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Production of Orthophoto and Volume Determination Using Low-Cost Digital Cameras

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ABSTRACT

The objective of this study was to investigate the capabilities of low-cost digital cameras in volume determination. Low-cost digital cameras are capable of many applications including aerial photogrammetry and close-range photogrammetry. Low-cost digital cameras have the potential to be used in landslide monitoring and mapping. In this study, a low-cost digital camera was used as a tool to acquire digital images of a model of a simulated landslide. The model was constructed using cement and sand with the dimensions of 3m in length and 1m width. Digital images of the simulated model were acquired using the technique of aerial photogrammetry and were subsequently processed using digital photogrammetric software. A portion of the simulated model was excavated to simulate a landslide and volume determination was carried out for the excavated sand. The results showed that low-cost digital cameras can be used in photogrammetric application including volume determination.

Keywords: Low-cost digital camera, orthophoto , DEM, photogrammetry

INTRODUCTION

Landslides are a common occurrence in many countries including Malaysia. Many of the landslides that have occurred in Malaysia have involved the loss of lives and high costs for the parties involved in clean-up and follow-up work. Landslides can occur anywhere in Malaysia without any warning (Talib & Taha, 2005). Most of these landslides occur to manmade slopes and natural slopes based on slope gradient. The Malaysian government has spent millions of Ringgit Malaysia (RM) to manage landslide-prone areas. Landslide analysts are engaged in efforts to find the best method to determine the volume of soil loss after a landslide at the lowest cost (Suhaimi Jamaludin & Ahmad Nadzri Hussein, 2006).

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The best method should be established by landslide analysts to estimate the clearance cost after a landslide. There are many methods of mapping landslides. Aerial photogrammetry, which utilises aerial photographs, is one of the methods that can be used for mapping a landslide area. The aerial photographs show images of the features on the ground, allowing for easy interpretation of the information on the ground. Aerial photographs are usually captured using a metric camera. A metric camera is very expensive and should be handled by skilful, professional personel (Wolf & Dewitt, 2004).

Today, there are many low-cost and high resolution digital cameras of different makes and models that are available in the market. The rapid development of digital technology has created oppurtunity for low-cost digital cameras to be used in acquiring digital images for photogrammetry. These images, which are good quality,can be used in many applications at certain degrees of accuracy. Low-cost digital cameras today provide different image resolutions from low to high. The term “low cost” refers to the low price of the digital camera i.e. less than RM1000 and “high resolution” refers to image resolution of more than 0.5 megapixel. The image resolution is defined by the sum of the number of horizontal pixels multiplied with the number of vertical pixels (Tahar & Ahmad, 2011). In this study, a Nikon Coolpix L4 digital camera which has an image resolution of about 4 megapixels (i.e 2272 pixels x 1704 pixels) was used (Fig.1).

Close-range photogrammetry is a technique in photogrammetry which can be used for obtaining object information from the object to a camera position of less than 100 metres (Atkinson, 1996). Images or photographs can be acquired from locations or positions in the air or on the ground. In this study, the close-range photogrammetry technique is used with a low-cost digital camera attached to a fixed platform. A fixed platform is a platform of fixed height; the low-cost digital camera is attached to a hole drilled on plane wood at a fixed height. In this study, the fixed platform was used to acquire digital aerial images of a simulated landslide model for volume computation.

In the photogrammetric method, a pair of aerial images or photographs with 60% overlap and 30% sidelap is commonly used; these images should comprise well distributed ground control points (GCPs) in the overlap area. The photogrammetric method allows a digital

Fig.1: Nikon Coolpix L4 used in the study

elevation model (DEM) to be generated automatically with a sufficient number of tie points established in the overlap area. In this study, images acquired from the low-cost digital camera were processed to generate a DEM and the material subsequently excavated from the simulated model was used to compute its volume.

