AUTOMATION IN VIDEOGRAMMETRY

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ABSTRACT

In the last few years the automation of digital industrial photogrammetric systems has increased dramatically. Due to advancements in digital image processing software, coded targets and auto-correlating methods, a large number of photogrammetric measurement tasks can now be fully automated. In many cases a "one button click" is enough to provide 3D-coordinates of measurement points without any manual interaction, as soon as digital images are acquired. The evolving technology of intelligent cameras is the next logical step towards automated photogrammetric measurements. An intelligent camera containing an integrated computer can process the image immediately after it is taken. The technology provides not only a much shorter processing time for the images but also more control over the measurement process precisely at that time when it is needed most, namely during image acquisition. This is taking place in the form of real time feedback from the camera itself. This paper describes the role of a digital intelligent camera in the automation of an industrial photogrammetric measurement system and gives an overview of existing automation techniques in industrial photogrammetry. As an example of an intelligent camera, the performance of the new digital intelligent camera INCA, developed and manufactured by Geodetic Services Inc. will be described through reference to a number of example measurement applications.

1. INTRODUCTION

Close range digital photogrammetry, which is also termed vision metrology or videogrammetry, has been successfully applied in a variety of metrology applications for a significant period of time. The principles of such systems are well known (Fraser and Shortis, 1995) and they have gained widespread acceptance for industrial measurement applications (Ganci and Shortis, 1995a;b).

Initially digital photogrammetric equipment and techniques were not sophisticated enough to match the accuracy attainable through the use of other metrology systems such as theodolites, laser trackers and more traditional film-based photogrammetry systems (Shortis, and Fraser, C. S. 1991). Fortunately developments in large area CCD sensors and target image location algorithms have pushed the accuracy attainable using digital photogrammetry to a level where it can comfortably challenge these systems. (Gustafson and Handley, 1992) (Ganci and Shortis, 1996). In a modern vision metrology system for industrial measurement, object space positional accuracies surpassing 1:100,000 of the principal dimension of the object are now routinely attainable with large-area CCD cameras and photogrammetric data processing (Fraser et al., 1995). High-resolution digital cameras, such as the Kodak MegaPlus 6.3 with a sensor array of 3000 x 2000 pixels, are readily available and represent a significant improvement over earlier generations of CCD cameras.

The general thrust in industry has been to develop sensor technology and computing facilities capable of supplanting film-based systems whilst challenging other metrology systems. The push to replace film systems has been largely successful with all but a few traditional high accuracy users still using film systems. It is interesting to note that many of these users are using the video systems to provide initial “drive-back” for their film-based counterparts.

As with most technological developments the initial development drive has come from the academic and industry research sectors where the measurement accuracy envelope is continually being stretched. However, users of vision metrology systems, who are usually relatively untrained in the technology represent the largest sector of the close range videogrammetry market. Meeting the practical commercial needs of these users is the responsibility of vision metrology system manufacturers and vendors, whose primary objective is to develop the available technology to a point where it can be offered as a fast, robust, accurate and ultimately useful off-the-shelf measurement tool. The transition between the laboratory and industrial work place is often difficult due not only to the change in environment, but also to the transition from highly trained to relatively untrained operations personnel. The ultimate goal of system automation is to make videogrammetry as simple as possible for largely untrained practitioners.

The pace of technological change is relentless. Often due to considerable product development costs and risk, it is difficult to simply supplant existing product components with new and improved components. Within a research environment it is obviously far easier to embrace technological advances. For example, replacing a sensor in a commercial system may take 6-12 months due to the potential commercial repercussions associated with such a change. Manufacturers also face the challenge of finding the middle ground between rapid full-scale development and proven product reliability.

It is obvious that videogrammetry system developers would choose to adopt the goal of manufacturing a system that is as automated as possible. The reduction of processing time and significant simplification of the user interface are two of the main advantages of automation. Another less obvious advantage is the effect automation has in widening the potential user base of videogrammetry. Automating many of the operational aspects significantly reduces the requirement for the system operator to possess photogrammetric expertise. The videogrammetry user base will thus increase as the level of system automation increases.

