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Online Virtual Tour by Panoramic Photography

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The purpose of the project was constructing a virtual tour, usable by a web browser of Espoo city museum's mansion museum to ensure availability of the exhibition during renovation of the premises. The project included defining the scope with the client, technical implementation based on the specifications and instructing the client on installation of the application.

The virtual tour was defined as a 360 degree horizontal multi-room panorama presentation that can be viewed with both a traditional desktop computer browser and a mobile device. The virtual tour was implemented by using a DSLR system camera with high dynamic range imaging, a special panoramic tripod head and two pieces of computer software for stitching the pictures together and creating the browser platform for the virtual tour.

In addition to creating the virtual tour and specifying the software and hardware, the workflow was defined, with special attention paid to the possible issues of the process. Errors might occur in handling the dynamics of interior photography, specifying the camera settings, selecting a proper camera lens and tripod and stitching the images together.

The project acted as both a service done for a client and a definition of requirements for a panoramic virtual presentation. The paper can be utilised as a guide for future projects about virtual space or augmented reality.

Keywords	panorama, photography, virtual tour, HDR

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Insinöörityössä rakennettiin kaupunginmuseon huvilamuseosta internetselaimella käytettävä virtuaalikierros, jotta tilat olisivat yleisön tavoitettavissa huvilan tulevan korjaustyön ajan. Työhön sisältyi projektin määritys asiakkaan kanssa, sovitunlainen tekninen toteutus ja käyttöönoton ohjeistus.

Virtuaalikierros määritettiin 360 asteen horisontaaliseksi usean huoneen panoraamaesitykseksi, jota voi katsella sekä tavallisella työpöytäinternetselaimella että mobiililaitteilla. Virtuaalikierros toteutettiin käyttäen järjestelmäkameraa korkean dynaamisen alueen kuvaustilassa, panoraamakäyttöön rakennettua erikoisalustaa ja kahta tietokonesovellusta kuvien yhdistämiseen ja selaimella käytettävän virtuaalikierroksen rakentamiseen.

Valmiin virtuaalikierroksen ja välineiden kartoituksen lisäksi kehitettiin työnkulku, kiinnittäen erityistä huomiota prosessin mahdollisiin ongelmakohtiin. Virheitä voi tapahtua esimerkiksi sisätilakuvauksen dynamiikanhallinnassa, kamera-asetusten määrityksessä, sopivan linssin ja jalustan valinnassa ja kuvien yhteenliittämisessä.

Insinöörityö toimii sekä asiakastyönä että kartoituksena tämänkaltaisen työn vaatimuksista. Insinöörityöraporttia voi hyödyntää ohjeena tulevissa virtuaalitilaa tai lisättyä todellisuutta käsittelevissä tehtävissä.

Avainsanat	panoraama, valokuvaus, virtuaalikierros, HDR

Contents

1 Introduction

Espoo city museum contacted Metropolia University of Applied Sciences as one of their premises, mansion museum Villa Rulludd, was going under renovation in early 2013. The city museum wanted to keep the exhibition available to the audience, even if the premises were inaccessible, and requested a virtual online tour of the Villa. I had previously worked with the city museum in spring 2011, building a touchscreen interface to augment an exhibition, so it was easy to take up another task from a familiar client.

There are several ways to carry out a virtual tour, including video, still images or a 3D modelling. Two benchmarks from other museum locations were presented by the client, a panoramic video tour and a still spherical single room panorama. For Villa Rulludd, the tour was specified to be a 360 degree cylindrical multi-room panoramic projection that can be viewed online with either a conventional desktop browser or using a mobile device.

The scope of the project included researching the hardware and software required for the specified need and carrying out the task based on the discoveries. In addition, coming up with an efficient workflow, keeping track of errors and possible problem areas was considered a goal, so that the paper can be used as documentation for similar future projects. The schedule was rapid due to the approaching renovation of the museum premises.

2 Virtual Reality: History, Standards and the Future

While virtual reality as a technology dates back to the late 1950’s [1], for the purpose of this paper the timeline begins at 1994, when Apple Inc. released their QuickTime VR panoramic tour application. QuickTime VR was introduced as an alternative to 3D modelling of virtual space which had three major issues at the time. Modelling the geometrical entities for the projection requires lots of manual labour. Also, computers of the time were not up to the task of rendering 3D environments in real time, and most consumers did not have specialized hardware rendering engines that would have been required.

QuickTime VR presented an image-based approach to counter the problems, and the system has been the basis for virtual tour projections ever since. Instead of 3-dimensional models or a video walkthrough, QuickTime VR and related systems utilise still photographs taken at a location and project those to a virtual space, which generate an illusion of perspective and being there. As the projection consists of still images that are stitched together, the size, and in turn the necessary computing power required to run the application can be controlled by limiting the resolution of the images. [2,1-2;3]

Initially, the virtual reality (VR) content was intended to be delivered on CD-ROM format. Utilizing a panorama resolution of 2500x768 pixels, a single scene could be compressed to around 500 KB, so a 600 MB CD-ROM could hold over a thousand panorama scenes. [2,7] An early example of the technology was “Star Trek: The Next Generation Interactive Technical Manual”, an interactive CD-ROM that took its users on a virtual tour around the starship Enterprise. The CD-ROM featured 13 panoramic sets that could be navigated to, with narration provided by the cast of the TV series. However, a review by the Seattle Times criticized the low level of interactivity and awkward navigation and the long loading pauses when more data is buffered from the CD-ROM. [4]

As internet connections have become faster, cheaper and more available, the delivery methods and purposes of panoramic virtual tours have shifted. It has been possible to greatly increase the resolution of the images from the early 2 megapixels and still deliver the presentations fast and reliably online. Unlike a CD-ROM which usually needs to be purchased, online panoramic virtual tours can be utilized to advertise a location or provide additional content to users of a website. The foundation on which QuickTime VR was based still holds, however: even though modern computers can process real-time rendered 3D imaging much faster, generating the 3-dimensional scenes is still a lot of work, at least until recently.

Another major development is the introduction of standardized presentation technologies during the recent years of internet. With QuickTime VR, users needed to install the specialized VR viewer application or plugin on their computers to use the software [3]. Nowadays, virtual tours can run on standardized platforms that are preinstalled on most computers and devices: Krpano, the software that was chosen to provide the virtual tour for this project, runs using either an Adobe Flash or an HTML5 application when Flash support is not available such as mobile devices. [5]

Recently, however, there have been breakthroughs that might revolutionize the creation of virtual tours. Composing the panorama from still images allows photorealism and a degree of interactivity and mobility within the tour, but it is not as free as a true 3D projection. Autodesk 123D Catch is software that can generate 3D models based on photographs taken from several perspectives around a subject. The program can also be used to create 3-dimensional environments based on panoramic photography, and in addition to a conventional desktop computer, it also runs on iPhones and iPads, making it possible to sketch models on the go. Autodesk 123D a free hobbyist-level program, but it might hold foundation for similar professional systems in the future. Viewing the models requires a web browser plugin; supported browsers are currently limited to Google Chrome and Internet Explorer. [6]

3 Project Definition

The definition of the project breaks down to three major parts:

- specifying <u>what needs to be done</u>
- the workflow of <u>how it is done</u>
- the software and hardware <u>by which it is done with</u>

Once all of the aforementioned is mapped out, it is possible to get started on implementation. Careful planning in the definition stage ensures smoother workflow, which was particularly important as the project was carried out on a rapid schedule.

3.1 Specifications

As mentioned in the Introduction chapter, mansion museum Villa Rulludd was going to go under renovation early 2013, and Espoo City Museum wanted to preserve the tour in an online format while the building was closed from the audiences. Espoo City Museum has collaborated with Metropolia University of Applied Sciences, and as I had been part of a successful earlier project concerning a touchscreen interface to augment the museum tour experience, the virtual tour task was also offered to me and I took it up. The definitions and the implementation had to be done quickly, as the renovation work was going to start within a month from the client's initial contact and whatever pictures or video required for the virtual tour needed to be taken before that.

The client, the museum's account manager Marianne Långvik-Huomo, approached the school with the idea of a panoramic virtual tour, with the specific details still open for consideration. Two benchmark tours were provided: a video tour of Villa Gyllenberg, which allowed user interaction in selecting the areas to be viewed and then showed a video of the location [7], and a full 360 degree single-location spherical panorama of Aboa Vetus & Ars Nova museum. [8]

Before choosing the most suitable way out of the various options to present a virtual tour, one needs to consider whether the scene is reproduced by recording or modelling. Recording a scene by utilizing either still images or a video walkthrough allows for a higher degree of photorealism but less interactivity, while a 3D modelled environment is more navigable, yet harder to reproduce in similar quality.

