PROCEDURE FOR DEFORMATION DETECTION USING VISUAL METROLOGY

Mohd Sharuddin Ibrahim & Halim Setan
Department of Geomatic Engineering
Faculty of Geoinformation Science and Engineering
Universiti Teknologi Malaysia
81310 UTM Skudai
Johor
Malaysia
sudin_utm@yahoo.com, halim@fksg.utm.my

Abstract

Deformation detection via visual metrology (geodetic method) for inspection and data validity of an object has high potential in structure measurement. Visual metrology are based on close range photogrammetry i.e. V-STARS system. The V-STARS system is an enhanced (and portable) digital close range photogrammetric system for precise 3D coordinate measurement using special high-resolution digital intelligent camera (INCA), special target (high contras retro-reflective) and special software, for the automation of the entire measurement process. The typically accuracy of V-STARS is better than 10 ppm, i.e. about 0.010mm on a 1.0m object. This research focuses on the procedure and potential of deformation detection using visual metrology technique and S-transformation for geometrical analysis via displacement vector and graphic presentation. A simulation test is included to verify the practicality of the procedure.

1.0 INTRODUCTION

In geodetic method there are two types of monitoring network namely the reference and relative network. In the relative network, the references points are located in the deformable object. On the other hand, in reference network, the references points are located outside of the deformable object.

Visual metrology are based on close range photogrammetry, e.g. V-STARS system. It uses multiple images to capture the data of each epoch, and the results could be used for deformation detection between epochs using direct method. In the direct method, the changes of coordinate on each epoch (or each series of measurement) are referred to a set of stable reference (or control) points.

Deformation detection via visual metrology (photogrammetry technique) for inspection and data validity of an object has high potential in structure measurement. Series of movement can be measured in seconds. This research focuses on the development of procedure for deformation detection using visual metrology technique (via V-STARS) for geometrical analysis via displacement vector and graphic presentation.

2.0 PHOTOGRAMMETRY AND V-STARS SYSTEM

Photogrammetry is a 3-D coordinate measuring technique that uses photographs (currently digital images) as the fundamental medium for measurement. Figure 1 illustrates the principle of photogrammetry. Photography (using camera) is a process that converts the real 3-D world into flat 2-D images. Photogrammetry reverses the photographic process, and converts (or maps) the flat 2-D images back into the real 3-D world. In close range photogrammetry, multiple images are usually taken (using cameras) around the object, with the camera-object distances less than 100m (GSI, 2002).

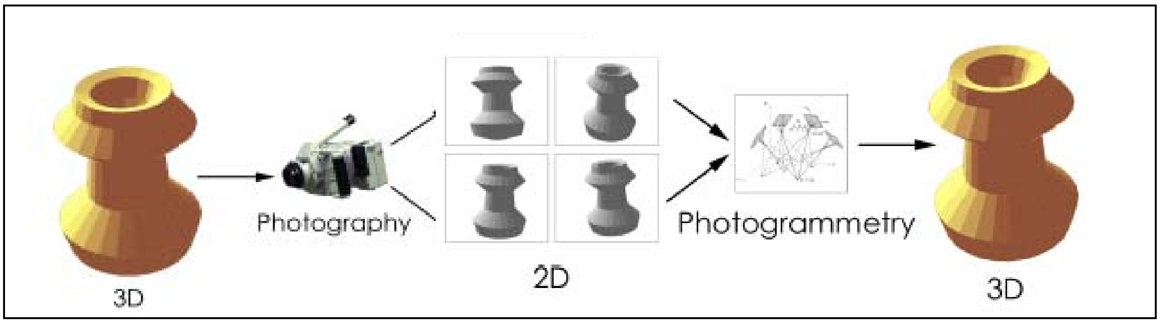

Figure 1 : Concept of photogrammetry (GSI, 2000)

