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HUMAN PHOTOGRAMMETRY: FOUNDATIONAL TECHNIQUES FOR CREATIVE PRACTITIONERS

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ABSTRACT

Photogrammetry has emerged as a leading approach for photorealistic digital replication and 3D scanning of real-world objects, particularly in areas of cinematic visual effects and interactive entertainment. While the technique generally relies on simple photography methods, the foundational practices for the field of human photogrammetry remain relatively undocumented.Human subjects are significantly more complex than still life, both in terms of photogrammetric capture, and in digital reproduction. Without the documentation of foundational practices for human subjects, there is a significant knowledge barrier for new creative practitioners to operate in the field, stifling innovation and adoption of the technique.Researchers and commercial practitioners currently working in this field continually distribute learnings and research outcomes. These learnings tend to centralise more on advanced practices such as capturing micro-geometry (skin pores), reflectance and skin distortion. However, the standard principles for building capture systems, considerations for human subjects, processing considerations and technology requirements remain elusive. The purpose of this research is to establish foundational practices for human photogrammetry systems. These practices encapsulate the underlying architectures of capture systems, through to necessary data processing for the 3D reconstruction of human subjects.Design-led research was used to construct a scale 21-camera system, designed for high-quality data capture of the human head. Due to its incredible level of surface complexity, the face was used to experiment with a variety of capture techniques and system arrangements, using several human subjects. The methods used were a result of the analysis of existing practitioners and research, refined through numerous iterations of system design.A distinct set of findings were synthesised to form a foundational architecture and blueprint for a scale, human photogrammetry multi-camera system. It covers the necessary knowledge and principles required to construct a production-ready photogrammetry system capable of consistent, high-quality capture that meets the needs of visual effects and interactive entertainment production.

KEYWORDS

Photogrammetry, 3D scan, body scan, photoscan, digital double, digital actor, face scan, photorealistic human, photogrammetry pipeline, digital replication, multi-camera, foundations

1. INTRODUCTION AND BACKGROUND

Photogrammetry has recently emerged as a leading approach for the digital replication of real-world objects in photorealistic quality. Through the use of consumer-grade photographic equipment, creative practitioners can generate accurate Three Dimensional (3D) models for use in any digital application; from 3D printing to cinematic visual effects sequences. This approach has also risen as a method for capturing photorealistic human 'digital-doubles', generally through the use of purpose-built multi-camera systems.

Despite some specialist practitioners operating within the domain of human photogrammetry, very little information is readily available regarding the fundamental practices and techniques for designing or building these systems. Without access to this information, practitioners looking to enter the field face significant knowledge barriers and uncertainty. The purpose of this project is

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to establish a foundational knowledge set for creating human photogrammetry systems, as well as processing techniques, to make the field more accessible to new creative practitioners.

This project was conducted using a design-led approach, to iteratively construct a scale, 21-camera human photogrammetry system that was informed by analysis of existing practitioners and rigorous testing of various designs. This resulting system, in combination with findings throughout the project, was used as a model to devise a foundational architecture and blueprint intended for future practitioners to adopt as a starting point when entering the field.

The creation of photorealistic, computer-generated characters for cinema and interactive entertainment has historically been a challenge. As technology provides us with the capability to render characters with an increasing amount of human likeness, creations become more susceptible to the ‘Uncanny Valley’ phenomenon. That is, when we realise something we initially thought to be a real human form is artificial, we experience a feeling of discomfort and see the subject with a negative sense of affinity [1]. Flueckiger[2]highlighted how detrimental this discomfort could be to the success of a work, in her discussion about the shortcomings of ‘unlifelike’ characters in *The Polar Express* [3].

Recent advancement in technology and techniques for the creation of digital human characters, or ‘digital doubles’, has led to some works crossing the uncanny valley with increasing frequency. One such example of this was Image Metrics’ *Digital Emily* [Figure 1] project in 2008 [4]which was followed closely by ICT’s *Digital Ira*[5], and real-time versions of this work through collaboration with Activision, Inc.

Figure 1. Still frame from the *Digital Emily* [6] project

Fundamental to each of these achievements was a modern process known as photogrammetry, which involvesphotographing a subject from many angles,to generate a 3Dreconstruction by computationally solving correlations between each image [7]. For human subjects, this is typically done through the use of multi-camera arrays [8], triggered simultaneously or in specific sequences. The image below [Figure 2] features a contemporary multi-camera array used for human photogrammetry. This system relies on 170 Digital SLR cameras to capture the human form in its entirety in 1/10,000th of a second, with the resulting reconstruction resolving under 2mm [9].

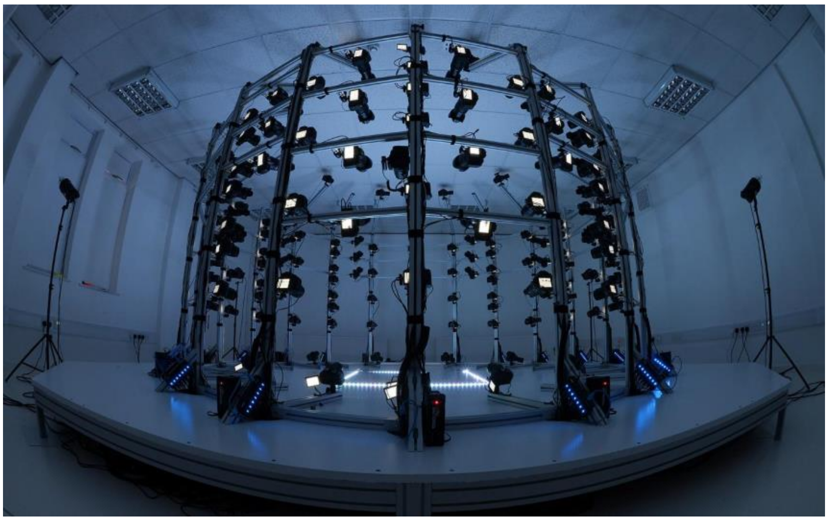

Figure 2. Ten24's [10]T170 Capture Stage

As several practitioners have advanced in this field, the process has become heavily utilised in cinematic visual effects production processes [11] and more recently, interactive entertainment. *Captain America: Civil War*[12] saw the technology used to create digital body doubles of actors [13], while*The Curious Case of Benjamin Button*[14] utilised the technology more creatively for photo-realistic ageing effects [15]. Interactive entertainment is progressively adopting the technology for character creation pipelines in games [16] such as *Infamous Second Son*[17], and emerging practices such as real-time cinematography and performance capture, as seen in Ninja Theory's collaborative work presented at SIGGRAPH 2016 [18].