METHODOLOGY

This study involves several phases, including volume determination from a simulated landslide model. These phases include flight planning, data collection, data processing and result documentation and analysis. Fig.2 shows the flowchart of methodology used in this study. This study only deals with the fixed platform to obtain digital aerial images of a simulated

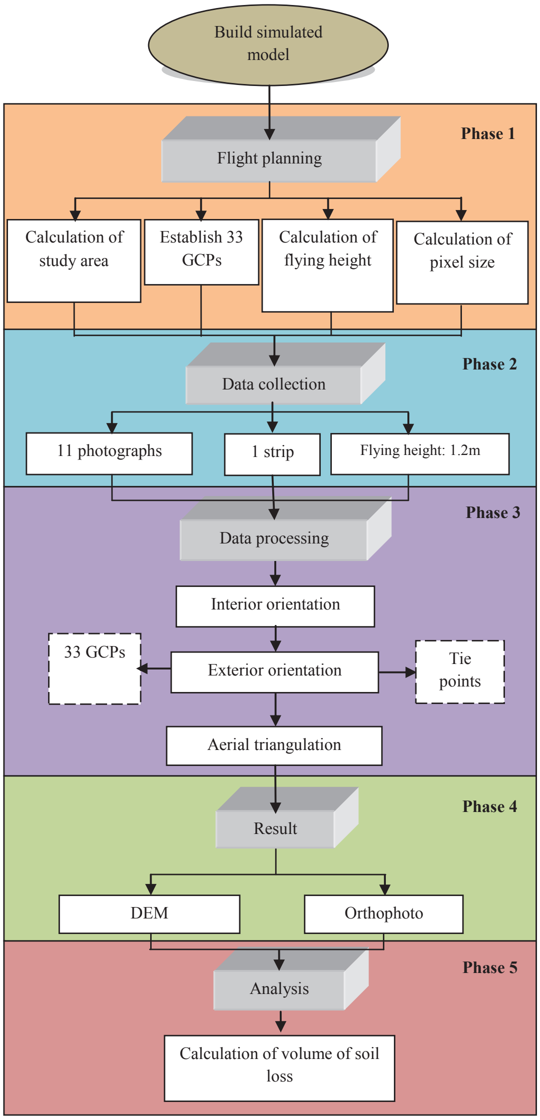

Fig.2: Methodology flowchart

landslide model. The simulated model was constructed using sand and cement with dimensions approximately 3m by 1m. Before photogrammetry work was carried out, all camera information was considered. In digital images, the main issue of importance is pixel size. Pixel size can be calculated using the following formula:

$$\frac{x}{X} = \frac{f}{H} \qquad (1)$$

where x = number of pixel on the image of an object
X = length of the object
f = focal length
H = flying height

Pixel size is calculated based on the number of pixels of the object image, length of an object in real measurement, focal length of the camera and flying height during acquisition of the digital aerial image. After pixel size is calculated, the area of ground coverage can be determined. The area of ground coverage for an image is determined by multiplying the scale of the photography with its dimensions (i.e. length and width).

Flight planning

In this study, flight planning involved calculation of the study area, establishment of GCPs, calculation of flying height and calculation of pixel size. The area of the simulated model was calculated to ensure all segments were covered in the image acquisition stage. In photogrammetry, each pair of overlap photographs should be overlapped by 60% in order to get a 3D photogrammetric product of good quality.

The details of data acquisition are shown in the methodology flowchart where 11 photographs were captured to cover the whole simulated model in only one single strip with a flying height of 1.2m above ground. The flying height was determined based on pixel size and ground dimension. There were 33 GCPs well distributed along the entire simulated model and were established using a total station. GCPs were marked at random on the simulated model and were used in image processing. The coordinates of each GCP were determined using the intersection method for X and Y coordinates while the Z coordinate was determined using the tacheometry method where the Z coordinate is transferred from one point to another point utilising slope angle, horizontal distance and vertical distance.

Camera calibration

In this study, self calibration bundle adjustment was carried out for camera calibration. The low-cost digital camera was calibrated to obtain camera calibration parameters and the best results for image processing. All the camera calibration parameters were utilised in image processing for interior orientation using digital photogrammetric software. Fig.3 shows the position of the camera in camera calibration using the convergence method. The convergence

