TECHNICAL
D I M E N S I O N

Photogrammetry: A Flexible CMM

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Photogrammety – its place in the metrologists tool-kit

Photogrammetry systems can provide a similar functionality to a CMM over volumes (1-30m^3) not catered for by the measurement range of conventional CMMs (1m^3). Typical accuracies are in the range 10 to 100 microns per m^3.

The impact of photogrammetry on society has been greatest in the production of maps for military and civil uses. What is not commonly known is that photogrammetry has been widely and successfully used as an industrial measurement system for the past forty years. To understand its position in the Aerospace industry a Laser Tracker is typically purchased some ten times more often but it is still a relatively rare instrument in the UK compared to the conventional CMM. However, things are changing as the technique has some unique characteristics required for advanced manufacturing tasks. One of the key capabilities is to provide multiple measurement at one instant in time and for this process to be repeatable as often as 100 times per second. As a result a photogrammetry system can be used to measure deformation of structures under loading or provide guidance to robots for assembly operations. In many new applications the term *photogrammetry* is not even referred to and users take the technology for granted, for example in motion capture systems. In this article the capability of photogrammetric systems is explained and some practical applications are discussed.

Where photogrammetry systems are used

The list of uses to which photogrammetry system have been put is very wide, for instance: alignment tasks in shipbuilding, production of architectural models of buildings or facades, archaeology surveys, medical e.g. human body scans for back problem or gait analysis, missile or plane tracking, antenna measurement, checking aerospace manufacturing jigs, verification of the design of manufactured structures, virtual reality and entertainment.

How photogrammetry systems work – basic principles

A number of features are identified in one or more images. Sometimes naturally occurring features such as edges are used, but for high accuracy measurement strongly contrasting features such as: projected spots of light; self-illuminating targets (light emitting diodes); or retro-reflective targets are used. The method provides results with accuracy between 1 part in 5000 to 1 part in 100,000 of the largest dimension of the object being measured. It can be applied to objects ranging from a few millimetres to many metres in size. The main steps in the measurement process are illustrated in the following figure.

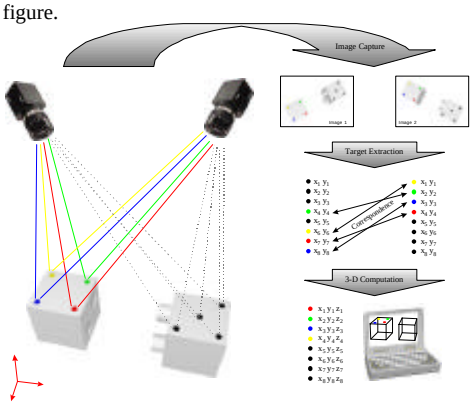


Illustration of the photogrammetric measuring process

To operate it is necessary to determine: where the cameras are and in which direction they are pointing; the camera specifications; some measurements in the object space to give scale; and a datum definition. This information may be collected as part of the measurement process, or as a series of steps e.g. camera calibration, physical set-up, and measurement. There are two methods of operation: single-camera, where the operator takes a number of images (typically between 5 and 100) of the object being measured from differing viewpoints; and multiple-camera, where typically 2 to 4 cameras are used.

Measurement capabilities

There are two main functional capabilities. The first is the measurement of the size and shape of a complete object – a structure such as an antenna, a gantry, or a jig, for example. The purpose of the measurements might be to check conformance to design or to record as-built dimensions. In some cases the structure might change shape and multiple measurements will reveal deformation or allow measurement of stress. The second functionality is to measure the relative orientation of one or more objects with respect to each other. In this situtation the measurement system could be used to report the location of components that require assembly or the position of a tool with respect to a workpiece.

The time required to perform measurements with a single camera off-line system will vary from job to job but in most cases the data capture time is relatively short and measured in minutes rather than hours. Processing of images and computation of results may take a few seconds to a few minutes. Analysis of collected data may take much longer. For the fastest multiple camera systems: image capture can take place in as little as 1/10,000 of a second and can be repeated as fast as 100 times per second. Processing of images to produce 3-D co-ordinates may take place on-line or off-line. For a system embedded in an application 3-D data production 25 times per second is feasible. However, systems using larger images will often be slower with measurement repeat rates of the order of seconds.

The accuracy obtained by photogrammetric systems is related to the number of pixels in the sensor and the size of the object e.g. a bigger sensor will produce more accurate results for the same size object. For a given camera, natural features such as edges produce the worst results due to apparent location changes with viewpoint, this is difficult to compensate for unless the environment is carefully controlled. Retro-reflective targets provide the highest accuracy as, when used with correct lighting, they are much brighter than even white objects and are largely position invariant to rotation. A typical professional system can produce 0.05 mm accuracy over a 5 metre object.

Limitations

The primary limitations are:

- ***geometry,*** clear lines of sight are required to each camera, when more than one is used these will usually occupy a large volume compared with the object being measured,
- ***set up,*** before measurement can take place the system must be initialised and if necessary cameras calibrated prior to use,
- ***complexity,*** these systems have many degrees of freedom and a reasonable level of expertise is needed to get the best results, and
- ***cost,*** there are few off-the-shelf systems so the expense can be high. Typical commercial systems cost in the range £30,000 to £250,000.

