9th INTERNATIONAL SYMPOSIUM ON MEASUREMENT AND QUALITY CONTROL (9th ISMQC)
November 21 – 24, 2007, IIT Madras

DYNAMIC DISPLACEMENT MEASUREMENTS BY VIDEOGRAMMETRY

Sriranga T. S., Samuel R., and Raghunatha Behara
ISRO Satellite center, Email: rangan/rsamuel/behara@isac.gov.in

Radhakrishnan P.
Vice-Chancellor, Vellore Institute of Technology, Deemed University. Email: rkp_n@yahoo.com

***Abstract**: Photogrammetry and Videogrammetry techniques are being applied for a variety of spacecraft structural applications including shape, dimensional stability and dynamic displacement measurements. Static object measurements serve to provide either shape or distortions in a statically loaded structure during qualification tests. Dynamic measurements are essential during motion measurement and determination of mode shape of flexible appendages and Synthetic Aperture Radar antenna panels. Configuration of a PC-based image measurement and processing system for motion measurements using two time-synchronized video cameras is reported here. Time synchronization hardware details, automated image processing using video module of PhotoModeler as also visualization are explained in this paper. The number of images, and target points that can be used for measurement are only limited by the PC hardware infrastructure. Displacement measurements have been done on targets mounted on crosshead of an X-Y motion system to ascertain the accuracy of measurements within the range of two video cameras. Laser Tracker was used to verify the camera measurements.*

Keywords: *Videogrammetry system, Dynamic displacement measurement.*

1. INTRODUCTION TO 3D MEASUREMENTS

Spacecraft requires thermo elastic/ hygroscopic distortion considerations in design and performance validation. This requirement is critical for a state of art communication, remote sensing and Radar Imaging satellites. Dimensions and stability are critical at integrated spacecraft in the on-orbit configurations. This aspect is taken care by design (materials, construction, structure design) as also by temperature and humidity control. However, require validation by theoretical analysis and ground experiments at subsystem and system level for selected conditions. Video/Photogrammetry is chosen for experimental evaluation for specified conditions to validate design and also establish accuracy of Finite Element predictions.

Photogrammetry is a well-known technique for non-contact measurements (Pappa.R.S, 2000). Advances in high-resolution digital cameras have popularized this technique as a portable Coordinate measurement machine for large volume metrology. Whole field deformation measurement on communication antenna reflector structures inside thermo vacuum chamber is an application being studied. Recognizing the versatile potential for a variety of applications, initially high precision Laser Tracker was procured and now V-STARS photogrammetry system is being applied to ongoing projects. This investment, probably the first in the country, proved very useful in space and aerospace applications. Several aerospace companies also took heart to make their purchase decisions.

Videogrammetry (Pappa. R. S, 2003) typically uses two video cameras to capture the motion of target objects in stereo, and then with suitable image processing and data analysis the targets 3d trajectories are measured.

Videogrammetry technique relies on photogrammetry and tracking of features across time-correlated frames of video images. No standard high-end systems are available for Videogrammetry.

V-STARS does not allow processing of other camera image formats. Non-contact 3D measurements on static and moving targets have been well-established using standard PhotoModeler software (Naveen, 2005; Pappa, 2003). To fulfill this need for a videogrammetry system, development efforts were initiated to configure a low-cost hardware. Dynamic displacement measurements using two time-synchronized video cameras are reported in this paper. With an eye on future spacecraft structures including large sized thin membrane structures Videogrammetry technique is being studied and expertise being built-up.

Two video cameras, triggered by a special hardware, provide two time correlated image sequences. Each image frame pair corresponds to an instant in time (Epoch) at which the target position was captured. First frame pair is processed as a static Photogrammetry project to provide the camera position and orientation. The target employed being coded, automatic marking and referencing was possible. The target centroid is determined to sub-pixel accuracy by the Photogrammetry software.

In this work, videogrammetry measurements were verified with Laser Tracker (Gurumurthy et al., 2006).

2. 3D MEASUREMENTS BY VIDEOGRAMMETRY (VG) SYSTEM

2.1 System Overview

The VG system (Fig.1) consists of two Basler cameras, Two IEEE-1394 PC cards, a PCI-6220 DAQ card, two RJ-45 cables, a high performance PC (512 MB RAM, 3 GHz Pentium Processor, 512 Kb cache), Image acquisition software, IMAQ, and the Photogrammetry software (PhotoModeler.)

- The A600 series Basler cameras are triggered via an external sync signal. The camera specifications include sensor resolution of 640 x 480 pixels, 60 frames / s max.
- IEEE- 1394 PC cards: Two IEEE-1394 controller cards are used one for each camera. These cards act as controller for the cameras for communication with PC.
- PCI-6220 DAQ card: This NI card offers 16 analog inputs, 24 digital I/O lines and two counters / timers. The DAQ card is used for hardware trigger to ensure synchronization between the two cameras.