V-STARS (**V**ideo **S**imultaneous **T**riangulation **A**nd **R**esection **S**ystem) is portable and enhanced (i.e. high precision, fast, fully automated) digital close range industrial photogrammetric measurement system for precise 3D coordinate measurement using high-resolution digital cameras. V-STARS employs special intelligent camera (INCA), special targets (high contras retro-reflective coded targets, autobar, scalebar) and special software for the automation of the entire measurement process. The typically accuracy of V-STARS is better than 10 ppm, i.e. about 0.050mm (or 50 micron) on a 5.0m object. The system is developed by Geodetic Services Inc (GSI) USA, and has been applied in many industrial applications (Brown, 1998; Fraser, 1999; Ganci & Brown, 2000; Ganci & Clement, 2000; Ganci & Brown, 2001; Leica Geosystem, 2002; GSI, 2002; Halim & Mohd Sharuddin, 2003a).

The V-STARS system has essentially replaced the old in-place coordinate measuring system (CMM) that requires a stable platform throughout the measurement. Videogrammetry ability to work in unstable measuring environments gave it a strong advantage over the in-place systems (GSI, 2002). V-STARS is claiming to be “second generation CMM” by CMM committee. It has more advantages then CMM (GSI, 2002).

V-STARS represents the borderless applications, most advanced and most capable line of 3-dimensional coordinate measurement system designed for industrial measurement in the world using digital close range photogrammetric. V-STARS measurements system contains special software for processing images (Figure 2), special camera (Figure 3) for data capturing (images) and special retro reflective target (Figure 4 & 5). This 3 main factor are able to control the accuracy of the measurement.

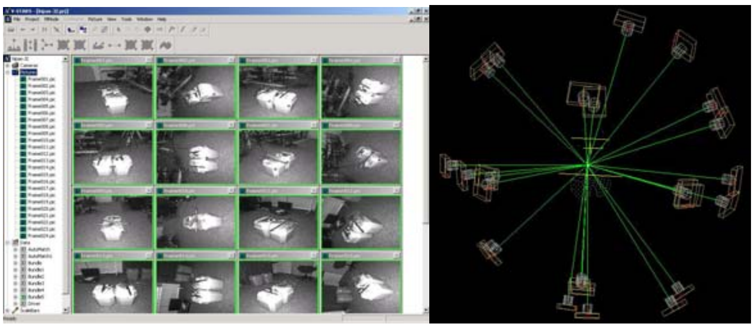

Figure 2 : V-STARS software

Figure 3 :Camera INCA 4.2

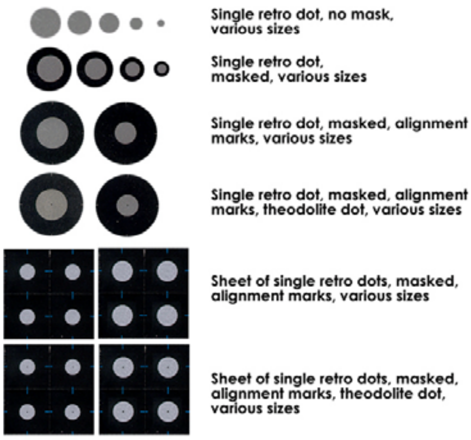

Figure 4 : Retro target

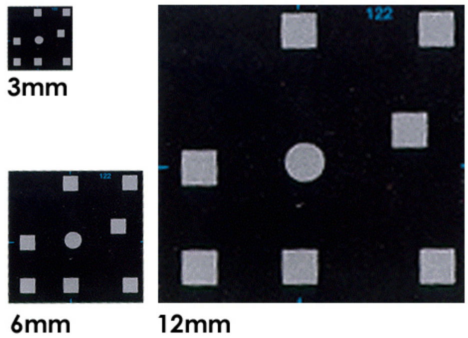

Figure *5 : Retro coded target*

2.1 Special software

The V-STARS software automatically process the images and the coordinates of points of interest computed using photogrammetric techniques and triangulations (Figure 2). There are several advantages of this processing software i.e. high accuracy (1:120,000 i.e. about 0.080mm on a 10m object), non-contact, fast results (lest then 5 minutes), flexibility, minimal temperature effect and immune to vibration (GSI, 2002; Halim & Mohd Sharuddin, 2004a)

2.2 Special camera

INCA (**IN**telligent **CA**mera) has been designed for the purpose of industrial measurement application using Kodak MegaPlus on 4.2 resolution (Figure 3). INCA camera are categorized as an array matrix camera (Fraser, 2003). INCA camera has the capability to provide high data capturing due to its high accuracy (advanced calibrations techniques), robust, portable, easy handling, image compression up to 10% from original size and automation in measurement.