Defining the methods of the media production was the first step of the project. Based on the benchmarks it was decided that a panoramic virtual tour should be constructed with still image recordings of the premise's rooms and navigation between the different rooms. After this, we also had to consider whether the panoramic scenes should be spherical or cylindrical.

Figure 1. Cylindrical and spherical projections [9]

As illustrated, both styles of panorama wrap the image on a container and allow full 360 degree horizontal panning. The main difference is in the vertical field of view: a cylindrical panorama only allows less than 180 degrees of vertical panning, while a spherical panorama also allows the viewer to look straight up and down. [9]

For this project, the consideration between the two methods was basically a weighing of the advantages of a spherical panorama versus the increased labour and equipment requirements. While a spherical panorama does present a wider vertical field of view, additional issues arise. A conventional camera tripod cannot be used, as the tripod would get in the way at the nadir point when the viewer is looking straight down. There are methods such as utilizing a fisheye lens and the Philopod technique and pitch variation to capture a full spherical panorama without special equipment, but the picture quality might not be satisfactory when photographing handheld. [10]

However, with a cylindrical panorama it was possible to take photographs very precisely by using a regular non-fisheye wide angle lens in the portrait orientation and a regular tripod head with modifications for panorama imaging. Based on my early tests, cylindrical panoramas also exhibit much less distorting when changing the view.

As the only drawback of a cylindrical projection is limited visibility of the floor and ceiling, but controlling the image quality is easier, in the first meeting with the client the project was specified as a 360 degree cylindrical multi-room panoramic virtual tour that covers the hall and four exhibition rooms of the mansion museum.

3.2 Workflow

As the Aboa Vetus & Ars Nova panoramic presentation was close to what was specified for the project, I analysed its implementation for the requirements and the workflow of an online virtual tour.

The presentation runs in a player that is viewed in a web browser. There are several different player software solutions, which are presented in the following chapter. The player then projects a stitched panorama image to a 3-dimensional environment and simulates the camera movement and transitions from one room to another.

The stitching – putting all the images together to form a panorama – is performed in another application. Stitching applications look for similarities in adjacent images, form control points based on these and then combines the images and corrects the perspective to a single 360 degree panoramic image file.

For the process of taking the pictures, careful control of exposure, vignette and other lens errors, white balance and focusing is required, so that the photostitcher software can provide a consistent result. [8]

The following figure summarises the workflow:

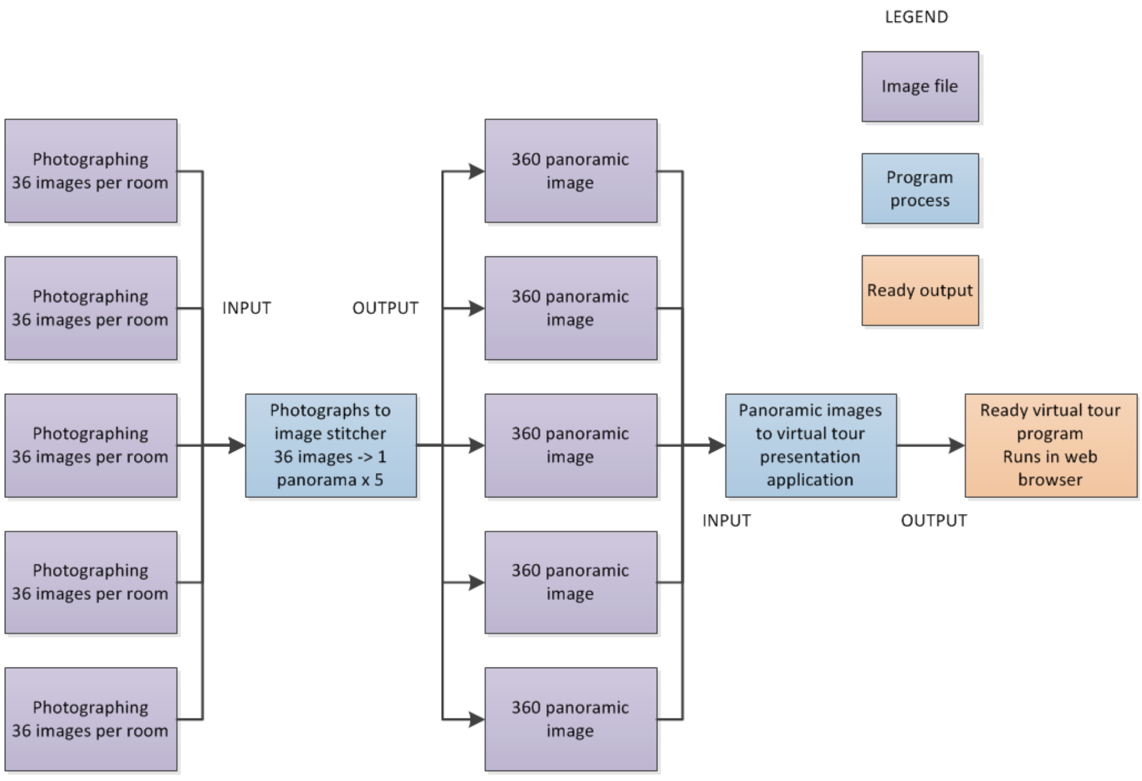


Figure 2. Rough workflow based on analysis of Aboa Vetus & Ars Nova panoramic presentation

Based on the analysis, four major steps can be discovered. The photographs are taken on location. 36 pictures for a 360 degree panorama provide plenty of image overlap, and it is a wise idea to rather take too many pictures than discover that the photographed material does not provide satisfactory results in the next phase.

The second major step is stitching the images together. As the third step, the stitched output is then adjusted and once the source images are deemed satisfactory, they are fed into the virtual tour presentation application. The fourth major step is using this source material to create the actual virtual tour: determining the hotspots for scene changes and other navigational elements, as well as defining the HTML content such as page title.

Once the software and hardware are defined further in the project, it is possible to update the workflow to be more specific.

3.3 Tools

Some cameras and nowadays even smartphones such as the iPhone 4S and 5 have inbuilt panoramic image photostitching tools. [11] Sony, for example, introduced a Sweep Panorama mode for their pocket cameras in 2009 for the DSC-HX1 compact. At the time of the technology's introduction, the area of the panorama was limited to 220 degrees, but David Pogue of the New York Times gave Sony's technology a very favourable review, highlighting that the panoramic imaging works very well as long as there is not much movement in the scene. [12] In 2012, the technology was updated to be able to capture 360 degree panoramas with a "press and sweep" –motion. [13] In addition to compact cameras, Sony's Alpha-series system cameras, including the full-frame A99, include the function. However, even a quick research of user experiences shows that automatic photostitching is too limited in options and control for a serious customer project. With Sony's cameras, the software gives priority to a fast shutter speed, opening the aperture to non-optimal values. [14]

Thus it can be concluded that a system camera and separate software for photostitching should be used as careful control of all the camera settings is desired for consistent results.

3.3.1 Software

As discovered by the analysis of the Aboa Vetus & Ars Nova exhibition panorama, two separate specialised software applications are required for a panoramic virtual tour: a photostitcher and a virtual tour platform.

Currently there are several applications for both tasks, and specifying which to use was a major consideration. When faced by many different options, an obvious solution was to ask for recommendations from someone who might have been involved with a similar project, and from my network of Twitter contacts I received a recommendation for Hugin panorama stitcher and Krpano virtual tour tools. [15]

Hugin is a photostitcher application, capable of several types of image stitching: flat panoramas with perspective correction from two to more images or cylindrical and spherical panoramas such as what is required for this project.

Hugin is freeware, which means that the program can be downloaded and used commercially for free, and the source code is even available for further modification, should there be need. The program is under constant development, with the latest version having been released in November 2012. [16] Despite being a free application, Hugin has an active community of volunteers, providing support and answers to new users.

The photostitcher software works by analysing the field of view of the taken images from the EXIF data in JPG type pictures. Hugin cannot import camera raw files. Based on the field of view, amount of images and their overlap the program then calculates the required perspective distortion to produce a panoramic image.

Hugin’s documentation recommends at the very least a 20-30% overlap between images, but as most wide angle lenses exhibit blurring, vignette and chromatic aberration, larger overlap should always provide better results. Manual exposure and white balance values should also be used for consistency.

