Pertanika J. Sci. & Technol. 22 (1): 123 - 138 (2014)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Assessment of Digital Camera in Mapping Meandering Flume using Close Range Photogrammetric Technique

Udin, W. S.[1]*, Ahmad, A.[2] and Ismail, Z.[3]

[1]*Department of Geosciences, Faculty of Earth Sciences, Universiti Malaysia Kelantan, Jeli Campus, Locked Beg No. 100, 17600 Jeli, Kelantan, Malaysia*
[2]*Department of Geoinformatics, Faculty of Geoinformation and Real Estate, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, Johor, Malaysia*
[3]*Department of Hydraulics and Hydrology, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, Johor, Malaysia*

ABSTRACT

In recent years image acquisition in close range photogrammetry relies on digital sensors such as digital cameras, video cameras, CCD cameras etc that are not specifically designed for photogrammetry. This study is performed to evaluate the compatibility of the digital metric camera and non-metric camera for the purpose of mapping meandering flume, using close range photogrammetric technique and further, to determine the accuracy that could be achieved using such a technique. The meandering flume provides an opportunity to conduct an experimental study in a controlled environment. In this study, the digital images of the whole meandering flume were acquired using a compact digital camera - Nikon Coolpix S560, a Single Lens Reflex (SLR) Nikon D60 and also a metric digital camera Rollei D30. A series of digital images were acquired to cover the whole meandering flume. Secondary data of ground control points (GCP) and check points (CP), established using the Total Station technique, was used. The digital camera was calibrated and the recovered camera calibration parameters were then used in the processing of digital images. In processing the digital images, digital photogrammetric software was used for processes such as aerial triangulation, stereo compilation, generation of digital elevation model (DEM) and generation of orthophoto. The whole process was successfully performed and the output produced in the form of orthophoto. The research output is then evaluated for planimetry and vertical accuracy using root mean square error (RMSE). Based on the analysis, sub-meter accuracy is obtained. It can be concluded that the differences between the different types of digital camera are small . As a conclusion, this study proves that close range photogrammetry technique can be used for mapping meandering flume using both the metric digital camera and non-metric digital camera.

Keywords: Close range photogrammetry, digital camera, mapping, meandering flume, accuracy

Article history:
Received: 5 July 2011
Accepted: 18 December 2012

E-mail addresses:
wanisofia@umk.edu.my (Udin, W. S.),
anuarahmad@utm.my (Ahmad, A.),
zulhilmi@utm.my (Ismail, Z.)
*Corresponding Author

ISSN: 0128-7680

INTRODUCTION

Triangulation is the fundamental principle which is utilized in photogrammetry. Triangulating the coordinates within three dimensional spaces often enable the object to be measured in the photographs. Early development in the theory and science of photogrammetry occurred many years before the actual invention of a suitable means to apply the application. Over the years, photogrammetry has gone through several development phases and has now entered into digital photogrammetry phase. Digital photogrammetry technique has been used for object modelling in various close range applications. Most industrial applications require surveyors to perform dimensional measurements as three dimensional (3D) digital views. Nowadays, the generation of 3D modelling can be achieved by using non-contact systems in co-operating the close range photogrammetry technique. Additionally, images taken by non-metric digital cameras can be utilized in this technique.

The digital camera is categorized as a non-metric camera where the camera is not specifically built for photogrammetric purposes. The digital camera is not characterized with fiducial mark, unstable calibration parameter, small format and many more (Udin *et al*., 2012). "Metric cameras" are specially designed for photogrammetric tasks (Peipe & Stephani, 2003). These cameras have a robust mechanical structure, well-aligned lenses with low distortion and do not have autofocus or other technologies that can uncontrollably change the internal geometry of the camera. All other cameras are referred to as non-metric cameras (Sanz-Ablanedo et al. (2009). The most important difference between non-metric and metric cameras is the stability parameters of the camera. Images used for photogrammetry can originate from a metric camera, an ordinary camera or from digital sensors. The image can be recorded from a device mounted on a satellite, on an aeroplane, or on a tripod which is set up on the ground.

Affordable digital cameras are making photogrammetric practices useful for a variety of applications. An example of this is the river channel studies. According to Geisler *et al*. (2003), research into the hydraulic experiment place considerable emphasis on the riverbed topography measurement, because the measurement of the surface structure of the river is essential in understanding both bed roughness and sediment transport. There are several existing techniques for mapping the surface of the river in the hydraulic model tests such as wool threads, depth pointers, digital photogrammetry, and projection Moire. Optical techniques such as photogrammetry and projection Moire allowed measuring the overall surface of the river bed immediately and with the experimental work to persist without delays. There is considerable evidence of photogrammetry being used to measure river channel information.

Several studies by a number of researchers were conducted (Chandler *et al*., 2001; Chandler *et al*., 2003; Lane, 2000; Lane *et al*., 2001) to develop ideas about the relationships between river channel flow, sediment transport and bed form development. However, in Malaysia the use of close range photogrammetric for the application of mapping stream is seen as a new approach. This paper describes an experimental study conducted for mapping a meandering flume. Close range photogrammetric technique used for data acquisition of the laboratory flume and the images of the flume were acquired using both metric and non-metric digital cameras. The purpose of using stream model is to get some idea on how to gain experience of measuring real stream in the field using close range photogrammetric technique. The digital cameras used are the metric camera Rollei D30, compact camera Nikon Coolpix S560 and Single Lens Reflex (SLR) Nikon D60 as illustrated in Fig.1(a), (b) and (c). Results are discussed and this paper concludes with a brief summary.

