

Development of a Tool to Create HDRI-Environments used for Rendering

Therese Do

DIVISION OF PRODUCT DEVELOPMENT | DEPARTMENT OF DESIGN SCIENCES
FACULTY OF ENGINEERING LTH | LUND UNIVERSITY
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MASTER THESIS

SONY



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Therese Do



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Supervisor: Per Kristav

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Abstract

This thesis aimed to develop and create a tool for 3D-artists at Sony Mobile Communications to improve and simplify the work when rendering new materials for their new products. The tool consists of a new product that would capture images for a panorama, where the images would contain a lot of light information, resulting in high dynamic range (HDR) files. This would be done by using the camera of the company's own product, a Sony Xperia Z5 Compact, and a method to assemble the images to create the environment with the 3D software Maya.

The thesis work has followed the product development method created by Ulrich and Eppinger and started with research on photography, 3D-visualisation and rendering. Since there was no existing product to compare with, benchmarking had to be done with other types of products that could implement the same usage of this new product with some modifications. The benchmarking resulted in purchasing an existing 360° camera modified with custom applications which made it possible to create the desired HDRI-environment for rendering. This modified product laid the foundation of the identification of the customer needs since it could be used as a reference at interviews.

Concepts were generated in different stages and the problem was broken down in to partial problems. In the end, a complete concept customized for rapid prototyping was developed and could then be manufactured. Wiring diagrams were designed and the product could be assembled. This part of the work was an iterative process that had to be re-made several times before all components were fitting and the product was complete.

The final product was tested out at the office at Sony where a user/employee had to use the product in its environment with the right surroundings. The product managed to capture the photos without any assistance of the user and the post-processing tools created a HDRI-panorama which was used as a lighting environment in the rendering program Maya.

Keywords: Image based lighting, HDRI-environments, Photography, Product development, Rapid Prototyping

Sammanfattning

Detta examensarbete syftade mot att skapa ett verktyg för 3D-visualiserare på Sony Mobile Communications till att förenkla och förbättra arbetet vid rendering av nya material åt nya produkter. Verktyget består av en produkt som fotograferar bilder för att skapa en HDRI-panorama med hjälp av kameran i företagets egna produkt, Sony Xperia Z5 Compact, och även en metod för att sedan montera ihop bilderna för att skapa en miljö i 3D-mjukvaran Maya.

Examensarbetet har följt produktutvecklingsmetoden framtagen av Ulrich och Eppinger och började med efterforskning och studier på fotografi, 3D-visualisering och rendering. Då det inte existerar någon likande produkt att jämföra med fick jämförelser göras med produkter avsedda för andra ändamål men som kunde implementera samma syfte som den nya produkten skulle med hjälp av några modifikationer. En existerande 360° kamera modifierades med en avsedd applikation som gjorde det möjligt att skapa HDRI-miljön avsedd för rendering. Denna modifierade produkt lade grunden till identifieringen av kundbehoven då den kunde användas som referens vid intervjuer.

Olika koncept genererades i flera stadier och problemet delades upp i flera delproblem. Tillslut utvecklades ett skräddarsytt koncept anpassat för friformsframställning som sedan tillverkades. Kopplingsscheman designades och den färdiga produkten kunde monteras ihop. Denna delen av arbetet var en iterativ process som fick utföras flera gånger innan alla delar passade och produkten var färdig.

Den slutgiltiga produkten testades på Sonys kontor där en medarbetare fick använda produkten i sin naturliga miljö. Produkten klarade av att ta alla korrekta bilder utan någon hjälp av användaren och med hjälp av efterbearbetning i datorn skapades en HDRI-panorama som användes som ljussättningsmiljö i renderingsprogrammet Maya.

Nyckelord: Image based lighting, HDRI-environments, Photography, Product development, Rapid Prototyping

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1 Introduction

For many companies today, product images are no longer created and photographed in the same way they used to do. At Sony Mobile Communications, many product images are digitally created and rendered from 3D-models into photorealistic images. When creating the looks of the materials for the products, the color and material designers choose the material for the components. Physical prototypes of the components are then created with the right material and sent to the 3D-visualisers at the company. Their task is then to recreate these materials digitally for the product images.

In order for the material samples to be recreated accurately to a perfect image, it is preferred that the lighting in the digital rendering environment matches the actual lighting where the real material samples are currently looked at. The manual light setting work is today done by the 3D visualizers themselves over a generic high-dynamic range (HDR) background. This makes it time consuming and difficult to recreate the materials accurately and the whole workflow gets inefficient and inflexible [1].

A possible alternative way to set the light could be to make a custom HDR background of the environment of where the 3D visualizers currently work and use as lighting in the digital environment, which would then automatically correspond to the actual lighting, if created correctly. The traditional method to create these HDR backgrounds for rendering is by manually taking multiple pictures with a digital single-lens reflex (DSLR) camera on a tripod in many different angles to create a full spherical $360^\circ \times 180^\circ$ image. The images also need to be taken at at least three different exposures to get a higher dynamic range of luminosity [2] [3].

However, creating light environments this way is time consuming and the equipment is not as portable as the work place requires, which is why it is not an option yet.

This is why the company requests a development of a new tool which will in a fast and easy way create HDR backgrounds of where the 3D visualizers currently work. This tool will use the camera of their own product, a Sony Xperia Z5 Compact, to capture the current lighting in the real environment where the 3D-visualizer

currently works, and turn it into a digital work environment that immediately can be used as a digital work environment to create materials.

1.1 Objectives

The project will focus on designing and developing a tool that will use a Sony Xperia Z5 Compact phone camera to capture a 360° x 180° spherical photo without any assistance of a human hand. The images taken will be used to create HDR environments used for rendering. Research will also be made on alternative existing solutions that will be tested and compared to the new solution. Evaluations will be made to decide if the company should use the new product in their workflow, use an already existing solution or stay with the current method for creating lighting environments.

The thesis work includes the following:

- Research and benchmarking of possible existing solutions
- Tests and evaluations of existing solutions as a tool to identify the customer needs
- Development of a new product that will be used with a Sony Xperia Z5 Compact mobile phone.
- Manufacturing of the new product
- Tests of the product prototype at the work place and in the rendering program
- Comparison of the new product with competitor product and evaluations

1.2 Delimitations

The phone will use existing software for automatically capturing images in multiple exposures and no software developing will be made. The developed product will also not be mass produced, thereof, no cost analysis will be made.

2 Background

2.1 3D Rendering

3D Rendering is the process of making 3D models into photorealistic 2D images. The 3D models are placed into a scenery, which usually is an image that contains information about the lighting, and the 3D models are given material settings that are applied to the surface of the models. The rendering engine will then calculate the color of every pixel and then create a 2D image out of it.

2.2 Camera Exposure

In photography, exposure refers to the amount of light radiation the image sensor in a camera is exposed to per unit area. An image sensor has a physically limited useful exposure range and this is often called its dynamic range [4].

A camera can control its exposure by changing either its aperture size or shutter speed and different combinations of these will give different given exposures. A measure of exposure is called exposure value (EV) and is defined in equation (2.1)

$$EV = \log_2 \frac{F^2}{\Delta t} \tag{2.1}$$

where F is the f-number (relative aperture) of the lens and Δt is the exposure time [5].

2.3 Image-Based Lighting

To create a background to the rendering environment, Image-based lighting (IBL) technique is often used. IBL is the process of using real-world light information to

illuminate scenes and objects in 3D rendering. It can produce realistic rendered appearances of objects and can be an effective tool for integrating computer modelled 3D objects into real scenes.

The first step to create an IBL environment is to obtain a light probe image. Light probe images are photographs of the real world with two main properties; they are omnidirectional, which means that the photograph covers the real world in both 360° horizontally and vertically. This can be acquired either by taking a photograph of a mirrored ball placed in a scene, as in Figure 2.1, or by taking multiple pictures in different directions and stitching them together afterwards. Also, the pixel values are truly proportional to the light in the real world. This is obtained by using high-dynamic-range (HDR) photography [6].



Figure 2.1 - Photograph of a spherical mirrored ball, sometimes used in IBL [7]

High-dynamic-range-imaging (HDRI) is a technique used in imaging where multiple exposures are taken within the same scene and then using these images to combine into a single image. Such an image has a higher dynamic range of luminosity and contains more information about the lighting than a normal photograph.

Finally, the light probe image is then projected onto a sphere to simulate the lighting for the objects in the whole scene. A computer modelled 3D object can then be placed inside the environment and the light from the environment will now illuminate the 3D object.

2.4 Creating $360^\circ \times 180^\circ$ Spherical HDR Environments by Stitching Multiple Photos

To make a photograph that covers the entire real world scene, also known as a spherical panorama, multiple images need to be captured and then stitched together. The method usually starts with taking multiple photos on the same horizontal level where the camera rotates a certain angle between every photo. The camera needs to rotate until the new photo will contain about 70% new information and around 30% contains the same information as the previous photo, depending on the stitching software, or the photos usually would not be able to be stitched together.

To cover the entire space, the camera also needs to rotate along its own axis, which is easily obtained by using a tripod. When a 360° horizontal strip is obtained, the camera is then angled along its vertical axis until the next photo will capture 70% new information again. A new horizontal strip will be taken and this will be repeated until there are horizontal photo strips of the whole scene with 30% overlap between every photo. It may also need a photo straight upwards and straight downwards to cover the entire scene [2].

In order to make this a HDR image, images with multiple exposures need to be taken at each direction. This is called bracketing. The smaller EV increment between every image will give less noise since the shots are closer together, but requires more amount of photos to capture the full dynamic range [8].

3 Methodology

To maintain a good structure within the project and to diminish chances of missing important parts, the product development process developed by Ulrich and Eppinger [9] was implied, but with some modifications to fit this particular project. In this chapter, all the steps in the complete project process will be presented in order and briefly explained.

3.1 Project Planning

A visual plan was created to give a better overview of the project and can be seen in Figure 3.1.

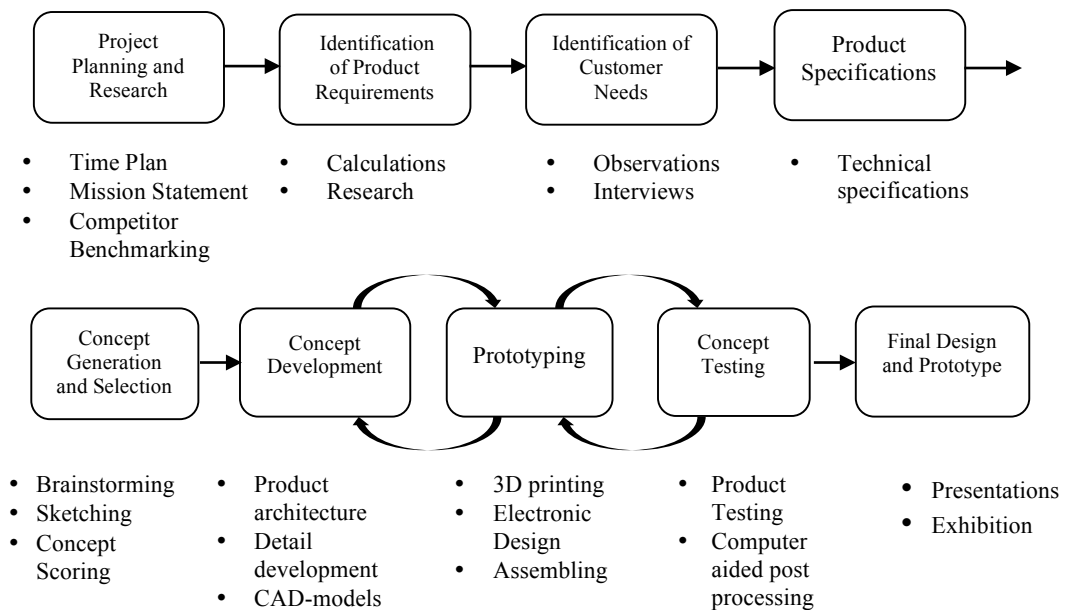


Figure 3.1 - Visual representation of the project plan

3.2 Identification of Product Requirements

In order to fulfill the customer needs, the technical requirements of the new product had to be identified. Research was made on how the images could be captured and how many of them were needed to cover an entire scene. Research on how to post process the images to create the final background file ready to be used were also made.

3.3 Identification of Customer Needs

To obtain the customer needs, the workflow of creating HDRI backgrounds had to be observed. The observed workflow needs to be as close to what it would have been with the new product, so the observations will be made when the customers are using a competitor product.

3.3.1 External Search

To find a suitable competitor product, research was made among similar products on the market. Multiple researched products were benchmarked to select one to study closer and use in the process of identifying customer needs.

