Real-time 3-D metrology for aerospace manufacture

Tim Clarke and Richard Gooch

The authors

Tim Clarke is a Research Fellow and Director of the Optical Metrology Centre, City Univeristy, London, UK.
Richard Gooch is a Principal Scientist at British Aerospace, Sowerby Research Centre, Bristol, UK.

Keywords

Aerospace, Assembly, Inspection, Metrology, Robots, 3-D

Abstract

High speed image processing is the basis of a unique 3-D measurement system developed by British Aerospace and the City University Optical Metrology Centre. 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 locations of components during assembly or guide a robot end effector in drilling operations. This work has recently won the 1998 Metrology for World Class Manufacturing Award for Innovative Metrology and a DSP in Action Award for 1998.

Sensor Review
Volume 19 · Number 2 · 1999 · pp. 113–115

Digital manufacturing

Commercial pressures are driving down the cost of acquiring and operating aircraft. Aerospace manufacturing is moving from traditional craft-based to technology-based manufacture. Industrial automation is expected to provide benefits in terms of: higher productivity, lower cost, and higher quality. The next leap forward in the aircraft industry will be based on manufacturing technology. This will lead to faster manufacture, lighter and more efficient aeroplanes, quicker product to market times, flexibility to accommodate design changes, and cheaper certification and better quality control.

To achieve this, UK industry (in common with the major industrial nations) is moving towards Digital Manufacturing – seamless integration of product design and manufacture. This will be facilitated through 3-D CAD, digital pre-assembly, flexible tooling, jigless manufacture and 3-D metrology. A key requirement will be for measurement systems to be in the real-time control loop. In the future jigs will be replaced, or modified, with advanced manufacturing technologies. Measurement will increasingly be the link between design and manufacture.

The embedding of a photogrammetric measurement system in a manufacturing control loop requires: on-line operation, rapid measurement, low latency, high reliability and digital data linking measurement and product design. Development work is currently being conducted in a manufacturing cell for robotic part positioning and robot drilling (Plate 1). Demonstrations carried out include:

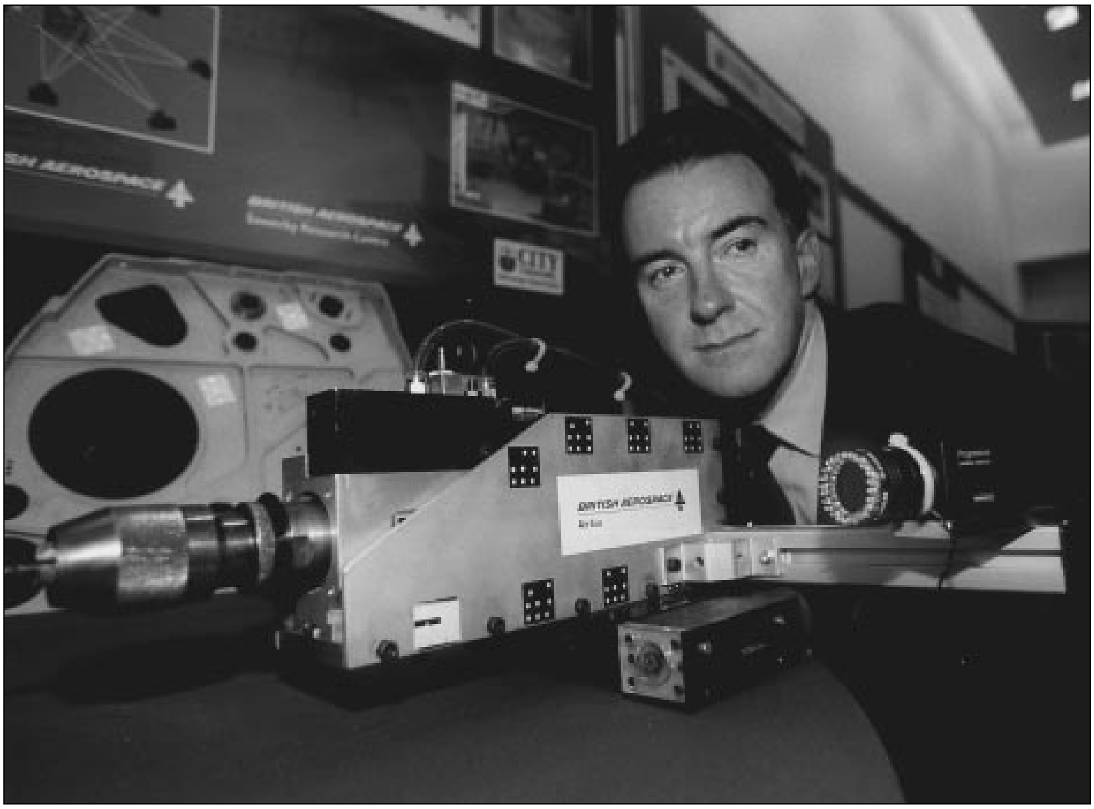
- high speed drilling;
- jigless assembly based on simultaneous measurement of multiple components;
- manufacturing to CAD data;
- automatic recognition of components;
- part-to-part positioning.