Due to its accuracy and efficiency of capture, the use of photogrammetric assets becoming more prevalent across several fields in addition to cinematic visual effects and interactive entertainment. Such applications include forensic documentation [19], anthropometry[20]and biomedical applications [21]. Findings in this paper can apply to wider domains of practice; however, this research remains focussed on determining foundational practices for human photogrammetry for the needs of cinematic visual effects and interactive entertainment productions.As such, this paper focussed on the design of a system that can capture detailed geometry and accurate colour information for use in these production environments. As this research focuses on establishing foundational practices, it is expected that outcomes may not reach the same fidelity as the leading practitioners. However, the knowledge acquired and the distilled set of practices should provide enough information for future practitioners to establish a system, and continue to move forward with the technology with significantly lower budgets.

2. METHODOLOGY AND METHODS

The overarching intent of the research was to reduce the gaps in readily-available knowledge of building human photogrammetry systems through the analysis of existing practices and the development of a functioning capture system. This project adhered to a Design Research methodology relying heavily on iterative design processes to achieve this outcome. Adopting Simonsen's [22] definition of Design Research, this project focused on changing the available knowledge of human photogrammetry system design. Referring to Simonsen's model, the design process is described as fostering change from a particular situation,"A", to another, "B"[22]. For this project, "A", refers to the current situation where available knowledge for human photogrammetry system design is scarce; and the alternative, "B", is the ideal situation where this knowledge is more clearly defined and available for creative practitioners.

Project activities were partitioned into distinct, yet interdependent areas of focus, and conducted using an iterative process. These partitions align with three objectives: design and development of a capture system, examination of techniques for high-quality capture, and establishing a data processing workflow.The crucial finalgoal – defining a foundational architecture, was the culmination of all other objectives. Each of the three partitions followed Simonsen's iterative design process.

Starting with a critical problem as the current situation, 'A', an idea, vision or strategy to solve each issue would be established. A plan to conduct activities would then be derived, and an iterative process of work would be undertaken to reach a workable solution 'B'. The resulting solution would be deployed as intended, with observations of outcomes documented and any relevant data stored for later analysis. The findings were then evaluated against the intent of the design to determine the next appropriate steps for the project.As an example of this approach, one of the first key activities was to design, plan and develop the first iteration of the scale system. Shown below in Figure 3, the early stage of this cycle involved analysis of existing practitioners, their methods and any relevant knowledge available ['A1')]A low-fidelity design was derived, and a plan made to begin iteration. Iterations of development activities occurred until a functioning capture system was created and put into use ['B1'].

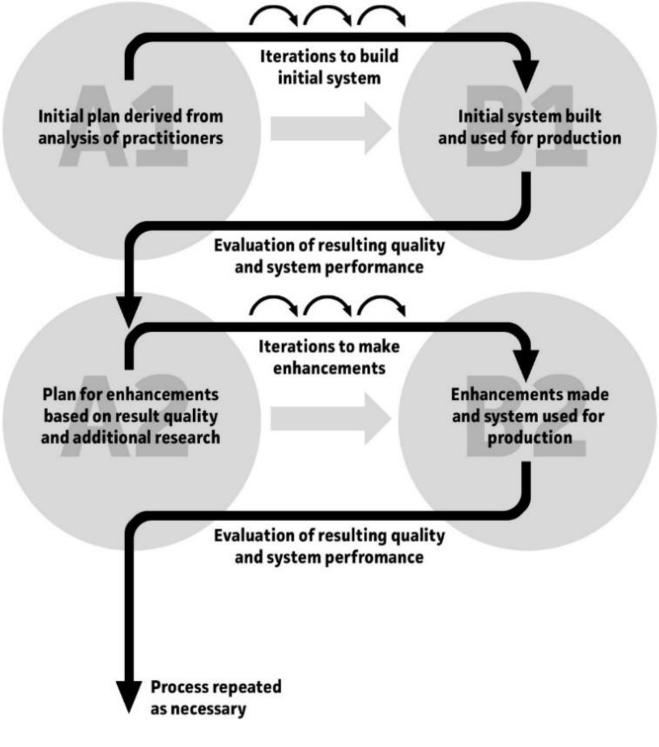

Figure 3. An adapted iterative design process used in this project.

The system behaviour, performance and characteristics were continually observed as it was in use. As the captured data was processed, the quality of results was compared to that of model practitioners to evaluate the next steps moving forward. In the first instance, this meant conducting additional analysis and research to find ways to improve scan quality. In Figure 3, a different circle, 'A2',demonstrates the pattern of continual iteration for the project.

Throughout the project, threesignificantversionsof system design and building occurred. Within each version, continual iteration was conducted to identify the best techniques for high-quality subject capture and reconstruction. The capabilities of the system progressed from partial, low-resolution facial capture, to medium resolution full head capture.These iterations continually worked towards building a system that could achieve results comparable to leading practitioners, with consideration given for differences in available hardware and resources. Each version's capture capability was tested against a variety of human subjects, with performance qualitatively assessed against the resulting 3D reconstructions. It was important that any resulting solution was also robust and efficient enough for rapid data acquisition and reconstructing subjects of varying dimensions to meet the needs of cinematic visual effects and interactive entertainment production.

Table 1 and Figure 4 below demonstrate the technical specifications and physical configuration of each significantversion, which is referred to as 'Build 1', 'Build 2' and 'Build 3', concerning the chronological order of their development. The cameras in Figure 4 are coloured blue to emphasise their physical configuration.

Table 1. Key technical specifications of the three main system variations.

Feature	Build 1	Build 2	Build 3
No. of Cameras	12-16	16	21
Camera Model	Canon 400D DSLR	Canon 400D DSLR	Canon 400D DSLR
Lens	18-55mm, varied	18-55mm, varied	18-55mm, all 55mm
Lighting	Continuous LED	2x Continuous Fluorescent	3x 300W Strobe
Shutter Control	Software via. USB	Software via. USB	Custom Hardware
Camera Positioning	Even distribution	Even distribution	Paired, with reference cameras
Subject Stabilisation	None	None	Rod behind subject head
Subject Seating	Fixed chair	Fixed chair	Adjustable height chair
Linked Computer	2x Laptop Computers	1x Desktop Computer	1x Desktop Computer

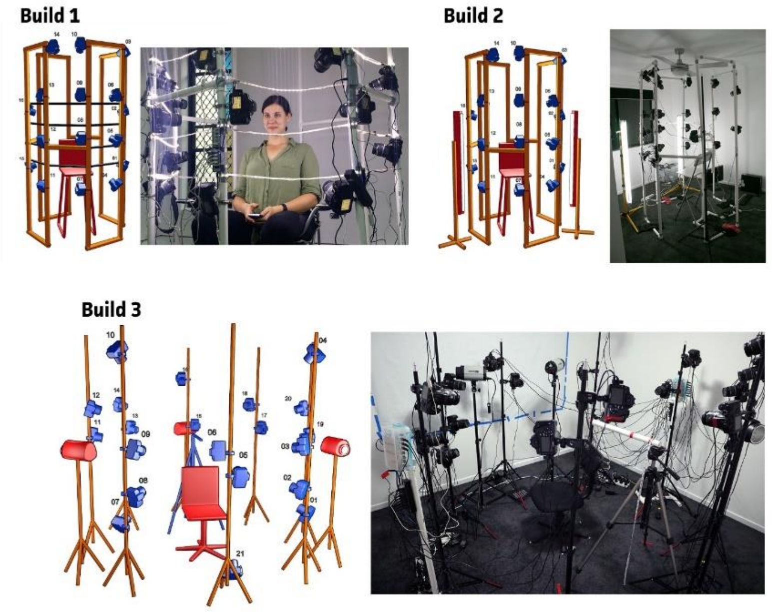

Figure 4Diagrams and photographs of Build 1 (top left), Build 2 (top right) and Build 3 (bottom).