3.3.2 Gathering Raw Data from Customer Needs

Two methods were used to collect raw data from customers, interviews and observations. The aim of the interviews was to receive information on what the customers think about the current solution they have at the company and what they feel could be changed for the better. The aim of the observations was to see how the customers interacts with a new tool which is similar to the product that is going to be developed and to receive information on what they think about it.

The information from the interviews and observation were then translated into customer needs which were organized hierarchically and given a relative importance, all according to the method by Ulrich and Eppinger [9]. This information was needed to create the product specifications.

3.4 Product Specifications

The product specifications were made based upon the customer needs. When setting the limits of the values for the specifications, no benchmarking and comparisons to other products were made. This, because the product has no intent to be sold as a commercial product but only to be used within the company. The limits were set based upon approximations and the observations and interviews that were made when identifying the customer needs.

3.5 Concept Generation and Selection

The complex problem was clarified in form of a black-box model where it was broken down into several partial problems according to Ulrich and Eppinger [9]. Concept generation and concept selection were both performed for one partial problem in order to move on to the next partial problem, since the problems and solutions were depending on each other.

3.6 Concept Development

The chosen concept was developed in detail and all the including parts were 3D-modelled and also 3D-printed out. This was an iterative process and the concept had to be tested and redesigned multiple times before the right dimensions and settings were found.

3.7 Results

Finally, the new and finished product was tested at the company and a simulation of a real work scenario was made, where the user had to use the product to obtain an HDR-environment of the work space inside the rendering program.

4 Product Planning

4.1 Time Plan

A time plan was made to schedule the activities with the company and to get a general overview of the time distribution of all the activities within the project. The time plan can be found in Appendix A.

4.2 Mission Statement

To clarify the aims of the project between the company and the university, a mission statement was written and can be found in Table 4.1.

Table 4.1 - Mission statement of the project

Mission Statement: Portable Lighting Capturer to create HDR Environments for Sony Xperia Z5 Compact

Product Description	<ul style="list-style-type: none">Automated, rotating stand that performs Spherical HDR bracketing with Sony Xperia Z5 Compact
Benefit Proposition	<ul style="list-style-type: none">Captures the required images for a HDR environment with a single press of a buttonIncreases work flexibility for the 3D visualizer
Key Business Goals	<ul style="list-style-type: none">Shortening production time of the product images at Sony Mobile Communications
Primary Market	<ul style="list-style-type: none">Employees (3D visualizers) at Sony Mobile Communications
Secondary Market	<ul style="list-style-type: none">Other designers and 3D visualizers
Assumptions and Constraints	<ul style="list-style-type: none">Compatible with Sony Xperia Z5 Compact
Stakeholders	<ul style="list-style-type: none">Employees/Users at SonyOther UsersLund University

5 Identification of Product Requirements

To figure out if it was even possible to create $360^\circ \times 180^\circ$ HDR environments with a Sony Xperia Z5 Compact, research on panoramic photography and tests with the phone was made and is presented in this chapter.

5.1 Creating the Panorama

In order to create an image that captures the whole scene, multiples images need to be taken and then stitched together. Different software for panorama stitching were looked into and tested but the final software chosen was PTGui [10]. For PTGui to be able to stitch the images together, it is necessary they are overlapping with each other with at least 20 % [11].

5.1.1 Parallax

It is important that all the photos are taken from a single viewpoint in order to avoid a photographic phenomenon called parallax [11]. Parallax is when objects seem to change position relative to one another when viewed from different viewpoints, see Figure 5.1 – 5.2.



Figure 5.1 - Parallax phenomena seen in two photographs taken with the camera lens not rotating around its own pivot point. The nozzle of the watering pot has shifted position in relation to the chair. If the camera would have rotated correctly along its pivot point, the objects relations would have remained the same in both pictures, while the images would portrait different angles of the scenery.



Figure 5.2 - Parallax phenomena in two pictures overlapped

This phenomenon will make it harder for the software to stitch the images properly and then the software is unable to stitch certain images, they need to be paired manually with a number of control points from the user, see Figure 5.3. This is not desired since it requires a lot more time than if the software would have automatically stitched it. To take all the photos from a single viewpoint, the rotation of the camera needs to be around the center point of its lens as much as possible.

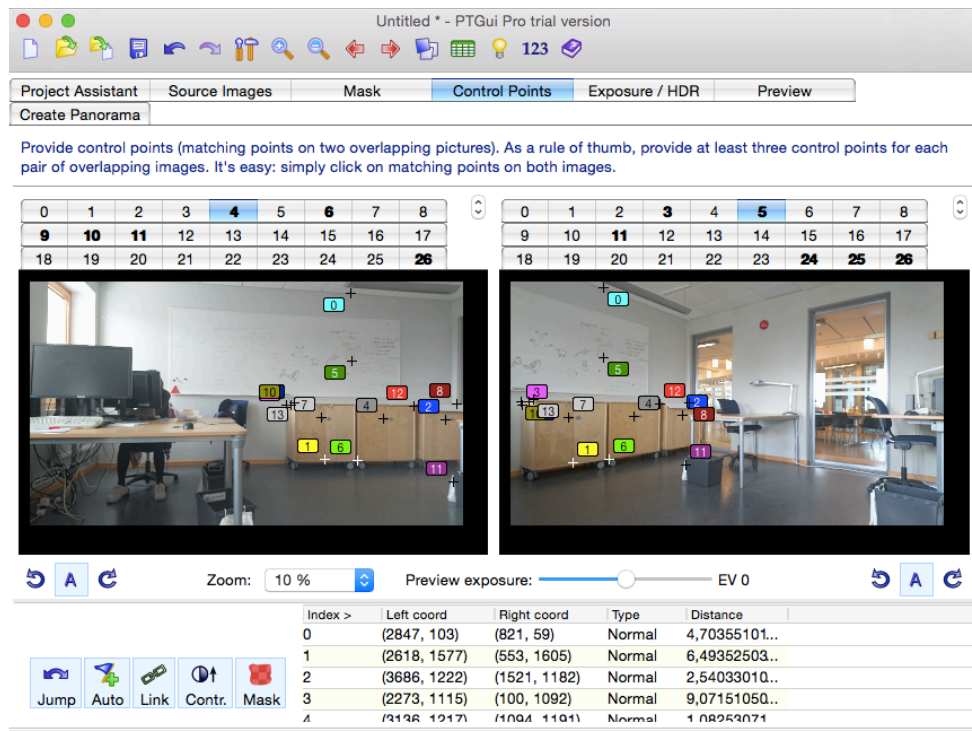


Figure 5.3 - Inside PTGui. The software automatically detects and places control points if photos are taken properly without any parallax.

5.1.2 Number of Images Needed to Cover the Entire Scene Using the Camera of a Sony Xperia Z5 Compact

The number of images needed to cover the entire scene with the camera can be calculated with equation (5.1) [12].

$$N = \frac{F}{(1 - overlap) * FOV} \quad (5.1)$$

N is the number of images needed, F is how many degrees' scene that needs to be covered and FOV is the field of view of the camera measured in degrees, as shown in Figure 5.4.

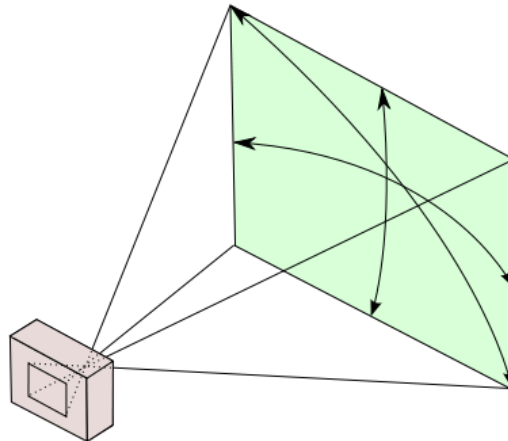


Figure 5.4 - Field of view of a camera

To reassure that the stitching software would not have a problem stitching the images, the overlap was chosen to 0.3 (30 %). The field of views are usually given by the manufacturer, but could also be determined by a test where the camera was pointing at a paper and the end corners were measured, along with the distance to the paper [13], see Figure 5.5. With this test and trigonometric rules [14] the horizontal field of view were measured and calculated to be 67.38° and the vertical to be 45.24° when the camera was in landscape mode. For portrait mode, the angles would be the opposite of one another.



Figure 5.5 - Measuring the field of view of a Sony Xperia Z5 Compact

This means, that to be able to cover 360° of the scene, the number of images needed were calculated with equation (5.1) to be

$$N = \frac{360}{(1 - 0,3) * 67.38} = 7.63 \sim 8$$

for the horizontal row of images, and

$$N = \frac{360}{(1 - 0,3) * 45.24} = 11.36 \sim 11$$

for the vertical series of images, when keeping the camera in landscape mode. To make the row even, 12 images were chosen instead of 11. All images required in the horizontal and vertical field are illustrated in Figure 5.6.

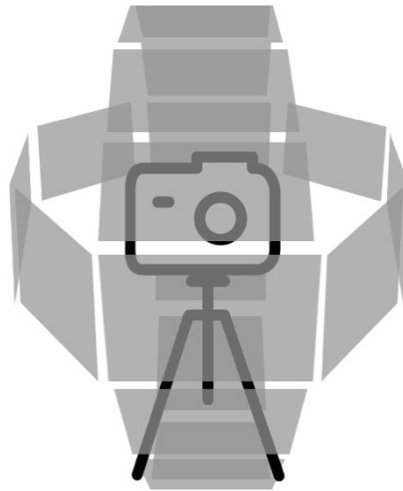


Figure 5.6 - To cover the whole horizontal field, there needs to be 8 images in that direction. The vertical field needs at least 11 due to smaller field of view in that direction when the camera is in landscape mode. To make it match evenly with the horizontal row, the vertical row was adjusted to have 12 images.

Next, calculations were made on how many photos that needed to be taken in between these images. To simplify, calculations will only be made for the top half of the scene, since the number of photos needed will be symmetrical in all directions.

Since there needs to be 12 images around the lens vertically, where one is pointing at zenith (90° upwards) and one at nadir (90° downwards), there needs to be two more strips between the horizontal line and the zenith image. The angle of these images were calculated to be 30° and 60° from the horizontal line.

This means that above the horizontal strip, another row of images had to be captured. This will be referred to as the second row of images. The number of images in this row needs to be as many as in the previous row (i.e. the first/horizontal row) to cover the scene completely without gaps. This is because the bottom of these images need to align with the top of the images in the first horizontal row, like it shows in Figure 5.7.

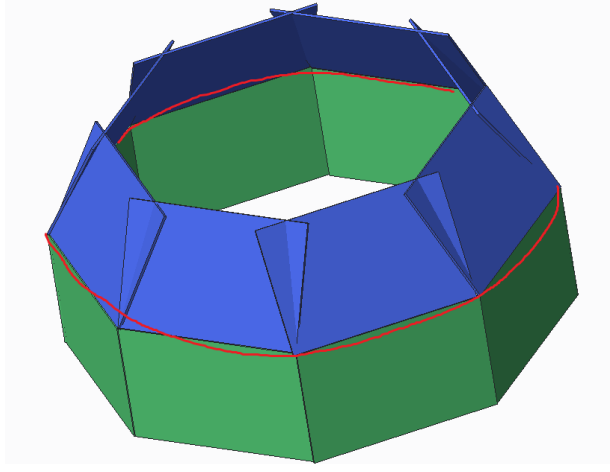


Figure 5.7 - The bottom of the images in the second row of images, indicated in blue, aligns with the top of the first row, indicated in green, which means that there needs to be as many images in the second row as in the first row. The red line indicates the circumference of the first row.

With this information, the number of images for the second row can be expressed as

$$N_2 = \frac{C_1}{W} \quad (5.2)$$

where C_1 is the theoretical circumference of the first row and W is the width of every image, which will stay the same regardless of row. The number of images, N , needed for a certain row can therefore be expressed as

$$N_r = \frac{C_{r-1}}{W} \quad (5.3)$$

where r is the particular row and C is the theoretical circumference at the top of a certain row.

At the top of the second row, the images will be angled and overlap more which means that it will also have a smaller theoretical length of circumference at the top, see Figure 5.8. Therefore, less images are needed for the third row of images.

