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Thesis

HARDWARE AND SOFTWARE FOR PANORAMIC PHOTOGRAPHY

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In this thesis, panoramic photography was chosen as the topic of study. The primary goal of the investigation was to understand the phenomenon of panoramic photography and the secondary goal was to establish guidelines for its workflow. The aim was to reveal what hardware and what software is required for panoramic photographs.

The methodology was to explore the existing material on the topics of hardware and software that is implemented for producing panoramic images. Later, the best available hardware and different software was chosen to take the images and to test the process of stitching the images together. The experiment material was the result of the practical work, such the overall process and experience, gained from the process, the practical usage of hardware and software, as well as the images taken for stitching panorama. The main research material was the final result of stitching panoramas.

The main results of the practical project work were conclusion statements of what is the best hardware and software among the options tested. The results of the work can also suggest a workflow for creating panoramic images using the described hardware and software. The choice of hardware and software was limited, so there is place for further experiments.

This Bachelor's thesis is not concerned with the mathematics of making panoramic images and the software for exporting and viewing panoramic images. These topics are good research questions for other researchers. The limitations of this study included the limited theoretical sources, limited hardware to test, as well as limited software. There was only one hardware setup and only three options for testing software. The final result, however, was good quality panoramas, and the experiment gave answers to the research questions.

Keywords: panoramic photography, 360-degree photography, stitch, merge



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**HARDWARE AND SOFTWARE
FOR PANORAMIC PHOTOGRAPHY**

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1 INTRODUCTION

1.1 Relevance of Thesis Topic

In this Bachelor's thesis the subject of 360-degree panoramic photography or sphere panoramic photography is researched. Panoramic photography as a phenomenon is not new. For centuries, people have liked to draw or to capture wide-angle images. However, modern development of technology has brought new ways of creating panoramas. Nowadays, special equipment like cameras with additional devices is used to capture panoramas and computers with software to combine all images together. For example, Panorama Tools is one of the popular open source software for immersive imaging, written by the German professor Helmut Dersch, was first introduced to the market in 2003 (Dersch 2012). Other example is Easypano Holdings Inc., a leading developer and marketer of virtual tour software, which was found in November of 2001 in Shanghai, China (Easypano Holdings Inc. 2010a).

The subject of panoramic photography has huge market potential, due to its ability to capture surrounding environment with great accuracy and precision. At the moment, virtual tour panoramas have a great use in maps, areal and premises shootings and tourist destinations. As an alternative, with use of panoramic images might be possible to capture crime scenes and other places for different kind of research.

This topic has a great personal relevance to the thesis author, because photography is one of the main interests. In panoramic photography there are at least three different characteristics to experiment: device complexity, software flexibility and photographic creativity. Thesis author is motivated to expand knowledge and skills in spherical photography and one of the goals for this thesis is to perform a work for a portfolio that can be used for future employment.

In this thesis, different types of panoramic photography are defined and all required equipment and software to produce quality panoramas are described in details. Furthermore, all acquired knowledge is implemented into practical work and sample panoramic images are produced. Additionally, workflow for creating panoramas is defined, where all difficulties of chosen

method of implementation are revealed. The last chapter evaluates the work done and summarize the results.

Nowadays, this particular field of photography is still relatively new and is in the process of development. Consequently, only a limited amount of information, related to the subject is possible to find. Presently, most of the sources about panoramic images, especially full spherical, can be found in periodical issues such as magazines or articles with practical knowledge, and also in the Internet. Therefore, the topic is challenging and requiring a lot of time for gathering and processing the information. Due to the newness of the chosen subject, it has not been studied properly on the academic level and, consequently, this thesis brings new information to the field of study and it will not repeat other researchers.

The main objective of this thesis project is to gain profound knowledge of the process of developing sphere panoramas and document gathered information. Hopefully, in the future, the thesis author will be able to produce panoramic images for employer or as entrepreneur. The second objective of this thesis project is to establish a workflow for creating sphere panoramas from planning to a final product. Since the topic is quite new, all of available information about panoramic images is still very limited and uncategorized; therefore, the demand for such knowledge will be high.

1.2 Research Question and Methodology

In this Bachelor's thesis, the main research questions are to define the method for creating panoramic images and to specify required hardware and software for the purpose of capturing panoramic photography. In addition, this thesis summarizes the full workflow for creating panoramic images.

Through research of existing material on this topic (which is mainly from magazines, periodical publications and the Internet) thesis questions are answered. Based on the collect material author does a practical project of creating a panoramic photography. Additionally, job evaluation is described based on the performed work.

This thesis is functional, because guidelines are created for professional practical operation, and rationalize operation of creation panoramic photography (Rovaniemi University of Applied Sciences 2010, 4).

1.3 Project Plan

In general, process of creating such kind of photography requires technical experience with camera equipment, which will help to produce quality images. Also it requires knowledge in various Internet platforms and ability to stitch photographs in special software. In order to produce quality panoramic photography one has to have basic knowledge of photographing techniques, for example, to be able to arrange accurate composition, choose appropriate settings and post edit photos, to correct white balance and etc.

This thesis project concentrates on partial and full spherical panoramic photography, however due to some technical issues, to produce a full spherical panorama is challenging. Hence, as a method in implementation phases only a partial spherical panorama is presented.

The following issues are discussed in this thesis

- what panoramic photography is
- various panoramic types
- usage of panoramas
- what hardware equipment to capture panoramic images is required
- what software to edit and stitch photographs is required
- advantages and disadvantages of existing hardware and software
- method of producing sphere panoramas
- summary of all collect information
- description of the results of performed work.

The above topics will help to understand the phenomenon of panoramic photography and to reveal available hardware and software methods of producing panoramas. Using the results of the practical project, basic guidelines are created for capturing sphere panoramas and implementation of one particular method and detailed description of it. The results of performed work are evaluated, as well as the implications for further work is described. However, author's personal goal and motivation is to gain the real

experience and ability to work as an expert in such field in future professional life.

2 PROJECT BACKGROUND

2.1 Panorama Definition and Types

According to the dictionary, panorama is a description or series of pictures that shows all the features of a subject, historical period, etc (Bullon et al. 2003, 1190). In other words, panorama is a group of pictures of particular place displayed in consecutive order, that depict all details of a subject in a exact perspective.

Due to the ability of 360° panoramas to display wide field of view, there exist alternative names like virtual tour and virtual reality panoramas (Rauscher et al. 2007). It is possible to distinguish two main types of panorama; they are partial panoramas and immersive panoramas.

In most cases, **partial panoramas** are captured with ordinary cameras. Subsequently, two or more images are assembled together to create a single image with wider field of view. The difference between partial and immersive panoramas is that partial panoramas cover only a fraction of view sphere, less than 360 degrees in longitude and less than 180 degrees in latitude. Partial panoramas are viewed as traditional images in print and digital form. (Rauscher et al. 2007.)

The demand for partial panoramas is high in cases when certain subject requires detail representation in high resolution. Max Lyons developed the best example of partial panorama in 2003, which represents the view from Bryce Point in Bryce Canyon National Park in Utah. It consists of 196 separate photographs captured with 6-megapixel digital camera, and stitched afterwards into a single composition. The final product is 40,784 x 26,800 pixels in size, and it contains about 1.09 billion pixels; this is huge image with very high resolution. (Lyons 2003.)

Immersive or full-spherical panoramas are panoramas viewed through special viewing software that covers image data of 360 degrees in longitude and 180 degrees in latitude. Immersive panoramas can be captured by special panorama camera or by ordinary camera, which will require subsequent stitching process. (Rauscher et al. 2007.)

2.2 Panorama Projections

To represent spherical point of view in flat monitor or print document, it requires some manner of mapping from the 3D spherical scene in which the camera and viewer are embedded to the 2D medium in which they are rendered. The techniques used for mapping are exactly the same as for transferring ordinary map from a globe to two-dimensional map. There are many classes of projections used for various purposes, but only few of them are traditionally used for panoramic imaging. (Rauscher et al. 2010.)

One of the most common type of partial panorama when working with panoramic imaging is **cylindrical projection**, which are commonly used for printing panoramas with a large range of longitude, more than 120-degrees. A full-range of longitude, up to 360 degrees, can be represented with a cylindrical projection, but near the poles, the images become very distorted, so full range of latitude cannot be used. (Rauscher et al. 2010.) Cylindrical projection is the best suitable for landscape photography.



Figure 1. Cylindrical Projection (Rauscher et al. 2010).

Among partial panoramas **rectilinear projections** are one of the fundamental, which can be envisioned by imagining placing a flat piece of paper tangent to a sphere and projecting a light out from its center. Therefore, only less than 180° of longitude can be represented with this projection, in practice it will be even less. Usually, most of non-fisheye lenses produce nearly rectilinear image over their field of view. The rectilinear projections are often used for

prints of panoramas which cover less than 120° of longitude, since straight lines are preserved. (Rauscher et al. 2010.)