After inputting the images to the photostitcher, the program analyses similarities between several adjacent image pairs and forms control points based on them, as seen in the following figure. [17]

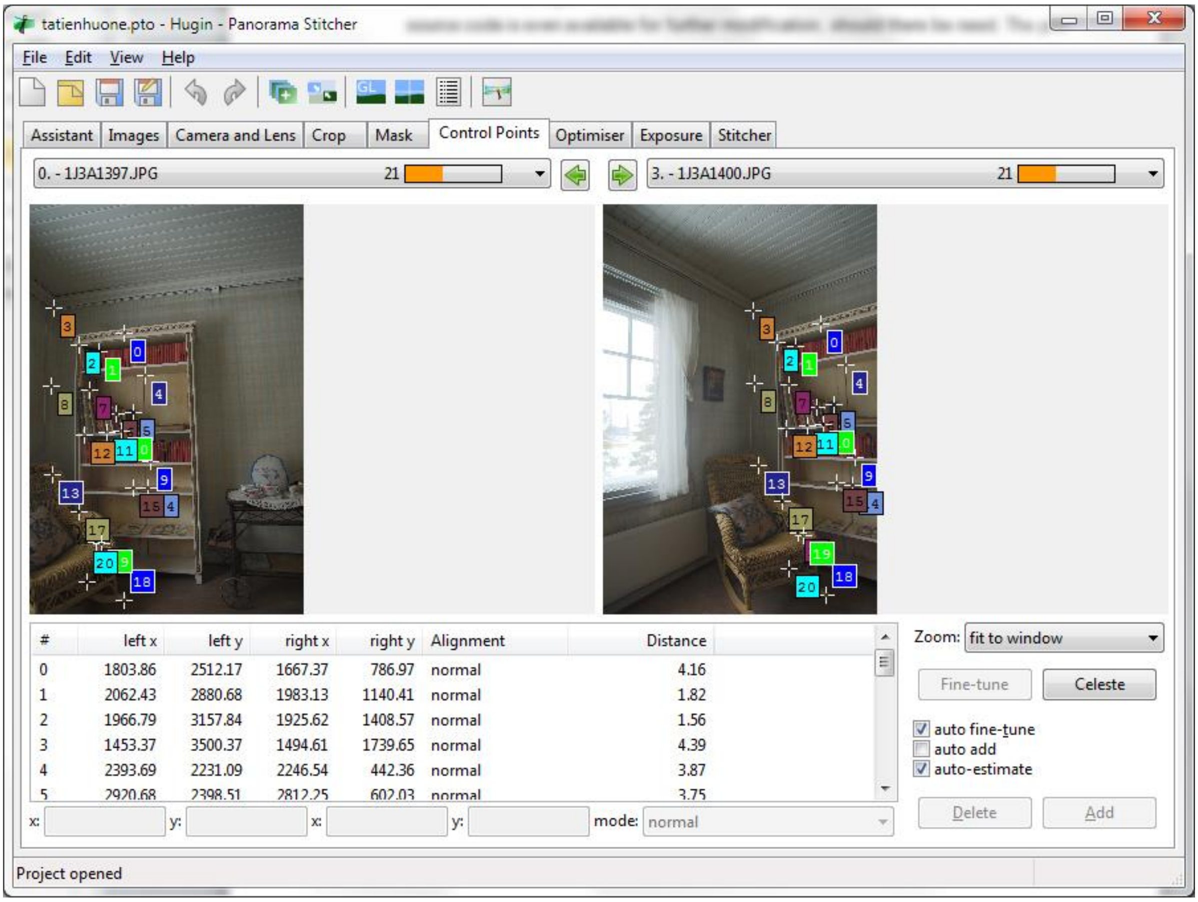


Figure 3. Hugin control points

Areas that are rich in unique detail are the easiest for the photostitcher, while repeating patterns such as wallpapers and ceilings cause problems. It can be seen in the above image that all of the 21 automatically discovered control points gather around the bookshelf and the chair instead of the walls or the ceiling, which can result in stitching errors near areas with little or no control points. This is discussed in closer detail in the Implementation chapter.

After discovering the control points and making required adjustments, Hugin outputs the full 360 degree cylindrical panorama file as a TIFF image. The images are then adjusted and corrected if necessary and converted to JPG format. Krpanotools then creates a virtual tour based on the images.

Unlike Hugin, Krpanotools is commercial software. It is free to use, but projects published without a licence have watermarking on them and can only be run locally on the computer they were created on. This is optimal as full functionality of the application can be tested before purchase to make sure it meets the specifications of the project.

In terms of professional software, Krpanotools is reasonably cheap, with the program license costing 90€ and an add-on license for an HTML5 viewer for iPhone, iPad and other devices without Adobe Flash support costing 39€, with additional VAT based on location and company status. Krpanotools was also used for the Aboa Vetus & Ars Nova –benchmark panorama, so it was chosen as the virtual tour provider software for this project. [18]

Krpanotools functions as a set of different droplet applications for different types of presentations. It can create single- and multi-resolution panoramas and a virtual tour by linking several panoramic images together. Similar to QuickTime VR, it is also possible to create objects with Krpanotools, where the object is in the centre and the camera orbits around it, creating the illusion of viewing the object three-dimensionally. The program again distorts the perspective of the panoramic image for the decided projection (flat, cylindrical, spherical or cubic) and projects the resulting images to a viewer. The viewer runs in a web browser window, utilising either Adobe Flash or HTML5 technologies, depending on which is supported on the device it is viewed on.

The elements of the virtual tour such as the default viewing angles of each room, possible viewing limitations, hotspots for moving to other locations and so forth are controlled by an XML file. The final virtual tour presentation is then constructed from the image data supplied to the droplet program and the commands specified in the XML file. The XML structure will be further introduced in the Implementation chapter. [19] The data structure can be seen in the updated workflow chart below.

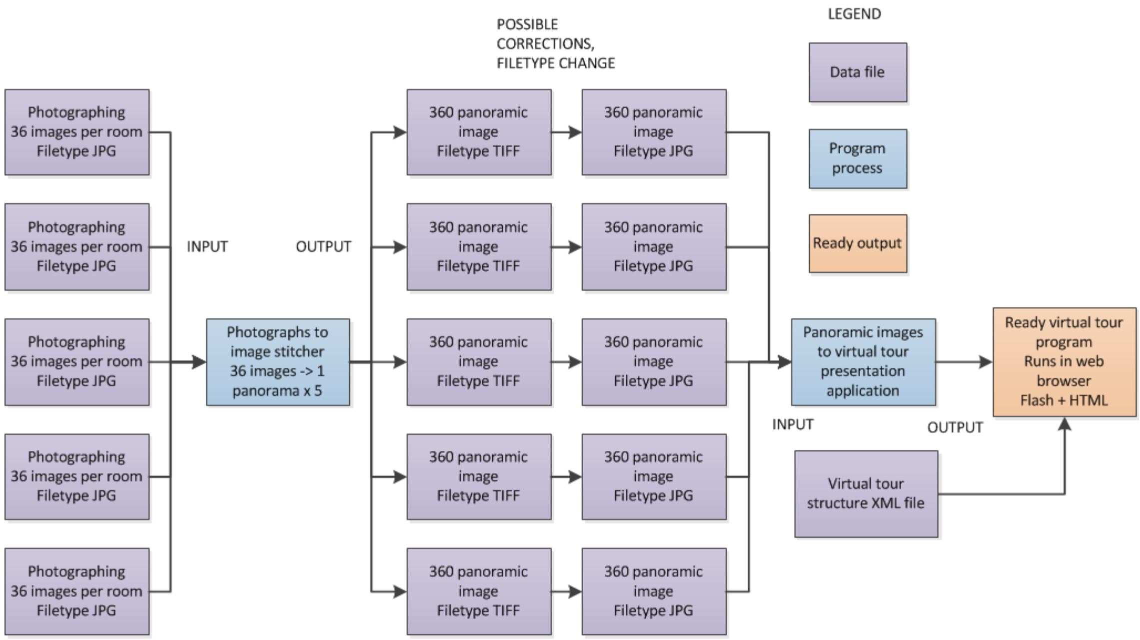


Figure 4. Updated workflow

Based on the software requirements and features, it is possible to update the workflow to be more specific. Due to a restriction in Hugin file type support, input images should be in JPG format instead of camera raw. This is further discussed in the Implementation chapter. Hugin photostitcher outputs TIFF files, which then should be converted to JPG format for Krpanotools. While Krpanotools also does accept TIFF input, it converts the output image files to JPG, and if the conversion is performed manually, it can be controlled to ensure maximum image quality instead of a possible compromise for file size reduction. The finished program in HTML and SWF formats then runs based on the panoramic images provided by the previous steps and an XML file, which controls the virtual tour elements.