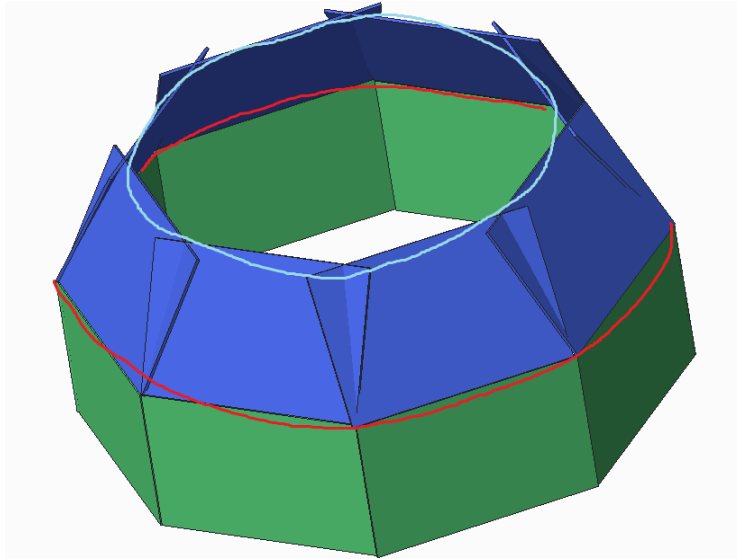


Figure 5.8 - The top of the second row of images will overlap and create a smaller circumference, indicated in blue, than the circumference around the first row of images, indicated in red.

To calculate the number of images needed for the third row, it is therefore necessary to find an expression for the theoretical circumference C for the second row. This can be written as

$$C_2 = 8 * w_2 \tag{5.4}$$

since there will be 8 images captured equally distributed around the scene, where w_2 is a the theoretical distance between the images in the second row, see Figure 5.9.

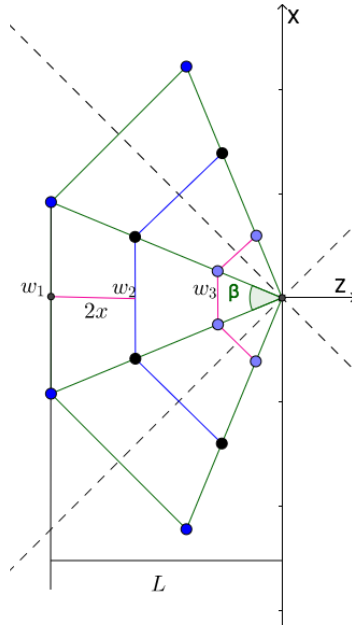


Figure 5.9 – Parts of the theoretical circumferences seen from above, where w_1 is 1/8 of the circumference of the horizontal row, w_2 is 1/8 of the circumference of the top of the second row and w_3 is the 1/8 of the circumference of the top of the third row.

In figure 5.9, $w_1 = W$ and $2x$ is the horizontal distance between the first horizontal row and the top of the second row, which will be the bottom of the third row and β is the angle between every image on that plane. With (5.4) inserted in (5.3), the number of images in the third row can be expressed as,

$$N_3 = 8 * \frac{w_2}{w_1} \tag{5.5}$$

To determine the ratio between w_2 and W , the theory of similar triangles is used [15], see equation (5.6).

$$\frac{w_1}{2L} = \frac{w_2}{2(L - 2x)} \rightarrow w_2 = \frac{w_1 * (L - 2x)}{L} \tag{5.6}$$

The distance x was portrayed from the YZ-plane, see Figure 5.10, and could then be expressed with trigonometric rules [14].

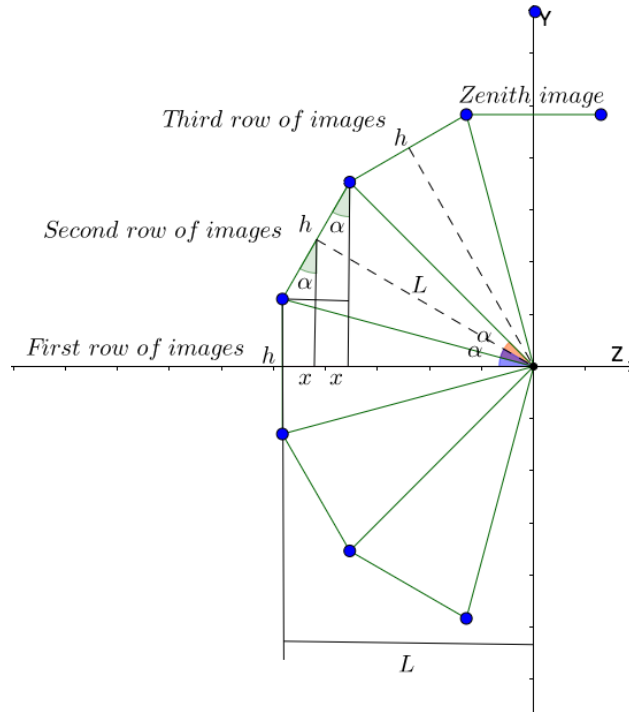


Figure 5.10 – The distance between the first row of images and the top of the second row of images on the z-axis.

Figure 5.10 shows that the horizontal distance between the first horizontal row and the top of the second row is $2x$, where h is the height of the image or the imaging sensor and α is the angle between every image on this plane. The relation between x and L is derived in equation (5.2) – (5.4).

$$x = \frac{h}{2} * \sin(\alpha) \tag{5.7}$$

$$\tan\left(\frac{\alpha}{2}\right) = \frac{h}{2L} \rightarrow h = 2L * \tan\left(\frac{\alpha}{2}\right) \tag{5.8}$$

With (5.8) inserted in (5.2), the relations between x and L is given as

$$x = L * \tan\left(\frac{\alpha}{2}\right) * \sin(\alpha) \quad (5.9)$$

Equation (5.9) inserted in (5.6) gives

$$w_2 = w_1 * (1 - 2 * \tan\left(\frac{\alpha}{2}\right) * \sin(\alpha)) \quad (5.10)$$

Which then can be inserted in equation (5.5) to express the number of images for the third row as

$$N_3 = 8 * (1 - 2 * \tan\left(\frac{\alpha}{2}\right) * \sin(\alpha)) \quad (5.11)$$

Since it is known that it is necessary to capture 8 images for the horizontal row, the angle α is calculated to be

$$\alpha = \frac{360^\circ}{12} = 30^\circ$$

and therefore, the number of images needed for the third row is calculated to

$$N_3 = 5.86$$

which is rounded up to six images, i.e. the least amount of images needed for the third row is six, in order for the stitching software to stitch the images properly. This means that there would need a total of 38 images to cover the entire scene. This was tested with the camera and it turned out that it was sufficient to only take four images for the third row, since there were such big margins. This reduced the amounts of images (camera angles) to 34. If the nadir image and the images in lowest row before the nadir image are excluded, the resulting number of images are 29.

5.2 Creating the HDRI

Only one external mobile application were found that could perform HDR bracketing, which were Camera FV-5 [16], and this would be the application to be used for the solution.

6 Identification of Customer Needs

6.1 External search

All the researched products were defined as cameras that would both take spherical photos and be portable. Therefore, no traditional methods like using a DSLR camera with a tripod were evaluated because of lack of portability. Cameras that had a viewing angle of 360° horizontally but distinctly less than 180° vertically were also not included since an image of the whole scene is required. The aim of this benchmark was to find a suitable device to test and to identify customer needs for the development of the new product and can be found in Table 6.1.

Table 6.1 - Comparison of four 360° cameras

	<i>Ricoh Theta m15</i> [17]	<i>Ricoh Theta S</i> [17]	<i>Bublcam</i> [18]	<i>Giroptic 360</i> [19]
360° Spherical Image	Yes	Yes	Yes	Yes
Size	42 x 129 x 22.8 mm	44 x 130 x 22.8 mm	Ø80 mm	Ø69 mm
Weight	95 g	125 g	280 g	180 g
Initial Price	\$299 USD	\$349 USD	\$799 USD	499 €
HDRI	With third party app [20]	With third party app [21]	Yes [22]	No
Exposure Range	± 2.0 EV	± 2.0 EV	N/A	N/A
Exposure Step	1/3 EV	1/3 EV	N/A	N/A
Maximum number of exposures per HDRI	12	12	3	N/A

<i>Available to Purchase from Sweden</i>	Retailer only [23]	Retailer only [24]	Yes, but with uncertain shipment date [25]	Not released yet [19]
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The device that were chosen to be used in the observations and interviews were Ricoh Theta m15 since the Ricoh cameras were the only ones available to purchase at that moment and the m15 model had the same camera specification as the S model but had a lower retail price.

6.2 Identification of Customer Needs

The observations and interviews were individually done among four employees at Sony Mobile Communications that were supposed to use the product in their future work. To observe the employers performing a task using the device, Ricoh Theta m15, an instructional manual was written and can be found in Appendix B. This manual was only to support and verbal instructions were also given to the participants. The result from the observations were that the product was intuitive and easy to use for all of the participants. Interviews were held immediately after performing the task and the interview and its responses can be found in Appendix C.

All the collected data from the interviews and observations were translated into customer needs and can be found in Appendix D.1. These customer needs were then organized into primary and secondary needs, where the primary needs are more general while secondary needs are detailed versions of the primary needs. The organized list of needs can be found in Appendix D.2. The relative importance of the primary needs was also defined and at this state a trade-off had to be made, where it was concluded that there was no time to do anymore customer research. Therefore, the relative importance of every need had to be estimated based upon the observations that were made. A final list of the primary needs and their relative importance can be seen in Table 6.2.

Table 6.2 - The primary needs and their relative importance, where 1 is the lowest and 5 is the highest importance.

No.	Need	Importance
1	The product is portable.	5
2	The product does not use much space.	3
3	The product is easy to use.	3
4	The product operates in a short amount of time.	3
5	The product is autonomous.	4
6	The product captures all the necessary images	5
7	The product is easy to charge	2
8	The post processing is easy.	3
9	The camera captures accurate photos.	3

7 Product Specifications

The product specifications describe the main functions of the new product in metric terms. A specification contains of a technical specification along with a value and a relative importance, which are all goals that the product strives to reach in the end. The specifications were established based on the customer needs that were previously determined.

The most important specifications were the ones that defined the functions of the camera, since the photos that needed to be taken could not be compromised in any way. It needs to have a horizontal field of view of at least 360° and 90° (all the way up to zenith) in the vertical direction upwards and at least 45° downwards (halfway to nadir). This because the ceiling usually contains more important lighting information than the platform right underneath the camera does, since the ceiling usually contains lamps and other light sources. Therefore, the camera needs to capture images of the entire room, including the ceiling, except for the space right underneath the camera itself.

Based on the customer needs, the product needs to be portable, but there was no exact value determined from the customers. A rough estimation of what size and weight of a product were considered as portable were made, where different existing products that were considered portable were measured and weighed. This included the previously tested 360° camera, Ricoh Theta m15, that was defined as very portable, and other products, like DSLR-cameras, compact cameras and mobile phones. The goal of the new product was to weigh less than 500 g and be smaller than 300 x 200 x 200 mm.

The customer also wanted the product to be easy to operate and to complete in a fairly short amount of time. This gave the product the technical specification that the user only would need 5 or less interactions with the product to complete the whole procedure of starting the product and have captured all the photos. An interaction could be a press of a button or to connect a cable. The total time to capture all images were set to have a goal of 4 minutes or less and the total time to create the final HDRI from the photos would have a goal to finish before 8 minutes.

A complete list of the technical specifications and their respective values can be seen in table 7.1.

Table 7.1 - A list of all the technical specifications and their relative importance's and values, where 1 is the lowest relative importance and 5 is the highest.

Physical Quantity no.	Need no.	Technical Specification	Relative Importance	Unit	Value
1	1	Weight inclusive phone	4	g	< 500
2	1, 2	Height inclusive phone	4	mm	< 300
3	1, 2	Width inclusive phone	4	mm	< 200
4	3, 5	Number of interactions needed from user from start until all images are transferred to a computer	5		< 5
5	4	Amount of time to capture all images	3	s	< 240
6	6	Horizontal field of view of complete product	5	degrees	360
7	6	Vertical field of view of complete product above the horizontal plane	5	degrees	90
8	6	Vertical field of view of complete product below the horizontal plane	4	degrees	>45
9	7, 8	Compatibility with micro USB charging/data cable	2		Yes
10	8	Amount of time to create the final environment from all images	3	min	< 8
11	9	Number of EV steps	5	EV	>= 2

8 Concept Generation and Selection

8.1 Clarifying the Problem

The project was divided into three main problems: Rotating the camera, capturing the photos and post processing. A black-box model of the partial problems that influences flow of materials, energy and signals, according to Ulrich and Eppinger [9] was created to break down the problem “Rotating the camera” even further, and can be seen in Figure 8.1. The partial problems of rotating the camera were identified as

- Store or accept external energy
- Convert energy to rotational kinetic energy
- Apply rotational energy to rotate camera along its vertical axis
- Apply rotational energy to rotate camera along its horizontal axis
- Controlling the system

Which, if solved, will lead to the camera rotating in all necessary directions.