Fig.1: (a) Rollei D30; (b). Nikon Coolpix S560; (c). Nikon D60

MATERIALS AND METHODS

In this study, there were seven stages that made up the methodology and it was conducted in a multi-disciplinary way. Fig.2 shows the flow chart of the research methodology.

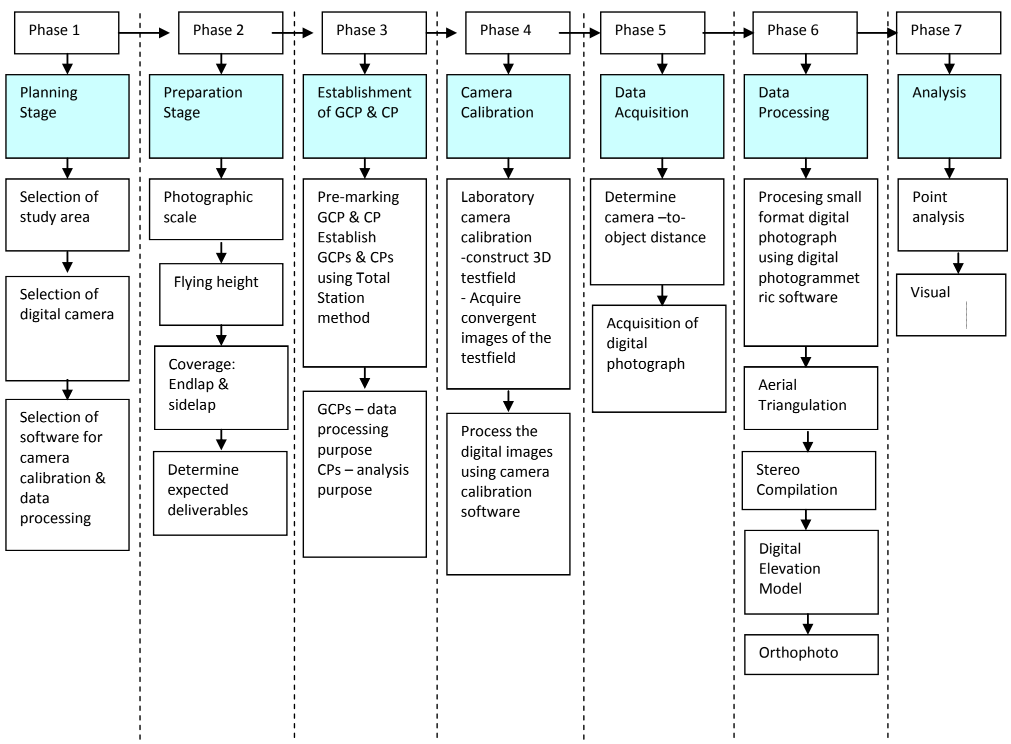

Fig.2: A flow chart of research methodology

Planning Stage

The planning stage included the selection of digital camera and establishment of control point and check point, method of calibrating the digital camera, planning the photography and selection of study area. The boundary of mapping area was determined. Selection of software for camera calibration and data processing was also made. The digital camera is perhaps the most important photogrammetric instrument, since it records the image on which the photogrammetric principles will be applied. Fig.3 depicts a laboratory flow channel or meandering flume. It is located at Universiti Teknologi Malaysia. The dimensions of this flume are 12.0 × 3.0m and the channel width is 0.5m. This laboratory flow channel was used as an attempt to replicate physical structures such as meandering streams found in the real world.

Fig.3: Laboratory meandering flume at UTM

Preparation Stage

The preparation stage is very important and it usually comprises of several steps such as converting project requirements to arrangements in terms of areas to be mapped and the desired map scale. Photogrammetric specifications include photographic height, the number of photographs, the number of strip, pixel size, photo scale, aerial triangulation, map compilation and percentage of end lap and side lap. The project planning stage is very important in as far as to obtain information related to the design and dimension of the mapping object. In addition, the expected deliverables including details on what features to be mapped and their graphic representation in the planning stage is defined.

Establishment of Ground Control Point (GCP) and Check Point (CP)

The ground control points (GCPs) and check points (CPs) need to be planned properly before the acquisition of digital photograph. It is necessary to relate measurements derived from the photographic images to a 3D site coordinate system. The most effective means of achieving this involves placing a number of photogrammetric target points throughout the area of interest.

Photogrammetric control targets (138) were established on the flood plain and inside the channel bed. Ninety (89) GCP were registered as a full control (XYZ) and 49 check points (CPs) were established evenly in the channel bed. The targets must be placed on the meandering flume and maintained until image acquisition is completed. The distribution of the GCPs is flexible and they need to be seen on a pair of photograph (i.e., stereo pair) at known location.

In this study, the designed blocks of the photographs consist of many stereo pairs and they are also used in aerial triangulation. Fig.4 shows where the control points were placed throughout the area of interest. These targets were 10 mm in diameter and of conventional red and black design. Horizontal and vertical angles were measured to these markers from two survey stations and their positions were coordinated using total station. Both horizontal and vertical angles were measured using a Leica TPS1100 total station. It has an automatic function of automatic target recognition (ATR). The ATR fine points to targets by itself. Manual sighting is no longer required. Surveys are completed quicker. Accuracy of total station measurement is 3mm and time for a measurement is 3 seconds.