All three system builds adhered to the same general process for capture throughout the project. A subject would perform a static facial pose inside a multi-camera array. Multiple images were then captured and parsed through publically accessible software for processing and 3D reconstruction. Eight subjects participated in this process, with some performing up to 20 different expressions for capture. Toward the end of the project, one sample progressed from acquisition to integration in a real-time rendering engine for performance capture in under 6 hours.

3. SYSTEM DESIGN

This section presents findings from investigating vital elements of the physical system design that influence both the quality of image capture and overlap of information captured from each camera. These two aspects were prioritised to aid the feature-based matching process [7]typically used by automated photogrammetry solutions, as this process requires apparent identifiable features in multiple images of the same scene for 3D correlation. From a technical standpoint, this meant acquiring sharp and evenly lit imagery, while positioning cameras in a way that balances overlapping fields of view and subject coverage. Additionally, blurry images are hugely detrimental to reconstruction processes [23], so a considerable depth of field and fast subject exposure was pursued to minimise the risk of blurred images.

3.1. Lighting

Subject illumination proved to be critically important to achieving consistently high-quality data. This project experimented with a varied use of continuous and strobe lighting to understand the impacts on image and reconstruction quality. As discussed in Section 6, as a result of these experiments, the most reliable and highest quality architecture relied on the use of strobe lighting, triggered manually during a 2-second camera exposure.

3.2. Continuous Lighting

Build 1 and 2 relied on variations ofconsumer-grade continuous lighting to achieve even lighting across the subject. The first build used LED strip lighting mounted to the system frame. The second build used 2, 2x600W 60hz fluorescent battens positioned around the capture volume in a butterfly pattern. Diagrams of these lighting configurations can be seen below in Figure 5.

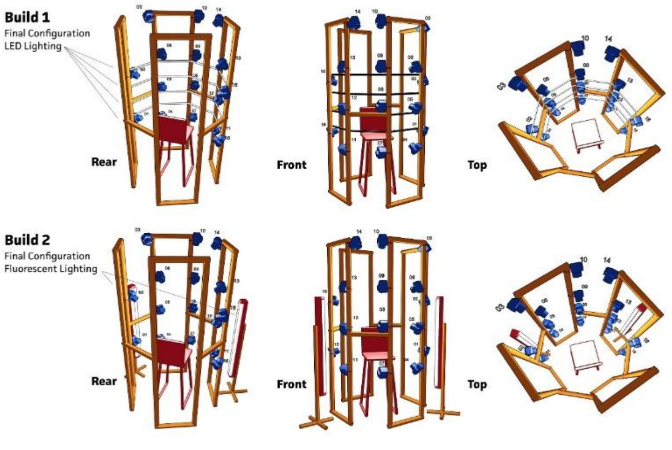

Figure 5Diagrams of LED strip lighting solution (top) and batten solution (bottom).

The essential advantage of continuous lighting was that it allowed asynchronous shutter activation across the sensors enabling the system to function without the need for any additional hardware.The lack of output and brightness was the main drawback of these solutions. In turn, this limited depth of field and generally relied on higher ISO settings to increase image brightness, which increased the noise in the images, as shown below in Figure 6.

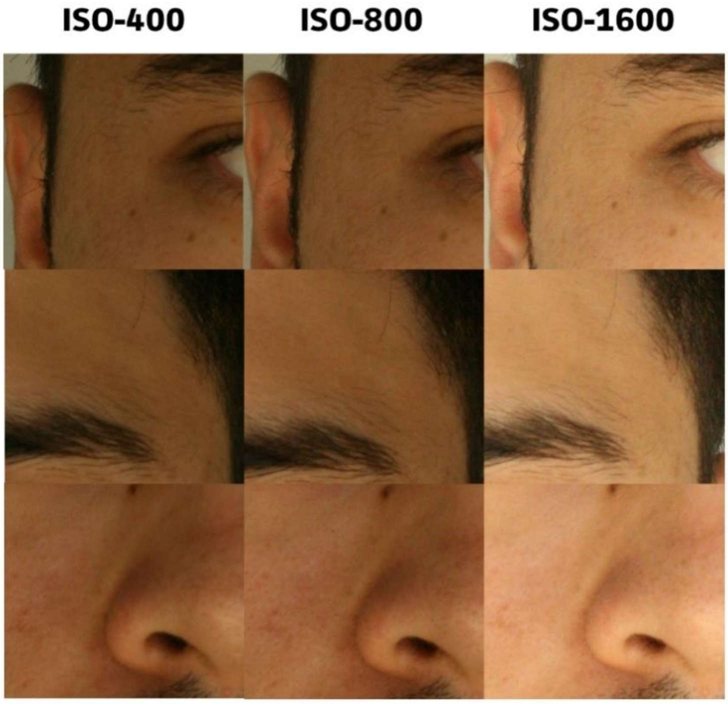

Figure 6. Comparison of coloured noise present in high ISO imagery

3.3. Strobe Lighting

Build 3 used strobe lighting, which depended on a synchronised trigger. The setup used 3x300W strobe lights at full power, evenly arranged around the subject and positioned for bounce-diffusion off clean white walls. The project investigated two capture techniques: strobe activation synchronised to a single sensor, and manual strobe activation during a long exposure. A diagram of this setup is shown below in Figure 7.

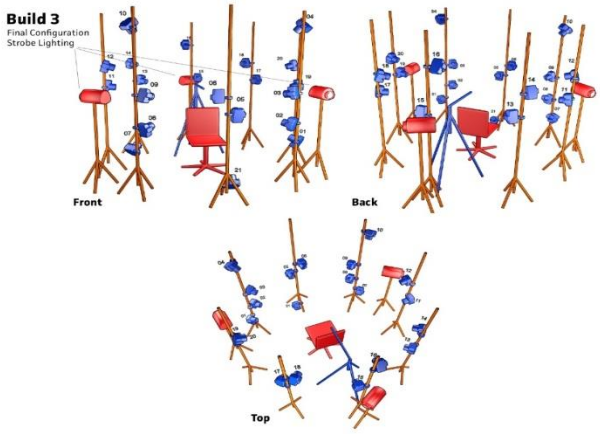

Figure 7. Depictions of strobe lighting setup.

