Nm for rotate. The PCB Motor is supposed to be used without any transmission and therefore the test rig was not used, instead the camera was attached directly to the PCB Motor starter kit. The torque created from the PCB Motor is 0.025 Nm, which was enough for moving the camera around the axis for pan. The results from the tests showed that both the Seiko X0565 and the PCB Motor are strong enough for creating the pan and tilt movements.

8.7 Result

Based on the result from the concept screening matrix it was decided that there was no need to make a concept scoring matrix. The concept screening matrix showed that the stepper motor and piezo motor are best suited for the application. Therefore, these concepts were further investigated. During the investigation two promising motors were found. The stepper motor Seiko X0565 and the piezo motor PCB Motor. The result from the tests showed that both motors would work in the application.

9 The Third Sub Problem

This chapter includes the concept generation of the complete concept.

9.1 Method

To be able to select the complete concept the first step is to generate several concepts. The concept generation will be based on the information that has been gathered during the previous parts but also new information from workshops and informal interviews with experts at Axis. The concepts will be evaluated in a concept scoring matrix. [3]

9.2 Background

Part three is the design of the complete concept which was based on the investigation made in part one and part two of the product development section. Therefore, the concepts will consist of stepper motors and piezo motors. Due to the fact that the problem was divided into three sub problems the amount of concept will be less than there would have been otherwise.

9.3 Identified Challenges

Prior to the concept generation some challenges were identified. When designing the complete concept the cable solution needs to be well thought out to make sure that the cables will fit and at the same time not be in the way. When designing the complete concept the positioning of the camera must also be taken under consideration. Finally, when designing the complete concept the suspension device needs to be designed. As mentioned before, the friction will most likely be a problem. It was decided that the friction and the positioning will be handled after the final concept is selected.

9.4 Concept Generation

Throughout the project a lot of ideas came up during workshops and brainstorming. Some of the ideas could be dismissed immediately due to price, space or feasibility. The concepts that seemed most promising was further discussed and developed. In the following part of the report these concepts are shown as sketches with description. In figure 9.1 sketches of all promising concepts are shown. All concepts except concept D consists of the Seiko X0565 and concept D consists of the PCB Motor.

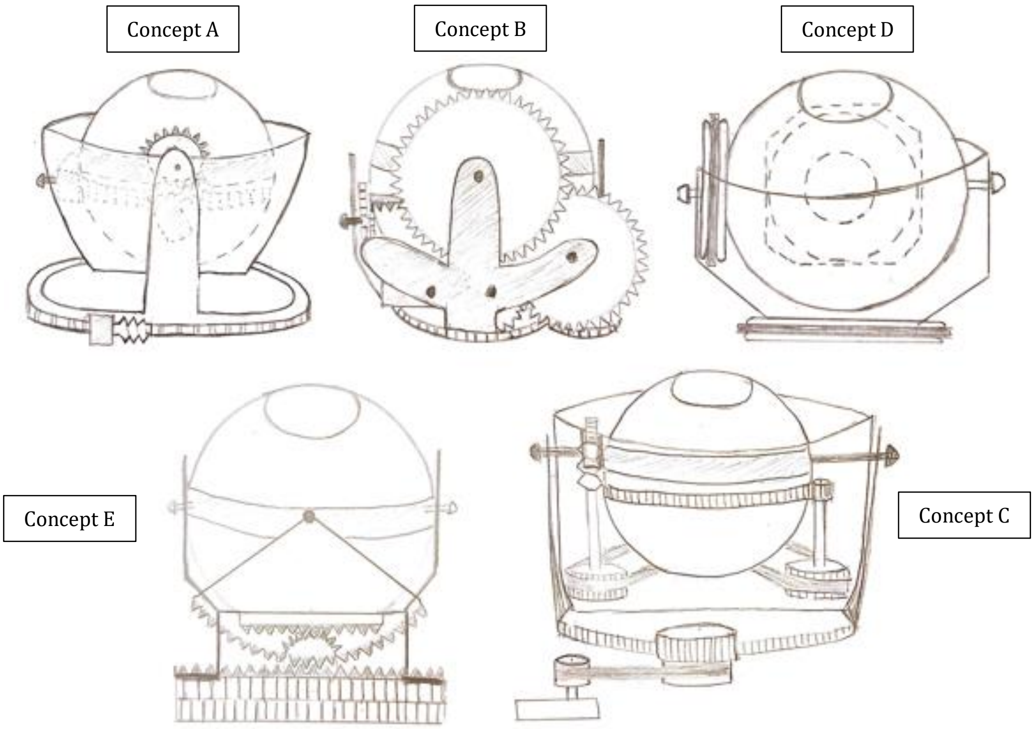

Figure 9.1 All concepts.

9.4.1 **Concept A**

This concept is inspired from the camera model AXIS Q36. For the pan and tilt a worm gear (1) acts as a single toothed gear, therefore the ratio is higher compared to two spur gears. Two spur gears are used to make the transmission for rotate (2), this choice was made on the fact that it is estimated that rotate needs less torque than pan. The camera is mounted on a suspension device (3), which is moved by the pan motor (4).

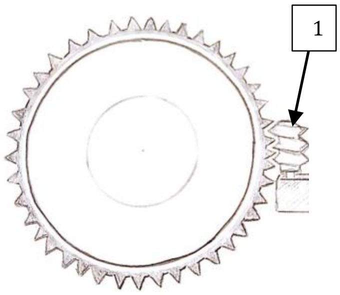

Figure 9.2 Pan.

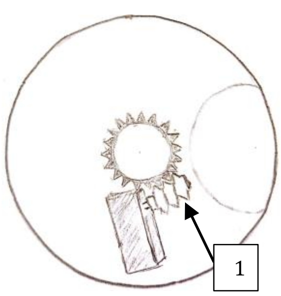

Figure 9.3 Tilt.

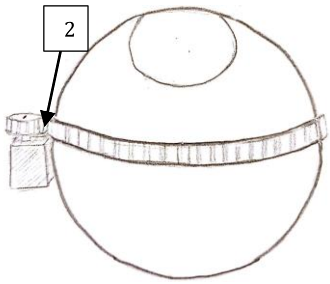

Figure 9.4 Rotate.

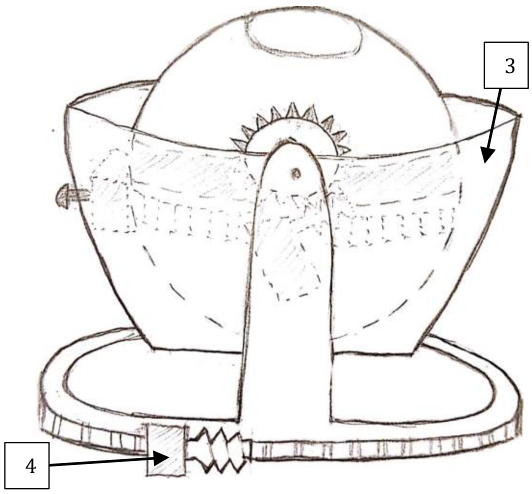

Figure 9.5 Pan, tilt and rotate.