3.3.2 Hardware

Metropolia University of Applied Sciences provided the project with a Canon EOS 5D Mark III DSLR system camera, recently released at that time, and a selection of lenses: Canon 24-105mm f/4L, Canon 20-35mm f/3.5-4.5 and Sigma 50mm f/1.4. A basic Velbon video panhead tripod was used as a base, but modifications for panoramic use were needed. This chapter will introduce the hardware selected, but further settings and usage will be described in the Implementation chapter.

As the EOS 5D Mark III is the flagship model of Canon's advanced DSLR cameras and the university had acquired one slightly before the beginning of the project, it was chosen without considering alternatives. For panoramic photography, the only absolute requirement is manual control of camera settings, mainly exposure and white balance, so any system camera will be able to do the task.

However, the EOS 5D Mark III has several features that ended up being particularly beneficial for the project, such as a full-frame sensor, in-camera high dynamic range (HDR) imaging and automatic correction profiles for lens errors including distortion, vignette and chromatic aberration. [20,147-148&173]

The Canon EOS 5D Mark III has a CMOS sensor with a size of 36 x 24 millimetres, equivalent to a traditional 35mm film camera. Most consumer digital SLRs have a smaller sensor with a crop factor of 1.5 on Pentax, Olympus, Sony and Nikon cameras and 1.6 on Canon cameras. What this means is that a crop sensor only picks up a limited amount of light gathered by the lens, effectively showing a narrower field of view and also requiring a longer exposure time. The EOS 5D Mark III's full-frame sensor is obviously advantageous for indoor photography, where a large field of view is desired, and with the same focal length, a full-frame camera shows much more. The figure below illustrates the difference between the Canon EOS 5D Mark III's full frame sensor and a simulated 1.6 crop factor. [20,2;21]

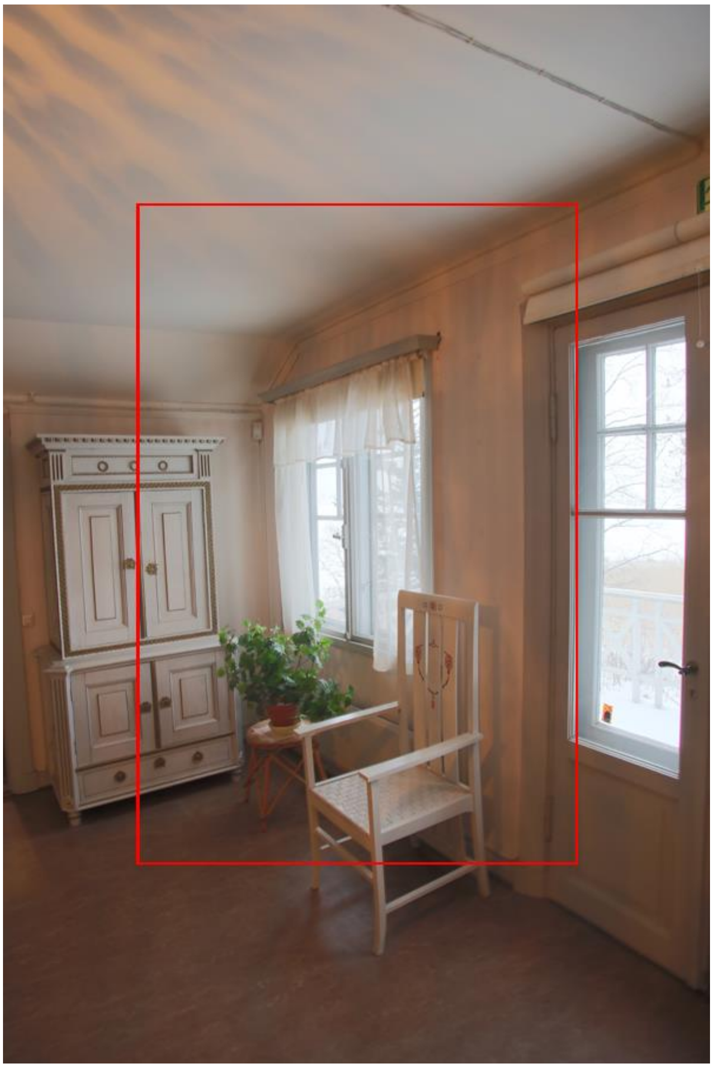


Figure 5. Full frame versus 1.6 crop factor

The above picture was shot using a 20 millimetre focal length, with the camera in portrait orientation. With the full frame camera, plenty of details from both the floor and ceiling are captured, while the crop sensor camera would deliver an unnecessarily tight framing, presented with a red rectangle. To achieve a similar perspective with a crop camera, a focal length of 12 millimetres should be used, and a specialised crop camera Canon EF-S mount lens is required. On the full frame camera, the more common EF mount lens with 35mm equivalent focal lengths can be used, which is less than half the price of the crop sensor EF-S lens. [22;23]

Out of the available lenses, the 20-35mm f/3.5-4.5 was chosen, as it provided the widest angle of view. While the maximum aperture is not very large compared to more expensive zooms or fixed focal length prime lenses, this is not an issue when shooting from a tripod. As a cheap wide angle lens, it exhibits a dramatic decrease in image quality towards the outer edges. A dark shadow (vignette or falloff) covers the edges, chromatic aberration (colour spilling over edges of details due to the optics failing to focus all colours to the same convergence point) appears and lens sharpness decreases near the edges. However, for this particular project this is not a problem. The lens errors can be reduced by stopping down the lens aperture, the photostitcher software mainly uses details from the centre of the taken photographs and it is also possible to load a correction profile into the Canon EOS 5D Mark III camera, which applies algorithms to reduce the errors in-camera as pictures are taken. [20,147-148.]

Also, the Canon EOS 5D Mark III is capable of producing high dynamic range (HDR) images with a single press of the shutter button. This is very beneficial and time-saving for interior photography, and the process will be described in more detail in the Implementation chapter. [20,173]

The Canon EOS 5D Mark III is a state-of-the-art DSLR body released at the end of March 2012, and being able to use a modern camera body for the project was very beneficial, as its predecessor, the Canon EOS 5D Mark II lacked the lens correction profiles and in-camera HDR processing features, which were very useful. [24]

A basic Velbon video panhead tripod was used for the project. The design was advantageous in the way that it allowed the camera to be positioned in the portrait orientation and had pan marks every 10 degrees, which helped taking the pictures. However, during the project it was discovered that using a regular tripod for panoramic applications can produce erroneous results, and modifications to the tripod had to be done. The causes of the issues and the required modifications to work around them are described in the Implementation chapter.

4 Implementation

This chapter details everything that was carried out during the project based on the specifications that were decided on in the previous definition chapter. This includes the camera settings for taking the pictures, usage of the selected programs and compiling the final product for the customer. Based on the results, the workflow graph can also be finalised.

4.1 Location

The museum Villa Rulludd is a mansion constructed in the late 19th century, located in Hyljelahti, Espoo. The lower level of the mansion was hireable for catering and festivals, while the mansion museum operates on the second floor. There are four exhibition rooms and a main hall, as seen in a non-scale layout in the below figure. [25]