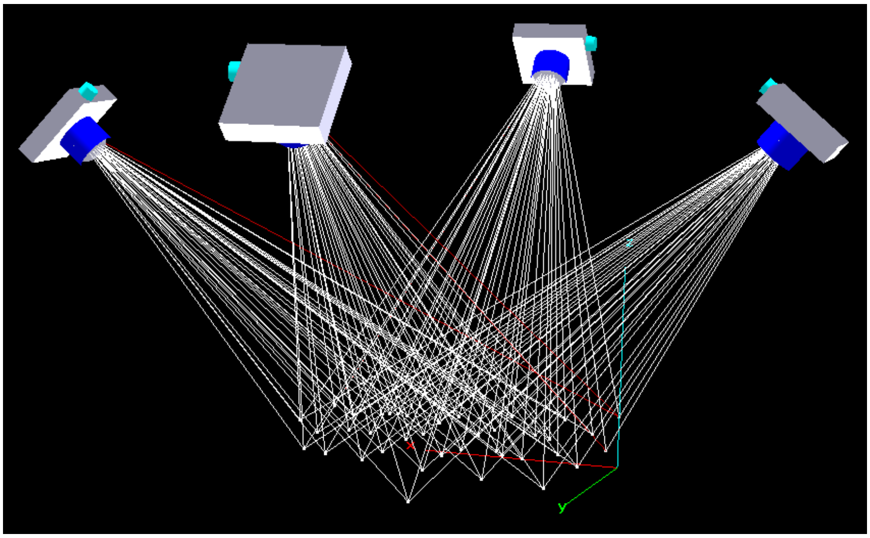

Fig.3: Camera calibration utilising the convergence method

method involves several camera positions in space during camera calibration using a calibration plate. The calibration plate comprises 36 points at different heights and it was arranged in grid form. The image of the calibration plate was captured at four positions. The angle and distance between the camera and plate calibration was approximately the same for the four positions.

The camera calibration process was carried out before it was used for capturing images of the simulated model. The results of the camera calibration are shown in Table 1. There were 10 parameters involved in the camera calibration including focal length (c), principal distance (Xp, Yp), radial lens distortion (K1, K2, K3), tangential lens distortion (P1, P2) and affinity (B1, B2).

TABLE 1
Camera Calibration Results

Camera Id	Nikon Coolpix L4
c (mm)	7.741
Xp (mm)	0.104
Yp (mm)	-0.078
K1	3.6905e-003
K2	-1.0933e-004
K3	6.4657e-006
P1	1.0691e-004
P2	1.1137e-004
B1	-2.4149e-003
B2	-6.0582e-003

DATA PROCESSING

Digital aerial images of the simulated model were acquired and then processed using photogrammetric software. In this study, ERDAS Imagine software was used for the production of photogrammetric products, such as DEM, contour lines and orthophoto. During the interior orientation, camera focal length and pixel size were obtained. GCPs were used for the exterior orientation process. This software needs at least four GCPs in each overlap photograph in order to perform aerial triangulation. The distribution of the GCPs and tie points for this study is shown in Fig.4. The figure shows the distribution of GCPs and tie points after performing aerial triangulation which involved interior and exterior orientations. Figure 4 also shows the footprint of a strip of digital images of the simulated model where the square represents the GCPs and the triangle represents tie points. There are 33 GCPs and 381 tie points used by 11 digital images. The tie points were selected automatically using the software based on image matching where the user could select any number of required tie points. It should be noted that if the surface is homogeneous, such as same tone, colour and texture then the software will fail to determine the tie points. Therefore, it is necessary that the material used, as was the case for the experiment, should be of different colours and textures i.e. not be homogeneous.

RESULTS

Two major results were obtained in this study i.e. digital orthophotos and DEM. The orthophoto for each overlapped pair is mosaiced in order to portray the whole simulated model. The DEM (Fig.5) and orthophotos (Fig.6) were generated after performing interior orientation, exterior orientation and digital mosaic operation. DEM is generated using a combination of GCPs and tie points after aerial triangulation, and the quality of the DEM and digital orthophoto depends on the accuracy of the GCPs. It should be noted that if the quality of the GCPs is poor then the results of the DEM and the digital orthophoto are less accurate.

The accuracy of the assessment of the DEM and the digital orthophoto was based on RMSE, mean and standard deviation of 30 sample dataset after image processing. The accuracy of the digital orthophoto and DEM are illustrated in Table 2.