Apart from 3D coordinates, contour line is also generated for visual purpose. The minimum contour line interval generated is 1.0 metre, while for the maximum contour interval is 5 metres. The maximum contour level is 2.263 metres. Fig.5 shows the contour generated from the survey of photo control targets.

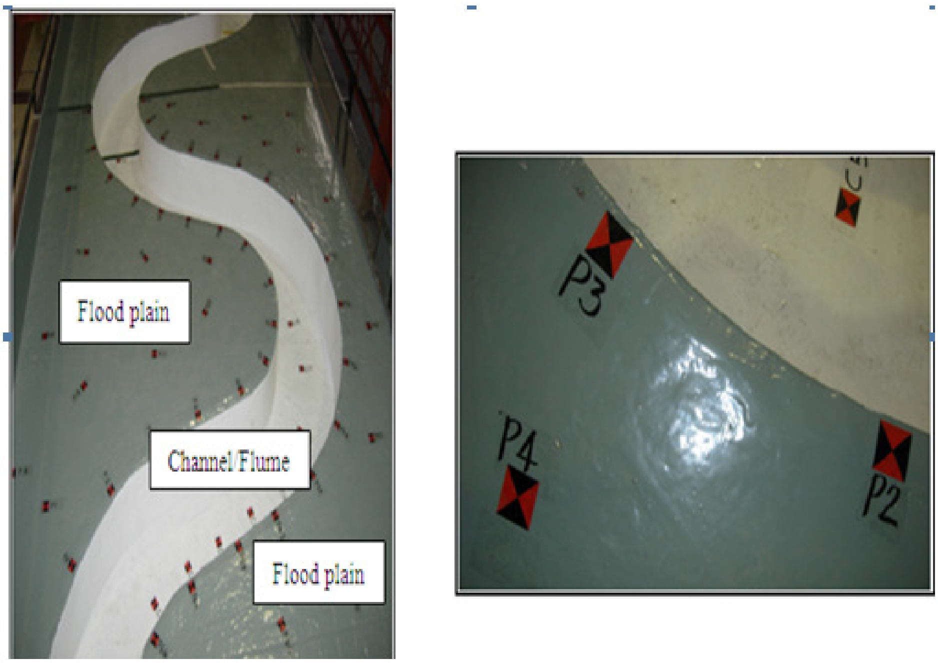

Fig.4: Photogrammetric target points

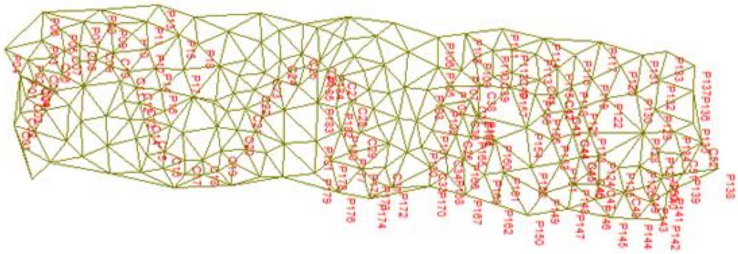

Fig.5: Contour line from installation and survey of photocontrol targets

Camera Calibration

Another critical aspect of photogrammetry is the calibration procedure. It is well established that accurate data can be only extracted if the parameters used to describe the internal geometry of the camera are known accurately (Chandler *et al.,* 2001; Wackrow *et al.,* 2008). The camera must be precisely calibrated to remove errors that are still present in the system. Both metric and non-metric digital cameras were calibrated in a process called self-calibration as a by-product of the actual measurement. The digital cameras were calibrated using a 3D test field. The calibration plate has a dimension of 0.4 meter x 0.4 meter and consists of 36 screws of different heights and arranged in matrix form of 6 x 6 units. Fig.6 shows an example of the calibration plate or test field. Retro-reflective target is adhered on top of each screw.

The digital cameras were used to acquire photographs of the photogrammetric test field at a constant distance (1 metre) from the camera to the midpoint of the calibration plate. Before taking any photographs, a scale bar of known value is placed in the calibration plate or the test field (see Fig.6). The retro-reflective targets were illuminated by the built-in flash on every digital camera. Convergent photographs were taken with eight pieces of photographs for each camera. The photographs were taken with the camera in normal landscape position and then when it was rolled at 90° and the photographs were acquired from four different camera locations in space. The digital camera needs to be rotated to 90° to recover the principle point (Ahmad *et al*., 2003).

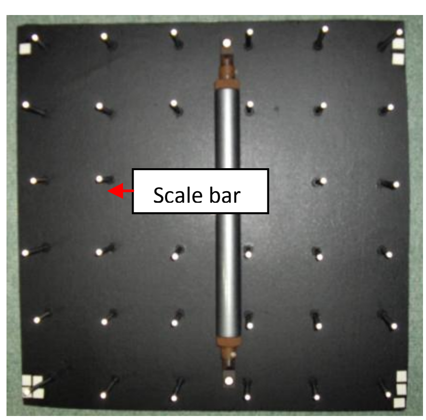

Fig.6: Test field of 0.4m x 0.4m

The images from four different positions were processed using Australis software. Australis performs the self-calibration bundle adjustment process and generates 3D coordinates of all the retro-reflective targets (Australis, 2001). Australis also provides the value of camera calibration parameters of each digital camera. This software can produce a value of precision known as posteriori variance factor (Sigma nought). The smallest value reflects the highest precision. The digital camera was calibrated three times. From the calibration process, 10 parameters were re-covered. However, only 8 parameters were used. According to Fraser (1996) and Shortis *et al*. (1998), not all the re-covered calibration parameters must be used. In this study, the 8 re-covered camera calibration parameters were then used in image processing for surface measurement of the meandering flume. The estimates and standard deviation for the camera calibration parameters are shown in Table 1.