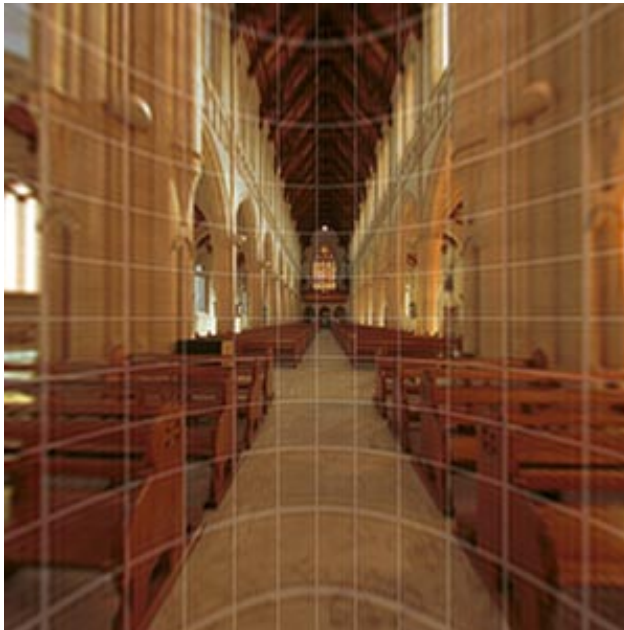


Figure 2. Rectilinear Projection (Rauscher et al. 2010).

To create full spherical panorama you need to combine 6 of rectilinear projections and arrange them like a face of cube. Consequently, that kind of projection is named **cubic projection**, where four cube faces cover front, right, back and left, one the zenith and one the nadir, each of them having $90^\circ \times 90^\circ$ field of view. Several spherical panorama viewers, including SPi-V and Quicktime Images are commonly use images in the cubic projection as the image source. (Rauscher et al. 2007.)

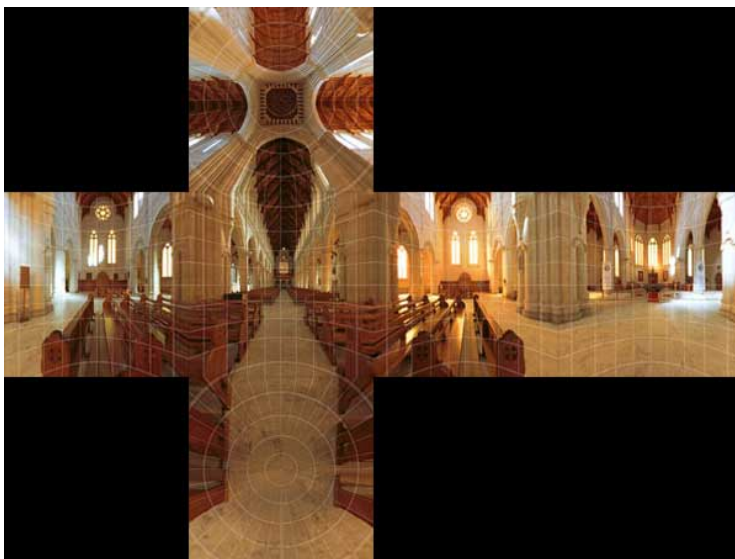


Figure 3. Cubic Projection (Rauscher et al. 2010).

Other projection type for full spherical panoramas is **equirectangular projection**, it is also called non-projection, since the horizontal coordinate is longitude and the vertical coordinate is latitude, with no transformation or scaling applied. The poles are located at the top and bottom edge and are stretched to the entire width of the image. The equirectangular projection is default output format for fisheye equipped lenses, which produce full sphere at 360° rotation. This projection is often used for the source images in panoramic viewers like PTVIEWER. (Rauscher et al. 2008.)



Figure 4. Equirectangular Projection (Rauscher et al. 2010).

In addition to full-spherical panorama and partial panorama it is possible to create partial spherical panorama using equirectangular or cubic projection. The difference often is that partial spherical panorama projection does not include zenith or nadir.

2.3 Applications of Panoramic Photography

During first years of the formation of the Internet, there were weightless websites with plain text, which were easy and quick to browse with help of low speed modem connection. During the past two decades, the Internet evolved greatly and due to the demand from the public, the capability of the Internet providers has grown and now they can support high speed connections for various customer groups. Nowadays, web users can upload and download heavy images and video files and share them around. Therefore, human habits of receiving information transformed from reading the data into watching and hearing the same information. As a result of these developments, it

became possible to display digital spherical panoramas and distribute them among Internet users.

Consequently, entrepreneurs and marketing analyst started to search for new development strategies and approaches. Through agility and accuracy of the spherical panoramas, they become widely adopted among businessmen and other Internet users.

It is difficult to define who first produced spherical panoramas for commercial use, but certainly, one of the most famous developers is Google Maps with their Street View service. At the beginning of the project, the quality of panoramas was low, but they made big improvements. Presumably, after the success of Google's Street View, various websites with more specific location panoramas started to appear. For instance, owners of 360 Cities project maintain world's largest 360-degree panoramic photography community.

Also, there are lots of collections of location-based panoramas, like interactive 360° panoramas of German cities that provides the chance experience them as you are present at the place, with the ability to zoom in or out, and to follow the hotspots to the next points of interest, making a virtual journey (Koelbach 2012).

Commercial examples of usage of spherical 360-degree panoramas or virtual tours are various presentations of tourist destinations and real estate advertising, houses, apartments, cottages and etc. More prospects of use are presentations of different businesses and services like restaurants. Detailed 360° panoramic photography might be in a great use for detectives to capture all details of crime scenes. Overall, virtual reality panoramas can be applied to any space in a purpose of revealing its dimensions, where users can roll over 360 degrees right and left, up and down and even moving to a hotspots.

3. HARDWARE

3.1 Hardware Required to Make Spherical Panoramas

To produce spherical panorama two major types of equipment is required: camera with support equipment to capture images and computer to edit, stitch and view. In general, it is possible to use any kind of equipment to make panorama, even using simple mobile camera and basic desktop computer it is possible to create satisfactory spherical panoramic photography. However, low-quality hardware will impact the panorama appearance and images will loose accuracy, which is one of the most important characteristics of spherical panoramas. Therefore, it is preferable to use quality equipment if possible, which will also save time of post-production and during stitching process.

In addition to the equipment, mentioned above, it is important to emphasize the importance of camera lenses, for example narrow, wide or fisheye lenses. To stabilize camera it is better to use tripods or monopods with special panoramic head that will lead to accurate juncture in panoramic photography. To achieve special effects one can take advantage of various lens filters, or add them later in photo editing software. To light up the surroundings one can use flash or some external light. Eventually, to capture high resolution images, one should preferably use high quality equipment, but high resolution pictures requires more memory on camera and computer.

3.2 Camera Classification

Nowadays, selection among cameras is wide and depends on customer demands, skills and income. All cameras can be roughly divided into four groups: mobile cameras, which produce the lowest photo quality from all existing cameras; compact cameras, which are the most common among amateurs; bridge digital cameras, which are more complicated than compact cameras, but yet not as professional as digital single-lens reflex DSLR cameras, that are most complicated and qualitative. (James 2012b, 97.)

Today most widely distributed cameras are **mobile cameras**, which are integrated into mobile phones and mobile industry is one of the most active and

developing elaboration field. However, due to complexity of mobile phones and different targets of usage, often photographic quality is the lowest among the camera family. Though, some of the cheapest compact cameras are very close in their parameters to mobile cameras.

Compact cameras are simple and easy to use and one can quickly start shooting by taking it out of the pocket. It gives a chance to capture moments that you do not have time to capture with a DSLR-camera. Modern compact cameras also offer a lot that DSLRs do not yet, like seamless integration into social networking websites and small size, however, they are not specifically designed for panoramic photography or professional usage. (Payne 2011, 87.)



Figure 5. Cyber-shot Digital Camera (Sony Europe Limited 2011).

Yet, their photo quality is acceptable for amateur, because compact camera produces small JPEG files, which often do not necessarily require any post editing and are ready for further use. Usually, owners of compact cameras are inexperienced in photography, so they prefer the camera, which can adjust all of the setting by itself. Hence, all compact cameras by default have different shooting modes, where features like ISO, white balance, aperture, shutter speed and even the flash are set by the camera automatically. Finally, one other important feature of compact cameras is live preview, which simplify framing process. Overall, compact cameras are very easy to use and are suitable for amateurs and beginners.

For more experience users there exist **bridge digital cameras**. They have satisfactory photographic quality, the price is higher than for compact cameras, but is still affordable. In comparison to compacts, bridge cameras have higher effective resolution up to 10 megapixels and faster sensor speed, which is useful for shooting moving objects. There is no usual sensor size for

bridge cameras and manufacturers use a variety of different sensor sizes. For example, the top quality bridge cameras can use up to 8.8x6.6 mm image sensor format (Lezano 2010b, 124).

Another big advantage of these cameras is fixed lens of high quality. More than often they are zoom lenses with auto or manual focus and in some cameras you can use additional filters to achieve different effects. Also, these cameras have such features as image stabilization, which avert a risk of blurriness caused by camera shaking. Moreover, bridge cameras don't only have various preset shooting modes, but also Program mode, where all settings are done by camera, which user also can adjust at the same time. Generally, bridge cameras have plenty of different features, they are easy and fun to use and bring you various photographic styles.



Figure 6. Fujifilm FinePix HS30EXR Camera (Fujifilm Corporation 2012).

Some of the cameras have possibility for shooting and making automatic panoramas. Fuji FinePix Hs10 camera, offers, for example this “amazing” camera feature, as it is described in the review in Practical Photography magazine. It claims that scenic fans will enjoy the Motion Panorama mode where you simply press the button and sweep the camera around to get a quick and easy panoramic shot. (James 2010, 108.) This can be used in both the vertical and horizontal plane, but one needs to be careful about the framing as the top and bottom may get cropped to create the final shot.