The first iteration synchronised the strobe flash to a single camera in the array. Triggering the camera shutters and flash in this fashion was inadequate, as some images were frequently appearing underexposed. Delays occurring in each camera, known as ‘shutter lag’, caused the underexposure. The Canon 400Ds used in this project were prone to lag times ranging from 66ms to 116ms [24], which was a large enough variance for shutters to cycle out of time with the strobe flash.An alternative capture technique was used to overcome this issue.

A wireless remote was used to trigger the system manually, instead of synchronising the strobes and a 2-second exposure was used in a darkened environment to eliminate the impact of shutter lag between the cameras. Similar to the approach used by Beeler et al.[25], roughly 1 second into the exposure, the strobe units were triggered, briefly illuminating the subject for capture on each camera. A graphical representation of these capture sequences is shown below in Figure 8.

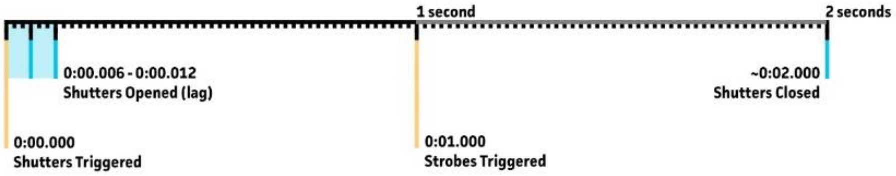

Figure 8. A timeline of trigger execution using a 2-second exposure.

Using a long exposure ensured there was enough overlap of ‘open shutter’ time between all cameras, illuminating the possibility of missing the strobe flash. A darkened environment was necessary for capture to avoid unwanted visual artefacts during the long exposure.

3.4. Data Connectivity and Trigger Mechanism

Underlying the design of each build was a motivation to minimise the hands-on effort required to operate the system, as this would reduce operational complexity. The two aspects focused on for these builds were: establishing computer connectivity to the system for data acquisition and enabling tight control of the camera shutters. The most effective method was to use a custom hardware shutter release for synchronised shutter release and rely on camera controlling software for automating the data acquisition step.

3.5. Computer Connectivity

During the development of Build 1, the controlling laptop computers had difficulty supporting such a high number of connected USB peripherals. Build 3 overcame these connectivity issues by using a desktop computer and three powered USB hubs connected to a 21 camera array.

3.6. Camera Shutter Control

This project explored two methods for activating the camera shutters. Builds 1 and 2 relied on activation via the camera controlling software and USB connection. Build 3 used a custom hardware trigger, activated with a physical push-button for synchronised shutter release. Each method possessed unique characteristics which influenced overall system architecture.

It was found that using the camera controlling software to activate the camera shutters, while convenient for system operation, had disadvantages for system synchronisation. When triggering the shutter release, each camera shutter activated sequentially. Depending on the chosen shutter speed and number of connected cameras, this could lead to extended capture times – creating a risk that the subject may move or change pose during the capture process. A sequential shutter activation also creates difficulty for using strobe flashes due to the lack of synchronisation.
The shutters of each camera could be activated almost simultaneously by using a physical push-button and custom hardware (Figure 9). Labels 1 and 2 feature the in-progress construction of the device. Labels 3 and 4 feature the device mounted into a sealed container with connections for synchronising cameras. Label 5 features the equipmentattached to a stand for easy access within

the system.Technical suggestions from Breeze Systems [26] and an existing product, Esper Design's Shuttercell [27] influenced the concept and design of this system.

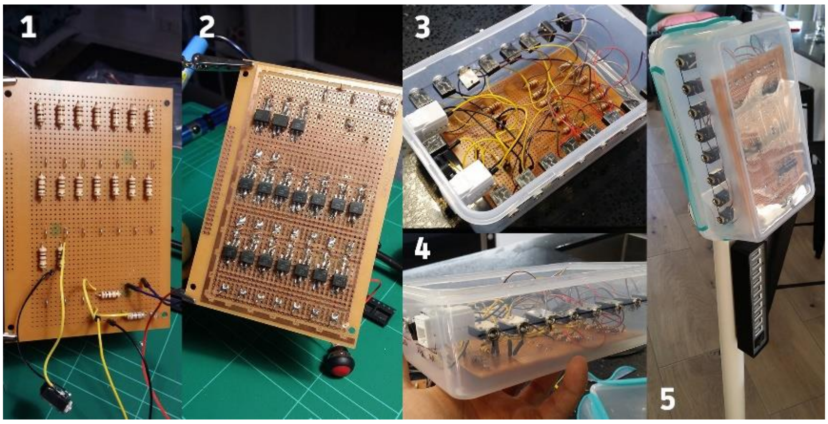

Figure 9. The custom hardware for synchronised triggering.

Although this created additional steps for system operation, it enabled the use of strobe flashes for lighting and mitigated the risk of subject movement as synchronisation could reach speeds of 1/200th of a second. A comparison of these two techniques is graphically represented below in Figure 10.

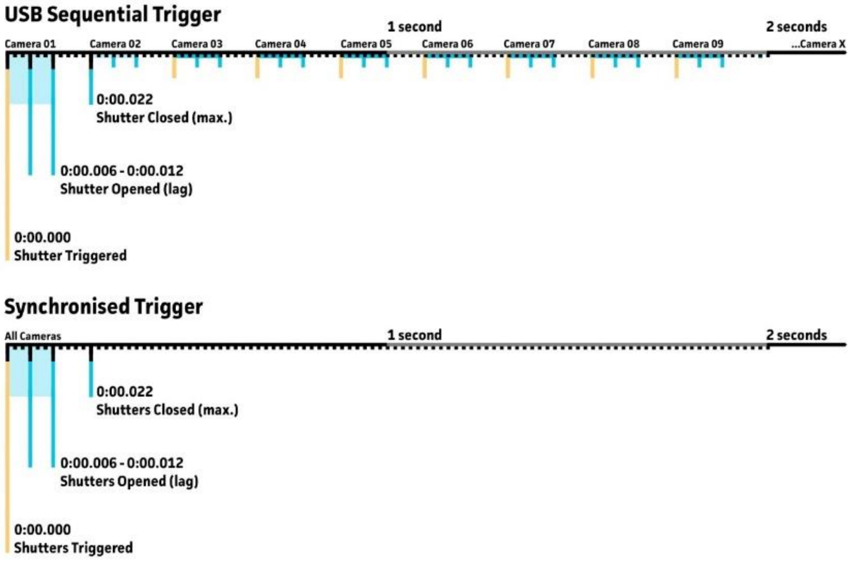

Figure 10. Graphical representation of a sequential (top) shutter control via USB vs. Synchronised shutter control (bottom) via custom hardware.