It demonstrates that similar inner orientation parameters, comprising focal length (c), principal point offset (Xp, Yp), and correction terms for radial lens distortion (k 1, k 2, k 3), tangential lens distortion (p 1, p 2), affinity (b 1) and the differences in scale factor (b 2) were recovered for the three digital cameras. By using the convergent configuration network, additional parameters for all the three cameras can be obtained. These parameters should be tested to determine whether it is necessary to compare with stochastical properties. If the estimated value is smaller than the standard deviation, statistical parameter estimation is not required.

Typically, additional parameters that are not necessary and associated with a high correlation between estimate parameters contribute to poor geometry. In this study, every time the camera is calibrated, only a slight difference of focal length is derived for the three cameras based on the observed dataset. However, the focal length of metric Rollei D30 camera is more stable (Udin & Ahmad, 2011).

TABLE 1
Camera Calibration Parameters

Parameter	**Digital Camera**					
	Nikon Coolpix		Nikon SLR D60		Rollei D30	
	Value	Std.Dev	Value	Std.Dev	Value	Std.Dev
c (mm)	7.7622	6.302E-03	21.1541	2.251E-02	10.6458	1.001E-02
Xp	-0.0643	7.667E-03	0.0896	1.935E-02	0.2721	9.605E-03
Yp	-0.1680	7.039E-03	0.1691	1.792E-02	-0.0480	9.859E-03
k1	7.38201E-03	2.777E-04	6.92793E-05	1.068E-04	1.25622E-03	1.439E-04
k2	-8.96198E-04	1.244E-04	6.58291E-06	7.876E-06	2.50733E-05	3.616E-05
k3	1.02754E-04	1.738E-05	-1.32093E-07	1.868E-07	-1.47722E-06	2.843E-06
p1	2.70813E-05	4.945E-05	-1.16266E-05	1.581E-05	-2.36032E-04	3.397E-05
p2	2.21556E-04	4.614E-05	-7.94448E-06	1.549E-05	6.39041E-05	3.324E-05
b1	2.04594E-04	1.098E-04	1.57694E-05	9.723E-05	-1.21875E-04	1.053E-04
b2	-1.50908E-04	1.314E-04	-6.95587E-05	1.112E-04	9.86266E-05	1.215E-04

Acquisition of Digital Image of Meandering Flume

The geometry of the meandering flume along with site constraints present several difficulties when designing the photogrammetric configuration. With digital photography, it is important to obtain adequate exposed images of the desired object using a wide range of pixel radiance values with good contrast. The provision of adequate illumination and selection of appropriate camera exposure settings is therefore critical.

According to Tahar and Ahmad (2012), the main thing that should be considered is pixel size when dealing with digital images. Pixel size will determine the smallest coverage of an area or of the object. The size of pixel engages a few aspects such as the number of pixel for object image, length of an object in real measurement, focal length of the sensor and flying height during the capturing of the images. Furthermore, each digital camera has a different pixel size and it must be calculated during flight planning phase. Pixel size will determine the ground coverage area that was covered by one digital image. The ground coverage area of the images from the digital camera could also be determined by multiplying the scale of the photography with the dimension of the digital image.

The meandering flume is located in a building and the existing lighting is adequate for photography. A moveable gantry across the meandering flume provided an ideal platform to position the digital cameras. The cameras were mounted 1.6m above the bed and were separated from each other by a distance of 0.5m. Such geometry provided approximately 70% overlap between the images with a base to distance ratio of approximately 1:3. The photogrammetric digital normal case was used, in which the camera base is parallel to the object and the camera axes intersect the object plane orthogonally. Images acquired from such geometry allow efficient coverage of an area and provided approximately 60% overlap between the images. Fig.7 depicts a strip of the digital photograph acquired using the SLR digital camera.

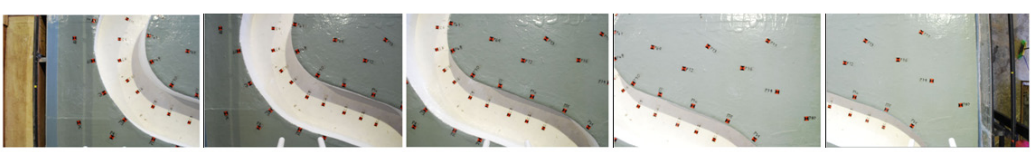

Fig.7: A strip of a digital photograph of the meandering flume

Digital Image Processing

All the digital images of the meandering flume were processed using Erdas Imagine software. Focal length, principal point offset (Xp, Yp) and the physical size of each pixel in the X and Y directions were an essential requirement for initial definition of primary inner orientation of the sensors in OrthoBASE Pro. Once image pyramid layers were generated, the point measurement tool was used to measure each target manually. The OrthoBASE triangulation algorithm, which implements a standard bundle adjustment, was then activated. It was essential to perform the procedures of interior, as well as exterior orientation and measure the control points before performing the triangulation process.

The GCPs are used to perform the aerial triangulation in order to produce a stereoscopic model. All GCPs were registered during exterior orientation. In the software, the 3D stereoscopic model was set up within a short period of time. The measurement of the image locations of the photogrammetric digital control points was performed manually. After the measurement of the first pair of digital images, the "automatic (x, y) drive" setting is activated to automate the measurement of corresponding points appearing on multiple frames. The digital images were added and measured in stereo pairs and the block triangulation tool was executed repeatedly to construct a valid block which was free of gross errors.