9.4.2 **Concept B**

Concept B was inspired from the ACTi camera found during the benchmarking. This concept is similar to concept A but instead of worm gears several spur gears (1) are connected to create higher gear ratio. The suspension device (2) needs to be more complex to hold up the different spur gears. This solution takes up more space compared to concept A and the cost for several spur gears needs to be taken under consideration.

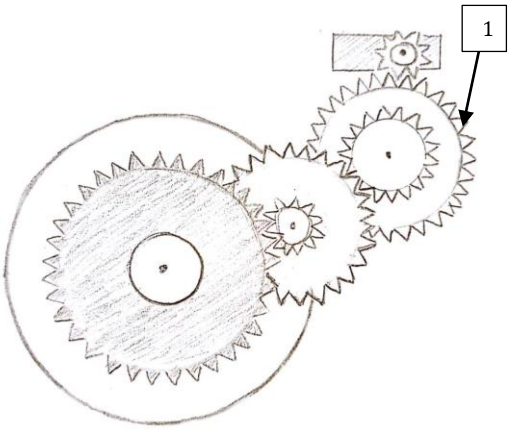

Figure 9.6 Pan.

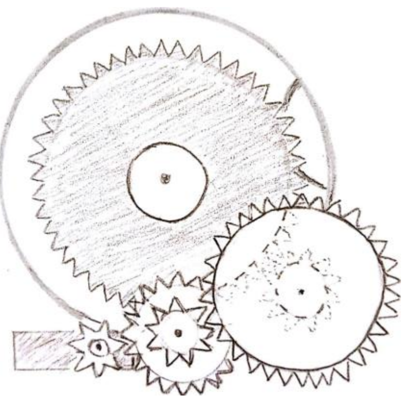

Figure 9.7 Tilt.

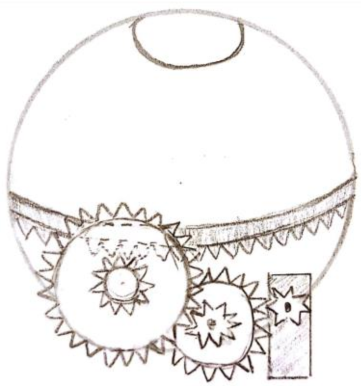

Figure 9.8 Rotate.

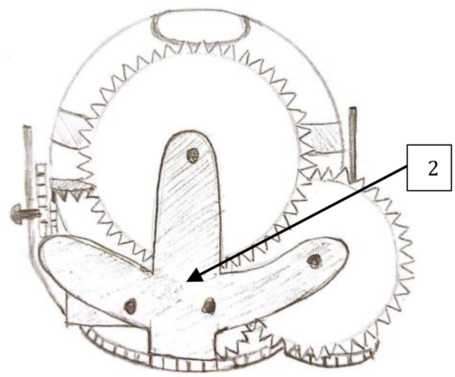

Figure 9.9 Pan, tilt and rotate.

9.4.3 **Concept C**

This concept is also similar to concept A but instead of a spur gear or a worm gear a belt is used (1) for pan. A spring (2) is used to make sure that the worm gear and spur gear is connected to each other. The usage of belts makes the design more flexible because the length of the belt could be adjusted as well as the placement of the motor.

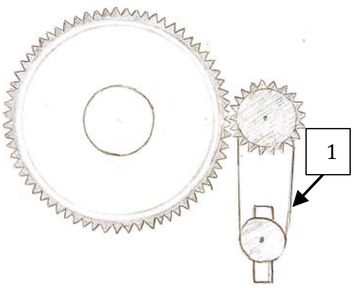

Figure 9.10 Pan.

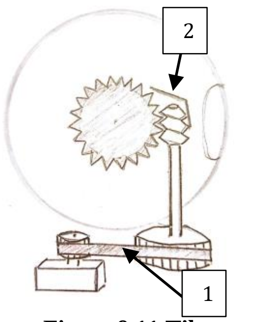

Figure 9.11 Tilt.

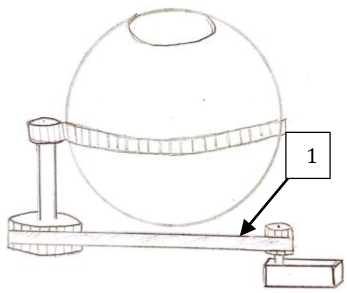

Figure 9.12 Rotate.

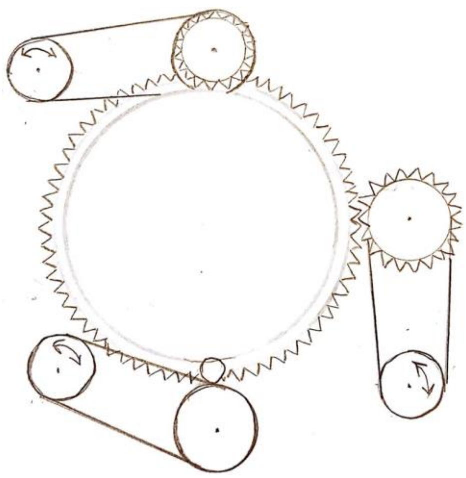

Figure 9.13 From above without the camera.

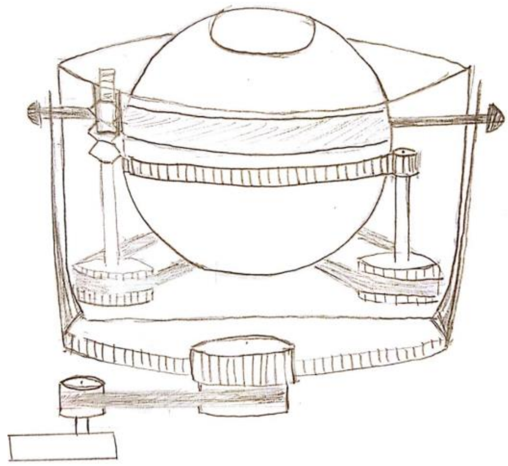

Figure 9.14 From the side with the camera.

9.4.4 **Concept D**

In this concept three piezo motors with hollow center is used. The pan motor (1) is placed under the camera. The motor consists of piezo elements, which can be seen on the pan motor (2). The tilt motor is placed on the side of the camera (3), the hollow center of the motor makes it possible to mount it directly on the axis. For this concept a CAD model was already made, the green parts (4) illustrate the piezo motor and its components. The gray part (5) is a wave spring, which creates the friction that is needed for the piezo motor to function.

