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3D scan process optimisation study for rapid virtualization.

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Abstract

Introduction – Many of the problems facing 3d scanning as a digitisation method around the human form are caused by the time it takes to scan the entity. This can be solved by using multiple cameras organised in a way to scan the extremity simultaneously from multiple directions. This paper is the exploration around the minimum number of cameras needed to obtain a usable model.
Methodology – Using a 5-stage experimental process for 17 subjects and batch processing each stage, determined the most efficient workflow.
Results – Excluding the exploration subject, it was found that the use of 4 cameras simultaneously was 5.5 times faster, including processing time then it was to use a single camera.
Conclusion – using multiple cameras makes the process 5.5 times faster, as well as batch processing, and having a standardised method to enable the use of algorithmic file processing.

Keywords: 3D Scanning; Process Optimisation; Virtualization;

1. Introduction

Our goal is to build a scanner for upper limbs orthoses to be manufactured using Additive Manufacturing methods. This system will provide a balance between time and quality, focusing on the sensitivity of the convergence between the two for a underpinning step in the design cycle.

We aim to speed up the design process for these orthoses, and reduce the complexity in obtaining the data so the system can be implemented in a clinical setting. The emphasis is to enable the use of technology that is normally used in manufacturing processes to easily create models that can reduce the time taken to provide a better outcome for the patient.

This study was conducted over 5 stages, each one with a review in between to ensure processes were being optimised before going on to the next. The break-down is as follows,

- Step 1 - process exploration – method design
- Steps 1-3 - single camera
- Steps 4-8 - two cameras
- Steps 9-13 - three cameras
- Steps 14-16 - four cameras

One problem during 3d scanning operations is the time it takes to scan an object in a 360° view[1]. This paper targets the scan accuracy with the goal of balancing the required accuracies during the available time.

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1.1. Objective.

We conducted a series of experiments to comparatively study multiple image file preparation methods, scanning procedures and software programs to design a process with the best qualitative result. The investigation focused on time and ease-of-use, with the goal to build a procedural algorithm to automate the process in further works. We expand on this by analysing the convergence between processing power, setup time, scan time and quality of output. Using this we can obtain an optimised result for current methods that will be independent of the level of technology used.

1.2. Background

The 3D scanner used for the virtualization was a custom built rig using up to 4 Microsoft Kinect cameras to obtain a 360° image. Our goal was to have the scan completed within 5 seconds, thus minimizing error caused by the subject moving.

The Kinect camera was chosen because it was an inexpensive and relatively straightforward camera to adapt for this study[2-5]. It is also able to be used in a simultaneous multiple camera format [6-8].

The reason to use of multiple camera's:

- Sensitivity – more pixels used in the images [9]
- Time reduction – no need to move the camera
- Accuracy – all images registered simultaneously [10, 11]

This process included the use of the software packages

- Kscan3D
- Materialise 3-Matic STL 10
- Materialise Magics

2. Method

The scanning workflow is segmented into four sections, Scanning, Scan Processing, File Processing, and File manipulation. These sections represent the different areas that are being assessed in the experiment. Quality checks were performed at both the completion of the scanning and the final model after it had been manipulated. This was done to ensure the standard was met during experiment.

2.1. Scanning.

To assess the validity of building a system that contains multiple cameras, there must be evidence that it is worthwhile. This will include assessing the time and quality associated with using a singular camera, up to four cameras simultaneously.

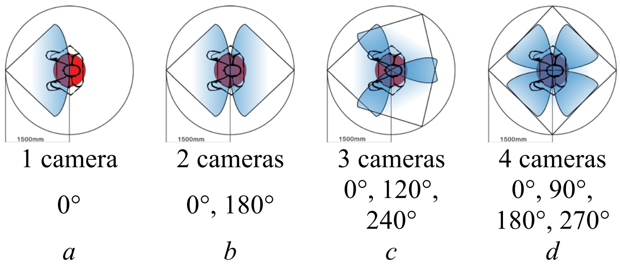

Fig. 1. Visual representation of camera field of view in the vertical plane

For the scanning system, a small stool was used, with the camera set at the middle height of the object, approximately 1500-2000mm away. The object was then rotated a full 360° ensuring that the scanning plane was kept at the same level to minimize aberrations caused by camera movement.