TABLE 2
Accuracy of Digital Orthophoto and DEM

GCP	RMSE(m)	Mean(m)	Std Dev.(m)
X	0.002	0.001	0.001
Y	0.001	0.001	0.001
Z	0.214	0.147	0.163

ANALYSIS

The objective of this study was to investigate the capabilities of low-cost digital cameras in volume determination. In this study, some portion of the simulated model was excavated to simulate a landslide. DEMs were generated before and after the excavation. The DEMs before and after the landslide simulation were used as a primary data for volume calculation. Fig.7 shows the differences between the DEMs before and after the landslide simulation. It can be seen that the pixel value for

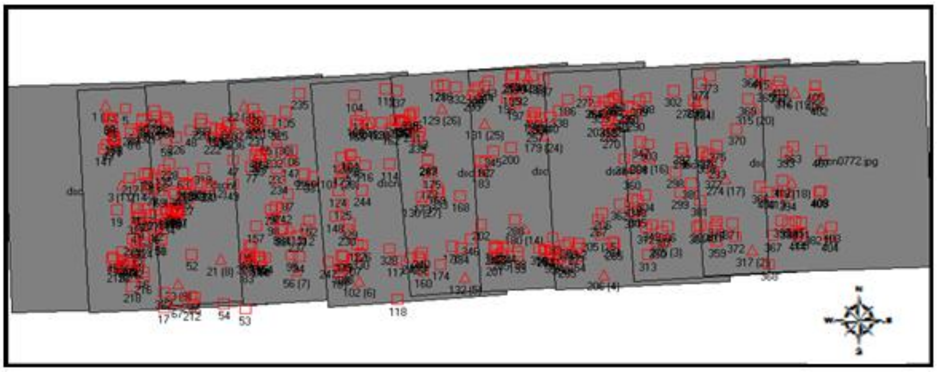

Fig.4: Footprint for a strip of 11 digital aerial images

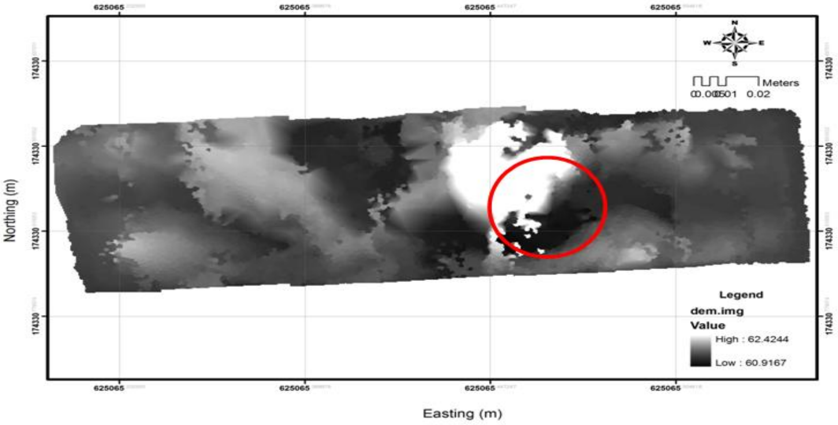

Fig.5: Digital Elevation Model (DEM)

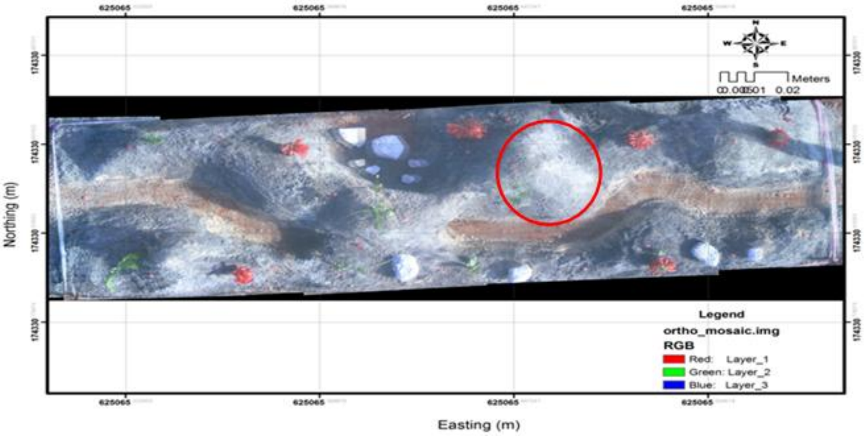

Fig.6: Mosaic of digital orthophotos

the DEM had changed after the excavation or simulated landslide. The two different images were observed in the DEM before the simulated landslide and after the simulated landslide. Contour lines were generated for both situations to determine the flow of landslide behaviour. The shape of the contour lines had changed after the simulated landslide (Fig.8). This figure also shows contour lines superimposed on the DEM in the landslide region. The contour lines followed the direction of the landslide. The data obtained from the DEM and orthophotos were used to generate a TIN (triangular irregular network). A TIN is a generated model for visualising three-dimensional models, in this case, the three-dimensional model of the simulated landslide region.