The automated videogrammetry process should commence with the camera and end not with the extracted XYZ coordinates but rather with the dimensional data required by the user. This distinction is very important as often the user is not interested in the extracted data per se, but rather the 'information' that the data represents in terms of key geometric characteristics such as planes, distances and surfaces, or perhaps the 'goodness of fit' to an existing data set. This is yet another area where automation is applicable.

This paper reports on the process of automation in videogrammetry from the initial photography to the final dimensional analysis. To better illustrate the potential of automation in industry, two case studies are considered. In each videogrammetry measurement case the image data was first processed using very limited automation, and then processed employing full automation. The V-STARS vision metrology system from Geodetic Services, Inc.(GSI) was employed for the test measurements. Prior to reporting on the results of the case studies, significant recent innovations in automation of vision metrology systems will be reviewed.

2. SYSTEM AUTOMATION

2.1 Intelligent Cameras

Commercially available digital cameras of the price and performance suitable for close-range photogrammetry fall into two basic categories: Those with proprietary interfaces that require special frame grabber hardware for acquiring the imagery and those with self contained storage capability. The former is useful for on-line triangulation (Edmundson and Fraser, 1998) where immediate data acquisition is needed for real-time processing. These systems require a desktop computer in order to house the frame grabber hardware. The most notable examples of camera systems in this category are the MegaPlus line of digital cameras from Kodak. The MegaPlus is very suitable for digital photogrammetry based on price and performance, however, due to the need to be connected to a computer for data acquisition, these camera systems are not very suitable for hand-held off-line use. This camera also lacks any form of onboard storage capability.

The second class of camera system has self-contained data storage (usually in the form of a removable PC card hard disk) and is appropriate for conventional off-line use. In this mode of operation images are taken from different viewing angles of the object being measured. As they are taken, the images are stored on the camera's removable hard disk. When the photography is complete, the removable hard disk is transferred to a computer system for processing. The Kodak DCS420 and DCS460 are perhaps the most popular examples of this type of still video camera. The disadvantages of such systems are that they are not suitable for on-line work and lack the structural integrity to absolutely ensure calibration stability between images (Shortis and Ganci, 1997).

Although it is true that some of these off-line camera systems also have on-line connection capability, this is usually in the form of a serial or SCSI interface that does not offer enough bandwidth to transmit the data for real-time use. A camera system that would truly satisfy the needs for on-line and off-line use in photogrammetry should have not only a self-contained storage capability, but also the ability to work in an on-line mode at data rates suitable for real-time operation. The obvious solution is a hybrid camera that utilises a true metrology sensor as a base and integrates storage and network components to increase its functionality. This camera would have the flexibility of a hand-held unit whilst retaining the robustness and reliability of the MegaPlus. The GSI INCA (Geodetic Services Inc., 1996) is the first commercial example of this type of camera.

Up until only recently, automation of the camera had been largely been overlooked by the photogrammetric community. This was perhaps due not only to the difficulty in manufacturing such a camera, but also to the associated cost of development. To implement some level of automation within a camera it is necessary to incorporate an additional processor or low level PC. Cameras with this type of processor, as exemplified by the INCA 6.3 camera shown in Figure 1, are sometimes referred to as intelligent cameras. The on-board PC is responsible for a variety of functions including image compression, automatic exposure setting and image measurement feedback. These features can significantly reduce the photographic burden on the user. Future systems will no doubt be more sophisticated and incorporate network analysis and on-line results verification, features which will assist the operator in assessing whether all the requirements of the project have been met prior to leaving the site. The potential advantages are therefore very significant given the tremendous cost of down-time in the type of industries that utilise high accuracy vision metrology equipment.