2.2. Single camera

Shown in Fig. 1.a the camera sensor was placed directly in front of the subject (0°), at approximately the center in the z direction (shown in Fig 2a). The subject was then rotated around the number of times listed in the results; this was done as consistently as possible.

2.3. Two cameras

The same method was used as for one camera apart from two cameras placed at (0°, 180°). at approximately the center of the object in the z direction (shown in Fig. 2.b).

2.4. Three cameras

The same method was used with cameras placed at (0°, 120°, 240°).

2.5. Four cameras

The same method was used with cameras placed at (0°, 90°, 180°, 270°). The number of position changes was reduced to 0 to test the accuracy of the system and to minimize the time taken.

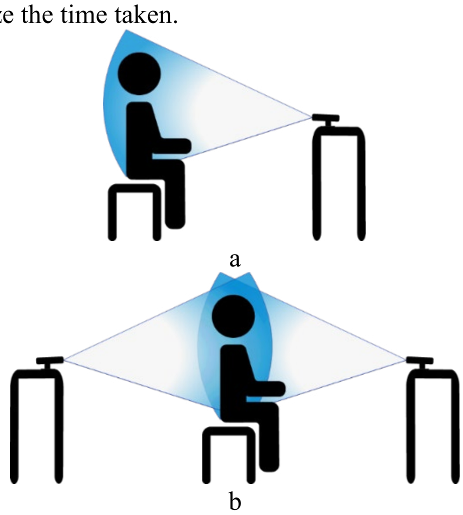

Fig 2. Visual representation of camera field of view in the horizontal plane

2.6. Scan Processing.

The Scanning was performed using the Kscan3D software that is an open source program that works with the Microsoft Kinect cameras. It also allows the use of multiple Kinect cameras, if the computer has enough bandwidth through the connection ports.

The scan process was mainly an alignment of the individual scan images and then join and decimate the other sections. As this was initially done manually because of the variations in the lighting inconsistencies.

As the tones of the subjects where relatively variable, it made the stitching together of scan images of varied difficulty using the automated alignment tool in kscan3D. This was due to the fall-off of the scan images as well as their texture maps at the edges of the images. It was found that a repetitive texture on the subject worked the best for a fine alignment using the tool. However this made the macro level alignment confusing at times and unless it was very close to final location in the virtual world, it would reposition the scan image incorrectly, requiring an initial manual alignment, the result is shown in Fig 3.

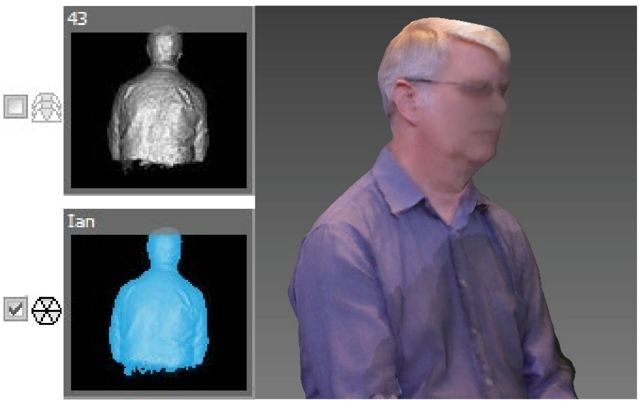

Fig. 3. Aligned scans

2.7. File processing.

File processing was done in Materialise's Magics program to ensure the models there solid without errors or holes.

2.8. File manipulation.

File Manipulation was completed in Materialise's 3-Matic STL program. This was used because it allowed for a secondary file quality check as well as a more familiar Boolean and scaling method. The goal was to be able to build a method that could be written into an algorithm for the process to be automated using macros that have been developed by Materialise.