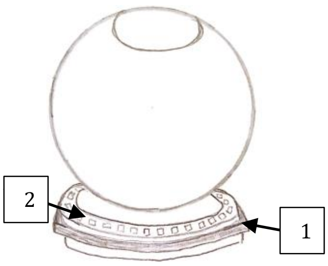

Figure 9.15 Pan.

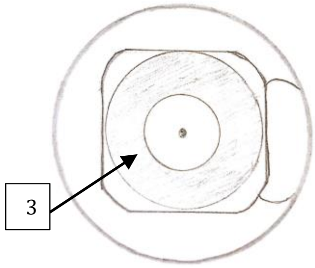

Figure 9.16 Tilt/Rotate-

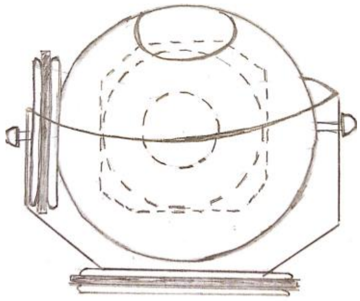

Figure 9.17 Pan, tilt & rotate.

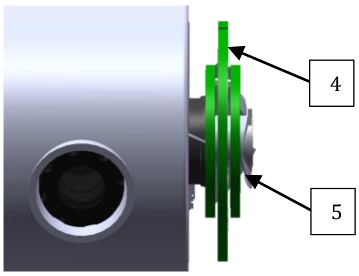

Figure 9.18 CAD model.

9.4.5 **Concept E**

This concept is designed with a small spur gear (1) attached to the motor (2) and a bigger spur gear (3) attached to the camera or suspension device. It is the same design for pan, tilt and rotate except the placement and size. Instead of having the tilt spur gear on the side of the camera the pan and tilt spur gear are above each other (4). This design was made because the space under the camera is bigger than the space on the side of the camera.

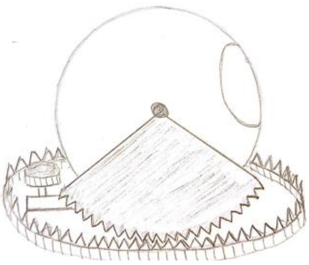

Figure 9.19 Tilt.

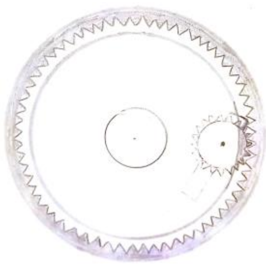

Figure 9.20 Pan.

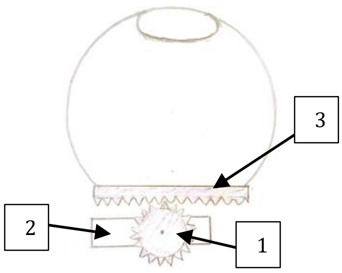

Figure 9.21 Rotate.

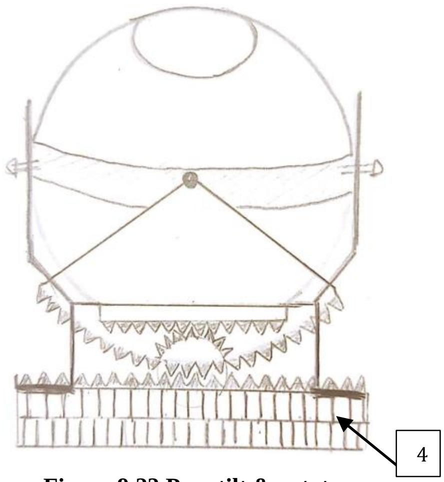

Figure 9.22 Pan, tilt & rotate.

9.5 Concept Selection

9.5.1 Concept Scoring Matrix

The selection criteria were based on the target specification, which was established previously in chapter 4. The weighting was selected based on the criteria's relative importance. The rating of the different concepts was made by the writer of the thesis together with the supervisor at Axis.

Table 9.1 Concept Scoring Matrix.

		Concepts									
		A		***B***		***C***		***D***		***E***	
Selection Criteria	***Weight (%)***	***Rating /Score***		***Rating /Score***		***Rating /Score***		***Rating /Score***		***Rating /Score***	
Durability	10%	4	0,4	3	0,3	2	0,2	5	0,5	4	0,4
Robust	10%	4	0,4	3	0,3	3	0,3	4	0,4	3	0,3
Long life	5%	4	0,2	3	0,15	3	0,15	3	0,15	4	0,2
Speed	5%	3	0,15	2	0,1	3	0,15	4	0,2	3	0,15
Low cost	15%	5	0,75	4	0,6	4	0,6	1	0,15	5	0,75
Temperature resistance	10%	3	0,3	3	0,3	3	0,3	3	0,3	3	0,3
Humidity resistance	5%	3	0,15	3	0,15	3	0,15	3	0,15	3	0,15
Size efficient	15%	3	0,45	2	0,3	2	0,3	4	0,6	3	0,45
Cable salutation	5%	3	0,15	3	0,15	3	0,15	4	0,2	3	0,15
Easy installation	10%	4	0,4	3	0,3	3	0,3	4	0,4	4	0,4
Easy maintenance	5%	4	0,2	3	0,15	4	0,2	3	0,15	4	0,2
Ease of manufacture	5%	4	0,2	3	0,15	3	0,15	2	0,1	4	0,2
	Total score	3,75		2,95		2,95		3,3		3,65	
	Rank	1		4		4		3		2	
	Yes/No	Yes		No		No		No		Yes	

9.6 Result

Concept B was ranked lowest together with Concept C. Both concepts have a low score on size and installation, this is because they have a lot of different parts. Concept B received a low score on speed due to the amount of gear wheels and Concept C received a low score on durability because of belts instead of gears.

Concept D was ranked third since it received a low score on cost and manufacturing. Although, both theses scores will most likely be higher in the future when the technology of piezo motors have matured.

The result from the concept scoring matrix was that two concepts, Concept A and Concept E, are to be further developed. The advantages with concept A compared to concept E is robustness and the advantages with Concept E is that the motors can be placed underneath the camera. The two concepts have the same score for size efficiency, although Concept A is wider and Concept E is higher. Therefore, it was decided to combine these concepts to obtain an optimized concept.

10 Final Concept

In this chapter the final concept will be presented and further developed.

10.1 Overview

The final concept is a combination of Concept A and Concept E. The solution for pan is a combination of Concept A and Concept E, the external spur gear is taken from Concept A (1) and the usage of a spur gear for the pinion is from Concept E (2). The solution for rotate (3) is a modified version of the one from concept E. The solution for tilt is a combination from Concept A and Concept E, the worm gear (4) is from Concept A and the external spur gear (5) is from Concept E. The decision to use worm gear for tilt was made to gain a higher gear ratio as well as creating a more robust design.