2.3 Special Target

V-STARS uses high contras retro-reflective target (Figure 4). There are various types of retro-reflective target to be used for multi purpose measurement. The scale bar (invar) uses retro target to scale the measurement, and the origin of the measurement is called Autobar. Coded targets are used to control the measurement network (Figure 5). Each coded have its own characteristic. INCA camera has the capability to recognize the coded after picture are taken. To get good result it is better to get at least 4 coded in 1 picture. For non-contact measurement, V-STARS can accept normal slide projector (dot slide) and providing accurate measurement (Figure 6).

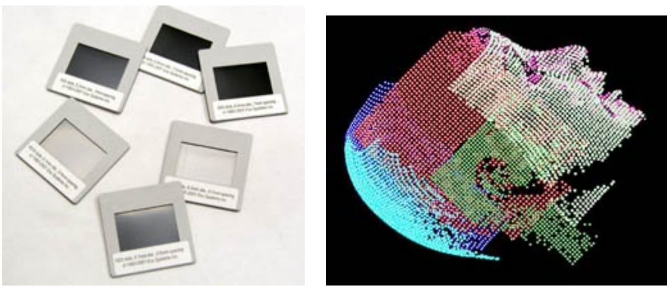

Figure 6 : Non-contact measurement and the result

3.0 PROCEDURE FOR DEFORMATION DETECTION

Currently, V-STARS system (using single camera) is used in related applications such as industrial and high precision measurement (Mohd Sharuddin, 2004). By adopting simple measurement steps, the accuracy of sub-mm level is easily achievable (Halim & Mohd Sharuddin, 2003a, 2003b, 2004a & 2004b). This research concentrates on the applications of V-STARS (using single camera, off line) for deformation detection.

There are a several steps in order to determine the deformation detection using visual metrology (Figure 7), i.e. network design, data capturing (using INCA), image processing (with V-STARS) and analysis (via S-transformation).