3. Results & Discussion

For a scan to be classed as 'usable' it had to be within 5% tolerance of dimensional accuracy, between the virtual and physical models. Because of this, there was a variance in the number of scans on each of the subjects. The 5% allowable tolerance has been used to reduce the time and will be addressed in future work. Below (Table 1.) are the results from the scans obtained for this study. The overall time includes the file processing and manipulation times, that have been excluded from this paper. However the time variances in the overall in this instance are looking at the ease-of-use of the scan data.

Table 1. Scan time by subject

Subject	Number of cameras	Number or scans	Scan time	Scan process time	Overall time
S1	1	9	5.00	25	55.00
1	1	12	4.50	20	49.50
2	1	10	4.00	22	46.00
3	1	9	3.50	15	33.50
4	2	12	3.00	15	33.00
5	2	10	2.00	12	26.00
6	2	6	1.00	10	22.00
7	2	8	1.75	12	23.75
8	2	8	2.00	10	21.00
9	3	9	1.50	7	17.50
10	3	6	1.00	4	10.00
11	3	6	0.75	3	8.75
12	3	12	0.75	6	11.75
13	3	9	0.50	5	9.50
14	4	12	2.00	6	11.00
15	4	8	0.25	5	8.25
16	4	4	0.08	2	5.08

If we create a trend line using a polynomial second order equation, we have the following procedure.

A second order polynomial was used to simplify the equation. Although it was possible to have a higher R^2 value with an equation of a higher order, it was decided that a second order was accurate enough with the minimal R^2 being 0.8841 in the scan time trend line, This is in part due to a longer time taken in subject 14, in which the time was very far out of trend.

Scan time - $R^2 = 0.884$

$$y = 0.0211x^2 - 0.6481x + 5.5876 \tag{1}$$

Scan Process time - $R^2 = 0.938$

$$y = 0.0917x^2 - 2.9132x + 27.118 \tag{2}$$

Overall Time - $R^2 = 0.974$

$$y = 0.2066x^2 - 6.6244x + 60.955 \tag{3}$$

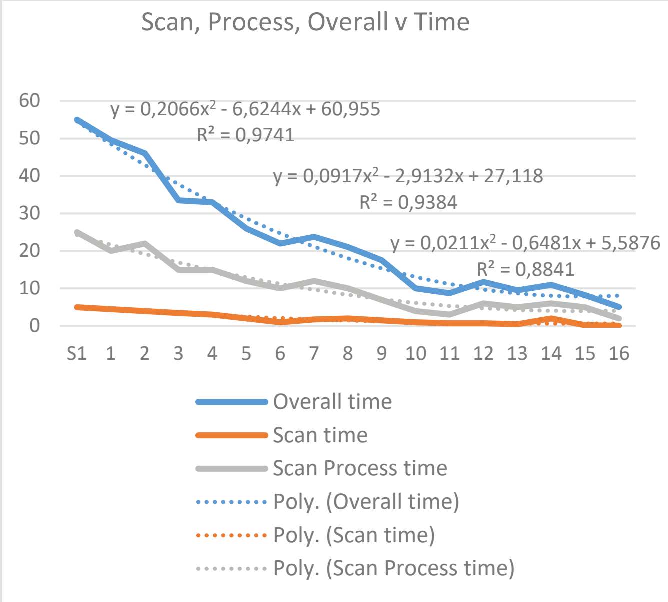

Fig. 4. Time variation and trend by subject

Taking this further, if we average out the results to the number of cameras that were used to scan the subjects and repeat the analysis, we get the following (Table 2).

Table 2. Scan time per number of cameras

Number of Cameras	Sample Number	Number or scans	Scan time	Scan process time	Overall time
1	1	9	5.00	25	55.00
2	1	12	4.50	20	49.50
3	1	9	3.50	15	33.50
4	4	4	0.08	2	5.08

Note that the timing for this sample had an outlier (Subject 14, Table 1.) that slowed down the timing significantly, however as this is the case in real life as well, the subject has not been omitted from the results.