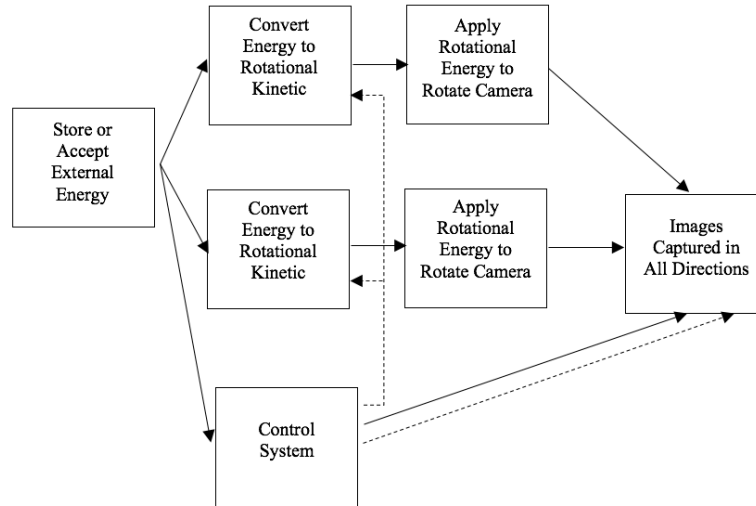


Figure 8.1 - Partial problems of a black box model, where the continuous lines shows transmission and transformation of energy, and dashed lines shows flows of signals and feedback.

8.2 Generating and Selecting Concepts

8.2.1 Store and Accept External Energy

A concept classification tree was made and can be found in Figure 8.2. Some of the branches were excluded early and in the end there were only two options left, both electrical sources and it would be either from a battery or from a wall outlet.

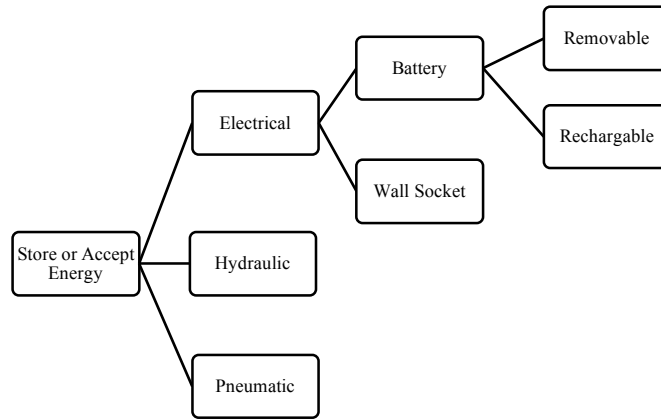


Figure 8.2 - Concept classification tree of storing and accepting external energy.

A concept scoring matrix were made to select the concept to be used and can be found in Appendix E.1. The concept chosen was to power the product through the wall socket via a direct current (DC) adapter.

8.2.2 Convert Energy to Kinetic Energy

The external energy needs to be converted kinetic energy in order for the system to move.

Another concept combination table were made where different motors were evaluated for the different movements, which can be found in table 8.1.

Table 8.1 - Concept combination table of how to convert electric energy into kinetic energy.

<i>Converting electrical energy to horizontal rotation</i>	<i>Converting electrical energy to vertical rotation</i>
Direct Current (DC) motor	DC motor
Servo motor	Servo motor
Stepper motor	Stepper motor

Every motor could be evaluated independently since the choice of each one would not affect the other.

When the camera in the phone would rotate horizontally, it would need to rotate a certain angle around its vertical axis and then stop in order to take the image, and then repeat that until it has covered 360°. The motor selected for this was a stepper motor. When computer controlled, very precise steps positions can be achieved, which is why this was chosen to be the most appropriate motor to select for this task.

For the rotation in the vertical direction, it needs to rotate up to 180°, also with several steps in between to stop at. This is why the stepper motor also were chosen to be the most appropriate for this task, even though a servo also would be possible. In the end it would be the motor that had the smallest size to keep the product as small as possible.

8.2.3 Applying Rotational Energy to the Phone

The camera needed to rotate 360° along its vertical axis and up to 180° along its horizontal axis. This problem was divided into two partial problems, rotation along its vertical axis and rotation along its horizontal axis. The main focus of this part of the concept generation were to generate ideas on where to place the rotational axes and on the overall structure. The closer to the lens the rotational axes are, the better the result will be and less post processing will be needed.

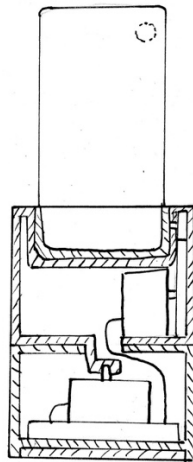
The Sony Xperia Z5 Compact, that will be used as the camera device, can also be oriented in two ways. Either in portrait mode, where more of the scenery in the vertical direction will be visible, or in landscape mode, where more of the scenery in the horizontal direction will be visible. Depending on which orientation the camera will be using, a different amount of stops in the different directions are needed.

A concept combination table was made where The problems and their solutions can be seen in Table 8.2.

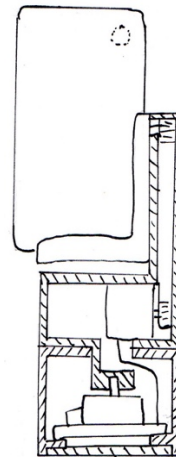
Table 8.2 - Concept combination table of the partial problems and their different solutions

<i>Placement of vertical axis</i>	<i>Placement of horizontal axis</i>	<i>Camera orientation</i>
Aligned with phone center	Under phone	Portrait
Aligned with camera lens center	Aligned with phone center	Landscape

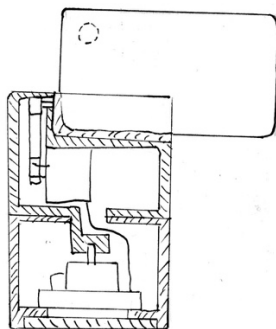
The combinations of the solutions can be seen in Figure 8.3.



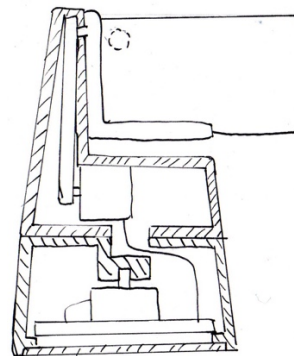
1. Vertical axis aligned with phone center, horizontal axis placed under phone center and camera in portrait mode.



2. Vertical axis aligned with camera lens, horizontal axis aligned with phone center and camera in portrait mode.



3. Vertical axis aligned with camera lens center, horizontal axis placed below phone center and camera in landscape mode.



4. Vertical axis aligned with camera lens, horizontal axis aligned with camera lens and camera in landscape mode.

Figure 8.3 – Concept combination tables

A concept selection matrix was made to evaluate the concept which can be found in Appendix E.2.

8.2.4 Control System

The motors would be controlled by a microcontroller placed inside the base plate among the lower stepper motor, which in this project were chosen to be an Arduino UNO.

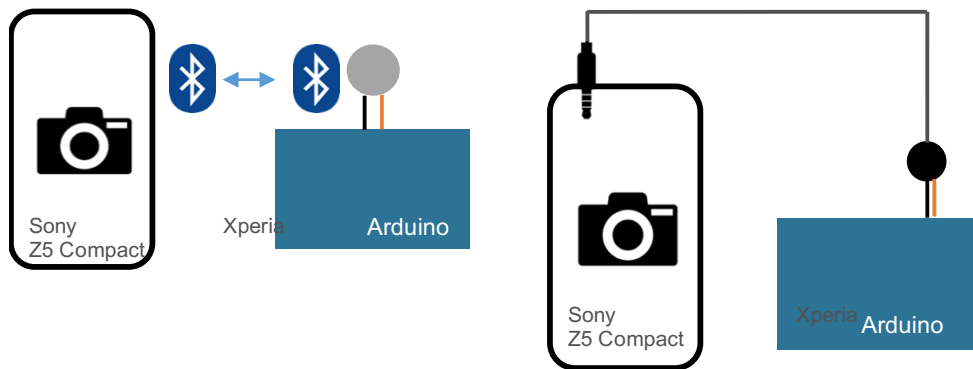
8.2.5 Capturing the Images

At every rotational angle, multiple photos with different levels of exposures (bracketing) were needed to be captured. This without any assistance of the human hand other than starting the device.

8.2.5.1 Internal Search

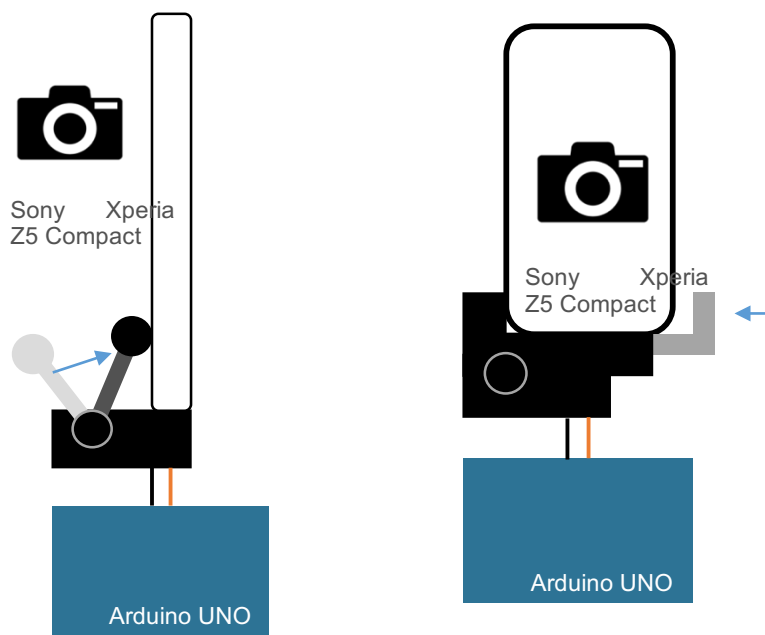
The internal search resulted in three concepts for capturing the photos, where all concepts uses an external mobile app to perform HDR bracketing, and can be seen in Figure 8.4. The concepts were:

1. Bluetooth shutter - An external Bluetooth shutter for smartphones is disassembled and connected to the Arduino micro controller. The Arduino is then programmed to tell the Bluetooth shutter when to capture an image with the camera program in the phone.
2. Headphone button - A headphone with a play/pause or volume button can be used as a camera shutter when the headphones are connected to the phone via a 3.5 mm connector. This button on the headphone is connected to the Arduino that will be programmed to tell the button when to capture an image with the camera program in the phone.
3. Mechanical touch arm - An arm with a touch stylus tip is attached to a servo motor that is attached to the part of the product closes to the phone. The servo motor is connected to the Arduino and programmed to tell the motor when to move the arm in order to touch the camera button on the screen of the phone.
4. Mechanical arm - Pressing the physical camera button on the side of the phone with a motor controlled by the Arduino.



1. Bluetooth shutter

2. Headphone button



3. Mechanical arm with touch stylus tip attached, pressing the touch screen camera button.

4. Mechanical arm pressing the physical camera button on the side

Figure 8.4 – Illustrations of the four concepts for capturing the images via an Arduino.

A scoring matrix was made and can be found in Appendix E.3.

9 Concept development

9.1 Electronic Components

9.1.1 Rotating the Camera

To find suitable motors, the required torque needed to be estimated. With a motor sizing calculation tool [26] the required torque was roughly estimated to be 60 Nmm for the top motor and 100 Nmm for the bottom motor. These numbers are not specifically accurate since the tool were calculating torques for DC-motors and not stepper motors that were going to be used in this case, but it still gave a hint on around what size the torque needed to be.

The motors selected were two small reduction stepper motors with a 250 Nmm holding torque. The operating voltage is 12 V and in order for the motors to be controlled by the Arduino they needed to be connected to a motor shield, which were chosen to be an Adafruit Motor Shield for Arduino V2.

9.1.2 Capturing the Photos

Initially, a Bluetooth shutter was connected to the Arduino to be programmed to capture photos with the phone camera via Bluetooth. This turned out to be an unstable way to capture the photos since the Bluetooth shutter rebooted every time the power was cut. This meant that the user had to perform a pairing sequence in exactly the correct order every time in order for the system to work. An option would be to have the Bluetooth shutter run on an external power source, like a battery, and be powered at all time. This idea was also dismissed since the problem would remain every time the battery needed to be changed.

The other alternative was to use a headphone button to connect and program via the Arduino. This showed to be much more reliable than the previous so this was finally chosen to be the method for capturing photos. At one end on the headphones, the button, that is initially meant for playing/pausing music on a mobile phone device, was connected to a single pole Reed relay which was then connected to the Arduino. The other end was connected to the phone via the 3.5 mm-connector. A schematic for this can be found in Appendix F.1.