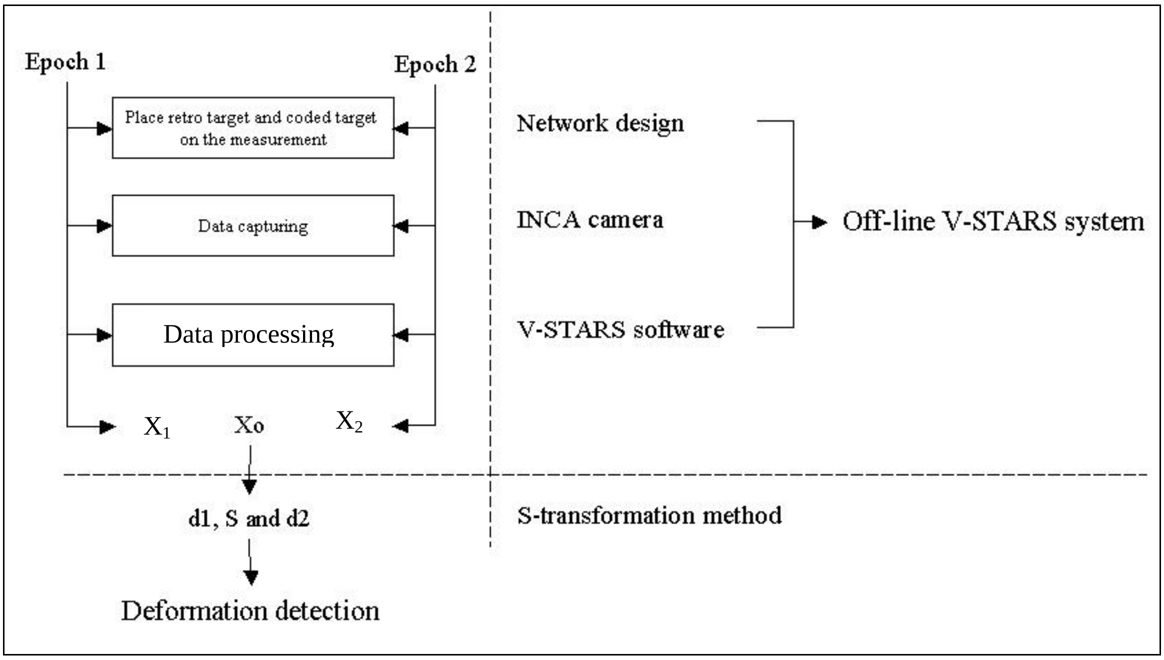

Figure 7 : Flow of deformation detection

Network design depends on many factors. Stable frames could be used as control stations or points. Coded targets can also be used as control points for measurement and should be placed outside the object point area, to get the absolute displacement vector. Targets are placed on both the control and object points.

A series of multiple images were then taken from multi stations (convergence method) for each measurement (epoch). In order to get better result, at least each target should be seen from 4 images from different stations. The images have to taken normal and horizontally to reduce the error of lens distortion.

The image processing is quickly done using V-STARS software, to produce accurate 3 dimensional (3D) coordinates of points. Then the output from V-STARS (X_1 (coordinate epoch 1), X_2 (coordinate epoch 2) and Xo (approximate coordinate, unscaled results of V-STARS)) are used in S-transformation for deformation detection.

3.1 S-Transformation

S-Transformations is introduced for deformation detection computation. The formulated computation procedure involves reducing coordinates to a centroid and normalization of matrix G (equation 1) to achieve numerical stability. Decomposition of matrix S (equation 1) is also carried out to speed up the computations. Use of the reduced coordinates is also recommended for flexible S-transformations (Halim, 1995).

$$G^T = \begin{bmatrix} +1 & 0 & 0 & +1 & 0 & 0 & \dots \\ 0 & +1 & 0 & 0 & +1 & 0 & \dots \\ 0 & 0 & +1 & 0 & 0 & +1 & \dots \\ 0 & +\bar{Z}_1 & -\bar{Y}_1 & 0 & +\bar{Z}_2 & -\bar{Y}_2 & \dots \\ -\bar{Z}_1 & 0 & +\bar{X}_1 & -\bar{Z}_2 & 0 & +\bar{X}_2 & \dots \\ +\bar{Y}_1 & -\bar{X}_1 & 0 & +\bar{Y}_2 & -\bar{X}_2 & 0 & \dots \\ +\bar{X}_1 & +\bar{Y}_1 & +\bar{Z}_1 & +\bar{X}_2 & +\bar{Y}_2 & +\bar{Z}_2 & \dots \end{bmatrix} \begin{matrix} \Rightarrow \sum \hat{X}_i = 0 \\ \Rightarrow \sum \hat{Y}_i = 0 \\ \Rightarrow \sum \hat{Z}_i = 0 \\ \Rightarrow \sum \left(\bar{Z}_i \hat{Y}_i - \hat{Y}_i \bar{Z}_i \right) = 0 \\ \Rightarrow \sum \left(\bar{X}_i \hat{Z}_i - \hat{Z}_i \bar{X}_i \right) = 0 \\ \Rightarrow \sum \left(\bar{Y}_i \hat{X}_i - \hat{X}_i \bar{Y}_i \right) = 0 \\ \Rightarrow \sum \left(\bar{X}_i \hat{X}_i + \hat{Y}_i \bar{Y}_i + \hat{Z}_i \bar{Z}_i \right) = 0 \end{matrix} \quad (1)$$

The elements of matrix G (equation 1)are translation (the first 3 rows), rotation (the next 3 rows) and the scale (the last row). In this research, the measurement has been scaled. Thereby, the last row is ignored. Matrix G is computed using approximate coordinate (Xo) from V-STARS.

$$\begin{aligned} d_1 &= x_2 - x_1 \\ S &= I - G(G^T W G)^{-1} G^T W \\ d_2 &= S d_1 \end{aligned} \quad (2)$$

Where;

d_1 = differences of 3D coordinates between 2 epoch=initial deformation vector
d_2 = differences coordinates after the S-transformation=new deformation vector
x_1 = epoch 1 adjusted coordinate
x_2 = epoch 2 adjusted coordinate
I = identity matrix
W = weight matrix and element of diagonals are zero (0) for don-datum and one (1) for datum definition.