The next step was to run the bundle adjustment. This step reconstructs the geometry of the block and provides XYZ locations for the measured points from the previous step. Blunders (mis-measured points) from the previous step may have to be removed to achieve a good result. During image processing, the accuracy was maintained by checking the value of RMSE. The value of RMSE must be less than 1.0 in order to obtain good results. RMS error is reported in pixels. The amount of RMS error that is tolerated can be thought of as a window around each source coordinate, inside which a re-transformed coordinate is considered to be correct (i.e., close enough to use). In this study, the highest RMS error tolerance of 0.17 was indicated by an SLR digital camera. It showed that the re-transformed pixel was 0.17 pixels away from the source pixel and still considered to be accurate. Acceptable RMS error is determined by the end use of the data base, the type of data being used, and the accuracy of the GCPs and ancillary data being used. Acceptable accuracy depends on the image area and the particular project.

After the adjustment succeeds with a good Root mean Square Error (RMSE), the results can be checked via a report file and the stereo pairs visually inspected in stereo. Y-parallax in stereo would indicate a problem with the adjustment. At this point, images have been triangulated and can start creating data products: terrain, orthophotos and 3D features. In this study, the triangulation summary for metric camera and non-metric digital camera are shown in Fig.8(a), 8(b) and 8(c), respectively.

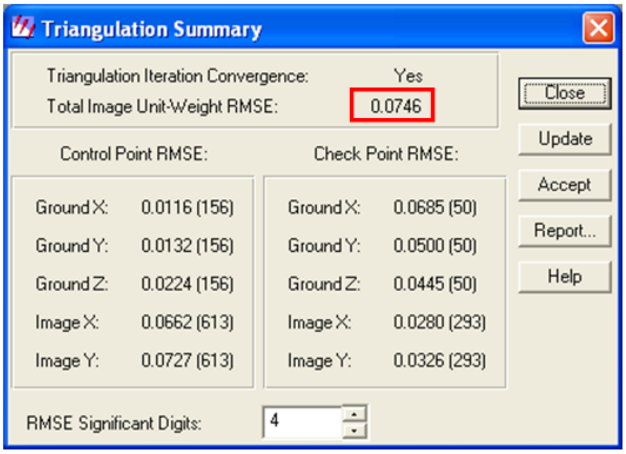

Fig.8(a): Aerial Triangulation (Nikon Coolpix S560)

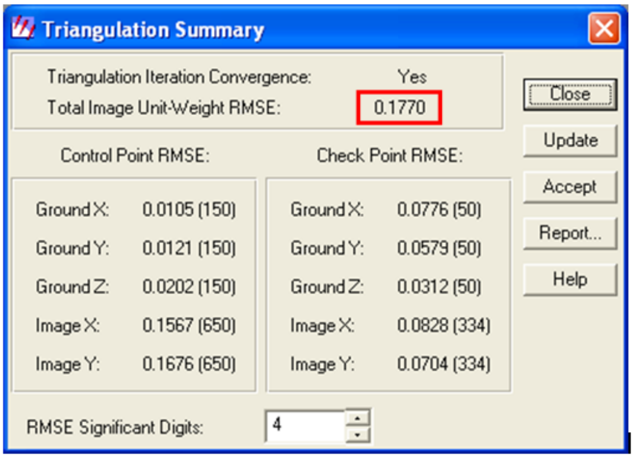

Fig.8(b): Aerial Triangulation (Nikon D60)

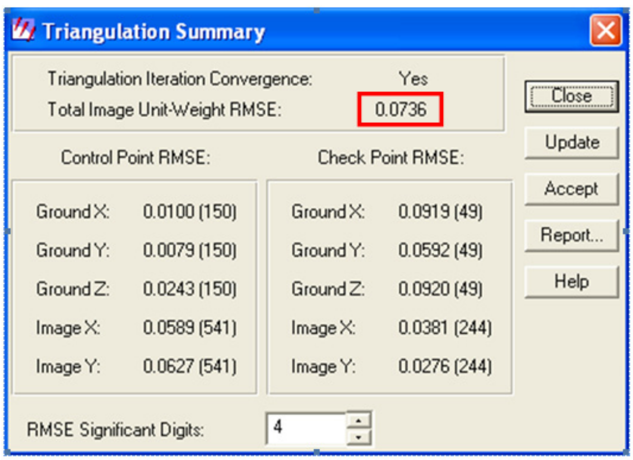

Fig.8(c): Aerial Triangulation (Rollei D30)

After performing AT, the footprint of the AT can be displayed. The foot prints of the digital photographs showing the location and names of all points (i.e., control points, check points and tie points) that participated in the adjustment. The distribution of GCP and CP for the three cameras can be viewed in Figures 9(a), 9(b) and 9(c). It shows the footprint of 100 images. It consists of 50 overlapping pairs based on the most efficient and reliable means of providing stereoscopic coverage to acquire a sequence of overlapping stereo pairs. These results indicate that the metric and non-metric camera can be used to acquire images of the meandering flume where the images were acquired in a controlled environment.