2.2 Experimental Set-up to evaluate Videogrammetry System

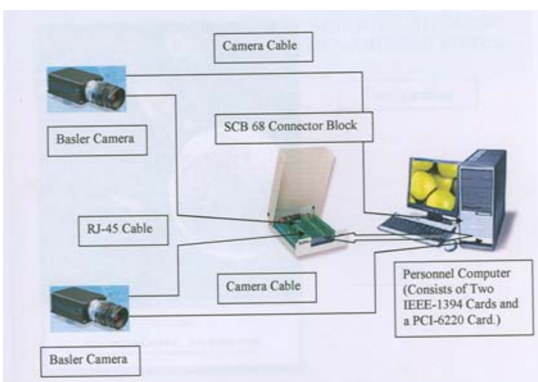

Fig. 1. Block diagram of the Videogrammetry system

The setup consists of photogrammetry targets mounted on cross head of the X-Y motion system, and a device used for circular motion of a target (a Ball bar- a calibration device supplied with Laser Tracker.)

Evaluation of accuracy was achieved with the following tasks:

- Tracking multiple points
- Straight line motion (along one axis of X_Y Table)
- In steps i.e. move, stop and move (Figure 2.)
- Continuous (Figure 3.)
- Tracking a single point after initial camera orientation
- Circular motion of target (Figure 4.)
- 2D tracking of targets using a single camera.

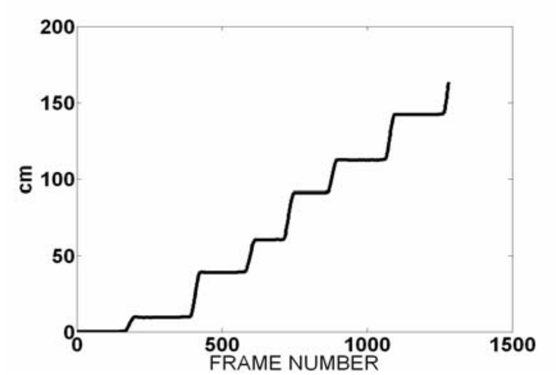

Fig. 2. Straight-line motion (along one axis of X_Y Table) in steps.

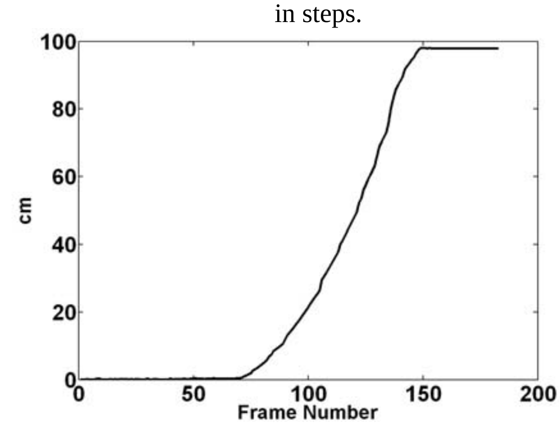

Fig. 3. Straight-line motion (along one axis of X_Y Table) in continuous fashion.

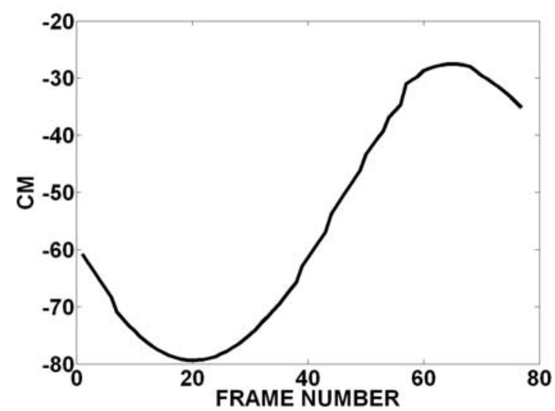

Fig. 4. Curved motion using a special Calibration device

Fig. 2 and Fig.3 also show that camera measurements are reliable as far as 175 cm, which is more than adequate for applications that we have in mind. Figure 4 shows tracking of a target executing circular motion. The calibration pattern was in the view of the camera only in initial frames. Later image frames had only the coded target and the Videogrammetry software successfully tracks the target.

2.2.1 Camera Calibration is carried out in two steps:

- Step 1 involves use of a standard calibration grid and the focal length setting that would be used for 3d coordinate measurements of the target. This step computes the distortion parameters of the lens used in the camera.
- Step 2 involves determination of the camera orientation for which well-defined and well-distributed targets that fill a large area of the image are used. This step computes the position and orientation of the cameras mounted on Tripods.

2.2.2 Target Identification

The target whose displacement is to be measured needs to be easily identifiable in the images recorded. Coded targets are used for automated marking and referencing.

2.2.3 Camera Viewing Angle

In deciding the camera positions, same principles followed in Electronic Coordinate Distance System (Theodolite) network are used. Camera viewing directions must keep the targets in view for the whole range of measurement volume. The position measurements are most accurate if the viewing directions are as close to 90 degrees as possible. Geometries, which work satisfactorily, are with Apex angles of 30 to 120 between the cameras' viewing directions. This is achieved by maintaining approximately a baseline to stand off ratio of 2.