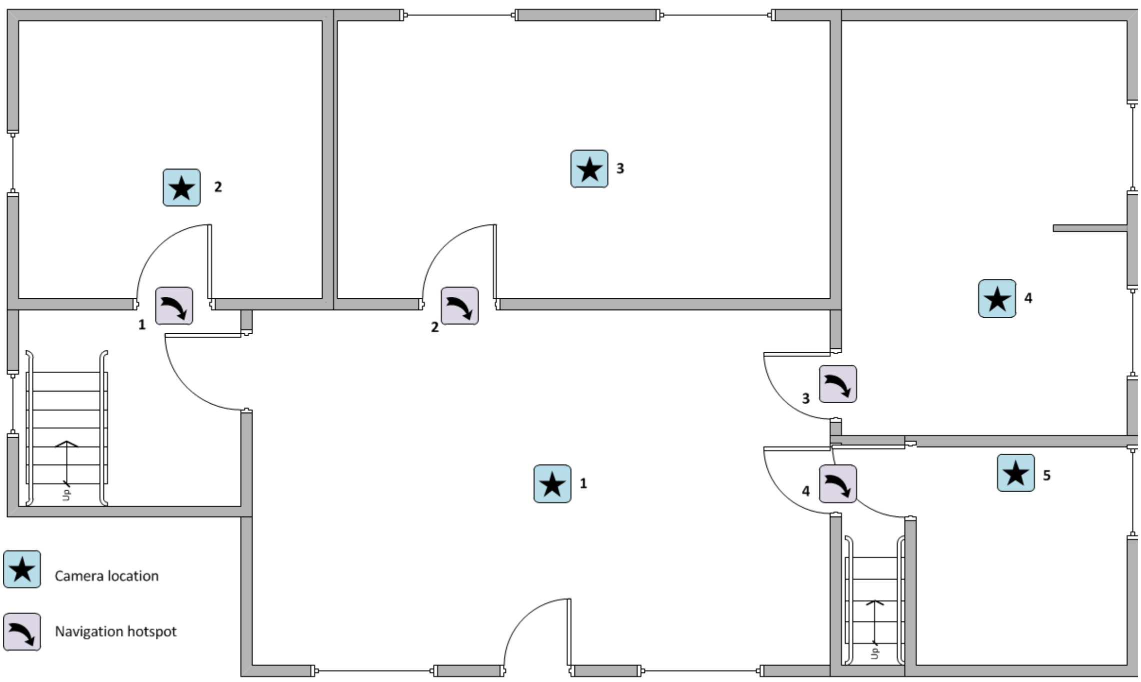


Figure 6. Layout of the mansion museum

The location was scouted beforehand to find out the sizes of the individual rooms and the amount of windows and ambient light. Most of the rooms were large enough to shoot 360 degree panoramas with the 20 millimetre lens that was decided on in the specification chapter, but with room number 5, only a 180 degree panorama was shot. The windows and electrical lighting in the rooms provided enough light for shooting before noon even in the winter, so no external lighting was needed for the photography. The camera locations were based mainly on central positions in each room, but due to positioning of furniture, the location of the camera was not necessarily the exact centre.

The hotspots for the virtual tour's navigation were also planned during the initial visit. All of the doorways to the exhibition rooms (rooms 2-5) are visible from the main hall (room 1), which acts a central hub for the virtual tour. The main hall has hotspots to each of the exhibition rooms placed in the doorways, while the exhibition rooms have hotspots for returning to the main hall. The layout is convenient as no transition locations are needed and navigating with the hotspots feels realistic and immersive.

4.2 Camera Settings

As previously described, the main demand for panoramic imaging is consistency between each of the images the panorama is stitched from. This consistency is best acquired with a system camera that offers manual settings. The following settings should be considered:

- Output file type
- Focal length
- Shutter speed, aperture and ISO value
- White balance
- Focusing
- Interior photography: fill flash or HDR
- Other settings

These are all described in detail in the following subchapters.

4.2.1 Output File Type

Modern DSLR cameras can usually output image files in either JPG or camera raw format. Raw image format means a direct representation of the light that the camera sensor has captured, which can then be manipulated in several ways. The white balance of raw images can be adjusted freely, as the reference point is included in the image metadata, and raw files also allow a lot more room for editing, as a raw file usually includes at least 12 bits of tonal information per pixel. This is very advantageous in most photography situations where careful control of each individual image is necessary.

JPEG images, however, are converted in-camera from the light information captured by the sensor. The automatic conversion allows for very little adjustment, and once the camera has created a JPEG image, it cannot be edited in a very versatile way. The white balance, for example, is locked, and about a stop worth of dynamic range is lost as the JPEG format is limited to 8 bits of image data per pixel. [26]

Comparing the two formats, in most situations it does not make sense to shoot JPEG images and lose data that could be useful in post-processing. A panoramic project of this scale, however, is one of the exceptions. While Hugin photostitcher software forces the file type to JPEG as it cannot read camera raw files, there are also other advantages to JPEG in this specific case.

File size is one consideration. A .CR2 raw image from the Canon EOS 5D Mark III is around 25 megabytes in size. JPEG files with the same resolution are less than 5 megabytes, and as 180 images (36 for one panorama, five rooms for the virtual tour) are required for the project, about 3.5 gigabytes of storage space is saved by using JPEG format. Smaller file sizes also means faster processing in image editor programs, as the raw files created by recent cameras are very heavy to process if the computer used is not of the latest models.

Also, the Canon EOS 5D Mark III's inbuilt high dynamic range (HDR) processor can only output JPEG images. HDR is explained in more detail in the following chapters, but for HDR imaging the camera captures three raw files of different exposures and then merges one high-definition JPEG image out of those. [20,173]

Raw files could be converted to JPEG and it would also be possible to create HDR imaging from raw files by manually taking several exposures and combining them in post-processing to form a HDR image. However, these extra steps would take a lot of time due to the large number of image files involved, and not really provide noticeable improvements in image quality. As JPEG is chosen for the file format, extra care needs to be taken in setting the correct parameters when taking the pictures, due to the lower possibility of editing the image files afterwards.

4.2.2 Focal Length

Focal length means the distance between the objective and the sensor plane, and it affects mainly the angle of view and magnification that the lens provides at the specific focal length setting. A lens with a focal length similar to the diagonal size of the film or image sensor is known as a normal lens. On a 35 millimetre film camera or the full-frame Canon EOS 5D Mark III, this length is 50 millimetres. A normal lens provides a field of view similar to the human eye, without particular magnification or perspective distortion. A lens with a focal length of less than 50 millimetres is considered a wide-angle objective, while lenses with a focal length of greater than 50 millimetres are considered telephoto lenses. [27,6-8]

For this project the field of view provided by a normal lens is not sufficient, and instead a wide-angle lens needs to be used. The selected Canon EF lens has a zoom range from 20 to 35 millimetres, and the widest possible angle of view at 20 millimetres was selected to gather the highest amount of vertical image data. The horizontal field of view does not matter as much as the overlap can be controlled by how much the camera is turned between taking pictures. Due to this, the camera should also be positioned in portrait orientation to capture the highest possible amount of vertical image data in one picture.

4.2.3 Shutter Speed, Aperture and ISO Value

While the focal length determines the area captured by the lens in an image, the actual formation of the image is governed by three variables: the shutter speed, lens aperture and the sensor’s ISO sensitivity.

The shutter speed determines for how long the camera’s shutter lets light through the objective to the image sensor. In this application, the exposure is controlled exclusively by the shutter speed, while the aperture and ISO values stay fixed. Situations where the camera is hand-held or the photo subjects are moving, a fast shutter speed is required and the exposure is adjusted by aperture size and ISO sensitivity, but since for this implementation still subjects are photographed from a tripod, a longer shutter speed is not an issue. [27,145-147]

The exposure for a set scene of the panorama should stay consistent in each of the images. Using shutter or aperture priority programs on the camera might cause the exposure to change between parts of the panorama, since light levels are not consistent. To prevent this, full manual setting where both the shutter speed and the aperture value are controlled by the photographer should be used, and the shutter speed and aperture values should be picked by taking test photographs from a part of the scene with average, neutral lighting. By doing this, darker parts of the rooms will stay darker and areas with more light appear brighter in the final panorama as well. This also helps the image stitching process to be done seamlessly as the exposures do not change between the pictures. Different shutter speeds were used depending on the lighting conditions of the different rooms, but in general the shutter speeds used were around 1 second for the main exposure. [27,147]

The aperture value means the size of the aperture hole in the lens. While the shutter speed determines for how long the shutter is kept open, the aperture controls the amount of light the lens lets in. A larger aperture can be used to compensate a shorter shutter speed. Aperture values are represented by f-stops. The f-stop means the focal length of the lens divided by the diameter of the aperture, and every step doubles the amount of light that comes through the lens. For the lens used in this application, the maximum aperture value, f/3.5, at the lowest zoom setting at 20 millimetres means that the diameter of the aperture is 6 millimetres, while on a common 50 millimetre f/1.8 normal lens, the maximum aperture is 27 millimetres. [27,147]

A larger aperture value means a shorter shutter speed required for producing an exposure, but changing the aperture value also has other effects to the image. The main consideration is depth of field. A large aperture results in pictures with a narrow depth of field, where objects close to the point of focusing are rendered sharp while everything closer to and further from the camera gets blurred. In many situations, this visually pleasing effect of using a large aperture value called “bokeh” is desired. A narrow depth of field can be used to direct the viewer’s eyes to the main subject of the image and to make backgrounds less distracting. However, for the purpose of a panoramic presentation where all the details should be visible, the depth of field should be large enough to keep everything in the image sharp. This is achieved by stopping down the aperture to a value like f/8 or f/11, seen in the below figure. Stopping down the aperture also has other benefits, as image quality usually is not optimal when lenses are shot wide open, so a larger f-stop value also helps eliminate lens errors such as vignette or chromatic aberration. The size of the image sensor also affects the depth of field: a similar f-stop value on a full-format camera provides a much smaller depth of field than on a compact camera with a smaller sensor. [27,150-152]

Figure 7. The effect of stopping down lens aperture

As seen in the above figure, a large aperture value blurs objects that are away from the point where the camera is focused, in the example picture the telephoto lens in the front. Stopped down to f/8 both objects appear sharp, and the difference of one more stop to f/11 is not significant. An aperture value of f/8 was used in the project.