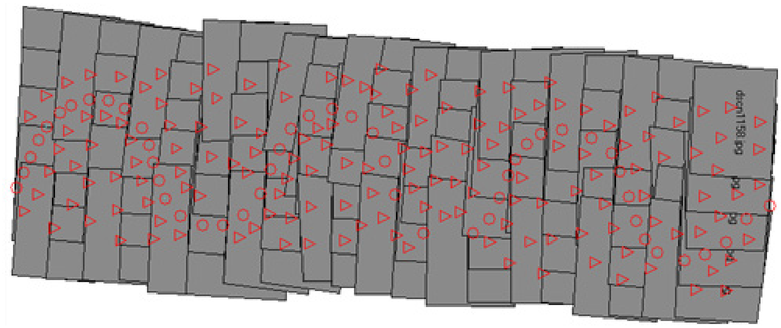

Fig.9(a): Footprint (Nikon Coolpix S560)

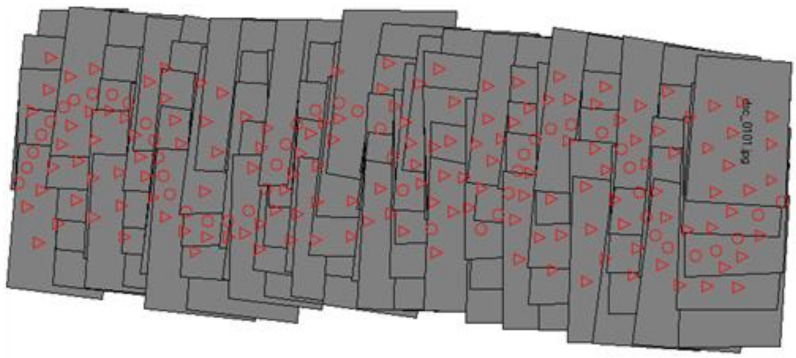

Fig.9(b): Footprint (Nikon D60)

Fig.9(c): Footprint (Rollei D30)

RESULTS

This study was conducted to assess digital cameras in mapping meandering flume (i.e.. controlled environment) and to determine the accuracy that could be achieved from close range photogrammetric technique. One of the important outputs produced after performing interior orientation, exterior orientation and aerial triangulation using Imagine OrthoBASE module is digital orthophoto of the entire flume.

Orthophoto

For orthophoto production, a "bare-earth" terrain model is necessary. Terrain is normally generated with DEM Terrain Extraction, which runs an auto-correlation algorithm to generate terrain points. Orthophotos are the data product created by the photogrammetric processing. Most commercial applications have orthorectification capability. After orthorectification, there may be a need to produce a final mosaic or a tiled ortho output. This is a routine procedure and standard tools within Ortho Rectification-Resampling allow the user to generate this outcome. Individual orthophoto was generated for each individual digital image. These individual orthophoto was then mosaicked together to create a composite orthophoto. Fig.10(a), Fig.10(b) and Fig.10(c) represent digital orthophotos of the entire flume produced from metric and non-metric digital imagery. Digital orthophoto only gives a two-dimensional view which generally involves x and y axis. According to Tahar and Ahmad (2012), the quality of digital orthophoto and DEM depends on the accuracy of GCP. If the quality of GCP is poor, therefore the result of digital orthophoto and DEM will be less accurate.

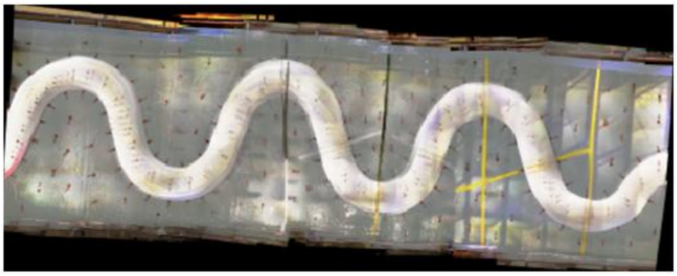

Fig.10(a): Digital orthophoto (Nikon Coolpix S560)

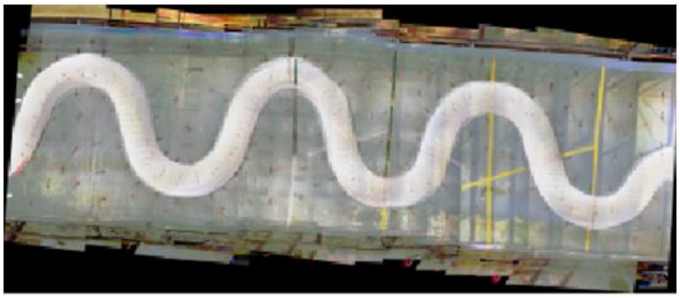

Fig.10(b): Digital orthophoto (Nikon D60)

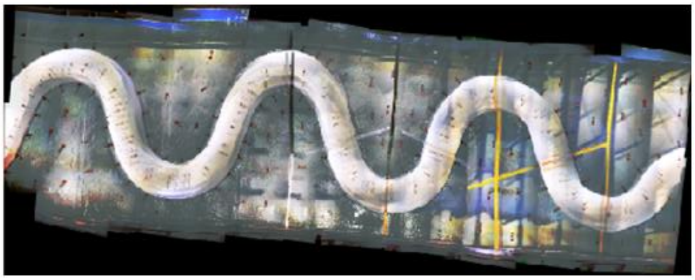

Fig.10(c): Digital orthophoto (Rollei D30)

ANALYSIS

Visual Analysis

Visual analysis is carried out by comparing the results of digital orthophotos generated from different types of camera. In this figure, it is clearly seen that the quality of the orthophoto produced from the metric digital camera was better than those proceeded by the other two non-metric digital cameras.