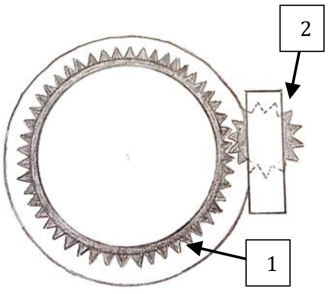

Figure 10.1 Pan.

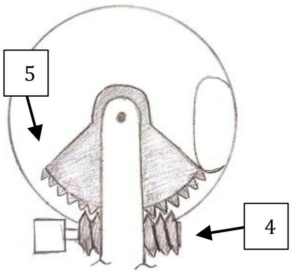

Figure 10.2 Tilt.

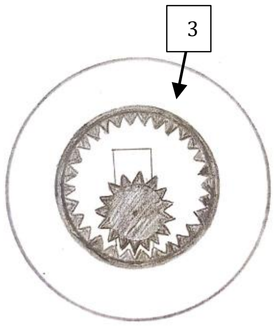

Figure 10.3 Rotate.

10.2 CAD Model

Based on the sketches an initial CAD model was made. The model shows that the overall concept will fit inside the shell of the old camera. It also shows that the lens can move in all three axes without interfering with other parts. Although, before building a prototype some parts needs to be further investigated and developed.

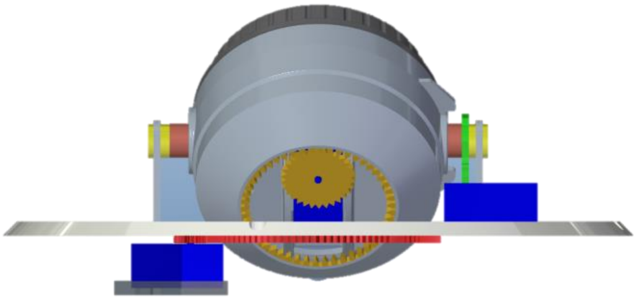

Figure 10.4 CAD model – back.

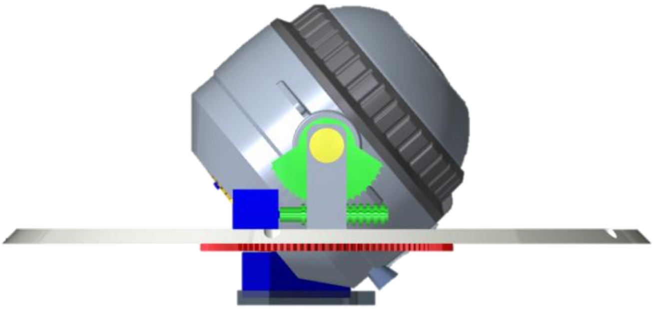

Figure 10.5 CAD model – right side.

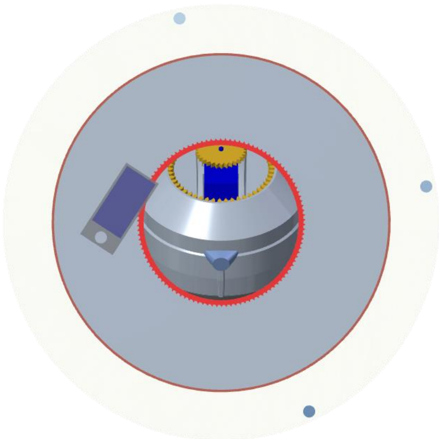

Figure 10.6 CAD model – bottom.

10.3 Further Development

10.3.1 **Gear Design**

The gear design is an important part of the chosen concept and the first step in the gear design is to select gear type. The gear type depends on the overall design of the concept and in this case the speed is not the most important aspect. For this application the accuracy of the gears are important and the backlash need to be as low as possible. The primary job for the gears is to transmit motion. Gears for applications like this are usually spur gears, bevel gears or worm gears [31]. When designing the gears some parameters have to be decided and some trade-offs have to be made. As seen in the CAD model several different gears will be used: external spur gears, internal spur gears and worm gears. In this design the choice of gears was made for several reasons.

Spur gears were chosen because they are easy to manufacture and they are often used in applications as this one. The tooth profiles on a spur gear are curved in the shape of an involute. The standard measure of a spur gears tooth size is called the module, which is the millimeters of pitch diameter per tooth. The most common pressure angle for spur gears are 20°, which will be used in this application.[31]

External spur gears are used for the pinions of pan and rotate as well as the gear wheel for pan. The pitch diameter for the gear wheels and pinions was already given in the specifications for the gear wheels. For the external gears equation 5.1 was used to calculate the center distance and equation 5.3 was used to calculate the gear ratio.

For the rotation movement an internal spur gears was chosen because it suited the design. When using an internal spur gear it needs to be connected to an external spur gear. The external gear cannot be larger than 2/3 of the pitch diameter of the internal gear. As in the case with the external spur gear, a pressure angle of 20° will be used. The formula 10.1 gives the center distance, a, for internal gears.[31]

$$a = \frac{d_{p1} - d_{p2}}{2} \tag{10.1}$$

The tests in the test rig showed that the torque needed for pan is at least 0.025 Nm and the torque needed for tilt is at least 0.015 Nm. The gears was designed in a way that made the torque a bit above the results from the test rig. The choice of material is injection-molded plastic gears because these types of gears are widely used in applications as this one [31].

Table 10.1 Values for the chosen gear wheels.

	Pan		***Rotate***		***Tilt***	
	Pinion	Gear wheel	Pinion	Internal Gear	Worm	Worm wheel
Module, m	0.4 mm	0.4	0.5	0.5	0.5	0.5
Pressure angle	20°	20°	20°	20°	20°	20°
Pitch diameter, d_p	8.0 mm	38 mm	7.0 mm	22.5 mm	3.5 mm	16.7 mm
Number of teeth, z	20	95	14	45	1	33
Centre distance, a	21 mm		7.75 mm		10.1 mm	
Torque	0.0285 Nm		0.01926 Nm		0.198 Nm	
Gear ratio	4.75		3.21		33	

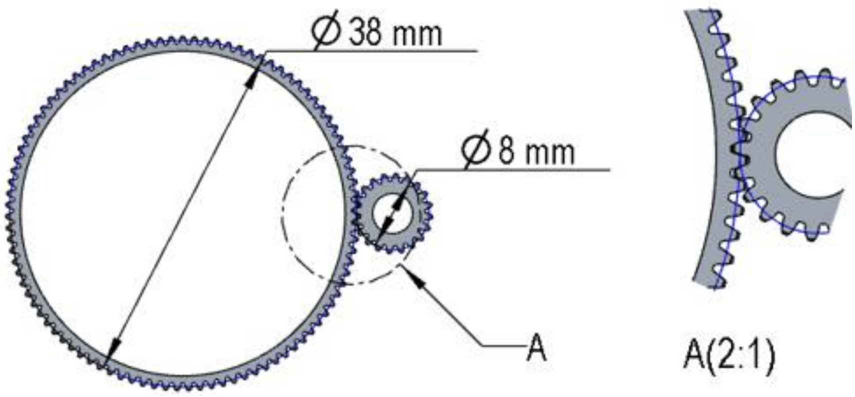

Figure 10.7 Gears for pan.