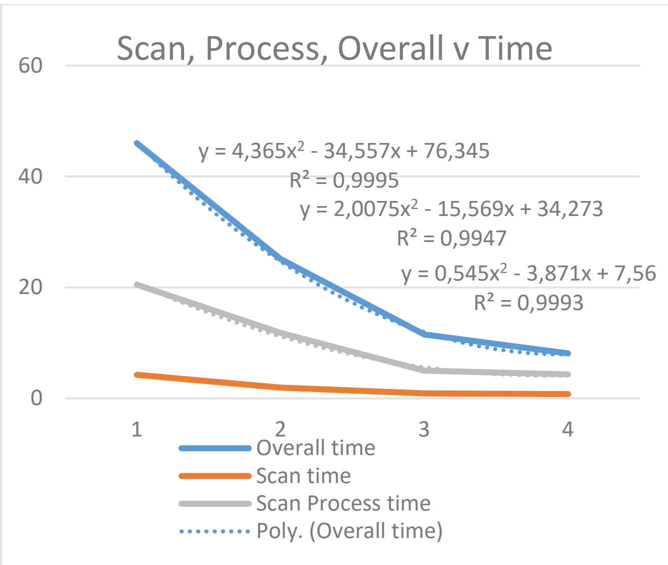

Fig. 5. Time variation and trend by number of cameras

Using the same method, we have created a polynomial trendline (Fig. 5.) to compare to the raw data.

Note: by including the outliers we are building a tolerance into the equations to ensure the study is repeatable in the future.

Scan time – $R^2 = 0.9993$

$$y = 0.545x^2 - 3.871x + 7.56 \tag{4}$$

Scan Process time – $R^2 = 0.9947$

$$y = 2.0075x^2 - 15.569x + 34.273 \tag{5}$$

Overall time – $R^2 = 0.9995$

$$y = 4.365x^2 - 34.557x + 76.345 \tag{6}$$

From these you can see that we have a much higher R^2 when we take the trend of the averages. This is to be expected because there are less data points, and this ensures the trends that we are seeing are less impacted by outliers, shown in Fig. 6.

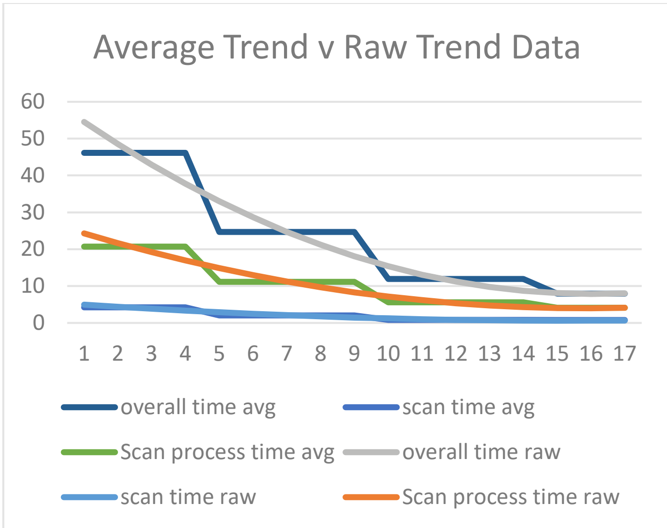

Fig. 6. Trend fit by subject and number of cameras

The steps shown in Fig. 6. are the average values that are calculated by the number of cameras, not of the samples. So, the graph above is showing the average time per camera against the trend calculated from the raw data obtained.

Overall, we have an efficiency of 5.5 times, i.e. using 4 cameras was 5.5 times faster than using one.

We can calculate the estimated time it will take for each section of the process by using the raw data regression and using that as the high and low values for each of the camera numbers.

Using 1 camera will take you between 3.50-5 mins to scan an object. Processing the scans to a useable file will take between 15-25 mins. With a 4-camera system it will take on average 25-40 seconds, and 3.3-4.15 mins respectively.

Incorporating a variational tolerance in the setup time allows the model to be accurate within an implied percentage of change, this will remain true up until the processing stages as the variance in the scan numbers will be larger then what is experienced in the scan and setup stage. i.e. If there is subject has a scan setup time that is outside of the tolerances, there will be a longer processing time experienced, as the image data will need more processing.