Fig.9 shows the three-dimensional visualisation before and after the simulated landslide. The TIN models were produced using ArcGIS 9.3 software. Fig.9 also shows the behaviour of the contour lines in the excavated area, which is indeed different compared to before the landslide. The DEMs of the area before and after the landslide were cropped in order to perform the calculation of soil loss volume in the landslide simulation area. Fig.10 shows an example of the landslide area that was cropped for volume calculation.

In this study, two surface profile graphs were produced before and after the landslide simulation, as shown in Fig. 11. The graphs clearly show the change of surface before and after the landslide. In general, the volume of soil loss can be calculated by subtracting DEMs before the landslide and after the landslide. The surface volume tool available in the ArcGIS 9.3 software was used to calculate the volume of soil loss automatically. The formula to calculate the volume of soil loss is as follows:

$$\text{Volume of soil loss} = \text{Volume before landslide} - \text{Volume after landslide} \qquad (2)$$

The area of the landslide was 0.000026m² and the volume of soil loss calculated was 0.002043m³. This result was later validated by comparing it using the conventional method where the excavated soil is placed in a cylinder of diameter 23cm and height 5cm. The volume of soil in the cylinder was found to be 2077.38cm³ or 0.002077m³. The difference in volume between the two methods is 0.000034m³ or 1.64% and can be considered as acceptable as the difference is very small.

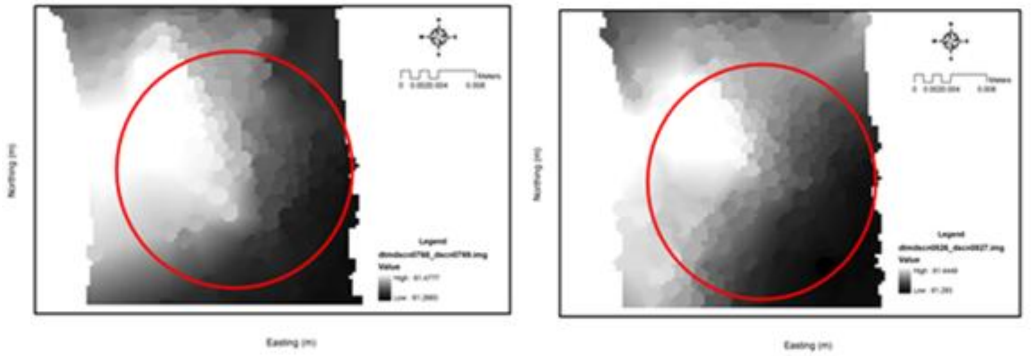

Fig.7: Digital Elevation Model before (left) and after landslide simulation (right)

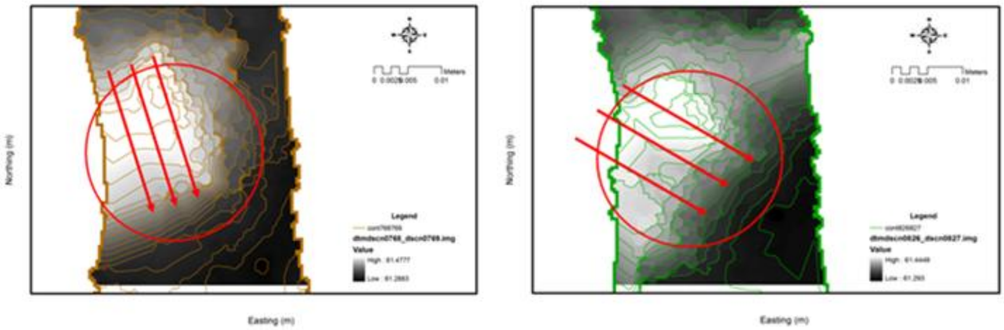

Fig.8: Contour line overlapping with DEM before (left) and after landslide simulation (right)

