Non-contact Measurement Using Digital Photograph

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Introduction

Digital cameras are becoming more affordable and more precise, i.e. with higher pixel resolutions. It is feasible to transform the pixel coordinates of two or more photographs (need not be digital) taken of an object into the real-world coordinates of the object using the photogrammetric technique of Direct Linear Transformation (DLT). The use of photographs as a measuring tool is thus beneficial in circumstances that do not allow contact measurements be made. A simulation experiment was set up to compare the accuracy of the results derived from the digital photographs with that of the conventional survey equipment and laboratory equipment.

Direct linear transformation (DLT)

The basic formulae of the technique can be written as:

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\begin{align*}
\hat{u} & = \frac{L_1 X + L_2 Y + L_3 Z + L_4}{L_5 X + L_6 Y + L_7 Z + 1} \\
\hat{v} & = \frac{L_8 X + L_9 Y + L_10 Z + L_11}{L_12 X + L_13 Y + L_14 Z + 1}
\end{align*}
\]

where

\[u, v\] are the pixel coordinates of a point on the image; \(L_1, L_2, \ldots, L_{14}\) are the 11 unknown parameters;

\[X, Y, Z\] are the object co-ordinates of the point and \(\delta_u, \delta_v\) are the systematic error of the image co-ordinates.

The 11 parameters can be obtained by iterative least squares adjustment if there are 6 control points with known object co-ordinates. After obtaining the 11 parameters, the image co-ordinates can be transformed to object co-ordinates of the corresponding target provided it is imaged in two or more camera positions.

Image enhancement

The digital images were enhanced using the Labview IMAQ Vision Toolkit. Figures 1 and 2 show the image of targets before and after morphology transformation. The transformation changes the contrast, brightness and establishes a threshold to segregate the image into particle zones and a background zone. The resulting outlines of the targets seen in Figure 2 were used to obtain the pixel coordinates of the centroid of the targets.

Set-up of the simulation experiment

Figure 3 shows the experimental set-up used to simulate a steel beam under loading. A steel rule of 1200 mm length was simply supported in the set-up. Blue paper circles of 40 mm diameter were used as targets. Thirteen such targets were pasted around the set-up and on the steel rule. Nine of the targets served as the control points.
and the remaining four as target points on the steel rule.

A laser-based reflectless total station was used to obtain the real-world coordinates of the centers of the 13 targets without the needing to have reflective prisms at the 13 targets. These non-contact measurements were made before and after the loading of weight to the steel rule. Two deflection gauges, in contact with the steel rule near targets P2 and P4, were also used to measure the deflections.

Digital images were photographed using a Kodak Professional DCS 315 Digital Camera with resolution of 1536 × 1024 pixels, a relatively low resolution by current standards. Two sets of four photographs each were taken at an angle of 15°, 75°, 105° and 145° with respect to the longitudinal axis of the steel rule before and after the loading. The camera positions are about 5 m from the steel rule. In this experiment, only one loading was carried out.

**Results**

Least squares adjustment using the DLT techniques was carried out to transform the pixel coordinates of the targets to their real-world coordinates. Using the pixel coordinates from all four photographs gave the best results vis-à-vis that of the total station and deflection gauge. Table 1 depicts the average absolute differences in the northing, easting, and height between the DLT results and that of the total station. Table 2 compares the deflections at points P2 and P4 as measured using the deflection gauges and calculated using the DLT technique.

**Analysis of results**

Taking the deflection gauge as the reference, the total station gave more accurate results than the digital camera. The maximum average absolute difference in the coordinates using four photographs as shown in Table 1 is about 2 mm in the northing. The differences in the heights were apparently the smallest, but it may not be conclusive from only two sets of observations. Conservatively, the accuracy of height determination using a digital camera would be in the region of 2 mm as shown in the comparisons made in Table 2.

When the coordinates of the control points are established. The merit of digital camera over total station is the speed of operation. It is definitely faster to take four photographs than performing accurate pointing of telescope to the targets, in this case four pointings. In fact it is technically possible to automate the image capturing process by having 3 or 4 digital cameras connected to a personal computer via the IEEE 1394 digital interface – commonly called the firewire cable.

**Conclusion**

With moderate pixel resolution of 1536 × 1024 pixels and the DLT technique, an accuracy of 2 mm using the digital camera was achieved. With higher a resolution digital camera, readily available and affordable, better accuracy is possible. Other factors to be considered are the size of the object, the imaging distance, the target design, the brightness and contrast of the image. These factors influence the accuracy of obtaining the pixel coordinates of the targets.
Deformation Measurement Using GPS and Surveying Robot

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Introduction
This article presents and compares the results of a study on monitoring measurements in a test site in Nanyang Technological University using (a) Global Positioning System (GPS) and (b) Motorised Total Station, also known as the Surveying Robot. The objective of the comparison is to investigate the feasibility of using GPS to monitor ground movement.