The highest quality images with the best efficiency resolution can only be achieved with professional **digital single-lens reflex cameras** or DSLRs. Those cameras are most suitable for professional photography, since they have a large and powerful sensor. Typical DSLRs have image sensor format

of 22x15 mm. However, top quality digital SLRs can reach size of classical film 35 mm format with frame size 24x36 mm (Canon 5D, Canon 1DS Mark, Nikon D3, Sony A900), which helps to obtain quality and natural images similar to film pictures. Huge image sensor formats enable good noise reduction and cameras produce clear and accurate images. (Lezano 2010a, 129.)



Figure 7. Canon EOS 5D Mark III DSLR Camera (mbbirdy 2012).

All DSLRs cameras have interchangeable lenses for different shooting occasions. They are, for instance, a macro, wide angle or very long telephoto lenses. Because of a wide choice of lenses for DSLRs cameras and due to expected consumers' experience, the body of the cameras is usually sold separately from lens. However, there are packages with a body and a basic, most salable lens sold together which are called a kits.

Professional, customer oriented DSLRs are able to produce images not only in JPEG format, but also in RAW format. Raw image format contains a minimally compressed or processed picture, which allows avoiding any data loss. Such image does not have clear specification and consist of full information from received source. Hence, these photos require post edition, where user can change parameters of exposure, brightness, contrast, white balance sharpness, saturation and etc.

The best DSLRs cameras, for example newest Canon EOS-1D X, are very complex and have big amount of features, including huge connectivity terminal. The Canon EOS-1D X includes a system extension terminal (for wireless file transfer and GPS), gigabit Ethernet port, HDMI, A/V digital terminal, flash/PC sync socket, remote control terminal, and external microphone port. The Ethernet port allows professionals to transfer images quickly without the need for an adapter. (James 2012a, 95.)

Usually, each consumer can find the best option for his or her demands from enormous amount of existing cameras. In respect of panoramic photos, user can use any type of camera, but as mentioned earlier, it is better to use the most professional quality camera. Hence, mobile and compacts cameras are not appropriate choice for quality 360° panorama. Bridge cameras can be used, but the best choice would be digital single-lens reflex cameras. Even from DSLR cameras, it is better to choose top quality cameras to achieve professional sphere panorama. For instance, Canon 5D, Canon 1D, and Nikon D700, Nikon D800, Nikon D3, and Nikon D4 are among the best full frame sensor cameras.

3.3 Lens Selection

Every DSLR camera needs a proper lens in order to generate high resolution panoramic photography, but the question is what lens is appropriate. Basically, two types of lenses are suitable for making sphere panoramas; they are narrow angle lenses and wide angle lenses.

Narrow angle lenses have the field of view of less than 90 degrees and are often used to create high quality panoramas for print. Fisheye lenses are more often used to create comparatively lower quality panoramas for web display, etc. With wide angle lenses fewer shots are needed to capture a complete scene. Fisheye lenses are typically used for creating immersive sphere panoramas, whereas longer focal length lenses are more normally used to create cylindrical panorama because it is much harder to assemble the large numbers of tiled shots these require to cover top and bottom of a complete spherical panorama image. (Rauscher et al. 2011.)

More than often, stitching software define recommended equipment, but Easypano.com, for example, says that their software can stitch any photos together. However, for high quality 360x180 degree sphere panoramas, they recommend to use Nikon or Canon DSLR. (Easypano Holdings Inc. 2012a.)

3.4 Tripods and Heads

In the process of panorama capturing, it is important to shoot non-parallax images, hence usage of tripod or monopod becomes valuable. Advantages of tripod are that it has three legs, therefore it is very stable. While monopod is not steady due to only one leg, its weight is lower than tripod's, so monopod is suitable for trips and for "shoot and go" method of capturing images. Consequently, for creating panoramic photography tripods are more suitable.

High quality tripod will have carbon fiber legs, with not more than 3 support sections. Carbon fiber tripods are very light due to material properties and small amount of support sections enhance stability. Another important tripod feature is presence of bubble spirit level, which helps to align horizon, what is very usable in capturing images for panorama.

In addition to be able to capture images, tripod or monopod must be assembled with special panoramic head. It is useful for shooting panoramas with high quality due to two features. First, it is easy for users to set the camera position on nodal point, which is the intersection of horizon axis and vertical axis. Users can rotate camera horizontally with vertical axis unchanged, avoiding the problem of parallax. Second, a panoramic head also makes panorama processing easier and more systematic. (Easypano Holdings Inc. 2010b.)



Figure 8. JTS-Rotator SPH Panoramic Head (Easypano Holdings Inc. 2010b).

On the above illustration is an example of panoramic head - JTS-Rotator SPH, which consists of three basic parts: horizontal rotator, stand and camera sliding plate. When the horizontal rotator and the stand are added to a tripod, the camera fixed on the sliding plate can be rotated horizontally 360° in the same point relative to the position of tripod. Also, with adjustment to the node of JTS-Rotator SPH it will be possible to shoot zenith and nadir, to capture full sphere panorama. (Easypano Holdings Inc. 2010b.)

3.5 Choice of Hardware for Panorama

3.5.1 The Camera

After making the research the knowledge to start making thesis project is gathered. The choice of the camera was also because of the available equipment. Of course, it would be great to have the most professional hardware, however the price is usually too high. Recently, thesis author have bought a professional DSLR camera Canon EOS 5D Mark II. It has 21.1-megapixel full-frame sensor, which is same as a 35 mm film frame (36×24 mm). It is one of the cheaper full-frame cameras, but it is still professional and significantly better than bridge digital cameras, because normally, they have a “cropped” sensor, which is smaller and cheaper than DSLR. Full-frame sensor, such as in Canon EOS 5D, has better image quality and better noise reduction.

Author bought Canon camera only a few months ago, therefore not enough experience is received. In spite of the fact that this camera is used for photography hobby, thesis author has never made panoramic photography, therefore making a new project was a challenge, and a new professional experience and practical skills are gained.

3.5.2 The Lenses

With the camera author bought two lenses. One lens is Canon EF 24-105mm f/4L IS USM. It is a good all-purpose lens, which is very popular and sold as a kit with the camera, and that way the price for the lens is smaller than sold separately. Technically, it is a zoom lens, meaning that you have optical zooming, which makes possible to take pictures from far distance. It has image stabilizer and integrates very good with camera. With this type of lens it is possible to make images to receive rectilinear projections. It is only partial panorama, so if you want to have a 360 degrees panorama, you have to stitch at least six images.

In author's point of view, the best lenses are manufactured for Canon cameras are original Canon lenses, regarding mechanical construction and usability. The price for them is high, but the quality of captured images is excellent. And the huge advantage to author's original lenses is their full compatibility. Other companies also make lenses, but they have lower quality and lower integration with the camera. Canon lens, for example, has autofocus, but other lens does not have it and all of the adjustments are manual.

Another lens author bought is a fish-eye lens Samyang 14mm f/2.8 IF ED UMC. Thesis author bought a Samyang lens, because Canon fisheye lenses are very expensive. However, this is a really good lens, which is used for shooting various events and landscapes. Compared to Canon lens, which has autofocus, Samyang fisheye lens requires manual adjustment each time for focusing and aperture. Furthermore, all of the adjustment must be done on lens body. Because there is no connectivity between lens and camera interface in terms of information, camera display shows all 0 for each available lens settings. The fish-eye lens is so-called ultra wide angle prime lens, because it has an angle 115.7° and there is no zoom. With this type of lens

you can shoot image to achieve equirectangular projections, which will create full spherical panoramas.

Shooting with both lenses is performed, because author wanted to define the lens difference. In additional, the workflow for creating panoramas with different lenses is examined.

3.5.3 Additional Hardware Equipment

In order to achieve good quality images it is better to use professional tripods. Thesis author is used a tripod Manfrotto 055xPROB. It is a semiprofessional tripod, which is good to use for overall shooting. It can also sustain the weight of the DSLR camera like Canon EOS 5D Mark II with a lens.

Probably, even more important is the use of the head, because in shooting images for panorama, camera has to move horizontally and sometimes, vertically. For this purpose it is possible to use ball head, which can move in any direction, however it is difficult to make head movement precisely same. In additional to tripod author has Manfrotto 327RC2 ball head, which integrates very well with Manfrotto tripod. There is also a easy-to-use locking mechanism to fix the position, so it is possible to unlock and change the position of the head with one hand.

3.5.4 Image Format

Usually, high quality 360-degree panoramic photographs are captured in RAW format, which contains raw pixel information. It means that after shooting images, during edition it is possible to change some settings. Consequently, pictures in RAW format contain more information then pictures in JPEG or TIFF, therefore RAW file are larger in size.

For example, Canon EOS 5D Mark II is able to capture three types of RAW files and they vary in size from 5.2 MB up to 21M. In order to create 360-degree sphere panoramic photographs, at least six images must be captured, but to avoid parallax it is better to capture overlap photographs with at least one third of the next shoot. Thus a camera should have a large memory card to be able to store a great quantity of images even from one shooting. Thesis author has bought three memory cards with capacity of 8 GB each.

3.5.5 Shooting Location

Normally panoramas are shot for a client or, as entrepreneur, for commercial use. For the purpose of the thesis a location was needed to shoot panorama. The Asemarinne area is chosen due to accessible location in the surrounding area. The first choice Kauppatori had a weak composition. All of the details and buildings are very far away. In general to capture good panorama it is better to avoid people, because they move and can leave artefacts later in the process of stitching the images to panorama. Other location is the square between the Central Library, and the Opera House. It is the quite space with a good composition and buildings close to the camera's point of view. The results of the shooting are presented in chapter 5: The Implementation Phase.