2.2.4 Reference Points to Calibrate Camera Position and Orientation.

At some time during the experiment, a calibration target must be in the field of view of the cameras. The reference target can be removed from the measurement volume once it has been imaged.

A reference target points should span the field of view and also differ in range from the cameras (if the points are all at the same range from the camera then the estimate of camera position perpendicular to the viewing axis will be inaccurate). The larger the proportion of the field of view occupied by the reference target, the better.

2.2.5 Camera Triggering and Time Synchronization of Frames

The video files from the cameras must be synchronized in time as well as registered to the same spatial coordinate system (which the camera position and pose calibration procedure achieves). The hardware trigger PCI-6220 DAQ card achieves synchronization. The two cameras continuously capture a one-milli second display and frame pairs are verified for synchronization.

2.2.6 Displacement Measurement Using Labeled (Coded) Targets

Evaluation of the system was done using circular coded photogrammetry targets, which automates measurement process.

2.3 Data Processing Sequence

Tracking a target and measuring its displacement involves essentially three steps namely calibration of camera (estimation of lens distortion parameters), time correlated Video image streams acquisition, Photogrammetry solution for the first frame pair to estimate the camera position and orientation and finally 3D Tracking of the targets in other frame pairs.

Steps in Videogrammetry measurement are as follows (Gurumurthy et al., 2006):

Image capture from time-synchronized video cameras

- Centroid Marking of Targets to sub-pixel accuracy and Referencing (Fully Automated because of use of Coded Targets)
- Photogrammetric processing of the First Epoch frame pair
- Tracking the target features in all frame pairs (other epochs) & Triangulation
- 3D Visualization

3. PRACTICAL IMPLIMENTATION OF VIDEOGRAMMETRY

The main application of the system uses a pair of cameras (Figure 5), however other configurations including many cameras are possible with the same software after some modifications. A single camera can give good measurements if the targets' motion is constrained in one dimension. Systems using more than two cameras take more time for data processing.

Fig.5. Test up used for Evaluation of Videogrammetry system

Essentially Videogrammetry is an offline process unlike a Laser Tracker (LT) where near real time tracking of a special retro reflector target is possible. The measurement volume for LT is considerably larger (35 x 35 x 70 meters). Although large structures could be measured with Photogrammetry, measurement uncertainty increases linearly with object size. In the case of videogrammetry, the field of view of the camera limits the range and lateral displacements of the targets. Trajectory capture is limited by the frame rate of camera. VG has the advantage of tracking multiple targets. Loss of Lock on target needs re-establishment of reference for the Interferometer in Laser Tracker. However no new measurements are required by VG to continue tracking. Despite a few targets not being marked in all frames, VG calculates 3D information for all the points for which intersections are possible.

The process of making measurements is lengthy and requires many steps and three different programs to be launched separately (IMAQ, PhotoModeler, Imageware).

All tests so far indicate that the measurements are of acceptable accuracy. Laser Tracker indicates Videogrammetry measurement accuracies of ±100 microns over displacement range of 1.5 m.

Practical implementation is planned on large spacecraft panel’s size 1 m x 1m or larger. Suitable cameras in terms of FOV and resolution are being identified. Large space structures are essentially characterized by low frequencies less than 10 Hz. This means displacements rather than accelerations are to be measured for dynamic characteristics. The image processing software is not dependent on the frame rate of the camera. The present camera system is being replaced with GigE cameras with high frame rate and longer cable length.

4. CONCLUSION

Configuration of a low-cost Videogrammetry system, its applications for spacecraft structural engineering, has been presented. Laser Tracker measurements indicate accuracies of ±100 microns over displacement range of 1.5 m. The Image acquisition, synchronization hardware can be used with suitable cameras for whole field strain measurements using Image correlation technique.

5. REFERENCES

Butler, B.; Ruff, J. & Thunborg, J. (1999). Photogrammetric Measurement of VLA and VLBA sub reflectors And VLA Primary Reflector. *National Radio Astronomy Observatory Socorro, New Mexico, Vla Test Memo # 220*

Gurumurthy; Sriranga, T. S. & Raghunatha Behara.(2006). Experimental Assessment of Accuracy of Videogrammetry system for Non-contact 3D motion measurements, *ME Thesis, Belgaum*

Naveen Gowd,O.; Sriranga, T. S, & Raghunath Behara (2005). Close Range Photogrammetry Measurements & Integration of CAD, *ME Thesis, VIT*

Pappa, R. S et al. (2000). Photogrammetry of a 5m inflatable Space Antenna with Consumer Digital Cameras.*NASA/TM-2000-210627*

Pappa R. S. et al. (2003*).* Videogrammetry Using Projected Circular Targets: Proof-of-Concept Test, *NASA/TM-2003-212148*

Sriranga, T.S.; Samuel. R. & Raghunatha Behara (2005). Non-contact shape measurement using close range photogrammetry with consumer digital camera - Accuracy Evaluation. *PPEG ISAC publication*