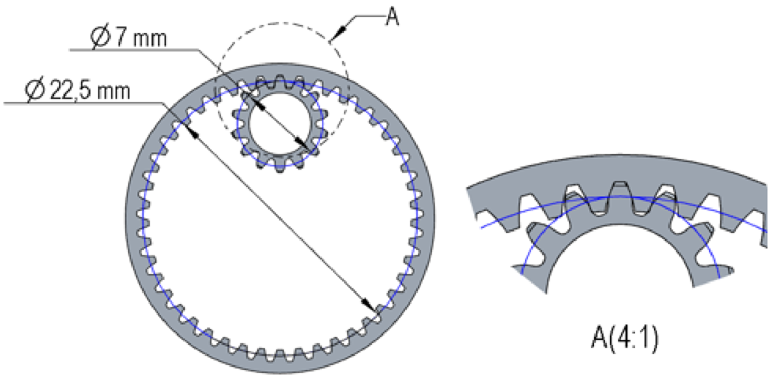

Figure 10.8 Internal and external gears for rotate.

A worm gear is a set up where one of the gears is a screw thread. A worm gear set consists of a worm and a worm wheel. It is important that the gears are aligned and have the correct center distance. The dimension that specifies the size of a worm thread is called the axial pitch, which is the distance from thread to thread in the axial plane. [31] In this application the worm gear set was copied from an existing worm gear set used in one of Axis other products and the design was adjusted to fit the worm gear set shown in figure 10.9.

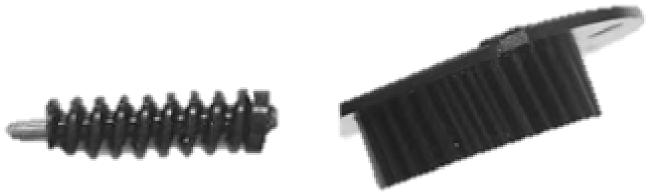

Figure 10.9 Worm gear set.

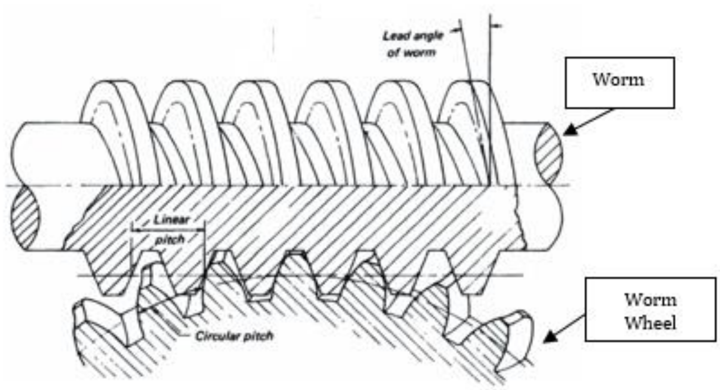

Figure 10.10 Single-Enveloping Worm Gear.

Backlash exists in all gears design, the definition of backlash is that the sum of the circular tooth thicknesses of two gears in mesh is less than the circular pitch. In other words it is the freedom of one gear to move when the other gear is not moving. One way to eliminate backlash is to size the gear teeth perfectly, 0.01 mm accuracy is needed to prevent backlash [31]. For this application it is vital that the backlash is limited. Therefore, some thoughts have been made on how to eliminate backlash. One idea is to use a spring for anti-backlash, especially on the tilt axis.

10.3.2 **Positioning**

It is important that the PTR movements does not exceed its specified value. For pan this is ±180°, for tilt ±90° and for rotate ±95°. The idea is that the movement will stop when it reaches its maximum value. This could be solved in several ways and in this chapter some ideas will be presented.

One way to do this is to count the number of steps on the stepper motor. This seems straight forward and easy but it has its drawbacks. The biggest drawback is the problem that comes up if steps are skipped. Then there is no way to know how many degrees the camera has moved. If the design is stable and robust this might not happen but during the tests it did not occur that way.

Another way is to implement a mechanical stop. The mechanical stop could be designed in the same way as it is today, see the green part in figure 10.11. Although, when using a stepper motor there are some problems with this. A stepper motor draws the same current even if it is stopped by a mechanical stop and therefore it would be difficult to detect if it has stopped or not. Furthermore, it wear down both the motor and the mechanical stop.

Figure 10.11 Mechanical stop.

Other ways to detect the position is to use some kind of sensor, for example an optical slot, an accelerometer or a hall effect sensor with a magnet on the rotating part.

10.3.3 **Electrical Components**

The electrical components needed to control the motor will most likely not fit on the current PCB. Therefore, the PCB needs to be extended (see figure 10.12). All the components for controlling the motor will fit in the area that is marked with red lines. When it comes to the cable solution all cables will go through the middle of the suspension device.

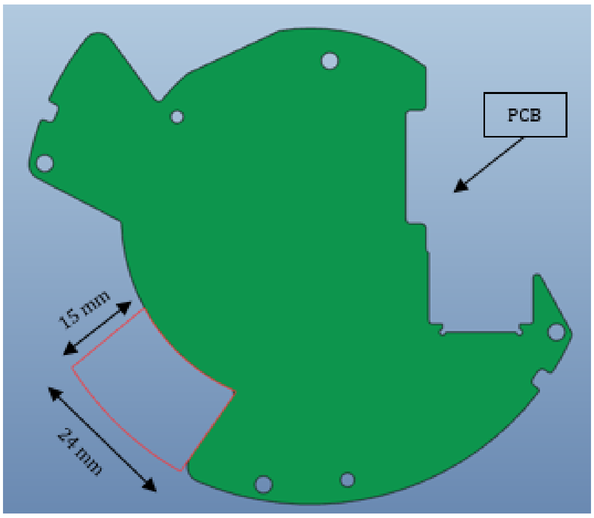

Figure 10.12 Placement of electrical components.

10.3.4 **Manufacturing**

How the concept is supposed to be manufactured is outside the scope of the thesis project. Despite this, some thoughts and discussions regarding manufacturing have been made. The idea is that all parts will be injection molded. Although, the concept is only a proof of concept and therefore the parts has not been adjusted for production but these parts could easily be adjusted for injection molding. The material choice will be some kind of standard plastic, for example POM, PC, PC/ABS. At this early state no external manufacturer or supplier has been contacted.