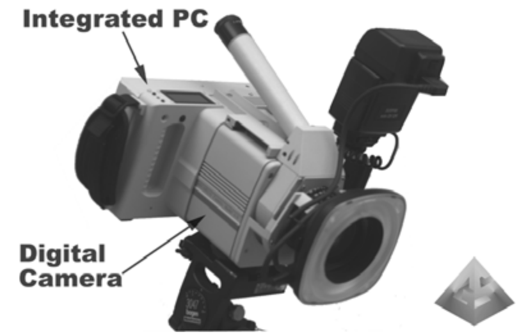


Figure 1. Image showing MegaPlus 6.3 with integrated PC back. This INtelligent CAmera is known as the INCA.

2.2 Software

Advances in automation in system software are clearly central to the goal of achieving a fully automated system. Automation software can be broadly defined into two categories. The first variety is designed to relieve the user of many of the functions associated with image processing and reduction, whilst the second makes decisions for the user.

Three common repetitive functions that are easily automated are the processes of line following, driveback and exterior orientation determination. The use of uniformly spaced retro-reflective target strips within industry is commonplace. This is especially the case in the antenna and aerospace fields. In order to simplify the labeling or re-labeling process it is possible to use two points at the start of a strip to define the separation and direction of the subsequent strip targets. With each subsequent target measured the direction of the line is recomputed and the search patch modified. The process terminates when no target is found in the reference patch. From a practical point of view, strip targets are measured instantaneously.

Another feature easily implemented is a process known as driveback. Once an approximate camera location has been established through space resection it is possible to compute the initial target xy locations in the image space. These xy locations are used in combination with a search patch. If a target is found within this search window then it is measured. If no target is found then the point is skipped in that image.

Determining the exterior orientation of an image in an automated fashion is considerably more difficult to implement than line following or driveback. The orientation of an image is typically determined by identifying four or more points of known approximate XYZ coordinates. Once these have been identified, the camera exterior orientation can be computed using a closed-form space resection. To automate the space resection procedure it is necessary to use exterior orientation (EO) devices and/or coded targets. Examples of these are shown in Figures 2a and 2b. If either an EO device or coded targets are seen in any image they are identified and decoded, and if enough object points with approximately known 3D coordinates are available the exterior orientation can be completed.

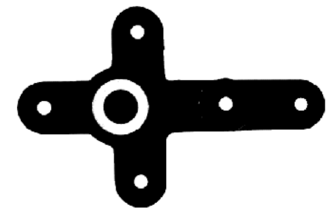


Figure 2a. Examples of an EO device (known as the AutoBar)

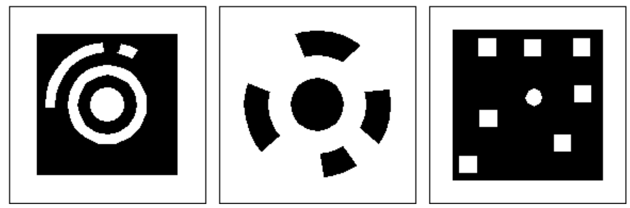


Figure 2b. Examples of coded targets.

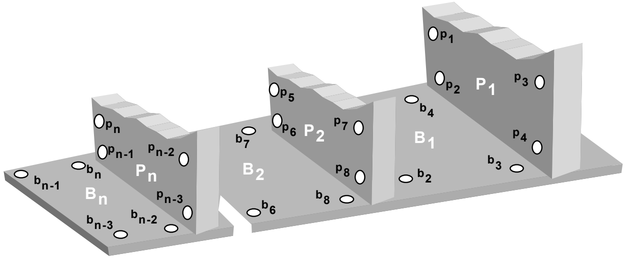
The second variety of automation feature, which is designed to alleviate the user of some of the decision making process, is more difficult to implement given the complex nature of decision making. The most common and time-consuming process is that of new point determination. To coordinate new points it is necessary to locate and label each and every unknown point in at least two images. Obviously this is a tedious process which is prone to operator error. To facilitate unambiguous labeling it is often necessary to introduce target identification labels.