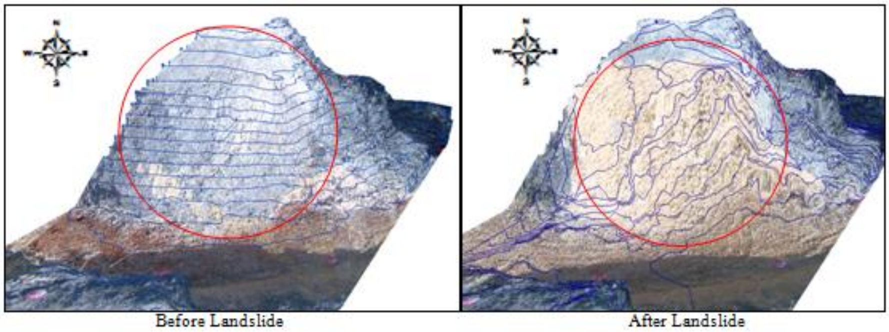

Fig.9: Superimposition of the TIN on the contour lines before (left) and after the landslide (right)

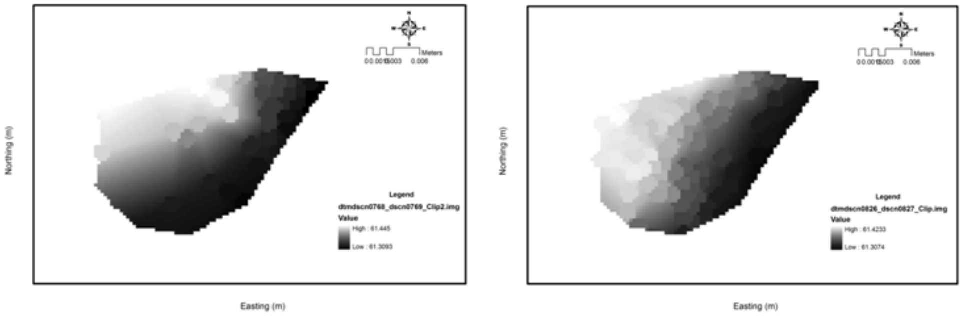

Fig.10: Cropped landslide area before (left) and after the landslide (right) simulation

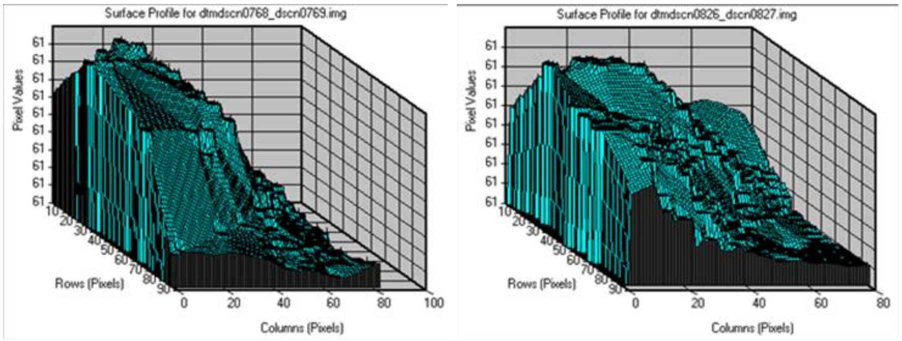

Fig.11: Surface profile graph before (left) and after the landslide (right)

CONCLUSION AND FUTURE WORK

From this study, it can be concluded that volume determination can be performed using low-cost digital camera images. Low-cost cameras might be used in many applications which do not involve a big budget. However, the accuracy of the photogrammetric product from a low-cost digital camera also depends on the accuracy of the GCPs. If good quality GCPs are used then good quality DEMs and orthophotos can be produced. This study successfully demonstrates that low-cost digital cameras are capable of generating DEMs and orthophotos of a simulated model. For future work, the low-cost digital camera can be attached to a mobile platform, known as an unmanned aerial vehicle (UAV), to acquire digital aerial images of the simulated model and subsequently processed using the procedure adopted in this study. The results obtained from this mobile platform can be compared with the results obtained using a fixed platform as done in this study to determine the better method. Finally, it can be concluded that the low-cost digital camera has great potential for use in many applications which require high accuracy.

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