3.7. Camera Positioning

Several variations were used throughout each build, with continual iteration to improve overall reconstruction fidelity and subject coverage. Build 3 used side-by-side paired camera arrangement to surround the subject. Some individual cameras also provided additional imagery from isolated locations. A balance was found between the camera distances to subject, desirable depth of field, and subject framing. Builds 1 and 2 used an even spacing method for the distribution of cameras around the subject. There were noticeable inconsistencies in the processing quality and camera alignment effectiveness across different test cases. Experimentation of camera position revealed insufficient image overlap between each image was causing the inconsistent performance.

Build 3, tested a variety of positioning options for reliability and reconstruction quality. Initially, the same method of evenly distributed positioning was used to validate the impact of lighting changes. Positioning patterns were then modified iteratively to improve outcomes. The Build 3 pattern relied on the use ofclose ‘pairs’ of cameras, in intervals of 45 degrees around the subject. Additional individual cameras were positioned to provide imagery of occluded areas, or to increase correlation with the paired cameras.The figures below illustrate example layouts of camera positioning in each build (Figure 11), as well as side by side results of paired and unpaired methodologies (Figure 12).

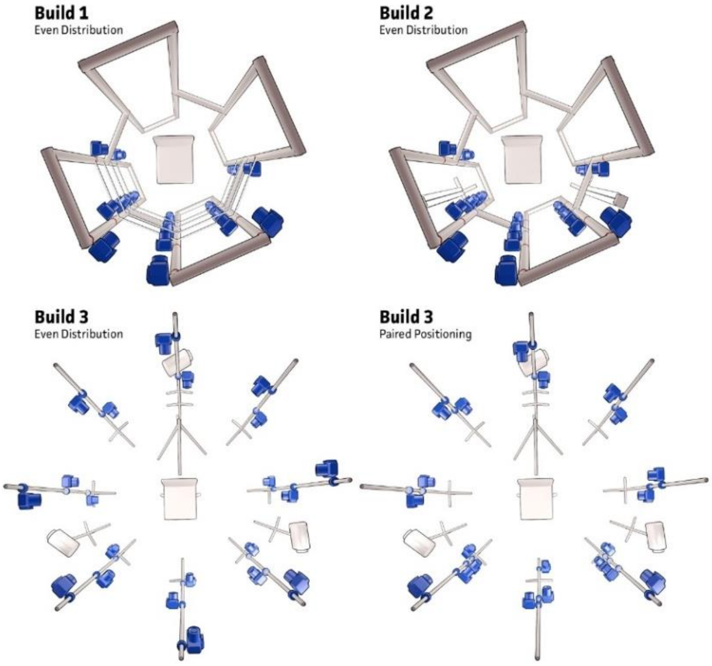

Figure 11. Example camera positions for Build 1 (top left), Build 2 (top right) and Build 3 (bottom).

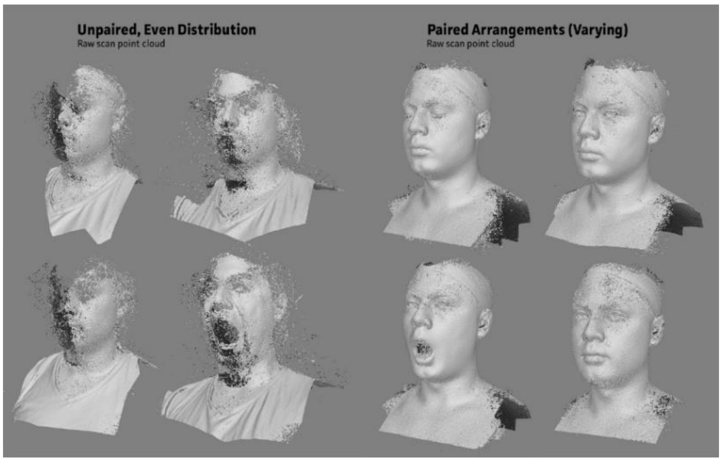

Figure 12. Comparison of reconstruction quality using unpaired (left) and paired (right) camera positions.

3.8. Subject Framing

For the duration of this project, each build aimed to ensure a fully framed subject was present within each image.An example of this framing is seen below in Figure 13. It is recommended by Agisoft (2013) not to be concerned with placing the entire object in the frames of the image, however using a solution with few cameras meant it was essential to capture as much subject surface information as possible. The impact of failing to encompass the entire subject in this scenario presented as issues with subject stabilisation.

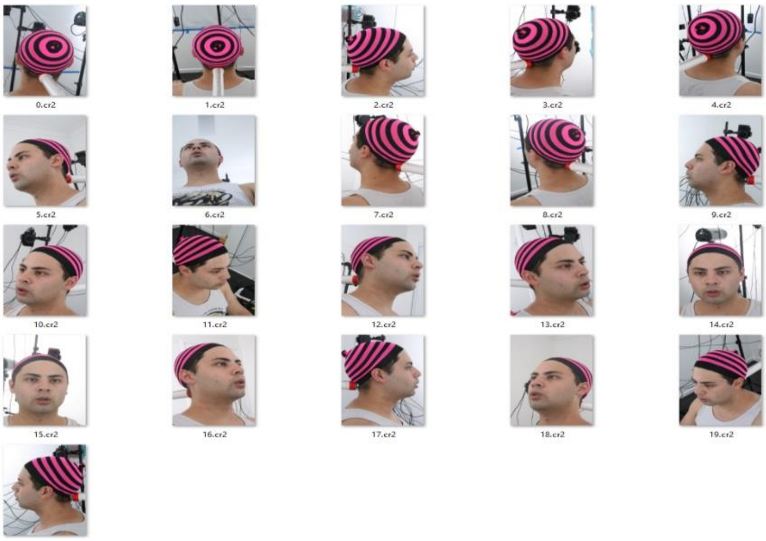

Figure 13. Afully framed subject within every image.

3.9. Subject Stabilisation

Having the subject entirely in-frame for each image captured was central to the design of each build. In practice, this leads to several situations where the subject would inadvertently move out of the frame as a result of postural adjustments. To overcome this, Build 3 used a rigid plastic rod to indicate the desired position for the subject. The subject would rest the rear of their head against the rod, and this would stabilise their positioning for each capture. Figure 14 shows acomparison of the resulting imagery.

Figure 14. Image taken without (left) stabilisation, and with a stabilisation rod (right).