To automate the coordination of target points it is first necessary to identify potential targets in each image. This identification process will also locate false targets such as overhead lights, flash hot spots or even return from discarded retro-reflective material. With these potential target locations it is possible to combine matching targets and derive an XYZ coordinate for each point that has been qualified as a valid target. In some cases false targets will be found but with appropriate checks it is possible to almost always identify and remove these errant points. This process is termed AutoMatching within the V-STARS system and as the case studies will show, it is a very powerful automation tool in vision metrology.

Yet another powerful automation tool is that of the construction template or macro. Construction templates can be utilised to complete all manner of repeated analysis. As an example, consider the situation in Figure 3 where the perpendicularity of two planes is required. To solve this problem it is first necessary to determine the location of at least three points on each plane (four for redundancy), fit planes to the data and then compute the intersection angles between the planes. This is a fairly simple piece of analysis and might only take a few minutes to complete. Now, consider the case where the same information is required for 100 planes. It is obvious that the remaining 99 will be solved in the same manner as the first.

A construction template would facilitate the automation of the remainder of this analysis. This makes it possible to extend the "one button" notion for photogrammetric triangulation all the way to the final 3D coordinate analysis phase. The emergence of construction templates will bridge the gap between simple

XYZ data and meaningful dimensions. It will also facilitate the introduction of real-time or quasi real-time measurement analysis in production facilities



$p_1\, p_2\, p_3\, p_4 \rightarrow P_1$
$b_1\, b_2\, b_3\, b_4 \rightarrow B_1$
$P_1\, B_1 \rightarrow \alpha_1$

$p_5\, p_6\, p_7\, p_8 \rightarrow P_2$
$b_5\, b_6\, b_7\, b_8 \rightarrow B_2$
$P_2\, B_2 \rightarrow \alpha_2$

:
:

$p_n\, p_{n-1}\, p_{n-2}\, p_{n-3} \rightarrow P_n$
$b_n\, b_{n-1}\, b_{n-2}\, b_{n-3} \rightarrow B_n$
$P_n\, B_n \rightarrow \alpha_n$

Where p = vertical plane points
b = horizontal plane points
P = vertical plane
B = horizontal plane
α = angle of intersection between P & B

Figure 3: Example of construction templates.

3. CASE STUDIES

3.1 Overview

In order to quantify the advantages of automation, two case studies will be considered. The first involves a modest sized network whereas the second is more complex, requiring a large number of images. The data collected has been processed both manually and automatically. Driveback and line following are such common features in modern videogrammetry systems that these have been used in the manual case even though they are clearly automation features.

Each of the case studies was carried out using the following equipment:

Camera: GSI INCA 6.3 (3K x 2K sensor)
Storage: Viper 340Mb PCMCIA Hard Disk
Processor: Pentium 133Mhz laptop with 48Mb RAM
Software: GSI V-STARS/S

The analysis was carried out by recording the time taken to complete the following key functions:

Image Acquisition: The time taken to photograph the object and store the acquired images to disk. The difference between the automated and manual case is that image compression and preliminary measurement are employed in the automated case. Image compression reduces the amount of time required to write the data to disk.

Image Transfer: Image transfer involves the transfer of the acquired images from the PCMCIA disk to the local PC hard drive. In the automated case these are compressed images while in the manual case there is no image compression. The time difference develops due to the difference in image size. This step is optional given that videogrammetry software can typically access the image data directly from the PCMCIA disk. For archiving, it is necessary to transfer the images from the PCMCIA disk to long-term storage media.

Initial Exterior Orientation: The Initial EO is necessary to approximately locate the camera locations at the time of exposure. As mentioned earlier, in the automated case this is achieved through coded targets and/or an EO device. In the manual case this involves manually locating coordinated points.

Initial Bundle Adjustment: The objective of the Initial Bundle Adjustment in the automated case is the coordination of coded targets. This is based on the coordinate system established by the EO device (i.e. the AutoBar). In the manual case the bundle adjustment is used to triangulate points measured manually to facilitate driveback in subsequent images.