Global positioning system (GPS)
Global Positioning System (GPS), a satellite-based system developed and maintained by the Department of Defense of the United States, is capable of determining planimetric position to centimetre accuracy. The accuracy of height measurement using GPS, however, is known to be two to three times less accurate.

Motorised total station or surveying robot
Surveying Robot, a servo-fitted electronic total station, is being used to monitor MRT tunnels in Singapore. Its angular precision is 2° or better and can measure distance with precision of 1mm ± 2 ppm or better.

NTU test site
The layout of the Test Site is depicted in Figure 1. The Surveying Robot Station (Figure 2) and the GPS Reference Station (Figure 3) are situated at the rooftop of Block N1 (about 35 m above ground level) of NTU. G2 to G5 in Figure 1 denote monitoring points comprising the GPS antenna and prism target mounted on a customised bracket (Figure 4). G2, G3, G4 and G5, all installed at the rooftop, are about 120m, 145m, 110m and 95m, respectively, from the Surveying Robot Station and the GPS Reference Station. G2 and G3 are about 5m lower than the two reference stations whilst G4 and G5 are at the same height with the reference stations.

Instrument set-up
The dual-frequency GPS receiver at the reference station is powered by AC main and operates non-stop collecting data from the GPS satellites at a sampling rate of 1 Hz. The data is transferred via RS232/422 cable (about 100m) to the computer in the Surveying and Mapping Laboratory.

The Surveying Robot is also powered from AC main and performs repeated observations to the prism targets at G2 to G4 at hourly intervals, i.e. 24 sets of readings per day. The data is also transferred via another RS232/422 cable to the Surveying and Mapping Laboratory.

Dual-frequency GPS receivers were installed at monitoring points G2 and G3 while single-frequency receivers were installed at G4 and G5. There were thus a total of 5 GPS receivers used in this test. Only three prism targets were installed, as G5 is not visible from the Survey Robot Station. In this initial test, the GPS receivers at G2 to G5 were powered using heavy-duty 12V wet cell batteries, which can last 3 to 5 days before re-charging.
The changes in northing, easting and height coordinates of the GPS antenna at the furthest monitoring point G3 computed at hourly interval are shown in Figure 5. The observations began on 0600hr (GMT) 13 August 2001 and ended at 0800hr (GMT) 15 August 2001. The sampling rate of the GPS observations is fifteen seconds, i.e. one reading every 15 seconds. The height refers to the ellipsoidal height, i.e. the height above the WGS84 ellipsoid – the reference ellipsoid of the GPS.

Surveying robot observations and results

The raw and the adjusted coordinates of G3 are depicted in Figure 6. The raw observations, shown as grey lines in Figure 6, were subject to the changes in the scales of the distances measured due to the changes in pressure and temperature, and changes in the vertical angles due to the changes in the vertical temperature gradient and changes in horizontal directions due to the differential heating on the pillar supporting the instrument.

The observations were corrected for the systematic errors. A reference set of coordinates for the monitoring points G2 to G4 was used to determine the scale error, refraction error and the orientation correction for each epoch of observation.

Analysis of results

A daily pattern in the changes of the northing, easting and height coordinates is discernable in Figure 5. This is not surprising as the rising and setting of the GPS satellites repeats every 23 h 56 minutes. The effect of multipath caused by reflective surfaces in the vicinity of the GPS antennas will, thus, also repeat everyday. The changing elevation and direction of the moving satellites will attenuate or strengthen the effect of the multipath.

Assuming that the building is stable (judging from the constant level of the overall trend, this is a reasonable assumption), the maximum fluctuations in the northing, easting and height coordinates from the respective mean coordinates are 7 mm, 5 mm and 20 mm, respectively. This re-affirms the accepted belief that GPS heights are two to three times less accurate than the planimetric position.

Data from the surveying robot show that, after eliminating the scale error, refraction error and orientation error, the maximum fluctuations in the northing, easting and height coordinates from the mean coordinates are 2 mm, 1 mm and 10 mm, respectively. Again the height coordinates is the weakest. Surges in the height coordinates are very pronounced as compared to the planimetric position. The effect of wind on the instrument may have caused the erratic readings of the vertical angles.

Conclusion

The precision of the surveying robot system in the planimetric and height coordinates as sampled in the test is less than 2 mm and 10 mm, respectively. It is far superior to that of the corresponding GPS results of 7 mm and 20 mm. The cost of the surveying robot system is also three times cheaper in this set-up. Despite the price disadvantage, GPS could be used in cases where it is not feasible to locate an instrument station for a surveying robot or the environment is too unstable to locate reference control points, such as in open-pit mining area.