3.10. Varying Subject Dimensions

Natural variation in body height required consideration in designing the system. In Builds 1 and 2, a rigid, non-configurable seat was used for the subject to sit in the capture volume. The lack of adjustment was found to be problematic, as subjects who were taller or shorter would frequently find their face and head out of frame.Use of a height-adjustable seat and the stabilising rod as an indicator enabled the subject to freely adjust their vertical seat positioning to become framed appropriately within the capture region - as illustrated below in Figure 15.

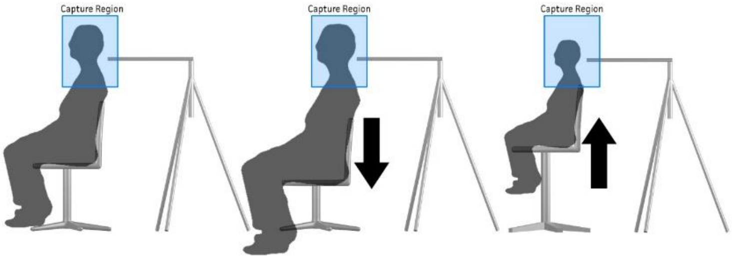

Figure 15. Diagram showing the use of an adjustable chair to cater to different body sizes. By adjusting chair height, the subject matter can remain within the intended capture region.

Full-body systems demonstrate similar considerations, such as Ten24's T170 Capture Stage which features an adjustable floor with a 3-foot range of motion [9]. Providing a mechanism to move the subject into an ideal framing minimises the repositioning and recalibration of the cameras across different capture sessions.

3.11. Occluding Hair

Attempting to capture and reconstruct subjects' hair proved problematic; typically, visual information within the images was noisy and featureless, which was detrimental to the reconstruction process (Figure 16).Furthermore, any successful reconstruction would suffer from a loss in facial geometry due to occlusion caused by the hair.

Figure 16. Subject reconstruction from capture with visible loose hair.

Wearing a cap to occlude the hair from capture maintainsthe fidelity of the head reconstruction and retains the general shape of a subject's head (Figure 17).

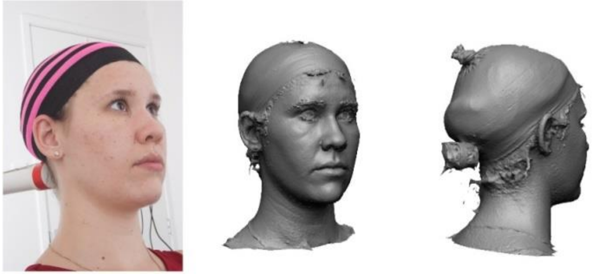

Figure 17. Cleaner reconstructions achieved by occluding hair from the capture process.

Early iterations of this practice utilised a skin-tone material for the hair occlusion – however,this provided few reference points for the reconstructive processes. Further analysis of Graham's captured imagery (2014) showed the use of a patterned material, likely for this reason. Also seen in Figure 17 is the use of a patterned material as a reflection of these findings, which typically provided higher quality reconstruction results.

4. DATA HANDLING FOR RECONSTRUCTION

This project pursued methods that aid in creating an optimised workflow, increasing reconstruction efficiency, and maintaining reconstruction accuracy across subjects. Section 4.1 focuses on the consumer-ready software packages used during this project and presents a quantitative comparison of capabilities, as well as a qualitative side-by-side comparison of reconstruction results. Section 4.2 explains the process for scale, alignment and colour calibration,and finally, Section 4.3 briefly outlines an efficient method used for automated data management.

4.1. Software Capabilities and Configuration

This project relied on existing software solutions for processing the image data and computing the resulting meshes. Two of these solutions, Reality Capture and Agisoft Photoscan (“Photoscan”), were compared for quantitative and qualitative analysis. Both were found to provide high-quality meshes, although Reality Capture generally appeared to more consistently solve camera correlation and extract more detail from the data at a higher speed. Table 2 contains some side by side results of reconstruction and alignment performance between software packages.

Table 2. Mesh processing performance comparison for Agisoft Photoscan and Reality Capture.

	Agisoft Photoscan		**Reality Capture**	
Cameras	**Matched**	**Time***	**Matched**	**Time**
21	18/21	00:05:47	19/21	00:05:16
21	21/21	00:10:39	21/21	00:06:14
21	21/21	00:08:41	21/21	00:07:34
21	21/21	00:08:13	21/21	00:07:24

The most noticeable difference between Reality Capture and Photoscan was the way interpolation was handled for floating points in the captured data. Generally, Reality Capture would attempt to ensure any 3D reconstruction was ‘watertight’, i.e. there are no holes in the resulting mesh. Photoscan, on the other hand, would leave holes visible. Figure 18 shows a comparison of qualitative reconstructions.

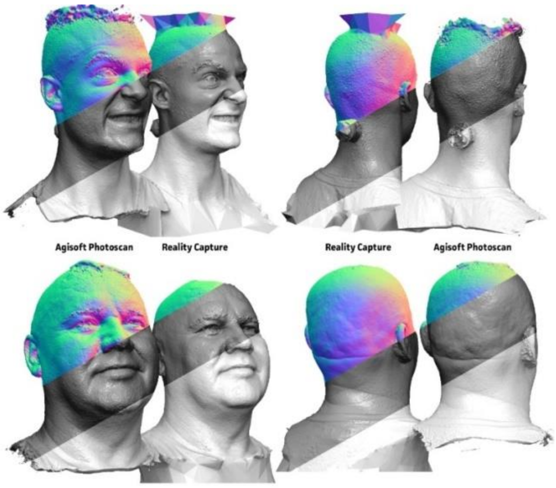

Figure 18 Qualitative comparison of results from side-by-side testing for Agisoft Photoscan and Reality Capture, rendered using different materials to highlight surface details.

4.2. Image Processing

Once captured, the images required some manual processing to ensure scale and colour correctness. Both software solutions had methods of saving some of these manual steps for reuse, which aided in processing efficiency and mesh consistency for later use.

4.2.1. Scale and Alignment

For the resulting mesh to be scaled and oriented correctly, points of a known distance and orientation needed defining in several images before processing. Reality Capture and Photoscan provided tools for this activity. A measuring tape was mounted to the previously mentioned stabilisation rod to give this visual reference for manual processing, as shown below in Figure 19.