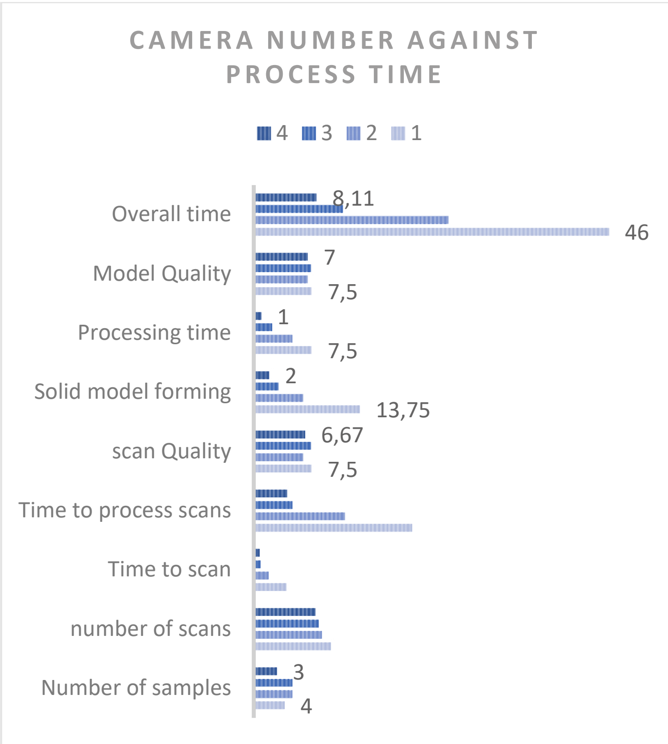

Fig. 7. Camera number against individual process time

The bar graph above (Fig. 7) is a visual representation that shows the slowest stage was the time to process the scan data and that this can be minimised by using multiple cameras. There is also a large decrease when there is an overlap of the 3D images obtained by the cameras, (shown by the large reduction in the scan process time from 2 to 3 cameras).

3.1. Process percentage breakdown

From Table 3. we can see that the slowest component of the process is the time spent processing the scan files.

Table 3. Percentage breakdown of process time by subject

Subject	Number of cameras	Number or scans	Scan time	Scan process time	Overall time
S1	1	9	9%	45%	55.00
1	1	12	9%	40%	49.50
2	1	10	9%	48%	46.00
3	1	9	10%	45%	33.50
4	2	12	9%	45%	33.00
5	2	10	8%	46%	26.00
6	2	6	5%	45%	22.00
7	2	8	7%	51%	23.75
8	2	8	10%	48%	21.00
9	3	9	9%	40%	17.50
10	3	6	10%	40%	10.00
11	3	6	9%	34%	8.75
12	3	12	6%	51%	11.75
13	3	9	5%	53%	9.50
14	4	12	18%	55%	11.00
15	4	8	3%	61%	8.25
16	4	4	2%	39%	5.08
AVG			8%	46%	

The file Processing time has been excluded from the results, as this is outside of the scope of this publication and would exceed the page limit.

This is where future work will be to automate the process to reduce the time component, as well as increase accuracy. Machine learning techniques will be used to ensure the accuracy of the scan model and reduce manual inputs before modelling is completed on the virtual model of the subject.

4. Conclusion

We have shown that 3D scanning and file processing is a prime candidate for automated design and automated file processing using machine learning for automating. As this addresses two of the largest barriers of the technology becoming a mainstream process, this will become the next stage of this project. Based on the results, using a second power polynomial, we can predict the quality of a scan, by the extrapolation of accuracy and time.

Regarding the time, we can see from the data, that the workability of the file is not governed by the number of images obtained as much as it is by the variation in the set up time and the time taken to obtain the scan data. This however can increase the complexity of the processing needed and reduce accuracy.

5. Future Work

Future work in this project will look at automation of the processes using the perameters obtained in this study, thus decreasing the complexity of creating custom additively manufactured upper limb orthoses. Other applications of the automation of the process will be looking at the rapid virtualization of physical forms in a verity of applications.

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