When to use a photogrammetric system?

It used to be said that the time to use a photogrammetric system is when you cannot use anything else. This is no longer entirely true, but photogrammetry still has a reputation for being difficult to use. This is partly due to one of its chief advantages which is the flexibility to configure it in many different ways and partly due to software which involves least squares estimation and statistics. However, large improvements have being made as software is made more user friendly, computing power increases, high resolution digital cameras replace analogue cameras, and coded targets are used to make setting up easier. Photogrammetric system should be considered when the particular benefits of a self-checking, high-accuracy, high-speed, multiple-point, measuring system are required.

Example commercial systems

There are a number of alternative ways in which photogrammetric systems can be used, these are now discussed with reference to how each method affects the object being measured.

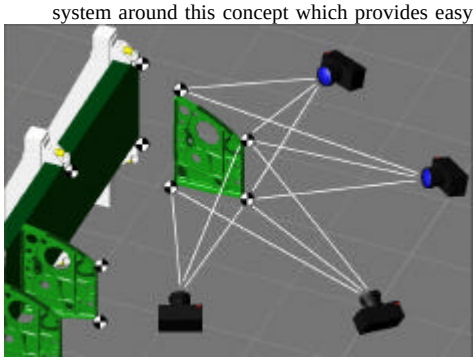
- ***Touch probe.*** A few suppliers produce a system that provides portable CMM functionality. This scheme uses one or more cameras to measure the position of a hand held device into which is inserted a range of typical CMM probes. One company, Metronor, has built up an extensive system around this concept which provides easy to understand procedures and measurement capability. At a range of two metres a resolution of 0.01mm is claimed and a measurement can be taken every second.

- ***Retro-reflective targets.*** The majority of high accuracy applications use retro-reflective targets that are fixed to the object being measured. These targets come in many forms, for example, some are mounted on holders that precisely fit into holes with known offsets while others are stuck to the object using self-adhesive or magnetic strips. Various coded versions exist to assist in identifying reference co-ordinates systems, components, etc.

- ***Projected targets.*** Leica/GSI offer a projected target system that avoids the requirement to use stick on targets and improves the speed of repeat measurements of similarly shaped objects.

- ***Projected patterns.*** Some hybrid systems integrate photogrammetry with projected pattern techniques. One of these consists of a projector and two cameras. In operation a number of patterns are projected on the surfaces being measured and a 3-D estimate produced for every pixel imaged by both cameras. As a result this technique is capable of such tasks as reverse engineering where fine detail is required. This system is able to measure large complex surfaces by linking measurement patches together.

- ***Natural features.*** Some companies specialise in integrating photogrammetric systems in the manufacturing environment where natural features such as holes or pipe bends are measured at the same time as targets.

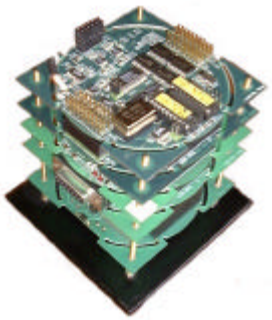


Measurement arrangement

Robotic assembly

Example of a current Optical Metrology Centre project

Photogrammetry is the basis of a unique 3-D measurement system developed by British Aerospace and the City University Optical Metrology Centre. A digital signal processor (DSP) system was developed in house to provide a real-time capability. The system can produce 3-D coordinates for over a hundred measured points up to every 1/25th of a second. As a result it can simultaneously measure the location of components during assembly or guide a robot end-effector in drilling operations. This work won the 1998 Metrology for World Class Manufacturing Award for Innovative Metrology and a DSP in Action Award for 1998. The concept is illustrated in the following figures that show the principle of operation, how the measurement system is used to guide a robot to position the component in the correct location, and the DSP system.



DSP System

The role of the Optical Metrology Centre

The Optical Metrology Centre provides a range of services, some examples are:

- ***Selection of non-contact measurement systems.*** A large database of commercial products is kept up to date and is used to advise clients on the best available system to solve a particular measurement task. A typical consultation will result in: an analysis of the application requirements, a description of the relevant techniques that could be used, and the selection of systems to meet the specifications.

- ***Partnerships.*** Assistance in the design and application of measurement techniques to provide measurement solutions for particular tasks. This activity may range in scope to one-off projects lasting a two or three weeks to longer term projects. In some cases a selected product is tested and installed together with appropriate software and methods of analysing data, in other cases instruments are designed and proof-of-principle or pre-production prototypes are build. Sometimes funding for such projects comes from government funding bodies.

- ***Consultancy to instrument manufacturers.*** An important aspect of the OMC's activity is to work with instrument manufacturers to provide assessments of future trends, assistance in the development of new products and analysis of ways in which existing products can be improved.

Details of current OMC projects and services in this and other areas can be obtained from Dr. Tim Clarke, Optical Metrology Centre, City University, Northampton Square, London. EC1V 0HB.