4. SOFTWARE

4.1 Image Editing Software

4.1.1 Corel PaintShop Photo Pro

According to Digital SLR magazine, improving images on a computer can be a creative and fun part of the process, in addition to the technical part of digital editing. Certainly, it is better to try and get images right in camera, but software like Corel PaintShop Photo Pro X3 Ultimate is convenient for making improvements and adjustments even to good images. (Payne 2011, 60.)

However this PaintShop version is already one year old, and recently, Corel has released PaintShop Pro X4 Ultimate, which has 75 new and enhanced features. The most valuable are improved "RAW lab" with larger preview area, with histogram that help fine-tune images quickly and with new highlight recovery feature that helps restore detail in overexposed areas. Other renewed feature is "Fill Light and Clarity", where is possible to brighten shadows without changing the rest of image that will help to draw attention to subtle details and increase the texture and depth of your photos. (Corel Corporation 2012.) In general, one can assume that Corel PaintShop Photo Pro will provide all necessary functions to edit images for creating panoramic image.

4.1.2 Adobe Photoshop CS

Corel Corporation is the competitor of Adobe System Incorporation with their Photoshop CS6 software, which is one of the most popular among photographers and image editors. Recently released beta version of Photoshop CS6 is very flexible and intelligent program, which requires some knowledge to be able to use it properly. Nevertheless, with use of this software, it is possible to create great pictures and also to retouch small details during creation of 360-degree panoramic image. For instance, it means editing out artefacts captured during shooting: if taking the image at nadir point, the tripod appears in the photo, one can retouch it. In Practical Photography magazine similar example was found, and using only several Photoshop function the unnecessary details can be removed in several seconds. (Abbott 2012, 42.)

In addition, Photoshop CS6 has RAW edition function, where it is possible to change the exposure in several steps. That feature is very useful for landscape panoramic images, due to different light conditions. Using RAW edition it is possible to improve captured images and use them for following stitching process. All information mentioned above makes Photoshop CS6 a suitable software for pre-edition of images, captured for making panoramas.

4.1.3 Adobe Photoshop Lightroom

Another alternative of image editing software is Adobe Photoshop Lightroom 4. In comparison to Photoshop CS, it is more suitable for photographers' use. For example, in *Practical Photography* magazine, Andrew James shows four steps how to process RAW images in Lightroom. One of his creative suggestions, for example, is to use black and white images, in cases when there is big amount of moving objects or noise in the scene. Making panoramas is, however, a more technical and less creative process. (James 2012c, 12.)

Overall, Adobe Lightroom 4 will meet requirements of editing panoramic images. Using this software it is possible to perform basic adjustments or even to process image a lot, if needed.

4.2 Software for Stitching and Viewing Images

One of the most important parts of creating panoramic photography is to stitch captured and edited images into one consistent and holistic picture. Therefore, great attention must be paid to the selection process of the software, which will assemble prepared images into final panorama. Nowadays, several options of software are available on the Internet, and they can be divided into three categories: free of charge, paid and partially paid software. The quality of stitching boundaries and the utilization simplicity usually is in direct proportion to the price of the software.

The first and easy solution to create panoramic images is to use bundled program that comes with the camera software (assuming that camera manufacture supplies any). For example, in Canon Utilities folder for Canon EOS 5D Mark II camera is bundled **PhotoStitch** application. The application interface is clear and simple and it contains only a minimum of necessary functions. In PhotoStitch application, the process of stitching is divided into three

steps. The first step is to select and arrange images for panorama; second step is to merge prepared images, and third step is to save obtained panoramic image. In general, using the available functions of Canon Photostitch application, it is possible to stitch basic panoramic images.

However, only to stitch images it is not enough. It is required to view sphere panoramic photography with special software. For this purpose, Canon supplies **Viewer** application in the same package in Canon Utilities folder.

Overall, Canon PhotoStitch is simple and free software received with camera package. However, it is only able to produce low or medium quality panoramas due to functions deficiency.

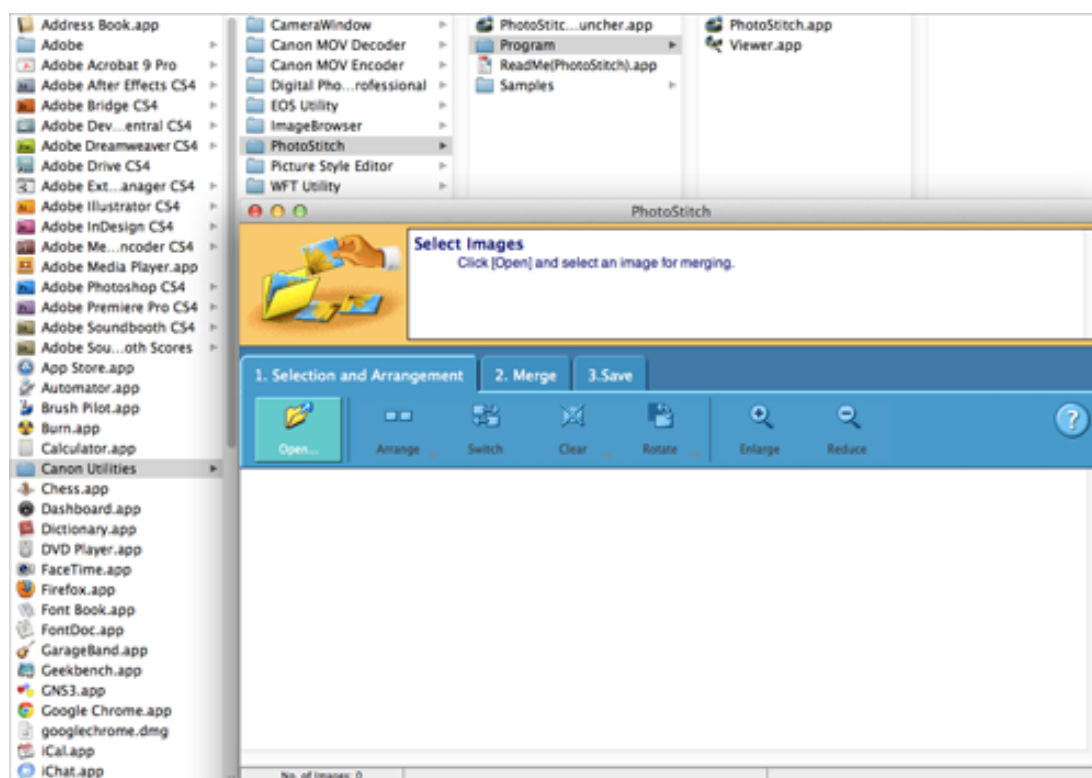


Figure 9. The Root to PhotoStitch Application and PhotoStitch Interface.

Another choice is to purchase more complex and professional software, like, for example, **Panoweaver 8**. Latest version of this program was released in 2012 by Easypano Holdings Inc. Panoweaver is claimed to be a “user-friendly panorama software”, and it is not only a professional photo stitching tool, but a great Flash panorama publisher. It can automatically stitch any type of photo into high quality full 360° or partial panoramic image, support-

ing HDR creation and manual stitching by inserting matching points. (Easypano Holdings Inc 2012a.)

Ready panoramic picture is possible to save and to print and also it is possible to upload them using HTML 5 VR. It is also possible to view panorama on mobile devices, such as iPhone or iPad, or to view on full screen html based Flash VR, Standalone SWF, QTVR and Java based VR. (Easypano Holdings Inc 2012a.)

Panoweaver is paid software, however it is possible to download a free trial version from their official web site. Among paid versions it is possible to buy Panoweaver 8 Standard Edition, which cost around 100 euros or Panoweaver 8 Professional Edition for approximately 400 euros. The difference between Standard and Professional Edition is that in Professional Edition it is possible to stitch rectilinear images into full 360 or partial cylindrical panorama. Afterwards, obtained panorama can be published into Flash or HTML 5 VR or QTVR. (Easypano Holdings Inc 2012a.)

In addition to all above features, Panoweaver 8 Professional Edition is able to stitch fisheye images, which will help to create more professional full 360° panorama or spherical panorama. Also, there is the ability to integrate Google map and hotspots into panorama and to customize the toolbar and branding of the user interface. (Easypano Holdings Inc 2012a.) In general, Panoweaver 8 Standard and Professional Editions are popular software among amateurs and professionals, because of excellent performance and ability to create high quality panoramas.

Easypano Holdings Inc. has one more software, which is able to merge several images into full spherical panorama, the **Tourweaver 7**. It is claimed to be “the industry leading virtual tour software”, it includes support of Flash 11 Player Engine, 3D object, Google map street view and multilingual tour. Additionally, with this version of 360° virtual tour software, it is possible to share virtual tour onto Facebook account and also to publish HTML5 virtual tour to iPhone and iPad. (Easypano Holdings Inc 2012b.)

Tourweaver 7 software has a Standard Edition and Professional editions for purchase and their free trial versions. Tourweaver 7 Standard Edition is suit-

able for achieving basic features like maps, hotspot, popup window etc. Also, Standard Edition supports such output formats as Flash, HTML5 for iPhone and iPad. The price for Tourweaver 7 Standard Edition is higher than for Panoweavear 8 Standard edition and it is around 200 euros. (Easypano Holdings Inc 2012b.)

Tourweaver 7 Professional Edition had more powerful features and a price near 600 euros. It has ability to customize virtual tour to the largest extent. Professional Edition also features Google map street view, 3D object, online video, Flash movie and multilingual presentation. (Easypano Holdings Inc 2012b.)