The system would work in such way that the Arduino would be programmed to tell the relay to shut at certain times, which then would trick the mobile phone to think that the original play-/pause button is pressed. The mobile phone would then tell its own camera to capture a photo. This would only work if the mobile phone is pre-set to capture photos within the camera application when the play-/pause button on a pair of headphones connected to the mobile phone is pressed.

The full Arduino source code of the program can be found in Appendix F.2.

To reduce the number of interactions needed from the user, the phone was pre-set to automatically start the camera application when the 3.5 mm cable was connected. It was also pre-set to return to the home screen when the cable was de-attached.

9.2 User Interface

The user would power the system from a DC connector on the back of the base part. When powered, a green LED at the front of the base would indicate that the system is ready to run. A button next to the LED indicator would start the system when pushed. When the button is pushed a red LED would indicate that the system is running. The indicator then switches back to green after the whole system has finished running. These components were mounted on a circuit board along with the relay and headphone button.

After the photographic process is done, the user needs to connect a Micro USB cable from the mobile phone device to a computer and transfer the latest 87 captured images to the computer.

9.3 Mechanical Design

The product would consist of two main parts - the base that would house one of the motors and the other electronic components and the top that would be a platform rotating on top of the base. Inside the top, the second motor would be mounted, and the phone would be connected to the shaft. The headphone cable would also run through the top since it had to connect to the phone. The cables from the motor at the top and the headphone cable had to be connected to the rest of the electronics, this while the top part would rotate between 0° - 300° (the horizontal field of view the camera was over 60°). To solve this, the shaft on the top part was designed to have an opening where the cables could run through.

9.3.1 The Base

The base part had to house the following components:

- Arduino UNO (75.14 x 53.51 x 15.08mm)
- Adafruit Motor Shield V2 (70mm x 55mm x 10mm)
- Stepper motor (28mm diameter, 20mm)
- DC Power connector panel mount (12 x 15 mm)
- Circuit board with various small components (40 x 40 x 12 mm)

The motor had to be placed closest to the top since it had to connect with the shaft of the top part. Next, the Arduino UNO would be screwed onto spacers that were attached on the roof of the base and the motor shield could then be directly stacked underneath, see figure 9.1.

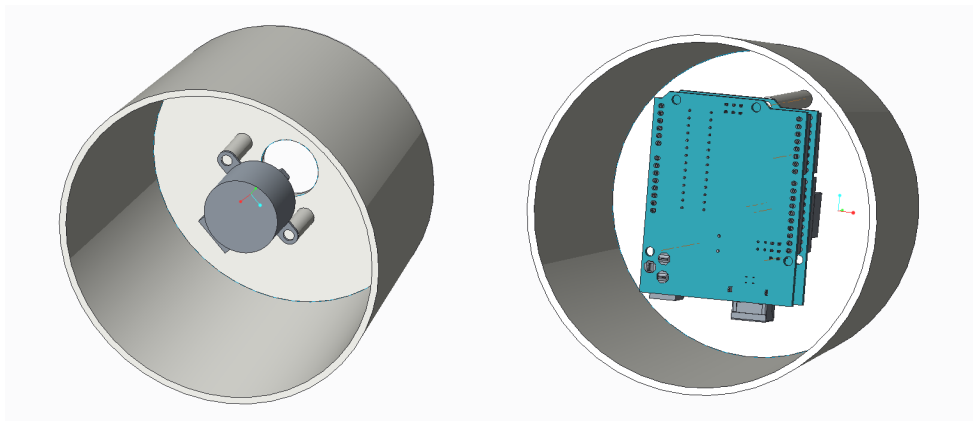


Figure 9.1 - Left: the base component with the stepper motor centered inside. Right: The Motor shield and Arduino assembled after the motor.

The circuit board with components would be slid into a space near the front surface of the base. This would allow the pushbutton to be reachable from the outer side and the LEDs to be visible as well, as seen in figure 9.2.

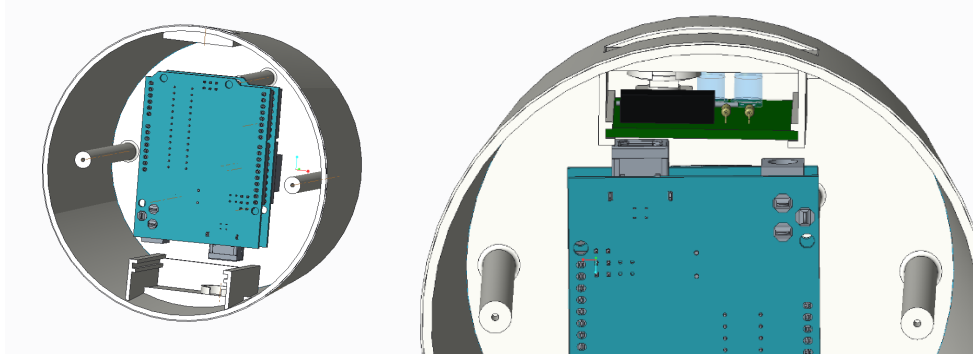


Figure 9.2 - The circuit board placed inside the base

9.3.2 The Top

The top part would consist of a platform on a shaft where the shaft would run through the base and onto the motor at the base. Through the shaft, the cables from the motor and the headphone had to run, so the platform were thickened and hollow along with the hole in the shaft, as seen in figure 9.3. At one end of the platform, the second motor would be mounted and above the motor, a hole was made for the headphone cable to run through, which is also seen in figure 9.3. The top assembled with the base component can be seen in Figure 9.4.

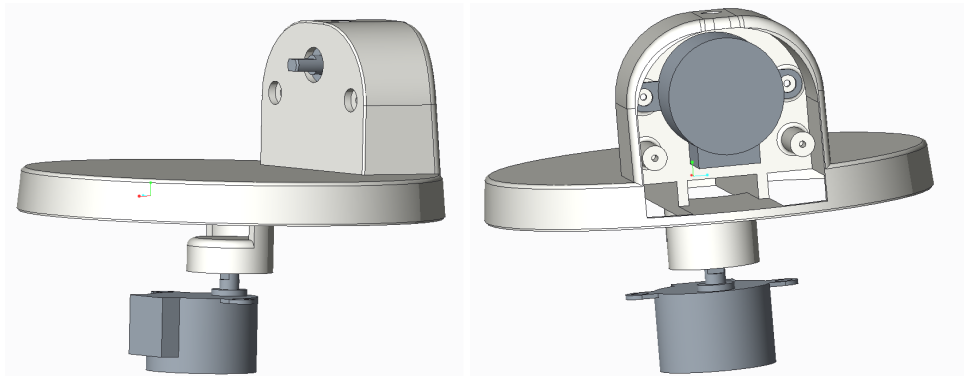


Figure 9.3 - The top part mounted on the bottom stepper motor with the holes where the cables are running from the top stepper motor to the bottom part. Right: The top stepper motor mounted inside the top part, with the hole in the top part where the cables from the top stepper motor are going to run through.

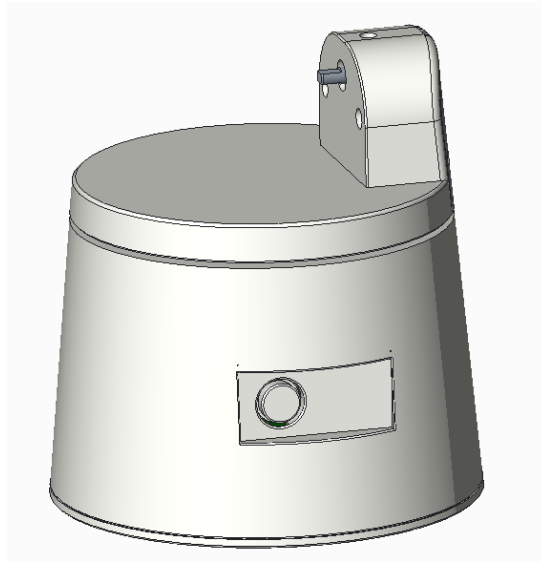


Figure 9.4 - The top and the bottom part assembled together.

9.3.3 The Motor Arm

The motor arm would be part that holds the phone and the rest of the product together. An initial design was made and can be seen in Figure 9.5 but after several assembling tests it was concluded that this design was not stiff enough. With the force from the phone pressing against it, it would deform until the arm hit the top platform underneath it. Therefore, a redesign of this arm in figure 9.5 was made.

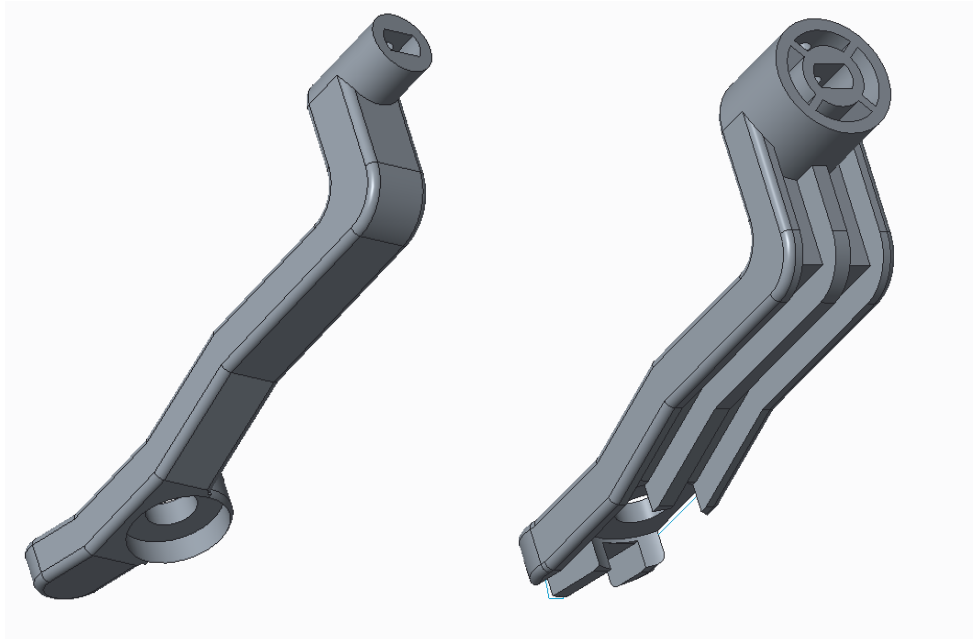


Figure 9.5 - Left: the old motor arm. Right: the new motor arm with ribs.

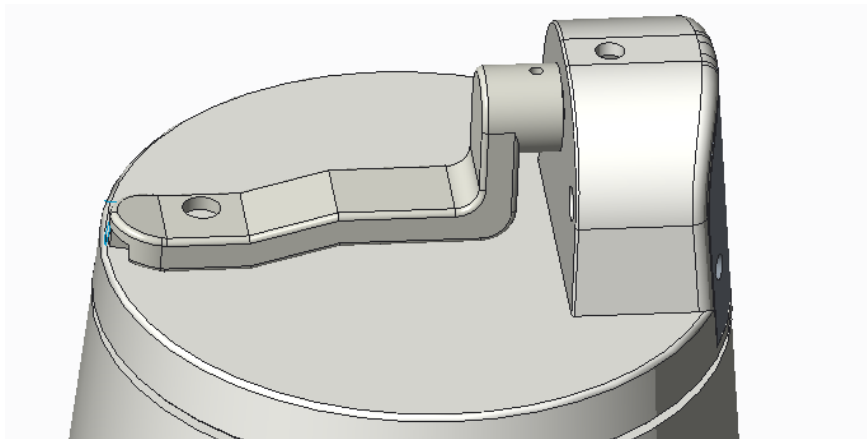


Figure 9.6 - The motor arm attached to the top part.

Additionally, FE analyses were also made to ensure that the deformation would decrease. The FE analysis of the old design showed a maximal deformation of 2.5 mm and the new design would only deform 0.07 mm at the most, see Figure 9.7 – 9.8.

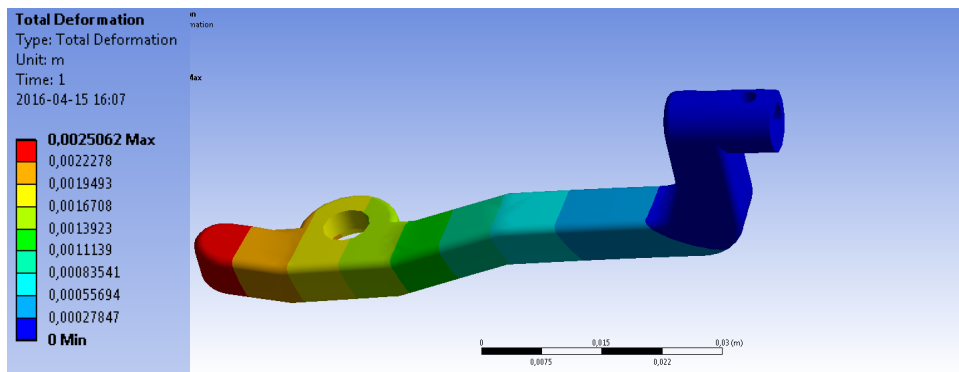


Figure 9.7 - FE analysis of the old motor arm, where the maximum deformation is 2.5 mm.