10.3.5 **Estimation of Costs**

The overall cost to implement a new PTR functionality in the AXIS M3044-V is less than the given budget for the project. Although, this is only an estimation of the costs and the cost could vary in reality. The financial analysis is confidential in will therefore not be presented in the report.

11 Prototype

To evaluate the concept a prototype was made. This chapter describes the prototype as well as the result.

11.1 Background

The prototype is a proof of concept and the main goal of the prototype is to see if the chosen concept works as well as if the motor and gear wheels are strong enough.

11.2 Design & Manufacturing

Most of the parts in the prototype were 3D printed in Axis own Ultra 3SP printer. The parts from the CAD model was modified and designed in a way that made it possible to assemble them with screws and nuts. An example of this is the design of the internal gear wheel. To the left in figure 11.1 is the design for the prototype and to the right is the design made for the concept. This modification was done to make it easier to assemble the part to the rest of the camera with screws and nuts.

Figure 11.1 Internal gear wheel design.

When the camera is mounted on the ceiling and wall it needs something that holds it to make sure it does not fall out. In the concept the thought was to use some kind of latches but the tolerance for 3D printing is not good enough. In figure 11.2 the design of the temporary latches is shown.

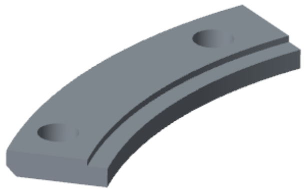

Figure 11.2 Temporary latches.

Some of the parts from the camera model AXIS M3044-V could be reused for the prototype. These parts are shown in figure 11.3-11.4. Furthermore, the actual lens from the real camera was mounted on the 3D printed parts to make sure that it will fit in reality and to make sure that the weight of the camera lens is the same.

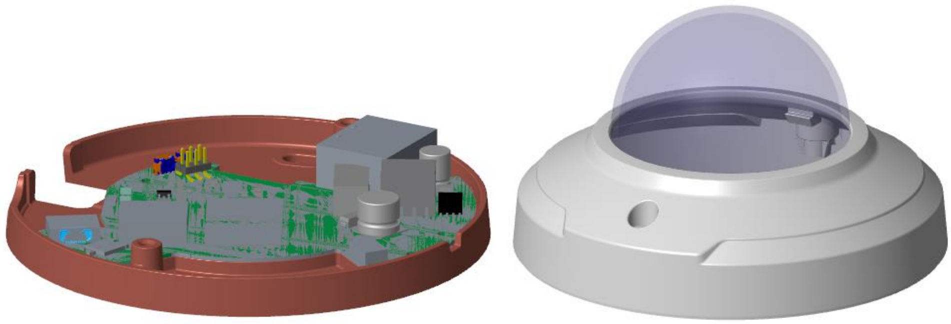

Figure 11.3 Printed circuit board, base plate (left) and shell (right).

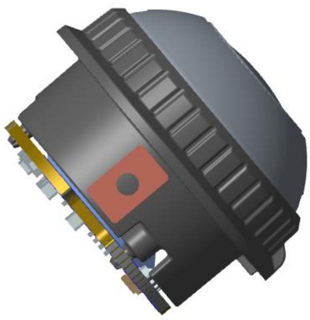

Figure 11.4 Camera lens.

When 3D printing the material becomes relatively rough, to simulate how the prototype would act when using proper material lubricants and metal foil was used to reduce the friction.

11.3 Result

The result of the prototype shows that the concept will in fact fit inside the current dimensions of the AXIS M3044-V. To test if the PTR functionality works three Seiko X0565 motors were mounted on the prototype and connected to a printed circuit board with driver electronics. When the set up was made several tests were conducted. The result from these tests showed that the prototype worked. The rotate functionality had to be tested separately due to the adjusted design. In figure 11.5 the prototype is assembled to test pan and tilt and in figure 11.6 rotation is tested.

Figure 11.5: Prototype without rotate gear.

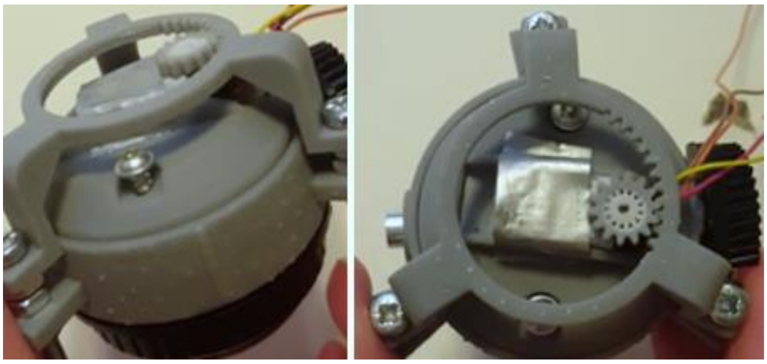

Figure 11.6 Prototype – rotate.

The conclusion is that the prototype shows that the concept will work. When looking at the target specifications in table 4.2 the final concept fulfills all specifications that could be tested. The camera can pan, tilt and rotate remotely and the camera is fixed even when the motors are off. The pan, tilt and rotate movements takes less than two minutes. Furthermore, the camera cannot be controlled from the outside and it is possible to mount it on the wall or ceiling. The cost for the new design is below the given budget and the height and diameter is within the specified values. The cable solution is discreet but this is something that could be improved during further development.

Some of the target specifications could not be tested with the prototype, although it is assumed that the design will fulfill these specifications as well. It is unknown if the PTR functionality will function for two years as well as if it will function for 200 cycles. The environment tests were not performed due to the fact that the prototype was not built in the proper material. Furthermore, the prototype did not go through Axis certification tests, this decision was also based on the fact that it was only proof of concept. Overall the evaluation is that the prototype fulfills all requirements that could be tested.

12 Discussion & Conclusion

The conclusion is that it was possible to design a PTR functionality for a miniature fixed dome camera. Furthermore, it was possible to design it in a cost efficient way. Even though this is only a proof of concept other conclusions could be made as well.

12.1 Conclusion

12.1.1 **Benchmarking & Patents**

The conclusion from the benchmarking is that all the cameras that have remote PTR functionality are either big or high-tech products. Therefore none of the benchmarked products could be directly compared to this project, but the benchmarking still provided inspiration for the concept generation. Another conclusion is that remote PTR functionality is not common on the market yet. When looking at the big companies, only Axis and Canon are selling fixed dome network cameras that can pan, tilt and rotate remotely. The conclusion from the patent search is that only two patents with PTR functionality was found. All of the patents except one use some kind of electrical motor and the most common transmission was some kind of gears, which was also the winning concept in this project.

Even though the final concept did not involve piezo motors it was found that Canon already have developed piezo motors, which they call USM Lens Technology. This is interesting because Axis was acquired by Canon and might be able to learn from Canon when it comes to piezo technology as well as benefit from their patents. Although, developing piezo motors in-house was outside the scope of this thesis, instead the focus was on already developed piezo motors.