New Point Determination*:* In the automated case new points are determined through the use of a set of mathematical rules governing image point correspondences, which must be satisfied by AutoMatching. To determine a new point in a manual system it is necessary to label the point in at least two images in which the point is seen.

Final Bundle Adjustment: Once all the points have been measured in the image files they can be combined in the Final Bundle Adjustment to produce the XYZ position of each point. The time taken to complete this task will not vary between the automated and manual cases.

Point Renaming: In the automated case the points found are assigned arbitrary labels. If specific labels are required, then each point must be located and re-labeled. This only has to be completed in one image for each point. Re-labeling is not a requirement in the manual case as the points are assigned the correct labels at the time of initial measurement. The underlying need for labels in the manual case is driven by the fact that the user needs to establish point correspondence between images. In most cases the labels of the points are not important and the step of re-labeling can be bypassed. In the case of repeat measurements the new points need only be placed approximately and a label transformation can be utilised to automatically re-label points.

Clean up and 'Re-Bundle': In some instances, the AutoMatch will coordinate points that satisfy the prescribed mathematical rules, but are not actual target points. These points are typically easily identified and deleted. Once these points are eliminated it is best, but not necessary, to 'Re-Bundle'. The corresponding problem in the manual case involves incorrect identification of points in the two initial images. This problem will normally emerge prior to the Final Bundle process.

3.2 Case Study 1 – Small Antenna

The first case study involved the measurement of a relatively simple object, namely a small antenna with eight orientation targets, one AutoBar and 16 rows of strip targeting (272 points in all). The antenna and target configuration are shown in Figure 4.

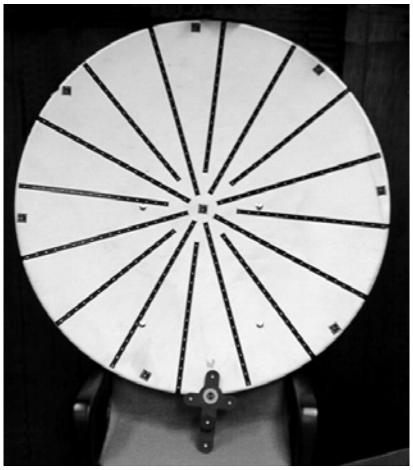


Figure 4. Antenna measured in the first case study.

The object was photographed and eight images were collected as shown in Figure 5.

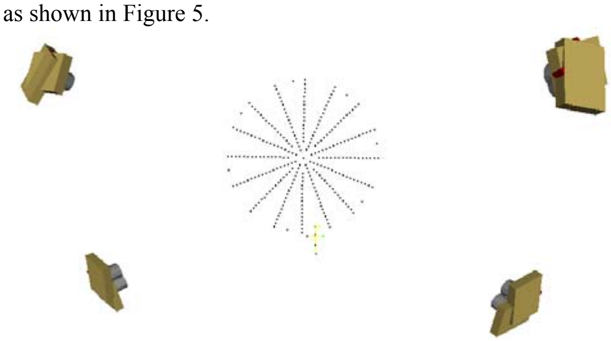


Figure 5. Network geometry for antenna measurement.

Four stations were used and the camera was rolled through 90 degrees at each of these stations. The images collected were processed both manually and with as much automation as possible. The times recorded in seconds for each of the steps described earlier are shown in Table 1 and represented graphically in Figure 6.