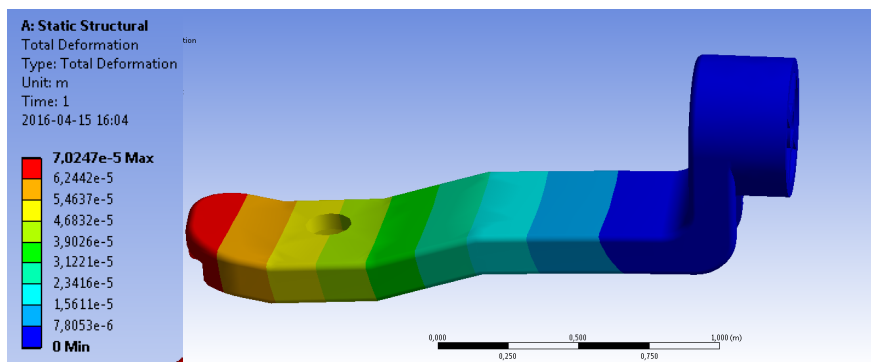


Figure 9.8 FE analysis of the new motor arm where the maximum deformations is 0.07 mm.

In the end, a final alteration was made to this part where it was given a crescent-shaped end to match with a rounded block on the top part to stabilize even more, see Figure 9.9.

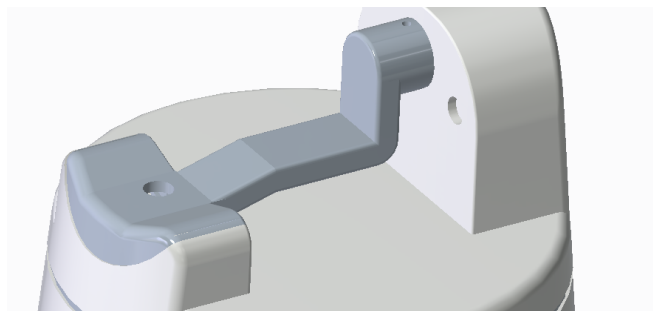


Figure 9.9 - The final motor arm on the final top part.

9.3.4 The Phone Attachment

Research were done on different ways to attach mobile phones to other objects, and for this prototype, an already existing attachment solution were found to be the best to use. The universal mobile phone attachment used, seen in figure 9.10, has a screw thread at the bottom which will be used to connect the motor arm.



Figure 9.10 - The universal mobile phone attachment [27]

9.3.5 Spacer

To reduce friction between the base and the top, an acrylic disc was placed between the two parts. A circular track on the disc was also cut out, see Figure 9.11. Inside this track, a pin attached at the top part would run and prevent the top from rotating over 320° to prevent the motor cables from tangling.



Figure 9.11 – Left: the spacer with the circular guiding track. Right: The acrylic spacer assembled between the top and bottom part.

10 Results

This chapter will present the results of the master thesis, where the product is finished and tests had been made. The final performance of the product is also reviewed and a simulation of the product in use is made at the office at the company.

10.1 Final Design

The parts for the final concept, as seen in figure 10.1 – 10.2, were 3D printed with a SLS-3D-printer, except for the spacer that was laser cut. All parts were then assembled with the electronic components and resulted in a fully functional product.



Figure 10.1 - The final concept with the Sony Xperia Z5 Compact mounted on it.



Figure 10.2 - Left: The final product seen from the front. Right: The final product seen from the left.

An exploded view of the assembly can be seen in Figure 10.3, and a rendered image of the product in the office environment can be seen in Figure 10.4.



Figure 10.3 - Exploded view of all the components in the final product.



Figure 10.4 - Rendered image of the product seen in the environment where it's supposed to be used.

10.2 Performance

The system was tested and its properties were measured and compared with the desired technical specifications from the initial phase of the project. The size of the product remained sufficiently small and the only interactions needed from the user was to plug in the electrical cord, plug in the camera shutter cord and press the start button. If the phone is asleep it could be wakened by double tapping the screen.

Capturing all required images took about 4 minutes and post processing took 8 - 15 minutes. This because the scripts that merged all 87 photos in Photoshop itself took 4 - 8 minutes to run and PTGui needed about 2 - 5 minutes to stitch the 29 HDR-images into one panorama, depending on the performance of the computer in use.

A detailed list of specifications can be found in Table 10.1.

Table 10.1 - The final technical specifications of the product.

Technical Specification	Unit	Value
Weight inclusive phone	g	500
Height inclusive phone	mm	190
Width inclusive phone	mm	180
Number of interactions needed from user from start until all images are transferred to a computer		3 – 4
Amount of time to capture all images	s	320
Horizontal field of view of complete product	degrees	360
Vertical field of view of complete product above the horizontal plane	degrees	90
Vertical field of view of complete product below the horizontal plane	degrees	45
Compatibility with micro USB charging/data cable		No
Amount of time to create the final environment from all images	min	8 – 15
Number of EV steps	EV	>2

The output image created with the new tool and stitched by PTGui can be seen in Figure 10.5.



Figure 10.5 - The output JPEG image stitched by PTGui

10.3 Tests at Sony Office

The product was also tested at the office where it was supposed to be used. An employee was given a detailed manual on how to use the product, seen in Appendix G, and tried it out according to the description. Co-workers at the office were walking around the scenery as the images were captured, but PTGui was able to stitch the images correctly anyway. As seen in Figure 10.5, the employee was able to create a HDRI environment in Maya with the product and the HDRI environment was reflecting the light from the office at a 3D model in the correct way.

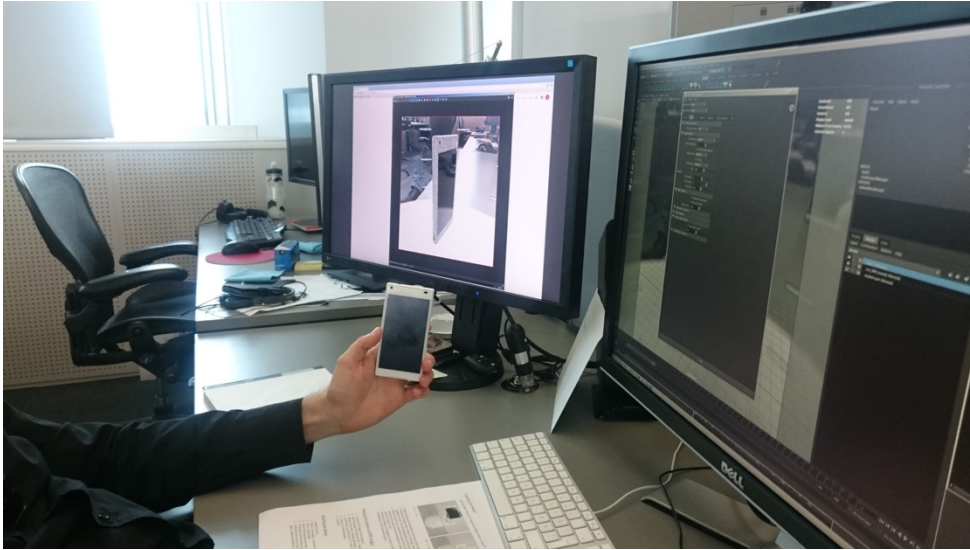


Figure 10.6 – A user testing the created HDRI environment in Maya. The HDRI environment lighted a 3D model of a Sony Xperia Z5 Compact on the computer screen while the user is holding a real model of the same product to compare the lighting.

11 Discussion

11.1 Discussion and Further Development

The main objective of this degree project was to develop a tool to create HDRI-environments for rendering materials at Sony. The product created was able to capture the necessary images to stitch such image, but compared to the system with the Ricoh Theta m15 camera, the time it took to capture all images was a lot longer. This because a lot more images were needed to cover up the entire field with a normal mobile phone camera with a limited field of view, than it does with a 360° camera that only needs one image per exposure value. This also meant that the final result with the new system gave an HDRI environment that had a lot higher resolution (around 90 MP) than the Ricoh Theta m15 did (6.4 MP). This resolution is usually not necessary, but it creates more possibilities and the product could be used to create other kind of images used in other applications. The high resolution could be reduced if the resolution settings in the camera application were changed. By doing this, the time it takes to merge and stitch the images could also be decreased significantly, since these steps were also taking a lot of time.

When comparing the 3D model in the rendering program, lit by the created HDRI-environment, to the real model in real life lit by the real surrounding, the 3D model was reflecting the lights correctly, but it did not really seem to have the same “white” as in real life. This could be due to a lot of different factors; one is that the white balance in the camera was not right, which wouldn’t be possible to correct, the other one could be that the model might had been retouched with a filter in another program prior to this, and therefore show another kind of white than it did in reality. It could also simply be that the material was not recreated correct in the first place, and that’s the reason why a product like this is wanted.

The current version of the product is powered via a DC adaptor which must be connected to a wall socket which makes it less portable than if it would’ve run on batteries. Batteries were initially looked upon, but both stepper motors needed a voltage so that at least 8 Alkaline AA-batteries would be needed, which would make the whole product a lot bigger and heavier. This is why a DC adaptor connected to a wall socket was finally chosen as the power source, although for future development, research on other types of batteries could be considered. This would make it possible to work outside the normal office environment where wall sockets are not available.

Another thing to consider if this product would've been developed further is that the device does not have a system to automatically rewind itself to the start position before every run. Today, the user needs to manually rewind the top part until it hits a stop before running the program, which could lead to the device not running properly if the user forgets to perform that step. This could be prevented if electronic switches were implemented at the stops so that every time the user presses the start button, the motors would be programmed to rotate the top until it hits a switch and therefore tell the system that it has reached its start position, and start from that position.

In the future, the Sony Xperia Z5 compact would be an old and maybe even an unavailable model, which means that the motor arm needs to be redesigned to fit a newer model if they would upgrade their mobile phone device. If the camera lens has moved a lot in future models, it is even possible that the top part needs to be redesigned, but with the 3D-printing of today, that would probably be simple.

11.2 Project Conclusions

Overall, this master thesis succeeded to reach its aim and the company was happy with the result. All of the thesis work was done at the university, except for tests and interviews.

The thesis was a very broad project with a lot of different areas included. The most challenging part was the electronic design since the knowledge of electronics in this matter was limited. The degree project could've benefitted from having another student working on it as well, in particular, someone that studies electrical engineering or similar. In that way, more time could've been spent on other areas, like optimizing the mechanical design, environmental studies or mass production.

The preliminary timeline, found in Figure A.1, Appendix A, was initially followed but as the project went on, work areas that weren't thought of in the early stages were discovered and had to be added to the project method, which delayed some activities. Some activities were also using more time than anticipated, like the concept generation stage, since there were so many partial problems that needed concepts to be generated on. This was done parallel with other work, like research, since research had to be done in every detail that were developed. The final time plan can be seen in Figure A.2, Appendix A. Another thing that affected the time plan was unforeseen missions and meetings for the company.

Working with the Ulrich and Eppinger method was good for some areas in this degree project, it was easy to integrate with some parts and harder for some other parts. It was a good guideline, especially when it comes to project structure and planning. It helped with covering all necessary parts in the product development process and it also helped sticking to the time plan. Some other parts were harder to

integrate, an example is the concept selection matrix that gave the Bluetooth shutter as the best solution to capture images. Theoretically it would be the best solution, but before any tests had been done it was hard to anticipate how it would actually work.

Benchmarking and identifying customer needs also needed to be adapted to this new product, since there are not really any similar products used to this purpose in the market today, nor have anyone really worked in this way before when rendering materials. The Ricoh Theta m15 camera was not actually intended to use to create HDRI-environments for rendering, so it was hard adapting that for benchmarking at first, but with some modifications it could qualify as a competitor product.

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Appendix A Time Plans

The preliminary time plan for the whole project can be seen in Figure A.1 and the actual time for the activities are seen in Figure A.2. Some activities, for example research and tests with the Sony Xperia Z5 Compact to determine the properties of the camera, were not anticipated at first but showed to be very necessary in the end. The concept generation was a much longer process than expected which also had to start a lot earlier than planned to get a brief overview of what needed to be worked on.