Based on the generated orthophotos, it can be concluded that there are no gaps or error in overlapping image regions but there are some technical difficulties of this matching process such as spatial continuity or edge matching and radiometric consistency. For spatial continuity, features that appear on more than a single image patch must be continuous. Channel flume must form a continuous meander line and show no jumps at the original photo edges where the images are connected. In the case of radiometric consistency, different photographs may have different contrast and brightness resulting from lack of uniform conditions during the photographic processing or from changes in illumination conditions.

Point Analysis

Assessment of digital camera and evaluation of close range photogrammetry technique in mapping meandering flume were identified as main issues in this study. Determining the accuracy that could be achieved by analysing the residuals of the control points provides a first indication of the accuracy of the network restitution but it is not dependent. On the other hand, using independent check point data would provide a viable means of assessing accuracy. Point analysis was performed by calculating the Root Mean Square Error (RMSE).

In point analysis, the difference between the coordinates obtained from Total Station with the coordinates in Erdas Imagine is calculated to compute the RMSE of the orthophoto produced metric and non metric digital photographs. RMSE is the square root of the variance, known as standard error. However, an assumption is made whereby 3D coordinates obtained from Total Station becomes the most principal reference and it is used for comparison of 3D coordinates in deriving accuracy of measurement. The smaller the RMSE calculated, the higher the accuracy of orthophoto produced. Hence, the accuracy of orthophoto is influenced by the RMSE value. Based on the analysis, sub-meter accuracy (<1 metre) is obtained. The achievable accuracy for the entire flume using a number of check points are summarised in Table 2.

Table 2
RMSE of digital imagery orthophoto and Total Station

Camera	Aerial Triangulation	GCP	RMSE(m)	Variance(m)
Nikon Coolpix	89 GCPs 49 CPs	ΔX ΔY ΔZ	±0.0159 ±0.0486 ±0.0432	±0.0003 ±0.0024 ±0.0019
Nikon SLR D60	89 GCPs 49 CPs	ΔX ΔY ΔZ	±0.0233 ±0.0572 ±0.0292	±0.0005 ±0.0033 ±0.0009
Rollei D30	89 GCPs 49 CPs	ΔX ΔY ΔZ	±0.0281 ±0.0535 ±0.0862	±0.0008 ±0.0029 ±0.0074

Based on Table 2, the accuracy of horizontal coordinates were low for the three types of camera but the accuracy can still be measured until centimetre level. Hence, it can be accepted in photogrammetric work. However, the accuracy of vertical coordinates was very high but it was constant for three sensors. Based on the table, it can be seen that the values of RMSE for metric and non-metric cameras were not significant. It might be affected by image matching algorithm that was used in the same software during image processing. The error might also be caused by image matching during image processing and motion movement during image acquisition.

Fig.11 shows the graph of RMSE versus ground control X, Y and Z for different types of digital camera. It was found that the residual error was not significant for all sensors. RMSE for ground control x and y was not much different but it was considerably different for ground control z , which represented the result for metric and non-metric cameras, respectively. The difference on ground control z might occur due to the effect of the automated tie point which implemented the image matching technique. The constant error of ground control z will be discussed further in a forthcoming paper and the method to improve the accuracy will be discovered.

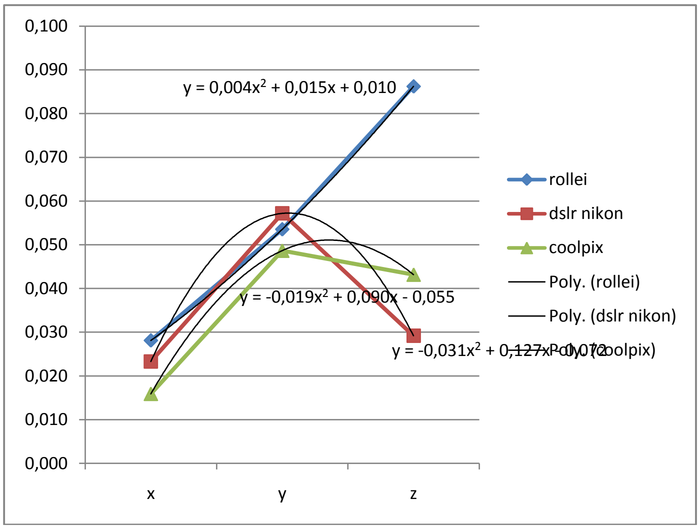

Fig.11: Root mean square error (x, y, and z)