Form all mentioned above, it can be summarized that Tourweaver 7 is a complex software, which allows creating virtual tour from several full spherical panoramas using hotspots to navigate. However, the high price for software might reduce the interest of amateur consumers.

4.3 Choice of Software for Panorama

4.3.1 Adobe Photoshop CS4

As mention above, the first step to process the image is to edit photographs, and author's software choice for this purpose is Adobe Photoshop CS4. Therefore, author is familiar with this software due to previous experience with photo editing in Photoshop CS4. Another advantage of Photoshop CS4 is its ability to process images in RAW format, which gives opportunity to change exposure, white balance and several other features without damaging the original image, while preserving the original photo quality.

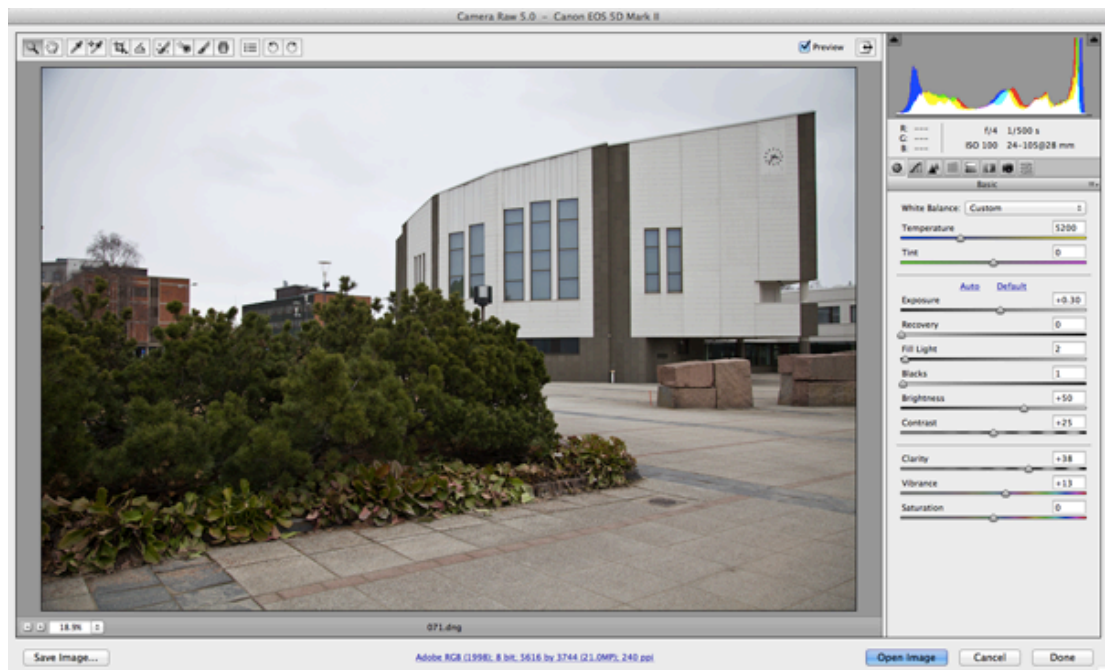


Figure 10. RAW Edition in Photoshop CS4.

Overall, Adobe Photoshop CS4 is great software for editing images, since it consists of various editing functions and it is possible to use this software for different editing purposes. But Photoshop CS4 is complex software, which requires special knowledge to be able to use it. However, for skilful user, it is relatively simple to obtain desired results.

For stitching purposes, several programs with different features and quality is used. Besides editing images, it is possible to merge several pictures into different panoramas in Adobe Photoshop CS4. This feature is called **Photomerge** and this function is very interesting in testing purpose to produce panoramic photography.

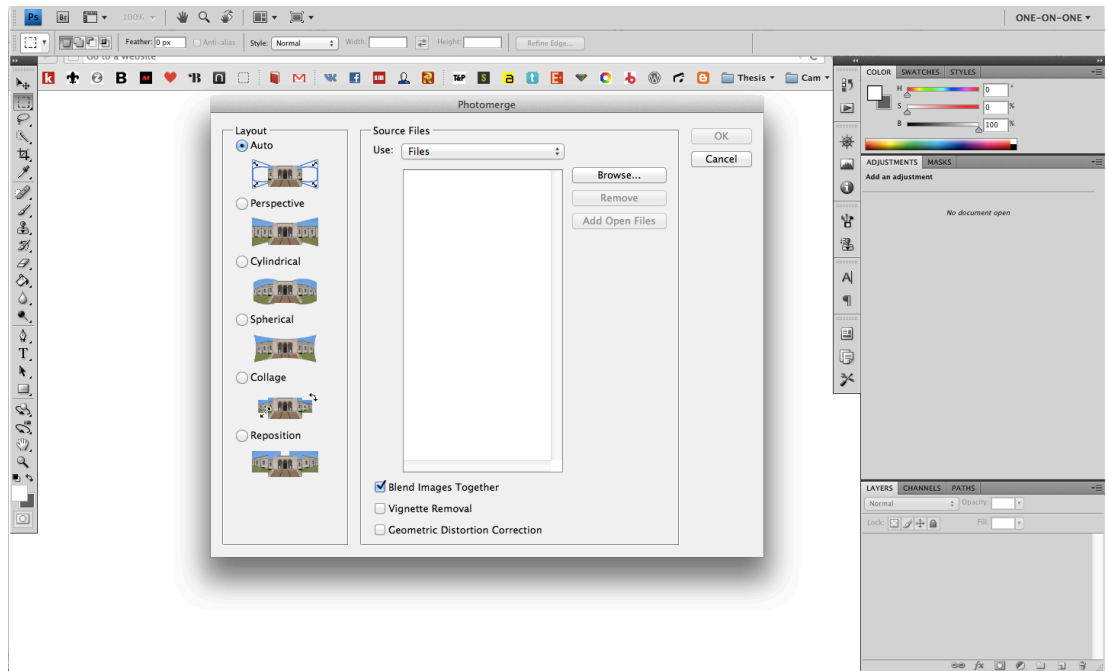


Figure 11. Loading Images for Stitching in Photomerge, Photoshop CS4.

4.3.2 Canon PhotoStich Application

The next choice was a very simple and basic application, which was attached to the camera package, Canon PhotoStich. This application includes only bare minimum of features that might challenge the process of stitching and affect the final result.

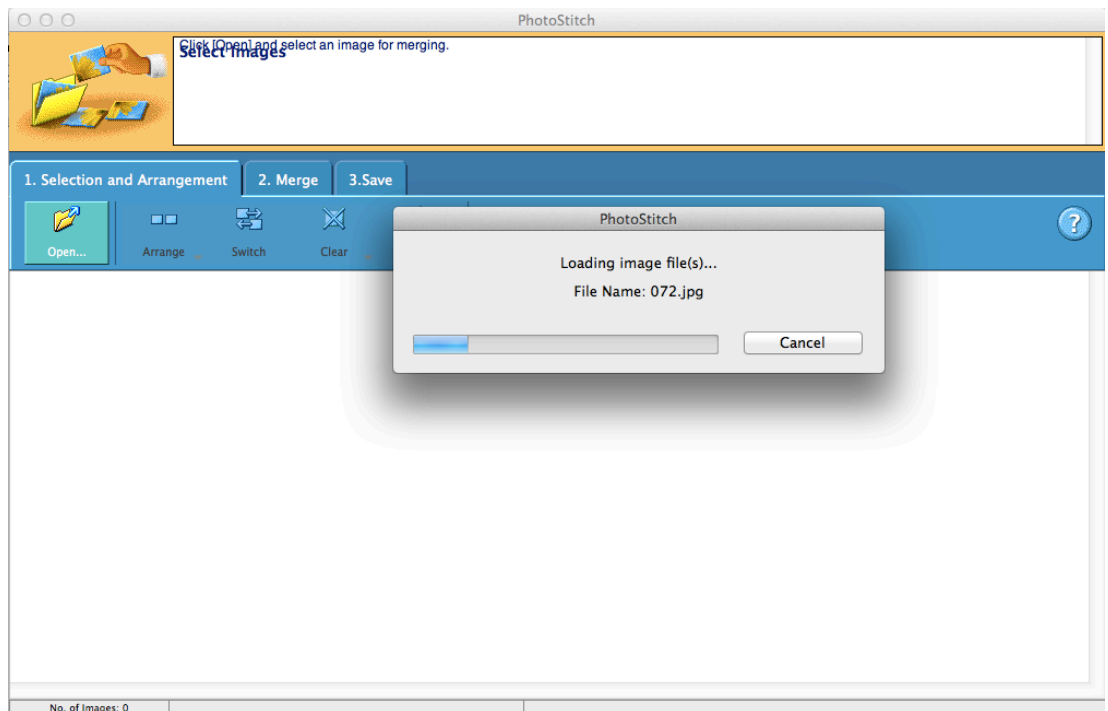


Figure 12. Loading Images to PhotoStich Application.

Nevertheless, the ability of this particular application are tested and compared with the result of other more professional software.

4.3.3 Panoweaver 8 Software

Third stitching software is Panoweaver 8, developed by Easypano Holdings Inc., was released this year. However, the Trial Version is used, since it is free. The advantages of this software are large quantity of features, which allows stitching images in various panoramas, like spherical, cubic and cylindrical. Moreover, it makes possible to select match points manually, which should reduce amount of mismatches and allows producing smooth images without parallax. In addition to this, Panoweaver 8 has possibility to create projects, which means that the process of stitching can be stopped and saved for future use.