12.1.2 **Tests**

The conclusion from the tests in the test rig is that the motor needs to be strong and size efficient to be able to create the movements for pan, tilt and rotate. Furthermore, it was noticed that the amount of friction and the center distance between the gears affected the result significantly.

12.1.3 **Prototype**

Prior to the prototype shown in the report a previous prototype was built. After building the first prototype some conclusions could be made which improved the final prototype. One of the lessons learned was that even though the torque was supposed to be enough, there were some problems due to friction. This problem was solved with higher gear ratios in the final prototype. Although, this might not be needed if proper material is used instead of 3D printed parts. It was also discussed to make a planetary gear for rotate but this idea was dismissed because it would take up too much space.

12.2 Discussion

The fact that only two motors were found that was below the size limit and above the torque limit made the concept generation somewhat limited. Although, most of the concept were promising and this is also shown in the concept scoring matrix (see table 9.1) where all concepts received fairly high score.

12.2.1 **Early Dismissed Ideas**

The reason for the high scores in the concept scoring matrix was that some of the first ideas were dismissed before the concept screening matrix. Parallel motors was one of these ideas. The idea was to solve the challenges with the limited amount of space and make the set-up slimmer with linear motors in parallel instead of rotary in serial. This option was dismissed due to the lack of linear motors within the size limits. Another idea that was dismissed was the usage of a solenoid or a spring to fixate the camera, but the problem with this is the space it will occupy. The thought was that the solenoid would be active when the motors are off and inactive when the motors are on.

12.2.2 **The Final Concept**

Finally, in a prototype that is ready for the market the design needs to be more robust and this might be a problem to fit inside the AXIS M3044-V. Therefore, a real product would be better suited for a bigger camera, for example one of the cameras in the P32 series. This thought came up already in the beginning of the project but it was said that it would be more interesting to see if it was possible to develop a concept for the AXIS M3044-V camera. With all facts on hand, the recommendation for further development is to create a concept similar to this concept but adjusted for the P32 series.

13 Future Work

For future work the recommendation is to implement remote PTR functionality on Axis P32 series. The reason for this is that the P32 series is one size bigger than the M30 series, the series where the Axis M3044-V belongs, and therefore the design could be improved in several ways. The gear wheels could be larger and therefore the gear ratio would be higher. Another improvement that could be made is the thickness of the parts. In the concept for the M30 series the parts are relatively thin, which might be a problem in a real product. The reason why most of the parts in the prototype are relatively thins is the lack of available space.

Before a realization of the concept some things needs to be further developed. One of these things are the internal gear wheel for the rotate movement. Due to the fact that the internal gear wheel is fixed, high forces are created and this needs to be taken care of to make the design robust.

The chosen motors for the M30 series, Seiko X0565, should be strong enough for the P32 series. In fact, in the concept as it is today the movements are a bit too fast. For the P32 series where the gear ration would be higher the speed of the movements will be slower and the torque higher. Therefore, the conclusion is that the motors will be strong enough even though the P32 weights approximately twice as much as the M30 series. An initial test for the pan movement was made in the test rig. In the test the Seiko X0565 motor was used with a gear ratio of 5 which result in a torque of 0.03 Nm. In the current design the gear ratio is 4.75 but it is assumed that the design for P32 series can have higher gear ratio. The result from the initial test showed that there was no problem to make the pan movement. This is a promising result and the idea to use the same motor seems to be working.

When it comes to the cost of the PTR functionality it should be the same as for M30 series except extra material costs due to bigger parts. The overall conclusion is that there should not be a problem to adjust the concept to the P32 series.

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13.1 Figures

Figure 2.1 The different phases of the project.
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Figure 2.2 Ulrich and Eppinger's concept development phases.
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Figure 3.1 AXIS M3044-V Network Camera.
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Figure 3.2 The camera with the shell separated.
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Figure 3.3 Dimensions of the camera model.
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Figure 3.4 Pan, tilt and rotate.
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Figure 3.5 Axis for pan, tilt and rotate.
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Figure 5.1 Camera head with pan roll and tilt movement.
Retrieved from Chapman, L. T. (2013). U.S. Patent No. 8,485,740. Washington, DC: U.S. Patent and Trademark Office.

Figure 5.2 Direct drive electric motor apparatus incorporating slip ring assembly.
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Figure 5.3 The test rig.
Photo taken by the thesis writer, Rakel Hed.

Figure 7.1 Concept Classification Tree.
Figure made by the thesis writer, Rakel Hed.

Figure 8.1 Spherical Stepper motor.
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Figure 8.2 Piezo Electric Technology.
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Figure 8.3 Seiko X0565.
Figure made by the thesis writer, Rakel Hed.

Figure 8.4 PCB Motor start kit.
Photo taken by the thesis writer, Rakel Hed.

Figure 9.1-9.22 Concepts.
Figures made by the thesis writer, Rakel Hed.

Figure 10.1-10.9 Final Concept.
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Figure 10.10 Single-Enveloping worm Gear.
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Figure 10.11 Mechanical Stop.
Figure made by the thesis writer, Rakel Hed.

Figure 10.12 Placement of electrical components.
Figure made by the thesis writer, Rakel Hed.

Figure 11.1-11.6 Prototype.
Figures made by the thesis writer, Rakel Hed.

Appendix A – Project Plan

The project plan and the outcome differs in some ways. The benchmarking took longer time than estimated. Customer needs and target specifications could be started earlier than predicted because Axis already had a lot of information. The test were done in parallel to product generation instead of afterwards. Despite the changes the selection of concept was done right on time. It was decided to have only one presentation, therefore the presentation was moved to week seven.