The ISO speed means the sensitivity to light of the camera’s sensor. The Canon EOS 5D Mark III supports an ISO speed range from 100 to 25600. [20,124]. As the ISO value doubles, the sensor detects double the amount of light in the same time. However, faster ISO speeds result in more noise to the image, and adjusting the ISO speed is generally done to compensate for low lighting. When the lens is at the maximum aperture for the specific situation and getting a correct exposure would require a shutter speed that is too long, the ISO speed can be increased to get the same exposure while keeping the shutter speeds faster, at the cost of image quality. [27,145-146]

As the panoramas are shot using a tripod and the previously selected exposure time of approximately one second is not an issue, the ISO value should be kept as low as possible to achieve maximum image quality. The lowest native ISO speed of the camera, 100, was selected to be used.

In conclusion, the ISO speed and f-stop value are static for each of the rooms, fixed at 100 and f/8, respectively. The exposures are controlled by changing the shutter speed, which is determined by using the light metering capabilities of the camera for a normal exposure on an average-lit part of the room.

4.2.4 White Balance

Different types of light have a different white balance. To a human eye, white objects look white regardless of surrounding lighting, but cameras need to adjust the colour temperature with software to produce natural-looking colours. Colour temperature is measured in kelvins, and it represents the colour that an ideal black body emits when heated to a specific temperature. [27, 118] Cameras can detect white balance automatically, usually providing reliable results. However, in situations where the automatic white balance setting does not produce a good result, cameras have pre-set white balance values for different lighting conditions. White balance can also be set manually, basing the colour temperature on a photograph taken of a neutral white object. [20,137]

The different exhibition rooms of the mansion museum had different lighting conditions, so the same white balance setting could not be used everywhere. However, for consistency in the image stitching phase, automatic white balance cannot be used either, as the colours would change depending on whether the portion of the room being photographed is lit by natural or artificial light. To achieve optimal results, the white balance was set manually for each room, by photographing a blank white paper and telling the camera to use it as a reference.

4.2.5 Focusing

Modern cameras have highly advanced and complicated focusing systems. The Canon EOS 5D Mark III has a state-of-the-art autofocusing system that utilises 61 focus points. [20,69] For this project where static subjects are photographed, automatic focusing in “One Shot” mode was used with 61-point automatic selection. This way, the camera focuses on anything in the focus area, and with a wide depth of field due to the large f-stop value, everything appears sharp, no matter which focus points the camera decides to use. For the few situations where there was only a blank wall in the focus area of the camera and the autofocus did not work, manual focusing was used instead.

4.2.6 Interior Photography: Fill Flash or HDR

Interior photography presents an issue when the difference in the lighting conditions between the interior and the exterior through possible windows is large. The mansion museum was photographed before noon, when there was a maximum amount of light outside, to achieve neutral and realistic lighting conditions in the panoramas. However, the dynamic range of a camera sensor is very limited compared to the human eye or even film, and it cannot reliably capture this range of different lighting conditions. If the picture is exposed so that the interior looks good, the light from the outside in windows will blow out and be overexposed. If the picture is exposed so that details remain in windows of the scene, everything on the interior will be underexposed. High dynamic range (HDR) photography is commonly associated with extremely high contrast candy-coloured images. Using HDR techniques, it is possible to achieve very dramatic and unrealistic results which are popular in online galleries, but the technique also does have a very proper use in situations such as this. [28]

Another solution to this would be exposing the image for a very short time, based on the amount of light outside, and then compensating the interior light using a fill flash. However, if the flash is just directly mounted on the camera, it produces a very sharp light that does not appear natural. Instead, the flash should be taken off-camera and softened with a light modifier. For single images this is a very valid technique, but for a panoramic scene, rotating the flash consistently with the camera for natural results would be cumbersome.

As the Canon EOS 5D Mark III is able to produce high dynamic range (HDR) imaging in-camera, HDR was instead chosen as the solution to this problem. HDR imaging solves the lack of dynamic range by taking several exposures (three in the case of the Canon EOS 5D Mark III) and combining them together to form a high dynamic range image. The range of the exposures taken for an HDR image can be controlled in-camera, and using a wider range of exposures results in a higher dynamic area. 2 stops of exposure difference was chosen, so with a single press of the shutter the camera takes one picture with correct exposure, one that is two stops underexposed and one that is two steps overexposed. Using these different exposures, the camera processes one image where image data that is overexposed in the normal exposure is instead taken from the underexposed image and parts that are underexposed in the normal exposure are taken from the overexposed one. The resulting image is much more balanced and looks realistic to the human eye, as can be seen in the following figure. [20,173]

Figure 8. Normal exposure compared to high dynamic range

As the above figure shows, the result of the Canon EOS 5D Mark III's in-camera HDR processor appears very realistic, natural and lifelike, but does preserve a lot of detail to both the lighter and the darker parts of the image such as the windows and the hallway to the exhibition room. The feature is also very easy to use: the camera operator activates HDR mode, adjusts the desired dynamic range from ±1 to ±3 exposure compensation and selects an effect. Natural is the only effect that makes sense in this context, the available "art" effects reduce the realism of the image. It is also possible to control whether HDR mode stays on for one shot only or for every shot, the latter option is selected for panoramic HDR imaging. [20,173-175]

With a camera that could not process HDR imaging in-camera the best option would be to shoot the same panoramic scene three times: one with a normal exposure, one underexposed and one overexposed. The panoramas should then be processed and stitched as normal, and the final HDR image should be created from the three ready panoramic scenes. However, as the file size of a ready panorama constructed from high-resolution source images will be very large, doing the HDR processing this way would require a very powerful computer.

4.2.7 Other settings

One more consideration is the use of delayed shutter or a remote switch. When shooting from a tripod, pressing the shutter button might shake the camera and result in an image that is not sharp. Using the 2 second delayed shutter gives the camera enough time to settle from the shutter button press before taking the image and a remote switch eliminates this problem entirely. [20,113-114]

There were also a few locations in the exhibition rooms with reflective surfaces that the camera was pointed at. Using the delayed shutter gave a frame of time to move away from the picture and not get caught in a reflection.

4.3 Photostitching

Once the source images are photographed on location, the panoramic scenes from each of the exhibition rooms are stitched together using Hugin photostitcher application. The stitching process is automated and straightforward, as described in the Project Definition chapter. The images taken on scene are input into Hugin photostitcher, which analyses the angle of view based on the image metadata, lines the images up, finds similarities in adjacent images to use as control points and then merges the pictures and applies perspective distortion for a horizontal panoramic presentation, which is then corrected in the final presentation as the panoramic picture is applied to the inside of the cylinder. However, due to the automatic nature of the photostitching, the source material needs to be close to perfect for an acceptable result on a project of this scale.

Two issues were discovered in the photostitching process. The issues and solutions to them are described in detail below.

4.3.1 Parallax shift

After doing the first set of shootings on the location using the camera settings described in the chapter before, I discovered an issue in the images that were produced, caused by the regular tripod I was using for shooting. I had done two test scenes before shooting on location, and no errors were discovered in those. However, two of the exhibition rooms had items so close to the camera that the problem of parallax shift surfaced.

Parallax shift is a perspective error that manifests on objects close to the camera when taking panoramic pictures. If a regular tripod is used, the lens of the camera moves in an orbit around the no-parallax point, which causes perspective shift in adjacent images. With objects that are further away from the camera the issue is not a major one and using a wide-angle lens also reduces the problem as it distorts perspective, making objects seem further away. However, if there is something very close to the lens, parallax error appears after stitching the images together, as the perspective of view has changed in the adjacent images, as can be seen in the following figure. [29]

Figure 9. Parallax error in panoramic photography

As can be seen, the objects further away from the camera such as the bookshelf and the window exhibit no irregularities, but the edges of the table which are close to the camera are jagged. I wondered if the issue was due to a lack of control points around the edges of the table and tried adding more manually, but the result was not any better, even after several manually placed control points. I asked about the issue in the “Hugin and other free panoramic software” group on Google, and the only way around the problem was either purchasing or constructing a panoramic head for the tripod. [30]

A panoramic tripod head eliminates the parallax issue by bringing the front element of the lens to the no-parallax point, that is, directly the axis which the camera is rotated around. This is illustrated in the below figure.