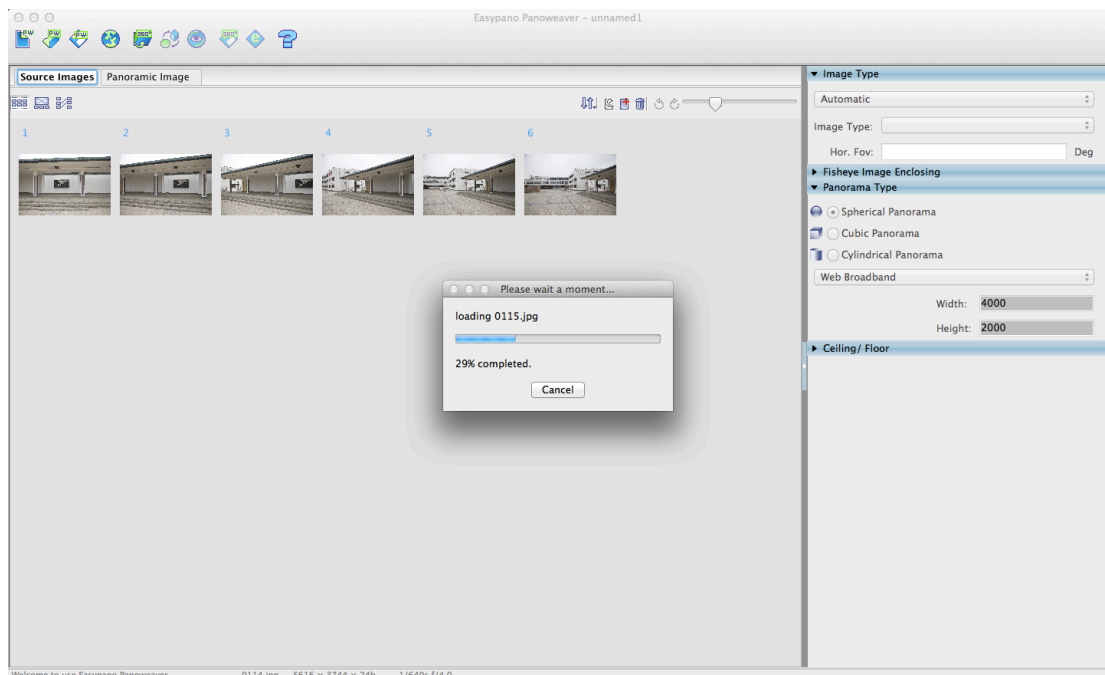


Figure 13. Loading Images to Panoweaver 8 Software.

Finally, Panoweaver 8 software has an option to preview panoramas and also to publish them in the web and even in social media, such as Facebook.

5. IMPLEMENTATION PHASE

5.1 Shooting Process

In previous chapters all the required equipment for shooting panorama was chosen. Moreover the shooting location was specified, the square near the library, where all possible difficulties were tried to overcome. However, in the chosen location, still some time to choose the exact spot was spent, for example, to hide the road and some unwanted objects.

Nevertheless, the spot was chosen and the tripod was mounted, and images were captured with Canon zoom lens. Firstly, several test images were taken, to determine the correct camera settings, such as ISO, exposure, aperture etc. When settings were chosen, author started to capture images for panorama. With the zoom lens at least 30% overlap had to be made and author decided to go even further and to make 50% overlap, so 25 pictures for a single panorama were taken. The images were captured consequently, making circle around the spot. Each time when the head of tripod was moved the head bubble spirit level was adjusted to align horizon and the focus point was set, since focused objects in the frame vary in a distance, depending on the direction.

After images capturing with Canon zoom lens were finished, the lens was changed to Samyang fisheye lens and the same workflow was repeated, as with Canon zoom lens was done. Since, fisheye lens captures wider field of view, less pictures were taken, compared to the zoom lens. The total sum of images for a single panorama was 14, with the same 50% overlap amount.



Figure 14. Left – Picture Captured with Canon EF 24-105mm f/4L IS USM; Right – Picture Captured with Samyang 14mm f/2.8 IF ED UMC.

In Figure 14 one can see the difference of lenses, when viewed to the same direction. Zoom lens captures less, but it is more uniform in lighting, because fisheye lens has some natural vignetting on the edges and corners.

Both of lenses were used, therefore the difference between lenses and between captured images was compared. The whole process of capturing images took around one hour. That time included pauses required to achieve a clear frame.

5.2 Photo Editing Using Photoshop CS4

During shooting process all images were captured in RAW format and during stitching purposes images were converted to JPG files. Not only to convert images was required, but also to edit some settings and to receive pictures with the same light balance and exposure. For that purpose Photoshop CS4 software was used, due to author personal experience work with this software and capability to use RAW editing function.

Photoshop CS4 opens RAW images directly in its application Camera RAW. There, editing process was started from finding the correct white balance, after that the exposure was adjusted. Editing was finished with some minor functions, such as "Recovery", "Fill Light", "Blacks" and "Clarity". That was done because thesis author always use this functions to correct the image settings, however this functions are optional and might be not applied.

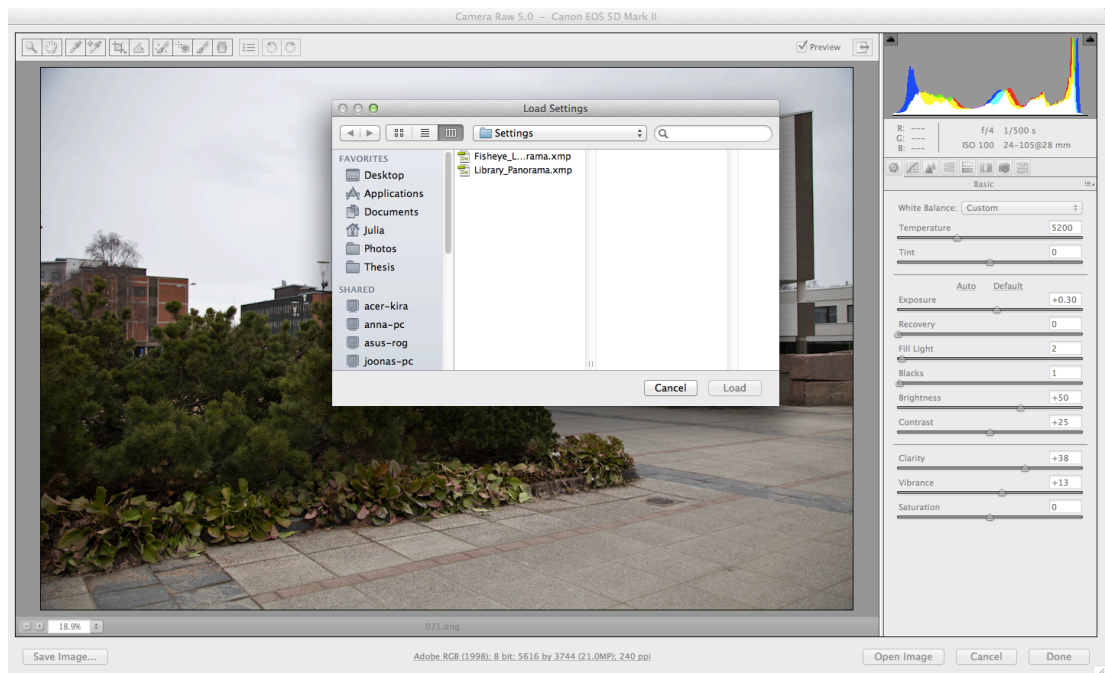


Figure 15. Loading Settings to Camera Raw Application.

Overall, 25 images were captured to produce single panorama, therefore all images must be edit exactly in the same way. Inside Camera Raw application there is an option to save settings and afterwards to load them for editing other images. That feature was applied to all 25 images. However, in some case some settings were adjusted manually in order to produce the same exposure.

After Camera RAW application, Adobe Photoshop CS4 opens image in standard screen mode. In case of producing panorama image, it is better to apply only limited amount of adjustment. Therefore, only two Photoshop features were used, firstly images were converted into smart objects and after that "Smart Sharpen Tool" were applied. The last step was to save images as JPG files. Consequently, the same editing process was repeated 25 times for images captured with zoom lens and 14 times for images taken with fisheye lens.

After all steps mentioned above were performed the images were ready for next step of producing panoramic image, which is stitching or merging pictures into final panorama.

5.3 Stitching Panoramic Image

5.3.1 Canon PhotoStitch Application

The first software that was used for stitching purpose was Canon PhotoStitch Application. The navigation in this application was very easy to understand and as a first step, images captured with fisheye lens were opened and then the merging process was started. Despite simple navigation, this application works very quickly and after several minutes of merging process, the panorama was ready.

After the panoramic picture was ready, the seams were checked and several artefacts in the panorama were found. Despite the two copies of the white building on the right, the total appearance was close to reality. Then the image was cropped and saved for further use. In addition, Canon provides Viewer application, where using scrolling it is possible to view the panoramic image.