S-Transformation (equation 2) has been used to check the movement between epoch using the same datum definitions. S-transformation is an algorithm to transform least square adjustment results (coordinate, displacement vector, variance covariance, etc) from one-datum definitions into another datum definition. There are 3 type of datum definitions, i.e. minimum constraint, minimum trace and partial minimum trace (Halim, 1995).

4.0 TEST AND RESULT

A simulation testing was performed to verify the developed procedure. The network (Figure 8) consists of 6 coded target (as control points), 1 scale bar and 22 selected targets (as object points). A total of 12 images (6 normal and 6 rotated) were taken, as the first epoch. The same network configuration is used for second epoch, with the object points replaced with 22 selected targets at different positions (Figure 8). The quality of the measurement is shown in Table 1. The simulated deformation between epoch (Table 2, direct method) was computed using module Wintrans (within V-STARS), which has the capability to compute differences between 2 sets of data.

The deformation detection is employed using S-Transformation, using all 6 coded targets as datum definition. The initial deformation vectors are transformed into new deformation vectors (via equation 2). The numerical and graphical results are shown in Table 2 and Figure 9 (S-Transformation) respectively. The estimated (via S-transformation) and simulated deformation (or displacement) vectors are very close (Table 2), indicating the practicality of the approach.

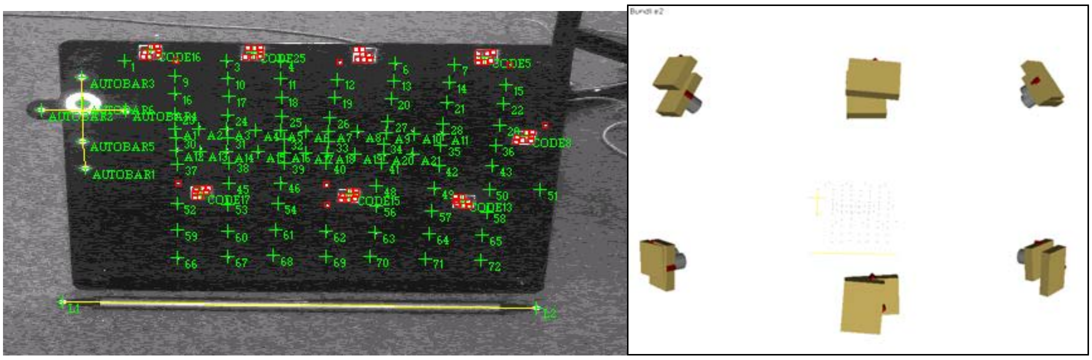

Figure 8 : Measurement to determine deformation

Table 1: Result of the measurement in millimeter

Measurement	Geometry	RMS of measurement	RMS Scale	RMS x	RMS y	RMS z
Epoch 1	1.028	0.162	0.000	0.008	0.005	0.005
Epoch 2	1.025	0.163	0.000	0.007	0.005	0.004