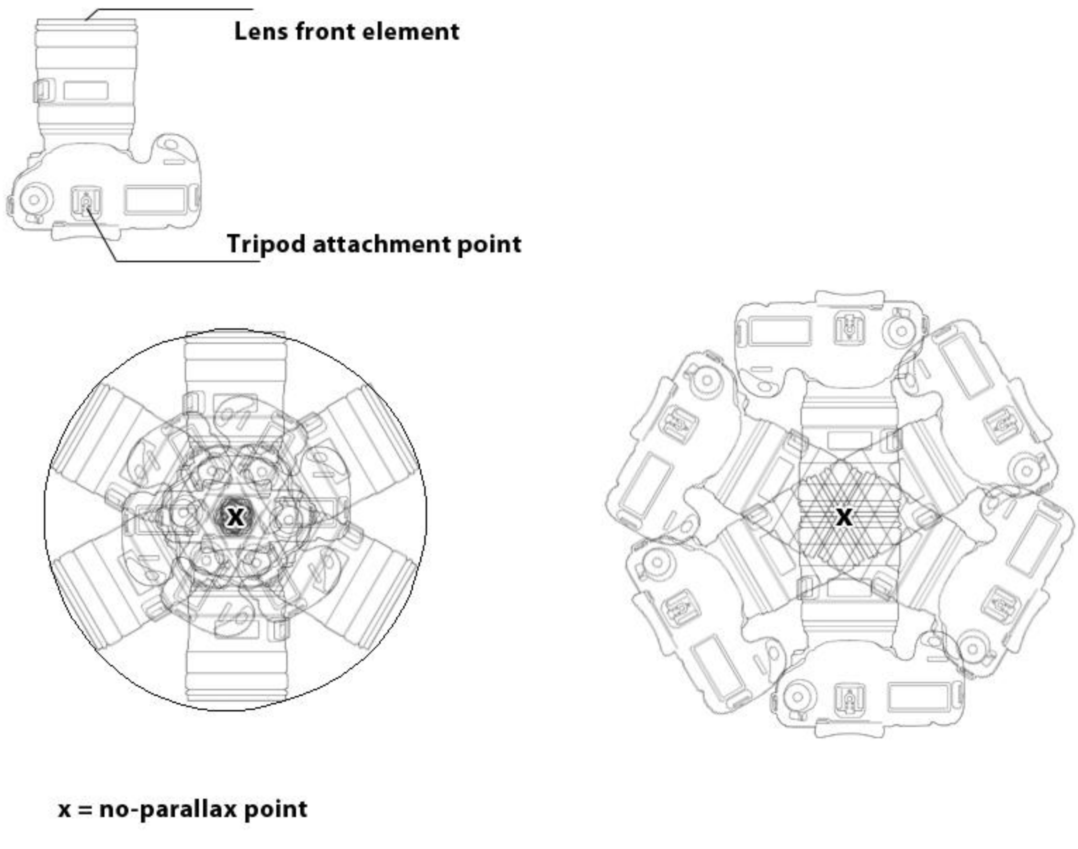


Figure 10. The cause of parallax shift error

As the figure shows, attaching the camera using a regular tripod causes the front element of the lens to orbit around the no-parallax point in the axis of rotation. For panoramic applications, the tripod head should be modified so that the lens front element rotates around the no-parallax point itself, eliminating the perspective shift.

There are commercial solutions to the problem, but they are very expensive, from 300€ to 500€, and need to be specially ordered as photography stores usually do not carry any in stock. [31;32] For a one-time project such as this, specially ordered equipment is out of budget and there was no time to wait for getting the item either. As the only requirement for a panoramic head is to bring the front element of the lens to the no-parallax point, I made a temporary modification the Velbon tripod I was using, seen in the below figure.

Figure 11. The temporary panoramic head

As the above figure shows, the makeshift panoramic head is no match for commercial applications and would not withstand prolonged use, but for photographing the two exhibition rooms again, it worked perfectly. The modified head uses two erasers to level the camera grip with the tripod’s panning handle. The camera is stabilized onto the handle with a CD case and everything is carefully taped together using strong tape. The result is not pretty, but brings the front element to the no-parallax point while retaining all required control of the tripod, and parallax shift error was eliminated on the images shot again with the modified panoramic head. As it was possible to shoot the majority of the rooms even without the panoramic head, it can be concluded that with a 20 millimetre wide-angle lens, parallax error starts to show when objects are closer than one metre from the camera and scenes where everything is further than this are safe to shoot even with a normal, non-panoramic tripod.

4.3.2 Regular patterns

Another issue that was discovered based on the results of the photostitching was that regular patterns were very hard for Hugin to stitch together reliably. As explained in Hugin's introduction in the Project Definition chapter, the program works by looking for unique details in adjacent images and using those as control points.
However, the location had many areas with repeating patterns such as ceiling boards and wallpapers. These repeating patterns do not have much unique detail for Hugin to gather control point information from, and the final results of the stitching showed many errors around these areas.

Figure 12. Image stitching errors around repeating patterns

While problem could be solved by adding control points and running the stitcher again, I decided to fix all the errors manually in an image editing program. Finding the errors and correcting them by editing tools is a lot of manual labour and does take a lot of time, but after modifying the control points the image would need to be stitched again, and on my computer the stitching process took several hours to perform, since the images were of a very high resolution and there were many of them. If the added control points would not fix all the problems, the process would have to be repeated, taking many hours yet again.

As the issue was caused by repeating patterns, they were also easy to modify and correct. Using a photo editing software, I selected a part of the problematic area and resized and rotated it so that the visible seam disappears. Most of the work was looking over the finished panoramas very carefully and finding all the errors, rather than the labour of fixing them.

After parallax shift and repeating pattern errors were fixed, the TIFF images output by Hugin were converted to JPEG format and were ready to be input to Krpanotools.

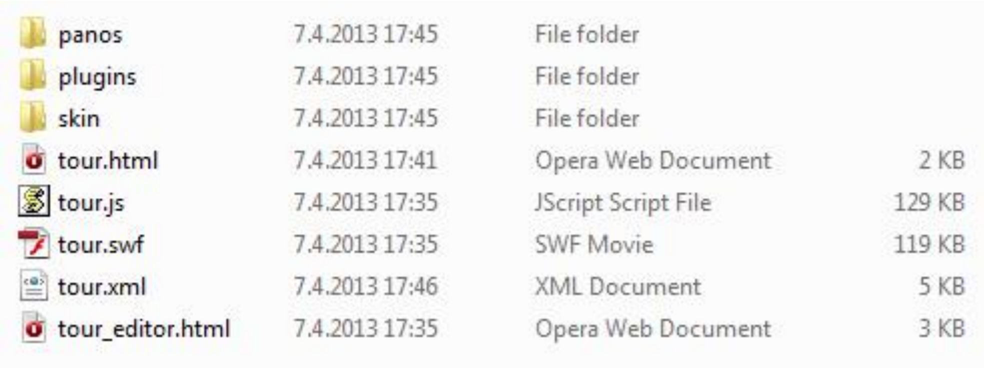
4.4 Building the Virtual Tour

Krpanotools operates as a set of droplet applications. The input files are dragged over the desired droplet, and the default installation features the following droplets:

- Object
- Flat panorama
- Multi-resolution panorama
- Normal panorama
- Standalone single-SWF panorama
- Multi-resolution virtual tour
- Normal virtual tour

Object means a presentation where the camera rotates around an object, creating the illusion of viewing it three-dimensionally. A flat panorama is stitched together from tiled images, and allows viewing something larger than the browser window by dragging with the mouse to look at different parts of the image. The normal and multi-resolution panoramas can present a single panoramic scene either in cylindrical or spherical format, utilising either a fixed resolution or several selectable ones. The standalone single-SWF panorama simplifies the installation of the application, as it outputs only one Adobe Flash file, which contains all the data of the panorama instead of the regular structure where the images are kept in one folder, metadata is read from an XML file and the player is a separate HTML or SWF file. The virtual tour droplets are similar to the normal panoramas, but also include an interface for navigating between the different scenes of the panoramic presentation. Normal virtual tour was chosen for this project, as it results in images that are 2200 pixels high when viewed in a regular web browser, and images that are 1100 pixels high when viewed with a mobile device.

After the files are dragged onto the droplet, the program asks the type of panorama (flat, cylindrical, spherical) for each scene in the virtual tour as well as the field of view (0 to 360 degrees). After the specifications are input, Krpanotools produces a folder with the virtual tour inside. The contents of the folder are seen in the following figure.



panos	7.4.2013 17:45	File folder	
plugins	7.4.2013 17:45	File folder	
skin	7.4.2013 17:45	File folder	
tour.html	7.4.2013 17:41	Opera Web Document	2 KB
tour.js	7.4.2013 17:35	JScript Script File	129 KB
tour.swf	7.4.2013 17:35	SWF Movie	119 KB
tour.xml	7.4.2013 17:46	XML Document	5 KB
tour_editor.html	7.4.2013 17:35	Opera Web Document	3 KB

Figure 13. Krpanotools virtual tour structure

The “panos” folder contains the images used for the panorama. The input 360 degree panorama is split into several parts and the distortion is corrected for cylindrical projection. The image data takes the most space in the application, but is compressed efficiently: the normal resolution image files for a single scene take approximately 1.5 MB of space, while the mobile resolution is half of that. A project of five rooms then takes approximately 12 MB of space altogether, and if the program is viewed over a limited mobile connection, approximately 3.5 MB of data transfer is spent on loading the images.