Table 1. Times recorded for each key component between Manual and Automated Case

Category	*Man(sec)*	*Auto(sec)*
Image Acquisition	180	30
Image Transfer	75	15
Initial EO	45	30
Initial Bundle	5	5
New Point Determination	270	15
Final Bundle	15	15
Point Renaming	0	135
Clean up and Re-Bundle	15	20
Total	**605**	**265**

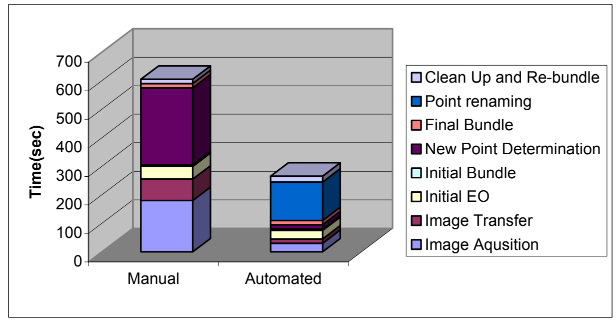


Figure 6. Graphical representation of times taken to complete each key component.

It is clear from the times listed in Table 1 that even in a small network there are considerable time savings. In this particular case automation led to a reduction in measurement time from 10 minutes to only 4 minutes. It should be noted that if no line following or drive back had been employed in the manual case then the time saving would have been considerably greater. The biggest savings were achieved at the stages of image acquisition and new point determination. The final point cloud for the antenna is shown in Figure 7.

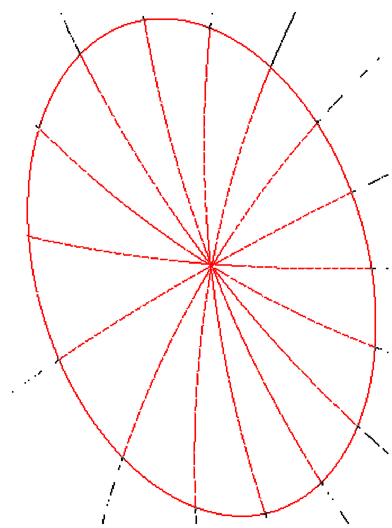


Figure 7. The final object point cloud for the antenna measurement.

3.3 Case Study 2 – Automotive Master Model

The second case study involved the measurement of a more complex object. The object selected was an automotive master model cubing block. The block consists of a number of parallel and perpendicular plates with component-securing points located in a grid. Each of the master model components are attached to the block in their prescribed locations. These components can then be checked against the CAD model that represents the particular vehicle. Production line parts can also be attached to the block to verify that production components meet design standards. The block consisted of five plates of interest. These plates were targeted with 83 coded targets, an AutoBar and 205 stick-on targets. The object is shown in Figure 8.

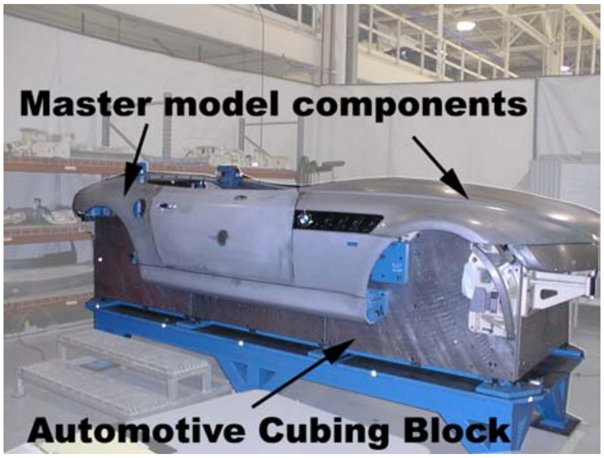


Figure 8: Cubing block used in second case study. Note that at this stage the master model was still in place.

A total of 71 images covering the 293 object points on the object were recorded from 45 camera stations, as indicated in Figure 9. Camera rolls were introduced at 26 stations. Once again the images collected were processed both manually and with as much automation as possible. The times recorded for each of the steps described in the overview are shown in Table 2, this time in minutes.