Metrology market

The CAD/CAM/CAE market is worth some $3bn per year today and metrology is worth some $1.2bn per year (Raab, 1998). This market is set to expand over the next few years, with major opportunities for UK industry. One area of growth is the non-contact measurement area. A survey of 200 non-contact metrology products (Williams and Clarke, 1998) indicates that

Sensor Review
Volume 19 · Number 2 · 1999 · 113–115

Plate 1 Rt Hon Peter Mandelson MP, former Secretary of State for Trade and Industry looks at the City University/British Aerospace project for jigless assembly



photogrammetry is the most practical technique capable of performing high accuracy, and simultaneous measurement of multiple points. However in common with other specialist dimensional inspection techniques, photogrammetry usually has the disadvantage that it requires an expert operator. Often the process of measurement is carried out off-line as a separate and self-contained activity. To produce a system that is suited to being embedded in a manufacturing control loop, key challenges have to be addressed:

- self-contained "Black-Box" solution;
- autonomous operation;
- robust, reliable measurement;
- digital data output integrated with CAD and process control;
- real-time measurement with predictable performance.

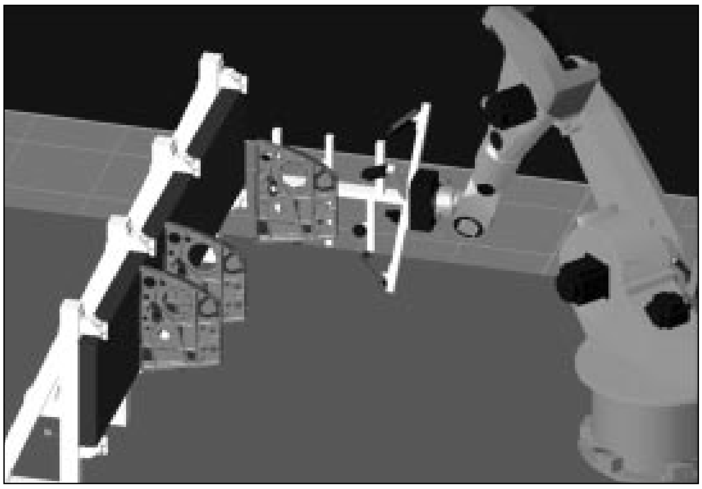
The system described here typically uses between two and four cameras and can achieve an accuracy of measurement better than 50µm within a $1m^3$ volume.

Measurement principle

The principle of operation is optical triangulation where several cameras are used as angle measuring devices. Accuracy starts at 1 part in 10,000 of the largest dimension being measured and extends to 1 part in 100,000 with the latest camera technology, thus the scheme is highly suited to close-tolerance measurement of large components typical of the aerospace industry (see Figure 1).

The measurement system uses a distributed digital signal processing architecture to analyse the video stream locally at each camera. High contrast target markers and associated target detection algorithms allow lossless real-time compression of the useful

Figure 1 Illustration of the measurement principle



Sensor Review
Volume 19 · Number 2 · 1999 · 113–115

video data to a maximum of 5 per cent of the raw video bandwidth. Target localisation algorithms operate directly on the compressed image data producing image co-ordinates for each target. These data are communicated by Ethernet to a central processor that computes 3-D co-ordinates at video frame rate. Various schemes are used to associate the 3-D co-ordinates with the objects being measured such that the measured data always relate back to the CAD data and the hence the manufacturing requirements.