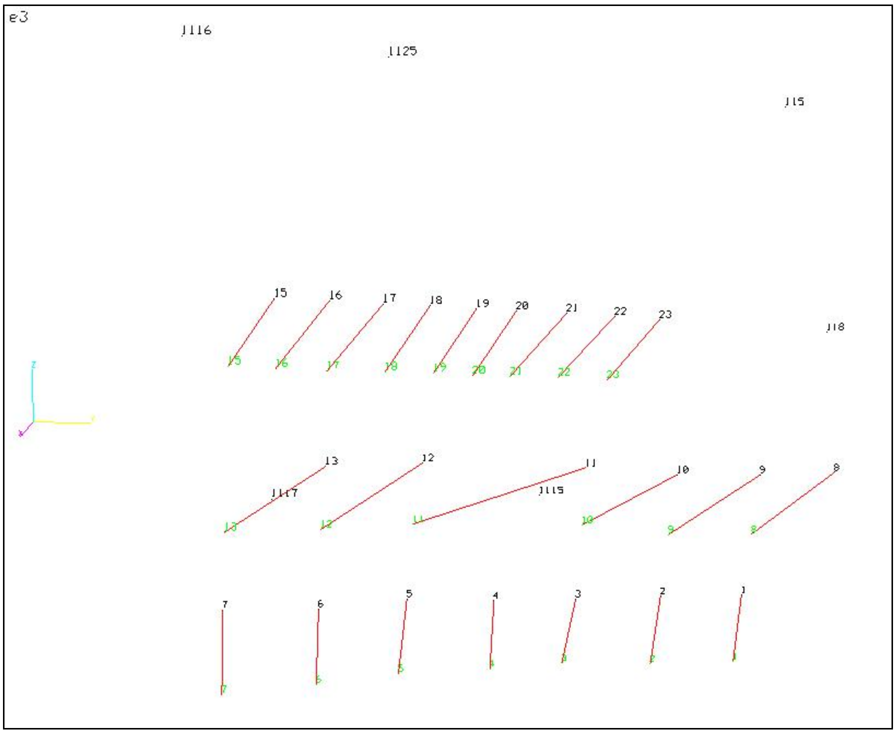

Figure 9 : Graphic presentation on 2 epoch of displacement vector (mm)

Table 2 : Numerical presentation on 2 epoch of displacement vector

Label	S-transformations (mm)			Direct method (simulated) (mm)			
	dX	dY	dZ	dX	dY	dZ	
1	0.604	0.531	-54.289	0.604	0.531	-54.289	Move point (object point)
2	0.688	-1.942	-53.890	0.688	-1.942	-53.890	
3	0.650	-5.986	-49.877	0.650	-5.986	-49.877	
4	0.727	1.042	-52.428	0.727	1.042	-52.428	
5	0.802	-2.859	-56.023	0.802	-2.859	-56.023	
6	0.917	0.554	-55.477	0.917	0.554	-55.477	
7	0.894	0.606	-60.938	0.894	0.606	-60.938	
8	0.669	-63.789	-47.885	0.669	-63.789	-47.885	
9	0.652	-69.103	-45.124	0.652	-69.103	-45.124	
10	0.536	-70.541	-37.065	0.536	-70.541	-37.065	
11	0.302	-121.997	-39.609	0.302	-121.997	-39.609	
12	0.234	-66.343	-45.686	0.234	-66.343	-45.686	
13	0.354	-64.067	-44.282	0.354	-64.067	-44.282	
15	0.147	-27.016	-43.005	0.147	-27.016	-43.005	
16	0.159	-32.033	-43.905	0.159	-32.033	-43.905	
17	0.258	-34.020	-43.996	0.258	-34.020	-43.996	
18	-0.073	-26.822	-43.643	-0.073	-26.822	-43.643	
19	0.264	-25.656	-42.535	0.264	-25.656	-42.535	
20	0.490	-26.204	-43.353	0.490	-26.204	-43.353	
21	0.223	-35.528	-43.051	0.223	-35.528	-43.051	
22	0.367	-36.372	-42.461	0.367	-36.372	-42.461	
23	0.591	-34.123	-42.630	0.591	-34.123	-42.630	
115	0	0	0	0	0	0	Control point
118	0	0	0	0	0	0	
1115	0	0	0	0	0	0	
1116	0	0	0	0	0	0	
1117	0	0	0	0	0	0	
1125	0	0	0	0	0	0	

5.0 CONCLUSION

Visual metrology are based on close range photogrammetry, e.g. V-STARS system. V-STARS uses special camera (INCA), special target (retro-reflective) and special software (V-STARS) for the automation of the entire measurement processing. The typically accuracy of V-STARS is better than 10ppm, i.e. about 0.050mm on a 5.0m object.

This research concentrates on the development of procedure for using V-STARS/S (with single camera) and S-transformation for deformation detection. The results from simulation testing indicate the practicality of the procedure.

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