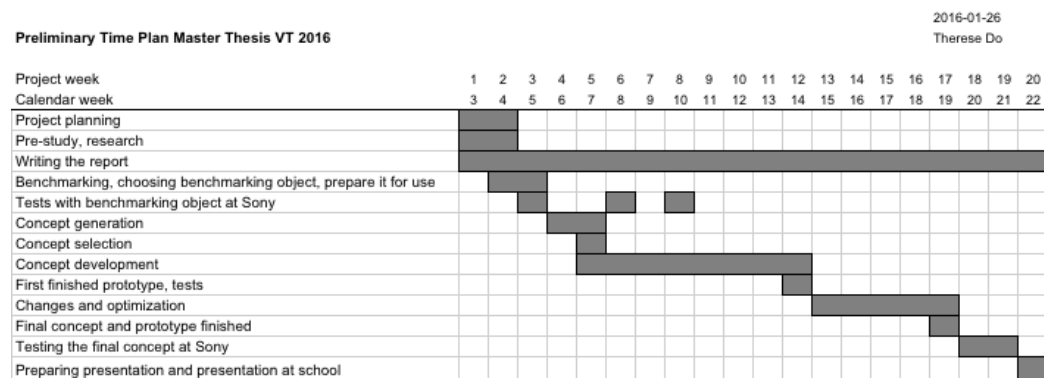


Figure A.1 - Preliminary Time Plan

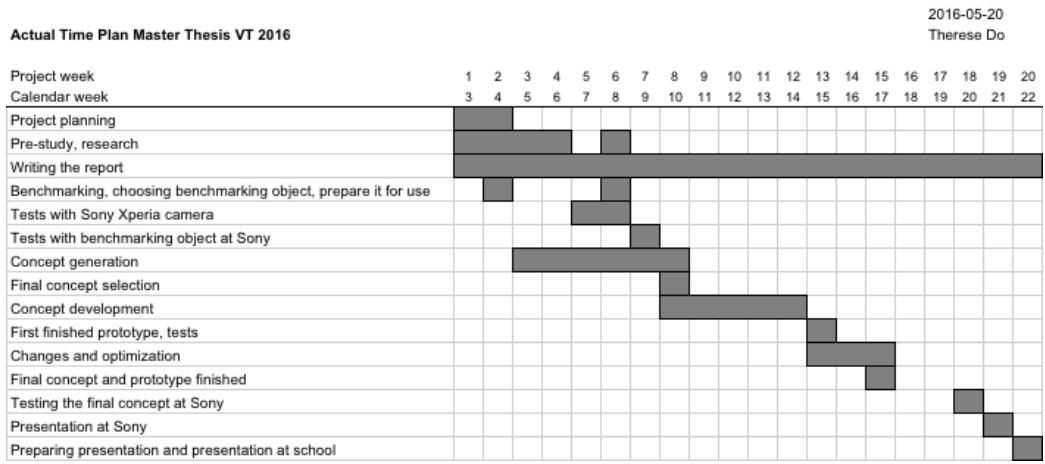


Figure A. 2 - Actual Time Plan

Appendix B Ricoh Theta m15 Guidelines

1. Place the camera with the tripod on a plain surface close to where you would intend to look at the material that would be created.
2. Turn on the camera by pressing the upper side button.
3. Pair the camera with your device by connecting your device to the wifi network “THETAXN00200702”. (You might need to press the lower side button on the camera to activate wifi pairing.)
4. Start the app called “Theta HDR” on your device. Choose your exposure settings and press Start.
5. Transfer the photos from the phone to your computer with a method of your choice.
6. Open Photoshop.
7. Press File > Automate > Merge to HDR Pro...
8. Press browse and choose the images to be merged, then press OK
9. Make any necessary adjustments, then press OK again.
10. Press File > Save As > Save file as Radiance
11. Open file in rendering program.

Appendix C Interviews

Johan Wiggberg. Genomförd 2016-03-03

Var uppgiften enkel att utföra?

Ja, jätteenkel.

Vilka exponeringar togs och var de tillräckliga?

-2, -1, 0, +1, +2
Jag hade helst behövt ha lägre än -2.

Är det viktigt att produkten är portabel?

Jag sitter alltid på samma plats.

Var produkten tillräckligt portabel?

Ja

Är utseendet på produkten viktig?

Nej

Vad var bra med metoden?

Väldigt enkel och snabb. Portabel. Bra att den fångade allt, både taket och bordet. Behöver ej få med botten runt produkten.

Vad var dåligt med metoden?

Knapparna i appen var för små. Väntetiden något för lång för att man ska sitta kvar och vänta. Lite svårt att matcha rätt position på bakgrunden i Maya.

Övrigt

Bra om den kan köras utan att jag är där. Vill gå iväg medan bilderna tas. Vill kunna överföra bilderna medan mobiltelefonen sitter i stativet (för den framtida produkten) via sladd. Använder ej molntjänster.

Nikola Petrovic. Genomförd 2016-03-03

Var uppgiften enkel att utföra?

Jätteenkel, smidig.

Vilka exponeringar togs och var de tillräckliga?

-2, -1, 0, +1, +2

Ja.

Är det viktigt att produkten är portabel?

Ja, så att den kan flyttas emellan mig och mina kollegor, så att alla kan använda den.

Var produkten tillräckligt portabel?

Ja

Är utseendet på produkten viktig?

Nej

Vad var bra med metoden?

Att man kan få fram material snabbare, utan att behöva gissa lika mycket.

Vad var dåligt med metoden?

Svårt att rotera bakgrunden rätt i Maya.

Olle Rydberg. Genomförd 2016-03-03

Var uppgiften enkel att utföra?

Superenkelt fram till Photoshop-steget och efterbearbetningen.

Vilka exponeringar togs och var de tillräckliga?

-2, -1, 0, +1, +2

Nej, det behövs högre och lägre för att få noggrannare bilder.

Är det viktigt att produkten är portabel?

Ja.

Var produkten tillräckligt portabel?

Ja.

Är utseendet på produkten viktig?

Nej

Vad var bra med metoden?

Produkten var smidig och tar inte mycket plats. Det räckte med ett knapptryck.

Vad var dåligt med metoden?

Hade behövt ta en lägre exponering än -2 för att få fler detaljer. Det var lite svårt att få bilden att matcha rätt i programmet. Kameran tog inte helt korrekta bilder, vitbalansen var till exempel inte helt rätt.

Övrigt

Hade varit bra att kunna gå iväg medan bilden tas. Hade varit bra om det fanns något som automatiskt roterade upp bilden rätt i Maya. Hade varit bra om produkten tog ett referensfoto på materialet medan/före/efter den fotar hela miljön. På så sätt kan man använda den bilden som referens när man korrigerar ljuset i Maya senare, istället för att titta på det fysiska materialet.

Jonas Teiler. Genomförd 2016-03-03

Var uppgiften enkel att utföra?

Ja, det var snabbt.

Vilka exponeringar togs och var de tillräckliga?

-2, -1, 0, +1, +2

Är det viktigt att produkten är portabel?

Ja, så att den kan användas på flera ställen, till exempel i fotostudion.

Var produkten tillräckligt portabel?

Ja

Vad var bra med metoden?

Appen var bra och enkel. Photoshop-steget var enkelt att utföra. Allt gick snabbt, från start till Maya.

Vad var dåligt med metoden?

Vet inte om den hade fungerat i en studiomiljö.

Appendix D Customer Need Tables

D.1 Interpreting Raw Data in Terms of Customer Needs

The customer statements and their interpreted needs can be seen in table D.1.

Table D.1 - Customer statements and interpreted needs.

	<i>Customer statement</i>	<i>Interpreted need</i>
<i>Portability</i>	I need to be able to move the product between me and my colleagues.	The product can be transferred between different desks at the office.
	I want to bring the product down to the photo studio	The product can be brought outside the office.
<i>Photographic functions and post processing</i>	It would be better if it could capture an exposure under -2 EV.	The camera can capture images with an EV under -2.
	I want it to be able to capture the images in a photo studio environment.	The stitching program can stitch images taken in a photo studio.
	It was easy to merge the photos in Photoshop.	The images are easy to merge into a lighting environment (.hdr or .exr).
	It doesn't necessarily have to capture the table closest to the camera.	The product captures images at all angles except for the space under itself.

Good qualities of the competitor product

The whole process was very fast.

The product operates during a short amount of time.

It was very simple to use.

The product is easy to understand.

It was good that the camera captured both the ceiling and the table.

The product can capture images at 360 x 180°

It's small.

The product does not use much space.

It only needed one push of a button.

The product operates with only one push of a button.

Bad qualities of the competitor product

The buttons in the app were too small and hard to use

The control mechanisms on the product can be reached and used easily.

The time it takes for it to run is too long for me to sit around and wait.

The user can leave the workplace after starting the product.

It was tricky to position the background in Maya.

The final lighting environment is easy to position in Maya.

	The post processing was a bit tricky.	The post processing is easy.
	The camera didn't take correct photos	The camera captures accurate photos.
	The white balance was not completely correct.	The white balance is correct.
<i>Suggestions for improvements</i>	It would have been good if you were able to upload the images via a micro USB cable directly from the product.	The product uploads the images via micro USB to the computer.
	The product should capture a reference image of the material that I'm working with so that I can use it to match my background image later.	The product captures an image of the material about to be rendered before or after capturing the lighting environment.
	It would have been good if the product could be charged and used at the same time.	The product can be charged as it's being used.
	It's good if it can run without me being there.	The product is autonomous.

D.2 Organizing the Needs into a Hierarchy

The interpreted needs were organized into a hierarchy and can be seen in Table D.2.

Table D.1 - The interpreted needs organized into a hierarchy. The primary needs are indicated in bold and the secondary needs are weighed with (*). Critical needs are indicated with (*) and latent needs with “!”.**

The product is portable.
*** The product can be transferred between different desks at the office.
*** The product can be brought outside the office.
** The product does not use much space.
The product is easy to use.
*** The product is easy to understand.
** The product operates in a short amount of time.
*** The product operates with only one push of a button.
** The control mechanisms on the product can be reached and used easily.
The product is autonomous.
** The user can leave the workplace after starting the product.
The product captures a sufficient amount of pictures
*** The product captures images at all angles except for the space under itself.
* The product captures an image of the material about to be rendered before or after capturing the lighting environment.
The product is easy to charge
* The product can be charged as it's being used.
The post processing is easy.
* The final lighting environment is easy to position in Maya.
*! The stitching program can stitch images taken in a photo studio.
** The images are easy to merge into a lighting environment (.hdr or .exr).

* The product uploads the images via micro USB to the computer.

The camera captures accurate photos.

*! The camera can capture images with an EV under -2.

*! The white balance is correct.

Appendix E Concept Selection Matrices

E.1 Storing and Accepting External Energy

The concept selection matrix for selecting a way to store and accept external energy can be seen in table E.1. The chosen concept was A, through a DC adapter.

Table E.1 - Concept selection matrix for storing and accepting external energy.

<i>Selection Criteria</i>	<i>Weight Factor</i>	<i>A</i>		<i>B</i>		<i>C</i>	
		<i>Points</i>	<i>Weighted Points</i>	<i>Points</i>	<i>Weighted Points</i>	<i>Points</i>	<i>Weighted Points</i>
<i>Portable within the office</i>	25%	1	0,25	3	0,75	3	0,75
<i>Possible to bring outside</i>	5%	0	0	3	0,15	3	0,15
<i>Easy to power and recharge</i>	25%	3	0,75	3	0,75	1	0,25
<i>Attractive Design</i>	5%	1	0,05	3	0,15	2	0,1
<i>Feasible to prototype</i>	30%	3	0,9	1	0,3	2	0,6
<i>Reduces product size</i>	10%	3	0,3	1	0,1	1	0,1
Total Score	100%		2,25		2,2		1,95

E.2 Applying Rotational Energy to the Phone

The chosen mechanical concept was number 4 since it was the only concept that kept the rotational pivot point inside the camera lens. A full concept selection matrix can be found in table E.2.

Table E.2 - Concept selection matrix for applying rotational energy to the phone.

<i>Selection Criteria</i>	<i>Weight Factor</i>	<i>1.</i>		<i>2.</i>		<i>3.</i>		<i>4.</i>	
		<i>Points</i>	<i>Weighted Points</i>	<i>Points</i>	<i>Weighted Points</i>	<i>Points</i>	<i>Weighted Points</i>	<i>Points</i>	<i>Weighted Points</i>
<i>Rotational pivot point close to camera lens</i>	20%	1	0,2	3	0,6	3	0,6	5	1
<i>Allows 360° horizontal rotation</i>	20%	5	1	5	1	5	1	5	1
<i>Allows 90° vertical rotation above horizontal plane</i>	20%	1	0,2	4	0,8	2	0,4	5	1
<i>Allows 45° vertical rotation below horizontal plane</i>	20%	1	0,2	4	0,8	2	0,4	5	1
<i>Portable</i>	10%	5	0,5	4	0,4	5	0,5	4	0,4
<i>Balanced</i>	7%	4	0,28	3	0,21	2	0,14	2	0,14
<i>Attractive design</i>	3%	4	0,12	3	0,09	3	0,09	3	0,09
<i>Total</i>	100%		2,5		3,9		3,13		4,63
<i>Rank</i>			4		2		3		1

E.3 Capturing Images

Using a Bluetooth shutter was selected to be the method to remotely capture images. A full concept selection matrix can be found in Table E.3.