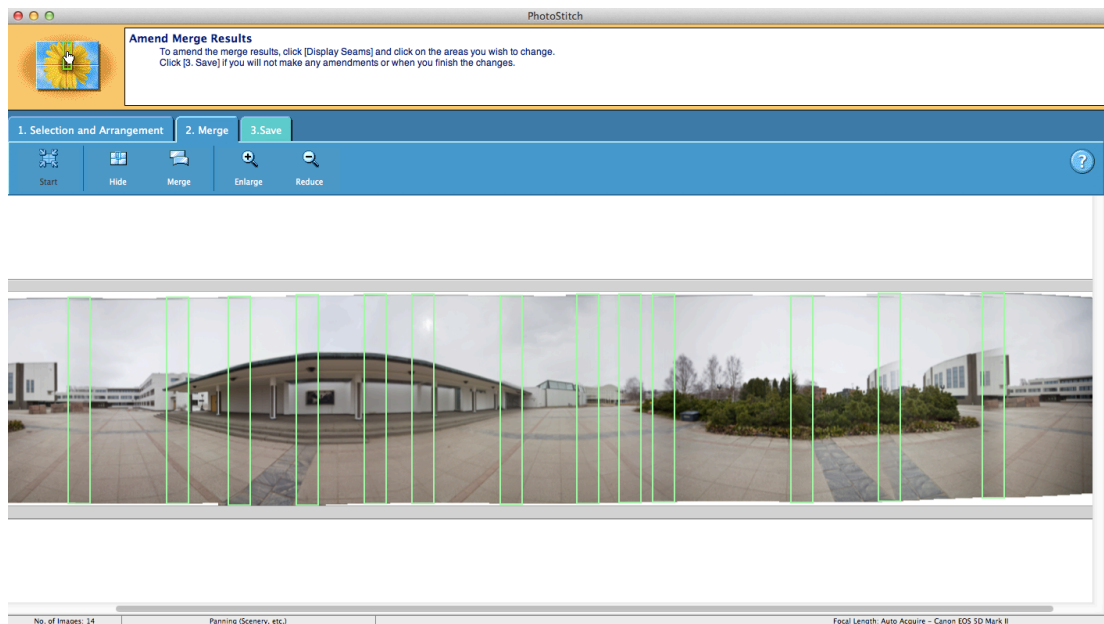


Figure 16. Merged Fisheye Lens Images in Canon PhotoStitch Application, Green Lines Show the Seams.

Next, images captured with Canon zoom lens were tested to stitch. Images were opened and merging process starts. However, in the end of stitching PhotoStitch gave me this message: “The image cannot be merged because an incorrect focal length has been specified or the scope of the merged

image is too broad". Unnecessary images were tried to delete and to scope again, but each time the same error message was received.

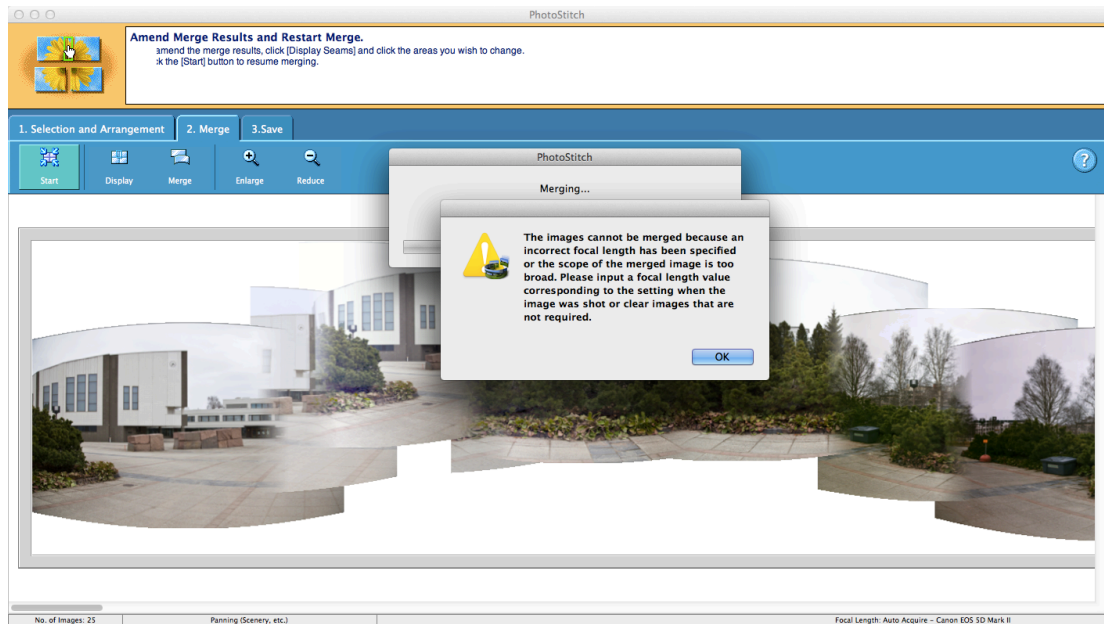


Figure 17. Merged Zoom Lens Images in Canon PhotoStitch Application, Error Message.

In general, Canon PhotoStitch is able to produce satisfactory panoramic images captured with fisheye lens, however to merge images captured with zoom lens becomes a difficulty for Canon PhotoStitch Application.

5.3.2 Panoweaver 8 Software

Next, Panoweaver 8 trial version software was used that was released by Easypano Holdings Inc. in 2012. Navigation of this software is more complicated than in previous application. Sometimes it required reading help page to understand the function of the software's features.

The first step was to start a new project in Panoweaver 8. Then the desired type of panorama was chosen and all required images were opened. In Panoweaver 8 it is possible to find match points manually or automatically. For the purpose of this report the automatic mode was chosen. Any additional steps to proceed were not found, therefore images were merged together. The result, however, was an error message, where it was said that the image is too big to achieve this operation.

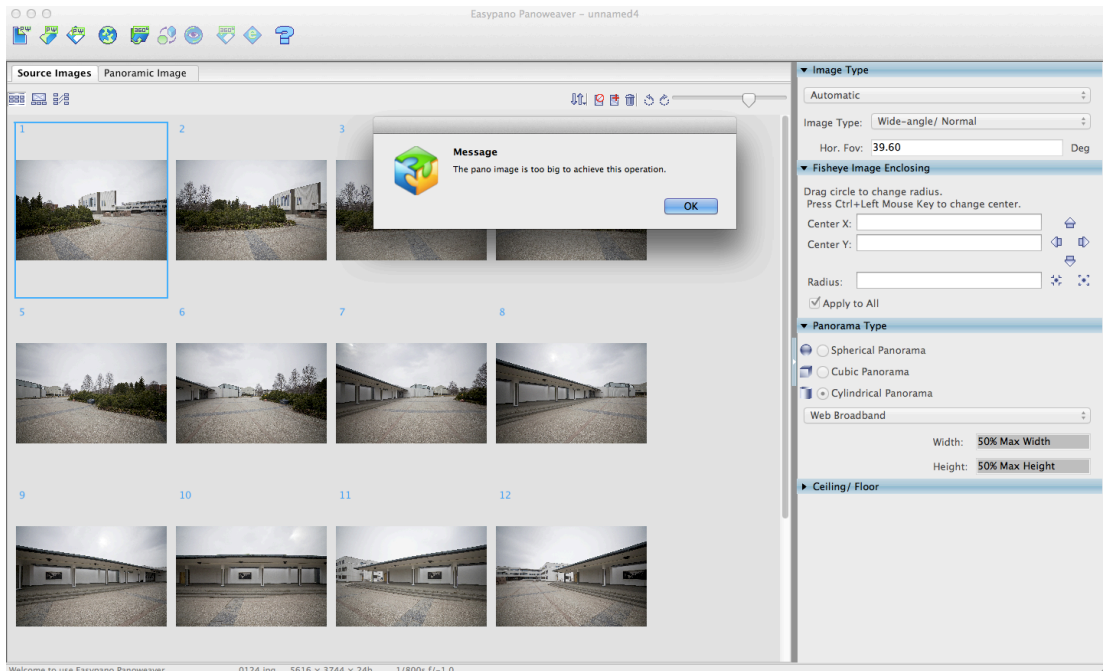


Figure 18. Panoweaver 8 Software Error Message.

Therefore, the size of pictures were reduced and merging was tried again. For Panoweaver 8 it took around ten minutes to stitch all images together and to display picture full of artefacts and parallaxes.

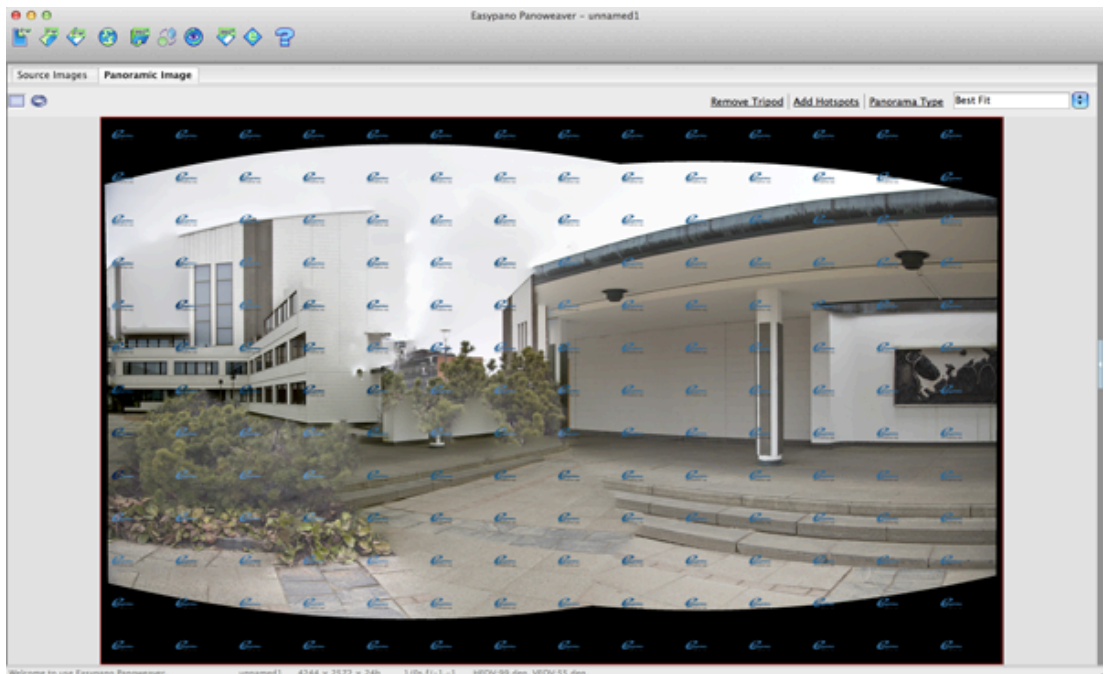


Figure 19. Panoweaver 8 Panorama Combined from Eight Images.