CONCLUSION

This study demonstrates that digital close range photogrammetry technique which utilizes a metric and non-metric digital camera is capable of mapping meandering flume successfully. The configuration of the photographs acquired has a direct impact upon the production of DTM and orthophoto. Besides, the achievable accuracy was found to be dependent upon other photogrammetric digital controls such as camera calibration and control point coordinates related to the grounds station network. When all of these errors are propagated and summed up following a valid error theory methodology, one can assess the spatial accuracy of the final product. Metric camera is already well known and proven (due to its correction parameters) to be the best camera for the photogrammetric application. For accuracy assessment, it was found that the performances of the non-metric and metric digital cameras in terms of RMSE for ground control x and y were not much different but it was considerably different for ground control Z. Both types of digital cameras were capable of producing orthophotos of the meandering flume but the pictorial quality of orthophotos produced by non-metric cameras was not as good as that produced by the metric camera. This study shows in all certainty that good results could be produced from the metric digital camera. However, this study also demonstrates that the non-metric camera was also capable of producing good results compared to the metric digital camera. In conclusion, all the digital cameras used in this study have the potential to be used for this application and other various applications where accurate measurement is required. This study also provides a guideline for digital camera users to select the appropriate digital camera for any applications. Finally for any future work, it is hoped that this research will be expanded to determine the accuracy and cost for data acquisition in places with large areas (i.e., measurement of the real stream in an uncontrolled environment). Furthermore, it is also hoped that a variety of sensors can be explored in stream mapping. Among the factors that make close range photogrammetric technique suitable for mapping stream is that it is a practical approach in Malaysia and no in-depth study has been carried out using this method prior to this. Close range photogrammetric technique adopted in this study could be benefited by various agencies in Malaysia such as the Department of Irrigation and Drainage, the Department of Environment and other government agencies or the private sector whose work involves streams and rivers.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of the Faculty of Geoinformation and Real Estate, Universiti Teknologi Malaysia, in conducting this study. The authors also would like to express their appreciation to Universiti Malaysia Kelantan (UMK) for their support in this study. Further, the authors would like to thank the Research Management Centre (RMC) of Universiti Teknologi Malaysia for their guidance and support in this study.

REFERENCES

Ahmad, A., Busu, I., & Desa,G. (2003). Digital Close Range photogrammetry: Calibration of Different Digital Sensor Using Different Field Test and Application. *International Symposium and Exhibition on Geoinformation 2003*, 13-14 October. 2003, Shah Alam, Selangor, MALAYSIA.

AUSTRALIS (2001). *User manual*. Department of Geomatic Engineering, University of Melbourne, Australia.

Chandler, J. H., Buffin-Belanger, T., Rice, S., Reid, I., & Graham, D.J. (2003). The Accuracy of River Bed Moulding/Casting System and The Effectiveness of a Low-Cost Digital Camera for Recording River Bed Fabric. *The Photogrammatic Record*, *18*(103), 209-224.

Chandler, J. H., Lane, S. N., Shiono, K., & Rameshwaren, P. (2001). Measuring Flume Surface for Hydraulics Research Using a Kodak DCS460. *Photogrammetric Record*. *17*(97), 39–61

Chandler, J. H., Wackrow, R., Sun, X., Shiono, K., & Rameshwaren, P. (2008). Measuring Dynamic River Flooding and Surface by Close Range Digital Photogrammetry. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol.* XXXVII (B7) Beijing, China.

ERDAS. (2001). Imagine OrthoBASE User's Guide. Erdas Inc. 524 pages.

Fraser, C.S. (1996). Industrial Measurement Application in Close Range Photogrammetry and Machine Vision. Whittles Publishing, Caithness, Scotland, U.K

Geisler, T., Breitenstein, S., Hammer, A., Mayr, D., & Klasinc, R. (2003). Hydraulic Modeling-Mapping of River Bed. *XXX IAHR Congress*, AUTh, Thessaloniki, Greece.

Lane, S. N. (2000). The Measurement of River Channel Morphology Using Digital Photogrammetry. *Photogrammetric Digital Record*, *16*(96), 937-961.

Peipe, J., & Stephani, M. (2003). Performance Evaluation of a Megapixel Digital Metric Camera for Use in Architectural Photogrammetry. In *Proceedings of the XX International Congress for Photogrammetry and Remote Sensing.* Ancona, Italy, July 2003, pp. 259-262.

Samad, A. M., Ahmad, A., & Ishak, N. (2010). Assessment of Digital Camera for Mapping Stream using Close Range Photogrammetric Digital Technique*. 2010 6th International Colloquium on Signal Processing & Its Application. (CSPA 2010),* 21-23 May 2010, Malaca City, Malaysia.

Sanz-Ablanedo, E., Rodriguez-Perez, J. R., Arias-Sanchez, P., & Armesto, J. (2009). Metric Potential of a 3D Measurement System Based on Digital Compact Cameras. *Sensors*, *9*, 4178-4194.

Shortis, M. R., Robson, S., & Beyer, H. A. (1998). Principal Point Behaviour and Calibration Parameter Models For Kodak DCS Cameras, *Photogrammetric Record. 16*(92), 165-186

Tahar, K. N., & Ahmad, A. (2012). A Simulation Study on the Capabilities of Rotor Wing Unmanned Aerial Vehicle In Aerial Terrain Mapping. *International Journal of Physical Sciences, 7*(8), 1300 - 1306.

Udin, W. S., & Ahmad, A. (2011). Calibration of High Resolution Digital Camera Using Self-Calibration Bundle Adjustment Method. *2011 IEEE 7th International Colloquium on Signal Processing and Its Applications* (CSPA), 4-6 March 2011, Penang, Malaysia.

Udin, W. S., Hassan, A. F., Ahmad, A., & Tahar, K. N. (2012). Digital Terrain Model Extraction Using Digital Aerial Imagery of Unmanned Aerial Vehicle. *2012 IEEE 8th International Colloquium on Signal Processing and Its Applications* (CSPA), 23-25 March 20102, Malacca, Malaysia.

Wackrow, R., Chandler, J. H., & Gardner, T. (2008). Minimising Systematic Errors in DEMs Caused by Inaccurate Lens Model. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXVII(Part B5).*Beijing 2008.

Yakar, M., & Yilmaz, H. M. (2008). Using In Volume Computing of Digital Close Range Photogrammetry, *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B3b.* Beijing 2008.