Selection Criteria	A		B		C		D		
	Bluetooth Remote	Headphone Shutter	Touch Button	Physical Button	Weight Factor	Points	Weighted Points	Points	Weighted Points
<i>Easy to integrate with the product</i>	5	4	2	1	25%	1,25	0,5	1	0,25
<i>Captures accurate photos</i>	5	5	3	2	40%	2	1,2	1	0,4
<i>Attractive design</i>	5	4	1	0,2	5%	0,25	0,05	2	0,1
<i>Feasible to prototype</i>	5	5	2	1,5	30%	1,5	0,6	1	0,3
Total Score	20	18	8	4,7	100%	5	2,35	5	1,05
Rank	1	2	3	4					

Table E.3 - Concept selection matrix for selecting a method to capture images.

Appendix F Electronic Design and Programming

F.1 Electronic Schematics

The schematics of the electronics for capturing images via the Arduino is seen in Figure F.1.

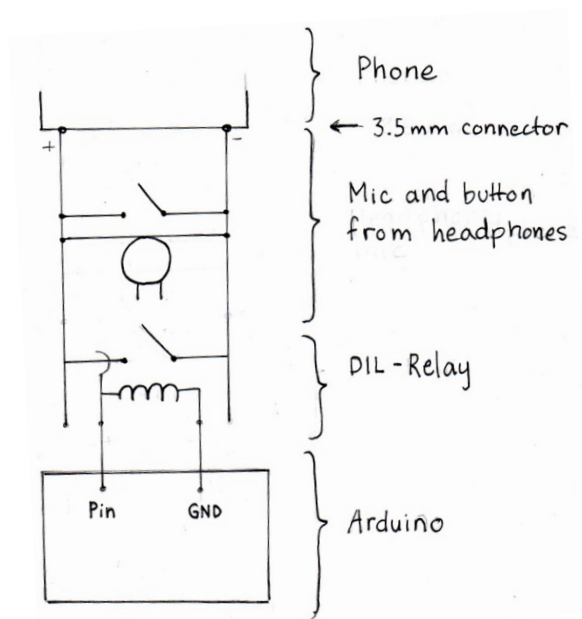


Figure F.1 - Schematics of the electronics for capturing images from the Arduino

F.2 Arduino Source Code

The source code that was programmed into the Arduino to control the motors, buttons and LEDs is shown below.

```
#include <Wire.h>
#include <Adafruit_MotorShield.h>
#include "utility/Adafruit_MS_PWMServoDriver.h"

// Create the motor shield object with the default I2C address
Adafruit_MotorShield AFMS = Adafruit_MotorShield();
// Or, create it with a different I2C address (say for stacking)
// Adafruit_MotorShield AFMS = Adafruit_MotorShield(0x61);

// Connect a stepper motor with 512 steps per revolution (1.8 degree)
// to motor port #2 (M3 and M4)
Adafruit_StepperMotor *myMotor = AFMS.getStepper(512, 2);

//conenct a stepper motor to port #1 (m1 and M2)
Adafruit_StepperMotor *myMotor2 = AFMS.getStepper(64, 1);

int photoPin = 2;
int buttonPin = 4;
int buttonState = 0; // variable for reading the pushbutton status
int greenLedPin = 7;
int redLedPin = 8;
int paus = 9000;
int angle1 = 64;
int angle2= 45;
int angle3 = 64*2;
```

```

int angleA = 160;
int angleB = 160*4+80;

void setup() {
  Serial.begin(9600);      // set up Serial library at 9600 bps
  Serial.println("Stepper test!");

  AFMS.begin(); // create with the default frequency 1.6KHz
  //AFMS.begin(1000); // OR with a different frequency, say 1KHz

  myMotor->setSpeed(10); // 10 rpm

  pinMode(photoPin, OUTPUT);
  pinMode(buttonPin, INPUT);
  pinMode(greenLedPin, OUTPUT);
  pinMode(redLedPin, OUTPUT);

}

void loop() {
  // put your main code here, to run repeatedly:
  digitalWrite(redLedPin, LOW);
  digitalWrite(greenLedPin, HIGH);

  buttonState = digitalRead(buttonPin);
  if(buttonState == HIGH){
    digitalWrite(redLedPin, HIGH);
    digitalWrite(greenLedPin, LOW);

    //First row: 8 images

```



```

for (int i=0; i <= 6; i++){
    digitalWrite(photoPin, HIGH); // sets the relay on
    delay(500); // for 0.5 seconds
    digitalWrite(photoPin, LOW); // sets the relay off
    delay(paus);
    myMotor->step(angle1, BACKWARD, DOUBLE);
}
digitalWrite(photoPin, HIGH);
delay(500);
digitalWrite(photoPin, LOW);
delay(paus);
myMotor2->step(angleA, FORWARD, DOUBLE);

//Second row: 8 images
for (int i=0; i <= 6; i++){
    digitalWrite(photoPin, HIGH);
    delay(500);
    digitalWrite(photoPin, LOW);
    delay(paus);
    myMotor->step(angle1, FORWARD, DOUBLE);
}
digitalWrite(photoPin, HIGH);
delay(500);
digitalWrite(photoPin, LOW);
delay(paus);
myMotor2->step(angleA, FORWARD, DOUBLE);

//Third row: 4 images
for (int i=0; i <= 2; i++){

```

```

digitalWrite(photoPin, HIGH);
delay(500);
digitalWrite(photoPin, LOW);
delay(paus);
myMotor->step(angle3, BACKWARD, DOUBLE);
}
digitalWrite(photoPin, HIGH);
delay(500);
digitalWrite(photoPin, LOW);
delay(paus);
myMotor->step(angle1*6, FORWARD, DOUBLE);
myMotor2->step(angleA, FORWARD, DOUBLE);

//Zenith: 1 image
digitalWrite(photoPin, HIGH);
delay(500);
digitalWrite(photoPin, LOW);
delay(paus);
myMotor2->step(angleB, BACKWARD, DOUBLE);

//Lower row: 8 images
for (int i=0; i <= 6; i++){
  digitalWrite(photoPin, HIGH);
  delay(500);
  digitalWrite(photoPin, LOW);
  delay(paus);
  myMotor->step(angle1, BACKWARD, DOUBLE);
}
digitalWrite(photoPin, HIGH);
delay(500);

```

```
digitalWrite(photoPin, LOW);  
delay(paus);  
myMotor->step(angle1*7, FORWARD, DOUBLE);  
myMotor2->step(120, FORWARD, DOUBLE);  
  
}  
  
}
```

Appendix G User Manuals

G.1 Preparing the Devices for the first time

Both the Sony Xperia Z5 Compact and the computer intended for preparing the images need certain software installed.

G.1.1 Software and settings required for the Sony Xperia Z5 Compact

The device need to have the application Camera FV5 installed, and can be purchased and downloaded from Google Play Store:

<https://play.google.com/store/apps/details?id=com.flavionet.android.camera.pro&hl=sv>

The settings inside Camera FV5 are:

1. Press the Image menu-icon shown in Figure G.1.1.1
2. Press the BRK-button. Set the number of photos to 3 and the EV to 2.0, seen in Figure G.1.1.1.
3. Press the Options-icon shown in Figure G.1.1.1.
4. Press the Camera-icon in the menu, shown in Figure G.1.1.2. Scroll down to “Hårdvarukontroller” and press “Volymkontrollens egenskaper”
5. Choose “Slutare/fokus”

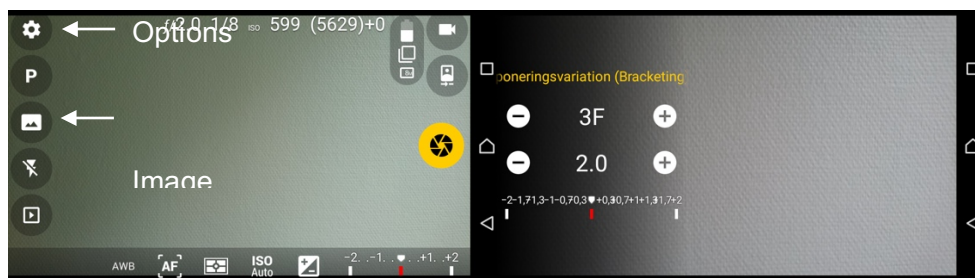


Figure G.1.1.1 – Left: Home screen of Camera FV5. Right: Inside bracketing menu.

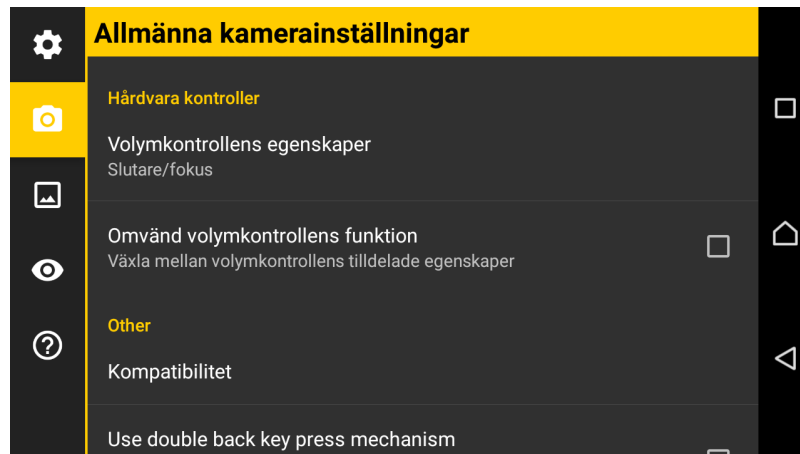


Figure G.1.1.2 - Inside the Options menu

The device also need to configure a Smart Connect™ event to simplify the usage of the new product. This is done by following the instructions below.

1. Open the Smart Connect™ application on the device.
2. Create a new event (+ symbol).
3. Add “headset” in “Add accessory” and move on to step 2.
4. Press “Add start action” and select Start an app.
5. Browse to Camera FV5 and select the app.
6. Go to step 3 and name the event. Press Finish.

The Sony Xperia Z5 Compact is now correctly prepared to be used with the new product.

G.1.2 Software Required for the Post Processing

To merge the 87 JPEG images into 29 HDR images, a version of Photoshop compatible with the Batch HDR script is needed (for example Photoshop CS 6). The Batch HDR script can be downloaded from Adobe Forum:

<https://forums.adobe.com/thread/1277672?start=0&tstart=0>

And Instructions on how to install it can be found on the same page.

PTGui is also needed and can be downloaded from the PTGui website:

<https://www.ptgui.com/>

The trial version is sufficient for this purpose.

G.2 Capturing the images for the first time

1. Attach the device (Sony Xperia Z5 Compact) according to Figure G.2.
2. Rotate the top part in the direction of the arrow until it hits a stop to set it to its start position. Also make sure that the motor arm is perfectly aligned with the support on the top part.
3. Double tap the phone screen to wake the it if necessary, then connect the 3,5 mm plug to the headphone jack. This will automatically start the camera application.
4. Make sure the device is connected to a power source using the included power adaptor (LED-indicator will be green) and start the program by pressing the white button at the front (LED-indicator switches to red).
5. Wait for the program to run (approx. 6 mins). It will stop automatically once it's done and the LED-indicator will switch back to green.



Figure G.2 - Left: Front side. Right: Back side. The phone must be placed properly so that the camera lens aligns with the rotating axes. Clamp the phone all the way back to the attachment and push it as far to the right as possible, viewed from the front.

G.3 Merging The Photos to HDR Images

1. Transfer all 87 images to the computer.
2. Open Photoshop and press File -> Automate -> Batch HDR...
3. Browse to the folder containing the images.
4. In File Filter, type JPG after the "*" (File Filter: *JPG).
5. In Save As, choose Radiance.
6. Press OK.

G.4 Stitching the Photos into a Panorama

1. Open PTGui Pro.
2. Press 1. Load images... and select all 29 HDR images previously created.
3. Press 2. Align Images
4. Preview the panorama and make sure it is a 360 x 180 equirectangular panorama.
5. If necessary, fix the missing control points.
6. In the top menu, choose Create Panorama and then press Create Panorama at the bottom of the page. A panoramic HDR-file will now be created and saved at the chosen destination folder.