Since, trial software version was used, the final panorama was full of Easypano logos. However, the image was not merged properly and it was not possible to use for further work.

5.3.3 Adobe Photoshop CS4 Photomerge

The last software that was used for implementation was Adobe Photoshop CS4. It was used previously for editing purpose and now for merging images it was used again. The required **Photomerge** feature is situated in File command folder, among "Automate" commands. After choosing this function, Photoshop opened a dialog box where source files were inserted. For the first test they were images captured by zoom lens. Based on the previous research, cylindrical projection for the stitching algorithm was selected. After that, "Blend Images Together" box was selected and "Ok" was pressed. Photoshop CS4 was merging images for about 20 minutes and displayed a ready cylindrical panorama. The panorama was cropped to make the image rectangular.



Figure 20. Cylindrical Panorama Captured with Zoom Lens.

The result was the best cylindrical panorama among previous attempt. The panoramic image resolution stayed the same as it were in the source files. In close look any parallax areas nor visible artefacts were not possible to distinguish. Therefore, the thesis author was fully satisfied with obtained cylindrical panorama.

Finally, the process of merging images capture with fisheye lens was begun. "Photomerge" dialog box was opened again and required images were selected. According to author experiment with fisheye images, the spherical projection was used. Fisheye lenses usually produce strong vignette on the corners, so to reduce it, "Vignette Removal" was selected. Again Photoshop merged images for about 20 minutes and cylindrical panorama was ready.



Figure 21. Spherical Panorama Captured with Fisheye Lens.

6. RESULTS

6.1 Method of Creating Panoramic Images

The goal of this bachelor thesis was to understand the phenomenon of panoramic image creation. In the second chapter of this thesis it was concluded that panorama is a series of images combined into single picture. Consequently, there are two types of panoramas that are possible to capture. One is partial panorama, which usually covers 360-degrees in latitude and does not cover the nadir and zenith of the image. However, in some cases, partial panorama can mean that this particular picture consists of several merged images, but they do not form any precise geometrical shape. Other panoramic type is a full-spherical panorama or immersive panorama that covers 360-degrees in latitude and 180-degrees in longitude. In other words, immersive panorama covers all space around the shooting point.

In order to transfer three dimensions of panoramic image into two dimensions surface, special mapping methods are required. For partial panoramic images there exists several mapping methods. Two of most common methods are cylindrical and rectilinear projections. Cylindrical projection is often used in landscape photography and is captured with use of narrow or zoom lens. Rectilinear projection often cover 120-degrees or even less in longitude, and six rectilinear projections can be used to create cubic immersive panorama, where each image will cover $90^{\circ} \times 90^{\circ}$ in any direction. The last method of mapping is equirectangular projection and it is a common product of images, captured by fisheye lens.

Consequently, in the implementation phase thesis author tried to create cylindrical and partial spherical panoramas, using various available software. In Figure 20 was showed the example of partial cylindrical panorama, which covers 360-degrees in latitude. The Figure 21 represented the example of partial spherical panorama that also covers 360 degrees of latitude.

6.2 Hardware and Software Required to Create Panorama

In third chapter, thesis author described required equipment to shoot panoramic images, like camera, lens, tripod and heads. Author mentioned that to be able to produce high quality panoramic images it is better to use modern

cameras with high pixel resolution. To avoid image parallax is important to use tripod and head with bubble spirit level. Finally, to capture images, it is possible to use narrow or fisheye lenses. However, the difference will be visible in distortion, therefore during mapping various projections are in use.

For author personal thesis project implementation, Canon EOS 5D Mark II camera body was used, which is one of the good quality cameras with full frame sensor. Among the lenses, Canon EF 24-105mm f/4L IS USM was selected as a narrow angle lens and Samyang 14mm f/2.8 IF ED UMC as fisheye lens. On both shooting location and afterwards the images from both of lenses were used for merging. The last significant part of equipment was tripod and head with bubble spirit level.

Using Canon narrow (or zoom) lens 25 images for creating single panorama were captured, with 50% overlapping. Samyang lens is a wide angle lens and requires less pictures to cover the area, therefore only 14 images were shoot.

In fourth chapter thesis author examined software with using which it is possible to edit and to stitch images into final panoramic picture. Author tried to cover different software with various capabilities. Basic Canon Photostitch application was described and in further chapter, it was used to test merging images. The result was a low quality image with several parallax areas.

Next, Panoweaver 8 Trial Version software was used to produce panoramic image. The software was slow in performance and it resulted in producing error messages. Consequently, the amount of pictures was reduced to nine and images were tried to stitch together. After 15 minutes of work Panoweaver 8 displayed panoramic image represented in Figure 19. Panoramic image received with Panoweaver 8 was not an acceptable result due to parallaxes.

In the end, author tested Adobe Photoshpe CS4 software, the same program, used for image editing purposes. For stitching images "Photomerge" function was used and both groups of images were merged that were received using Canon narrow lens and Samyang fisheye lens. In both cases, the result was excellent partial panoramic images. However, Photoshop encountered some difficulties during processing images captured with fisheye,

that were caused strong vignette in the image corners, which is a natural result of using fisheye lens. Hypothetically, using more precise image editing procedures it would be possible to remove extra vignette.

In general, Adobe Photoshop CS4 created excellent spherical panoramic images, Using zoom tool some minor mismatches were found, but Photoshop CS4 selected match points correctly, therefore there is no parallax areas. Photoshop leaves used images in layers with masks that can be edited, so it is possible to assume, that mismatches and artefacts could be removed if desired.

Overall, it can be conclude that among chosen software for stitching images, Adobe Photoshop CS4 performs the best with both cylindrical and spherical panoramic photograph, using both types of lenses, a zoom lens and fisheye lens.

6.3 The Workflow for Creating Panoramic Images

The first step is to define the needed hardware equipment. It is important to take into consideration that it is better to choose full-frame professional DSLR cameras, because they have better image quality. Also, during selection process great attention must be focused on features of tripod, such as height in assembled condition and weight. It is good to find a balance between possibility to transport tripod and great performance on the field. Next, it is important to choose the lens that will define the type of projection that will be used for mapping the image.

Following step is to specify the shooting location for desired panoramic image result. Next, it is possible to capture images on the location. It is better to repeat the process of shooting images several times in order to have several sets of images. It is better to shoot with same settings and it is also important to have enough overlap of images (30-50%). To produce high quality images, it is better to shoot in RAW format. Next one can continue the workflow with image editing using any of the software, listed above. During image editing, use similar settings to all images to make the same light condition and to avoid visible boundaries between pictures.

The next step is to stitch the pictures using special software, several possibilities to merge images were listed in this thesis. However, there are more available options in the Internet and in other publications. Final step is to change the image to a suitable color profile (sRGB, RGB, CMYK and etc.), save the image in a desirable file format (JPEG, TIFF, PSD and etc.) and to view it digitally or as a print, and then possibly continue to fine-tune it even more.

7. CONCLUSION

Writing this thesis and performing the practical work of creating a panorama have given valuable experience about panoramas. At the theoretical level it was learned about different panorama types, methods of making them, as well as available camera types. Moreover, different types of hardware and software used for taking images, editing them and stitching the panoramas were discovered. As a result, a workflow for making the whole process, from taking images to having the final result was proposed. Finally, several samples for author's portfolio were received, and hopefully the experience for future professional work was gained.

The knowledge gained in the experiment can be used for practical application of making panoramas. This knowledge is not perfect and can require further testing, because the choice of the hardware was very limited, however it was good quality. The choice of software was also limited, because many of the programs cost a lot of money and trial versions did not produce good results. It can be concluded, however, that Adobe Photoshop CS4 is good software for editing images in RAW format and stitching the images to panorama with Photomerge command.

The main difficulty in the theoretical part of the work was lack of previous theoretical material on the subject. Panoramas are relatively new subject and not many books or publications have been written about them. Most of the sources were used from the periodical press such as magazines about photography and the Internet. Those sources are less valid for research, because their main point is commercial. Many of the Internet sites had good and professional information about panoramas, however, they did not give permission to use the information and it had to be excluded from the work.

The topic of panoramas is also very wide and this thesis author could not cover publishing the panoramas in printed form or in digital form using Flash, Java and other related software. This is a good direction for future experiments. In addition, this thesis does not deal with mathematics behind the stitching of panoramas and this also represents a good topic for further investigation.

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