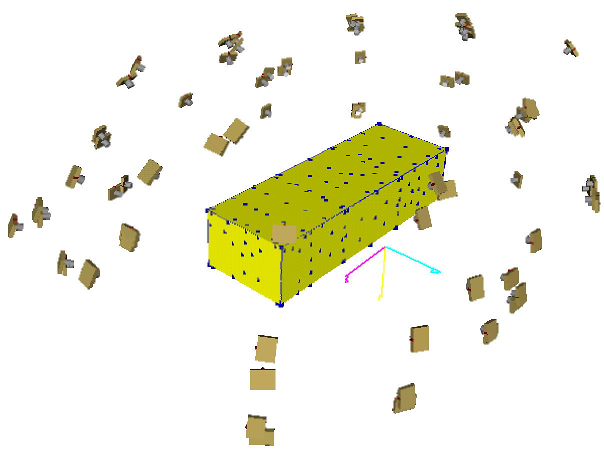


Figure 9. Image showing network geometry.

Table 2. Times recorded for each key component between Manual and Automated Case.

Category	*Manual(min)*	*Automated(min)*
Image Acquisition	30	6
Image Transfer	11	2.5
Initial EO	18	4.5
Initial Bundle	6	3
New Point Determination	124	2
Final Bundle	8	8
Point Renaming	0	32
Clean up and Re-Bundle	6	6
Total	**203**	**64**

These results are represented graphically in Figure 10. It is clear from the listed times in Table 2 that the timesaving is even greater for complicated measurement networks. In this particular case approximately 2.5 hours were saved. Once again, if no line following or drive back had been employed in the manual case then the time saving would have been far greater. Also, if there was no requirement for pre-determined point labels then a further 30 minutes could have been saved, reducing the overall time to just over 30 minutes. Figure 11 graphs the results in the case that no pre-defined labels were required. The biggest savings were achieved at the stages of image acquisition acquisition and new point determination. At the new point determination stage a time of 2 hours was saved.

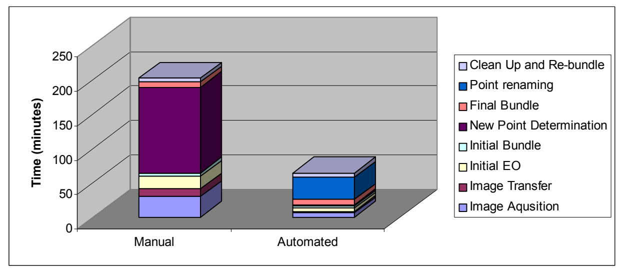


Figure 10. Graphical representation of times taken to complete each key measurement component in Case 2.

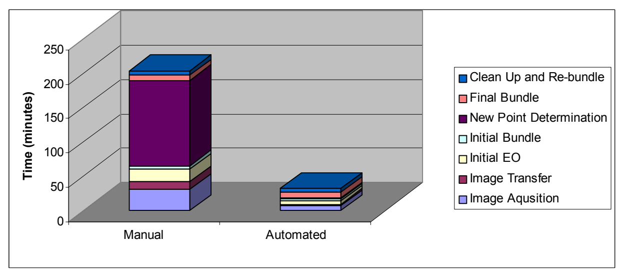


Figure 11. Graphical representation of times taken to complete each key component in Case 2, with no point re-labeling.

3.4 Evaluation

These case studies clearly indicate that there are significant advantages to be attained through an automated approach to Videogrammetry. In both instances the automated approach proved to be significantly faster. Perhaps the most remarkable outcome is the time discrepancy in the new-point determination of the second case study. The time difference between the manual and automated processes was two hours. Also of significance is the relative level of skill required to successfully complete the measurement. It is difficult to accurately quantify relative skill levels but it is obvious that the amount of skill required to successfully reduce a set of images manually is significantly higher than for automated processing.

4. CONCLUDING REMARKS

Videogrammetry has matured both on the hardware and software fronts. The introduction of intelligent cameras and improved software has had a considerable positive impact on the performance of commercially available vision metrology systems. These improvements have lead to a significant degree of system automation and this has helped widen the technology user base. The age of the "one button" approach to videogrammetry has clearly arrived.

5. ACKNOWLEDGEMENTS

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