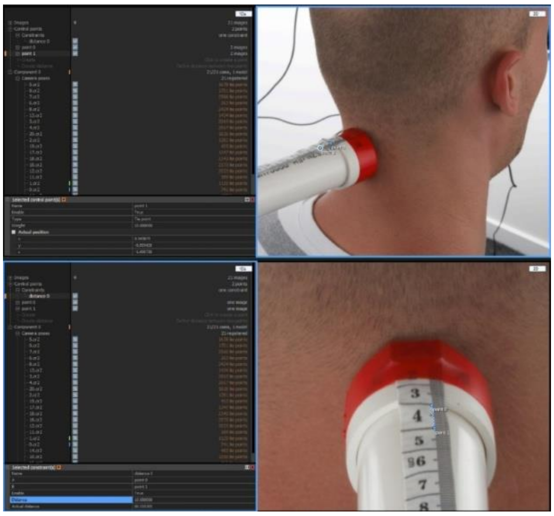

Figure 19. Manual alignment in Reality Capture using known distances for computation. Two points are defined, and a known range (10mm) is used to provide scale information.

Once this information is defined, the camera positions and reconstruction volume can then be solved with the correct orientation and scale with the real-world counterpart. The metadata for the camera positions, directions and other settings are then able to be exported for reuse with other scans using the same capture system. This step decreases the processing time and solves any previously misaligned cameras with greater accuracy.

4.2.2. Colour Calibration

Images were captured using Canon RAW (.CR2) format with manual white balance settings applied. Calibration of colours took place in Adobe Lightroom post-acquisition. At the beginning of each session, images were taken of the subject holding a colour chart. Using this card as a reference enabled the colour information to be corrected and the settings applied to all other session data. The before and after imagery is shown below in Figure 20.

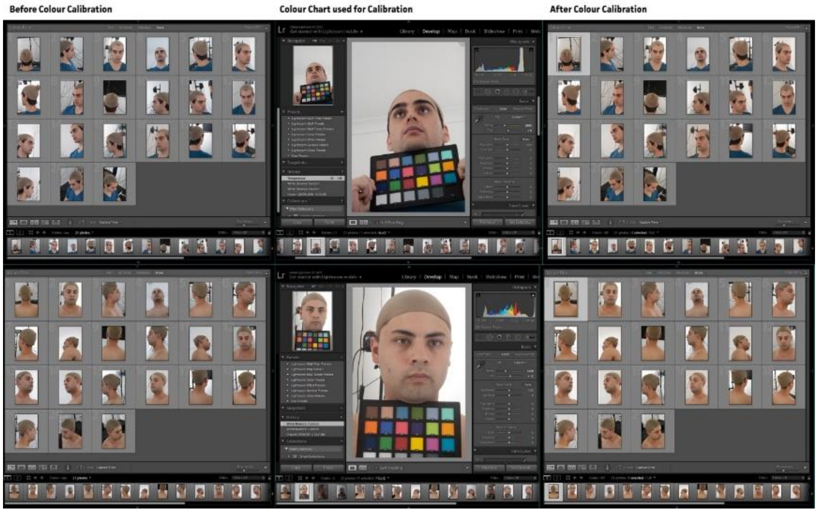

Figure 20. Before (left) calibration and after (right) using a colour chart (centre) as reference.

4.3. Data Workflow

Capturing images from 21 cameras for each session resulted in large volumes of data being stored and processed. Some key steps were taken to optimise the data workflow and maintain production efficiency. Using this workflow made it significantly easier to reuse the metadata mentioned in Section 4.2 and globally apply any calibrations as needed.

The reuse of metadata in Reality Capture relied on naming conventions to match cameras with resulting images. A similar constraint emerged when using some specific functions within Agisoft Photoscan. Mismatching filenames were found to be detrimental to 3D reconstruction due to misalignment of image data and camera positioning. Using the camera controlling software to maintain a stream of data from each camera during capture enabled this problem to be overcome.Images were stored directly on a computer's hard drive for later use, using an automated file hierarchy and naming convention, which is shown below in Figure21.

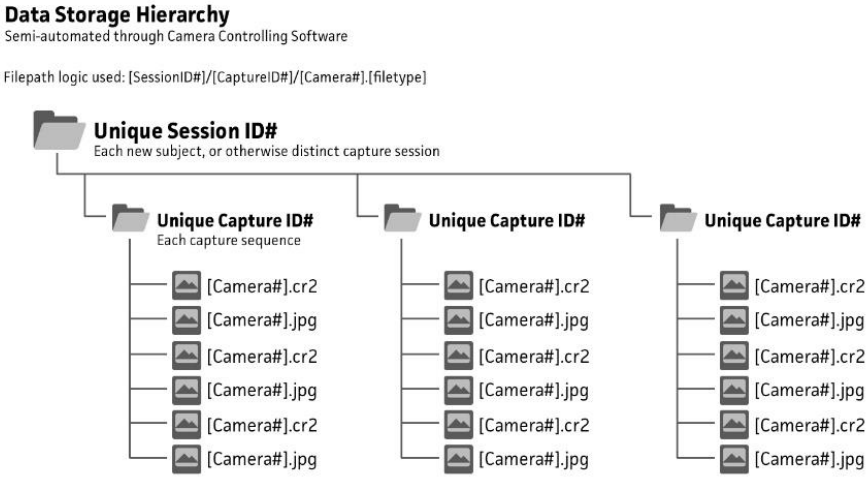

Figure 21. The automated data storage hierarchy, determined by file path logic set in the camera controlling software.

5. DISCUSSION& OUTCOMES

5.1. Recommendations based on Findings

This project examinedseveral key aspects that influence the overall efficiency and resulting reconstruction quality of a scale photogrammetry system across three distinctively different configurations. Based on these specific examinations, the highest quality, and most robust system architecture and process were found in Build 3. On this basis, the recommended architecture for a scale, foundational human photogrammetry system consists of:

- A multi-camera array with shutters synchronised using custom or dedicated hardware;
- Powerful strobe flash lighting for even, instantaneous illumination of the subject;
- A 2-second long shutter exposure in a dark environment to eliminate synchronisation issues;
- Cameras positioned in pairs around the subject, keeping the subject in the frame;
- A device for stabilising subject positioning, with a height-adjustable seat or platform;
- The use of a colour card or reference for colour correction;
- A measuring device, or scale bar for calibration; and
- An automated data synchronisation process between the cameras and controlling computer.

A diagram of this system architecture and process is depicted below in Figure 22. This architecture takes advantage of the methods found to produce the highest quality resultsthroughout this project.