DSP software design

On start-up the DSP resets the FIFO buffers and finds the beginning of the image frame. Using either a 20 msec fields, or 40 msec frames, the image data are read by the DSP. Target image objects are reconstructed on a line-by-line basis using only the information contained in the current and previous lines. The targets are located to sub-pixel accuracy within the object recognition process. In many cases, the 2-D co-ordinates are available immediately after the camera has output the image. The host uses Windows Sockets with the TCP/IP protocol, giving hardware independence on the PC side (see Figure 2).

3-D estimation

To estimate the 3-D co-ordinates of the target points there are several processes required: each target must be identified in all of the images; the orientation of the cameras must be known via a simple set-up procedure; the cameras must be calibrated to eliminate the effects of lens distortion; and the orientation of the cameras with respect to each other must be known. The software guides the user through each process. The 3-D point data are matched with the CAD information, the task requirements and the end effector characteristics. The capability of the system described here has many uses in manufacturing. A practical application could be the assembly of the leading edge of a wing (see Figure 3).

The technology could also be used in other areas. For instance: experimental research such as deformation analysis; medical applications such as surgical instrument tracking or gait analysis; entertainment such as in animation; or in space such as assisting robots in the construction of a space station.

Figure 2 DSP hardware

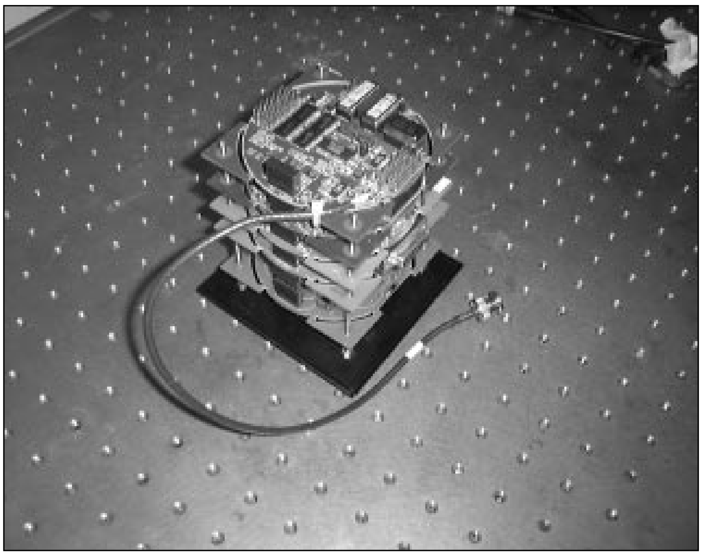
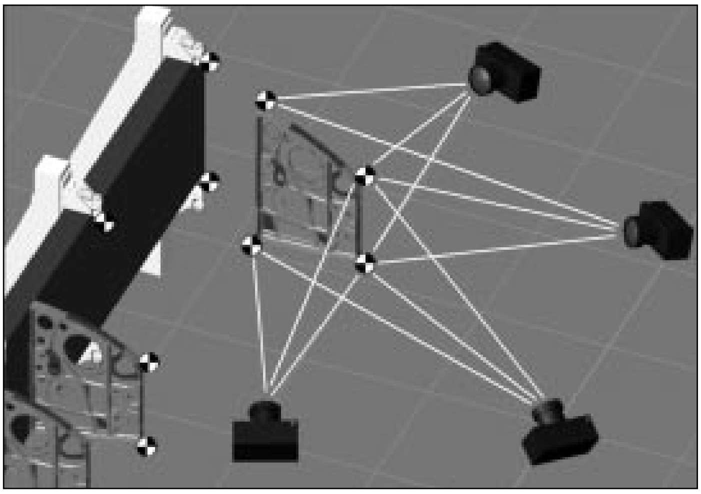


Figure 3 Visualisation of the assembly of the leading edge using an industrial robot and the 3-D measurement system



Conclusion

Embedded measurement systems that are tightly integrated with manufacturing processes are required to achieve the benefits of jigless assembly and flexible manufacturing in the aerospace industry. The development described here is one of only a few in this important area.

References

Raab, S. (1998), FARO portable CMM open day, Isleworth, June.

Williams, M. and Clarke, T.A. (1998), Non-contact measurement systems survey. EPSRC Jigless Aeronautical Manufacturing project report, 39 pages.