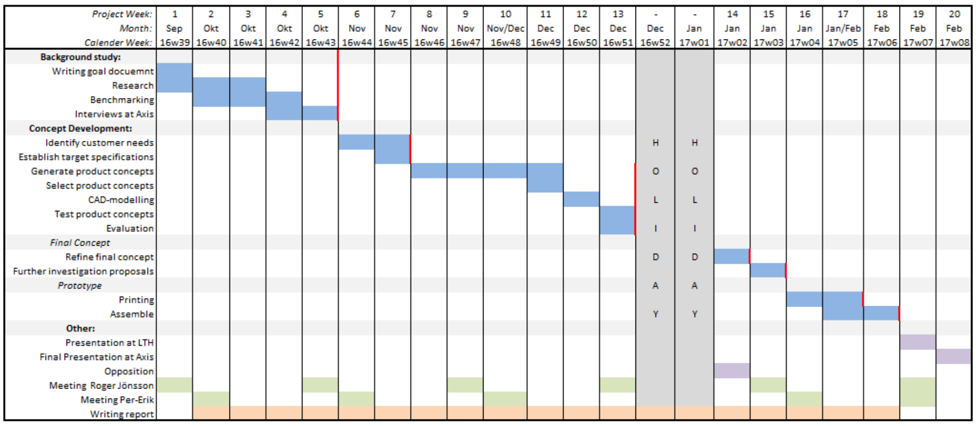


Figure A.1 Project plan

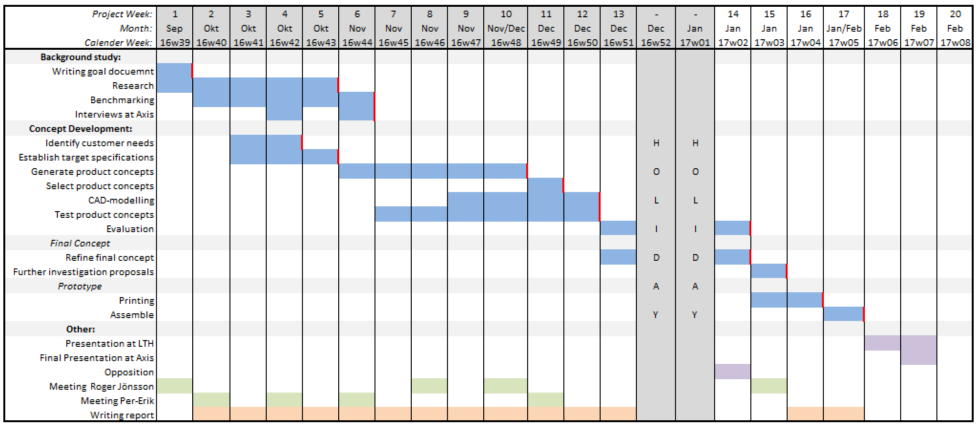


Figure A.2 Performed activities

Appendix B – Interviews

In this appendix the interviews with employees at Axis are gathered.

B.1 Interviews

A summary of the informal interviews is listed below.

- How often is the PTR functionality supposed to be used?
  - During installation and redirection, should be designed to withstand 200 full cycles.
- Is it important that it cannot be controlled from the outside?
  - Yes, for security reasons.
- What is the estimated budget for the PTR functionality?
  - The camera model is one of the cheaper models and therefore the cost need to be reasonable.
- The camera is ferly small, is it necessary that the PTR functionality can fit inside?
  - Not necessarily but the diameter needs to be the same otherwise the accessories will not fit.
- The cameras Axis develops have certain standards, is it important that the camera with PTR functionality follows the same standards?
  - Yes, otherwise it will not be commercially feasible.
- Is there a limit for how long time the PTR movements should take?
  - No, it does not have to be as quick as the PTZ cameras but it should be a reasonable time.
- Today, there is friction added to the manual PTR functionality, is it important that the camera is fixed after installation and redirection?
  - Yes, it has to be fixed and withstand vibrations.

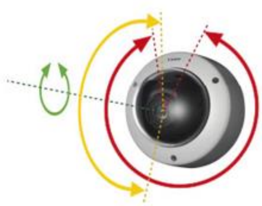
Appendix C – Benchmarking

In this appendix figures of the benchmarked products are shown.

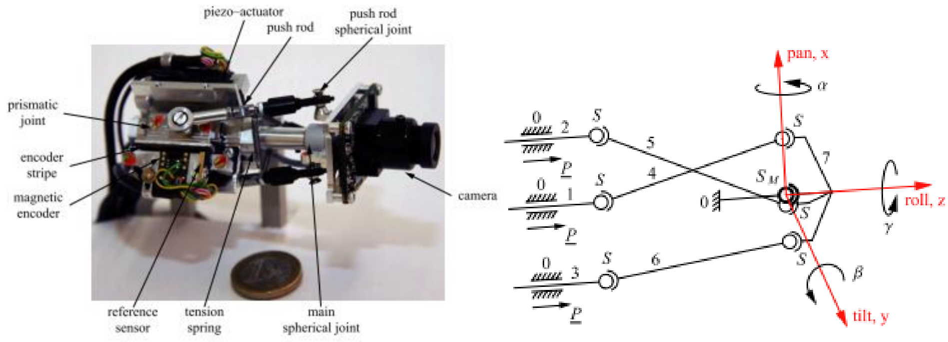
C.1 Camera Models

C.1.1 Axis Q3615-VE & Axis Q3617-VE

C.1.2 Canon



C.1.3 EyeSeeCam

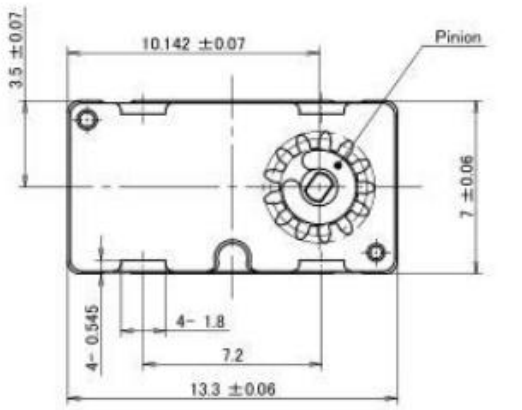


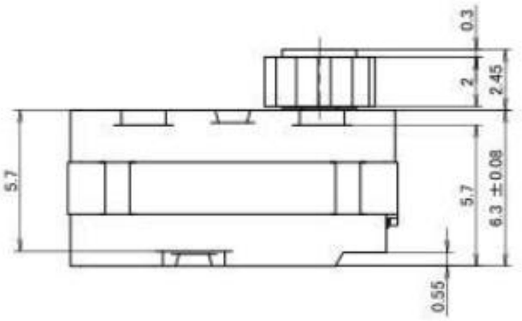
C.1.4 ACTi B97A

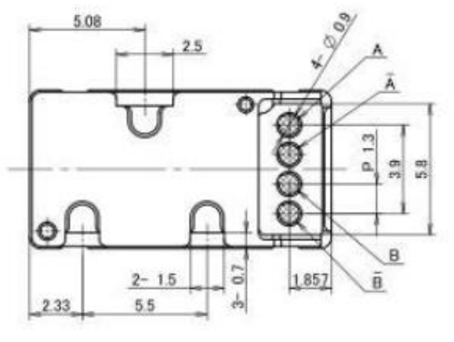
C.1.5 M3s Baby Monitor

C.1.6 Dahua

Appendix D – Seiko X0565







Pinion / Gear Specification of tooth form		
Tooth form	Involute	
Pressure angle	20°	
Module	0.3	
Number of teeth	13 Teeth	
Shifted coefficient	0.000	
Pitch diameter	ϕ3.900	
Outside diameter	ϕ4.500	
Root diameter	ϕ3.150	
Number of another teeth	– Teeth	Teeth
Center distance	–	
Backlash	–	
Surface texture		