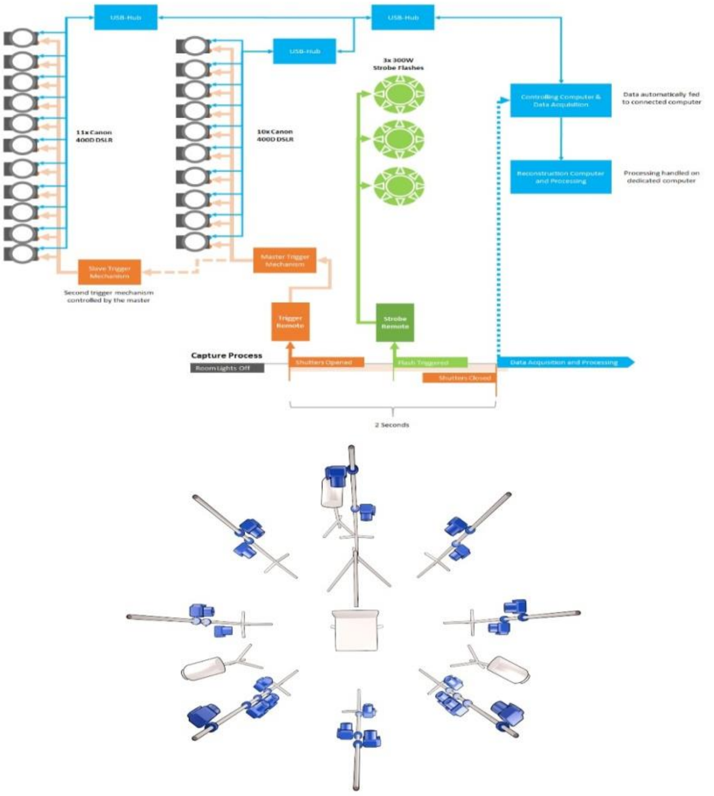

Figure 22. Recommended system architecture (top) and layout (bottom). A timeline for the capture process is depicted with the architecture, linking particular events into the system architecture to display the procedural flow.

These recommendations are the culmination of numerous iterations of configurations, capture techniques, and hardware arrangements. Below, Figure 23 illustrates a quality growth in 3D reconstructions gathered from the initial system version, through to the final configuration of Build 3 during the project.

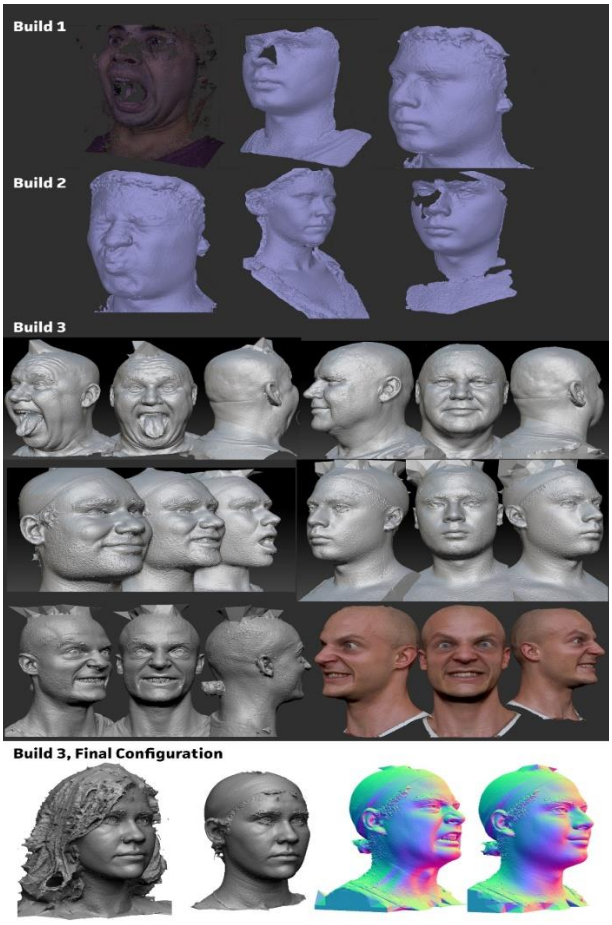

Figure 23. A collection of 3D reconstructions gathered throughout the project, illustrating the growth in quality and system capability over time.

5.2. Limitations

The hardware used in this project was typically low-end or dated. For example, the 21 Canon 400D DSLRs were a set of decommissioned hire-cameras that were nine years old at the time of this writing. It would be a reasonable expectation that newer hardware would possess higher image capturing capabilities. As such, the drawbacks of using continuous lighting presented in this work may not be as severe for practitioners using newer, or higher-end camera solutions.
Additionally, although this work recommends the use of strobe lighting for high-quality capture, it should be noted that more advanced approaches to system architecture and image capture are practised using continuous lighting. For example, practitioners at ICT Graphics Lab utilise custom hardware, and high intensity LED light to capture their subjects in phenomenal detail. However, the required knowledge and resource requirements for such a system deemed the approach out-of-scope for this project.

The camera positioning used in Build 3 meant some typically occluded areas of subjects remained challenging to capture, such as behind the ears or inside the nostrils.A reduction in occlusion occurs by increasing subject coverage with additional cameras. Unfortunately, other cameras were not available for this research, but the missing sections were considered to be low-impact quality losses and could be corrected in modelling software after the reconstruction process completes.

USB connectivity issues caused by a limitation on the maximum number of supported devices on the computer’s USB bus were a significant challenge that would prove more challenging to overcome as the system scales to a full-body system. Godse [28]states the upper limit should be 127, minus any number of device hubs used, which is consistent with the approachof Ten24 [9], and Infinite Realities [29]where they mention the use of 2 controlling computers in their architecture due to the high volume of devices; this is significant for any practice that scales beyond the findings in this research.

6. CONCLUSION

6.1. Summary of Outcomes

This project aimed to address the gap in available knowledge regarding the foundational practices and design considerations for the construction of human photogrammetry systems.A design-led approachwas adopted to analyse the existing solutions and techniques of leading practitioners and todesign a scale, 21-camera human photogrammetry system. Several iterative design cycles were used to build the final photogrammetry system. Throughout these iterations, varied capture techniques were examined and tested in the pursuit of reaching a compromise between image quality and resource availability.

An architecture for a scale, human photogrammetry system is presented alongside a simple processing workflow for practitioners. The given architecture includes specific details on system connectivity, capture procedures and arrangement patterns for equipment – including diagrams of positional pairing layouts for other practitioners. The architecture and recommendations made are grounded in the analytical findings from existing practice and results from the activities in this project.By condensing these findings into a succinct architecture and design pattern, future practitioners now have a foundational blueprint for building a basic human photogrammetry system – lowering the knowledge requirements to get started in the field.

6.2. Future Research Opportunities

As an extension of the work conducted throughout this project, two critical opportunities for future research have emerged.Firstly, as this project has been done using a scale system, the next step is to extend these findings and apply them to a full-body system. As an ongoing research project, this hasalready presented new challenges as the system and capture complexity increases. Creative Work C involved an artistic process for preparing the 3D reconstructions for animation and posing, which was beyond the scope of this project. Developing a clearer understanding of the methods and techniques of taking the reconstructed data from this system to a usable state may be grounds for further research -for instance, explicitly examining the process of preparing resulting assets for performance capture and representation as a digital double.

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