The “plugins” folder can be used to extend the virtual tour with new components if desired, such as including a map on a larger virtual tour or adding interactive elements. The only plugin used for this specific project was Gyro, which allows a mobile device to make use of its internal gyroscopes for viewing the panoramic tour, so that instead of viewing the panorama by dragging around with a finger on the touchscreen, the entire device is moved and the scene changes accordingly.

The “skin” folder contains the navigational elements of the virtual tour such as the transition hot spot icons and the icons on the bottom control bar. The default skin bundled with the installation was used for the presentation.

The “tour.html” file is the actual player which is linked to once the application is installed on a server. Depending on whether the used browser supports Adobe Flash or not, “tour.swf” is either loaded to the player or an HTML5 player is initialised. The player loads the image data from the “panos” folder, projects it to the specified type of panorama and takes control input from the user.

The JavaScript file “tour.js” contains the program library used by the player, and “tour_editor.html” can be used as a graphic user interface for controlling the tour.

However, some manual adjustment needs to be done to both the “tour.html” file and “tour.xml”, which is the control file for the parameters of the virtual tour. In the “tour.html” file the page title needs to be changed, as Krpanotools generates the title based on the name of the first file that is input. The encoding of the HTML file also should be changed from the default ANSI to UTF-8 to make sure special characters of the Finnish and Swedish languages show up properly in the browser.

The “tour.xml” file then controls the virtual tour, using a simple XML structure. The different rooms or scenes are determined by the XML element <scene> and include information of the name and title of the room as well as the locations of the panoramic images that are loaded by the player. The view areas of the scenes are also determined in the XML files, and this had to be adjusted for room number 5 of the museum, which was too small for a full 360 degree panorama.

If the field of view is limited to less than 360 degrees when creating the panorama, the particular scene will not work with the HTML5 player on a mobile device due to lack of support in the program code. For room number 5 I decided to fill half of the panoramic image with blank space, created a 360 degree panorama out of it and then limited the field of view to 180 degrees by modifying the XML file’s <view> element to preserve full functionality with a mobile device, as well. [33] The XML file also contains information on the transition hotspot locations and to which scene they link to. As the room titles are read by the web browser from the XML file, its encoding should also be changed to UTF-8 for the same reasons as the HTML file.

Once the required modifications to the HTML and the XML files are done, the installation of the virtual tour onto a server is very simple. The folder containing the virtual tour is transferred onto the server and a link is generated to the HTML file. By managing the file and folder rights on the server, it should be made so that users can only access the HTML file, everything else is restricted.

An example installation was tested to work at least on Internet Explorer, Firefox, Google Chrome and Opera desktop browsers, as well as on an iPhone, iPad and Samsung Galaxy III and as long as either Adobe Flash or a HTML5 compatible browser is installed, no additional components are required to view the panoramic presentation.

No components are required server-side, either, it is enough that the application is hosted and linked to.

4.5 Final workflow

Based on the issues found out during implementation, the workflow can be updated in the figure below with steps to minimise problems as well as the file sizes of each individual step, showing the process of controlled compression.

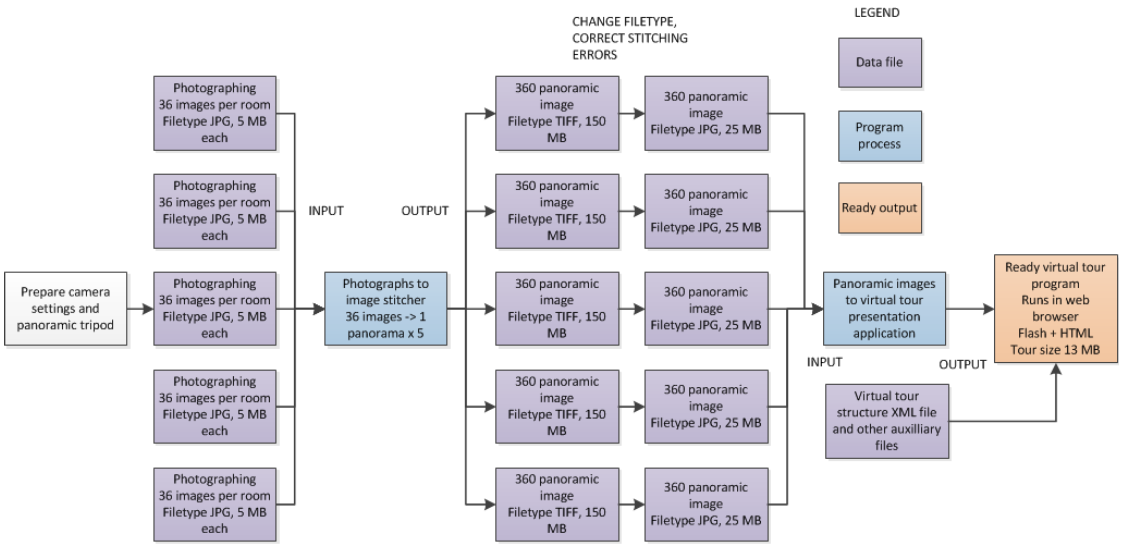


Figure 14. Final workflow

The finalized workflow, as seen above, adheres quite accurately to the initial one. File types and sizes have been updated and a few steps to ensure highest possible quality were added, but the rough workflow remained as planned and no major restructuring needed to be done.

The main consideration for this kind of project is specifying the tools used as well as the camera settings. Being aware of parallax shift error and the possible issues of interior photography is also essential.

5 Conclusions

Even though QuickTime VR as a technology is almost 10 years old by now, its basic idea of a virtual space being composed by taking photographs that cover a scene entirely still holds.

The main drawbacks of QuickTime VR were problems concerning delivery as online connections could not reliably deliver a presentation of even 10 megabytes. Also, a separate VR viewer program needed to be installed before the content could be enjoyed. Neither of these issues hold true anymore: online connections are much faster and presentation technology has shifted from specialised programs to mainstream browser components that are found on nearly every device: Adobe Flash and HTML5. This makes browsing panoramic content such as the one described in this study instantly possible on any device, as there is no need to install additional viewer software or even browser components. This is important in many ways: the attention span of a person is known to be very short when browsing the internet, but additionally there might be technological or know-how restrictions to installing additional programs on the computer the content is viewed on.

The workload of creating an online panoramic presentation is also very reasonable. The workflow described in this study is very straightforward and most of the work is done off-location. Therefore, making a panoramic virtual tour of a location that is closing down from the audience such as the mansion museum is very efficient, as taking the pictures to use as source material only takes from some hours to a day's work at most, depending on the size of the premises and the amount of scenes required to photograph. This sort of a virtual tour presentation is also very flexible and extends itself to applications of many sizes and scales: from single-room presentations to huge tours with several scenes and complicated transition paths. Additional information such as close-up photographs of items of interest, accompanied with description text can also be embedded into a panoramic presentation to provide additional information.

Recent steps in improving online panoramic virtual tours have been about the presentation technologies as such. However, the methods of delivery have also improved due to faster online connections. Finally, in-camera photostitching technology has improved, as well.

As Sony cannot compete with the larger camera manufacturers in sheer volume, they have a lot of interesting innovations in their devices, and the Sweep Panorama feature does sound interesting. While it can produce 360 degree panoramas in some devices already, an additional degree of control over the settings would still be required before it could be used for a serious project. Still, stitching the images together and correcting all the possible errors was the heaviest part in the workflow, so eliminating that step by processing all the data in-camera would make the process much faster.

The future of virtual reality presentations most likely will implement actual 3D elements to the viewer application, instead of just projecting images to a flat plane like now. Early tools such as Autodesk 123D Catch are already in the works, and if the technologies do catch on, mainstream player software will most likely also include web 3D support so that models created this way could be viewed without needing to install additional components.

As the future developments build up promisingly on the base laid out by QuickTime VR, a possible future workflow might include the camera automatically capturing and stitching an HDR 360 degree panorama, which is then input to a program that turns it into a 3D model. The 3D models of the scenes could then be combined together to form a virtual tour where the user could navigate around freely and examine objects from several angles. This would provide both an easier workflow when creating the panorama as well as a richer user experience when viewing it.

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