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## DEVELOPMENT OF MOBILE MAPPING SYSTEM USING GPS AND PHOTOGRAMMETRY TECHNIQUE

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### Abstract

*The development of Mobile Mapping System (MMS) is still at initial stage in Malaysia. The research in MMS has been carried out quite awhile since the first prototype introduced by the Center of Mapping at The Ohio State University (Bossler et.al., 1991). This system integrates some navigation sensor such as Global Positioning System (GPS), inertial navigation system (INS) and mapping sensor such as Charge Coupled Device (CCD) camera. The strength of the MMS lays in their ability to directly georeferenced their mapping sensor by GPS. A mapping sensor is georeferenced when it is positioned and orientated relative to a known mapping coordinate frame. Once georeferenced, the mapping sensor can be used to determine the position of object points bases on the digital image in the same mapping coordinate frame. This research concentrates on georeferencing the geographic and topographic features and updating a GIS (Geographic Information System) base map using consumer digital camera and GPS positioning technique. The GPS provides the position of the camera and the images from the camera are used to determine the geodetic position of the object points using PhotoModeler software and developed program.*

### 1.0 INTRODUCTION

The last two decades have shown an increased trend in the use of GPS technology in several applications in Malaysia which included land vehicles and automated car navigation, GPS-equipped KLIA limousines, land and marine survey job which currently applied in private sector and government sector such as the Department of Surveying and Mapping Malaysia, deformation monitoring and others.

The development of Mobile Mapping System (MMS) is still at initial stage in Malaysia. The research in MMS has been carried out quite awhile since the first prototype introduced by the Center of Mapping at The Ohio State University (Bossler et.al.,1991). This system integrates some navigation sensor such as Global Positioning System (GPS), inertial navigation system (INS) and mapping sensor such as Charge Coupled Device (CCD) camera.

The strength of the MMS lays in their ability to directly georeferenced their mapping sensor (i.e *digital camera*) by GPS. A mapping sensor is georeferenced when its position and orientation relative to a known mapping coordinate frame. Once georeferenced, the mapping sensor can be used to determine the positions of points external bases on the digital image in the same mapping coordinate frame.

This research is concentrates on mapping the geographic and topography features and updating map using a consumer digital camera and GPS positioning technique. The GPS provides the position of the digital camera and the images from the digital camera are used to determine the positions of the object of interest.

## **2.0 LITERATURE REVIEW**

The mobile mapping technology has been developed since 1980's. The development of the mobile mapping system became possible due to the availability of GPS signal to the civilian community.

During the past year, tremendous advances have taken place in GPS technology especially the satellite receiver, data collection hardware and field data collection software. The autonomous GPS accuracy has been improved, the data collectors have become smaller, lighter, and less expensive. The GPS and GIS software has become cheaper and easier to learn. All of these advancements have made the GPS/GIS data collection tasks easier, faster and more economical.

Each GPS satellite transmits signal on two frequencies: L1 (1575.42 Mhz) and L2 (1227.60 Mhz). The L1 frequency contains the civilian Coarse Acquisition (C/A) Code as well as the military Precise (P) Code. The L2 frequency contains only P code. The P code is encrypted by the military- using a technique known as anti-spoofing and is only available to authorized personnel. The encrypted P code is referred to as the Y code. Civilian GPS receivers use the C/A code on the L1 frequency to compute positions, although high-end survey grade civilian receivers use the L1 and L2 frequencies' carrier waves directly. Military GPS receivers use the P (Y) Code on the both L1 and L2 frequencies to compute positions.

GPS receivers need at least three satellites for computation. Satellites position computation method is called trilateration. This position is accurate from about 10 to 15 meters. Now that selective availability, an intentional degradation of the satellites signals, has been turned off down to centimeters or less, depending on equipment and conditions.

It is important to understand that there are some amounts of uncertainties or errors, inherent in these positions. A number of factors that contribute to these errors, which included satellite clock drift, atmospheric conditions, measurement noise and multi-path. In addition, due to the satellite geometry, vertical accuracy (i.e elevation) is generally one and a half to three times worse than horizontal accuracy.

For close range photogrammetry, due to recent advances in micro-electronics and semiconductor technology, photogrammetry in general has received a substantial push forward towards the fully digital domain. The development of new sensors, such as solid state camera, and more powerful computer hardware has opened new technologies and fields of application. Hybrid and fully digital acquisition and processing system have triggered much interest among photogrammetrist since the 15<sup>th</sup> International Congress of Photogrammetry and Remote Sensing in Rio de Janeiro in 1984. Within ten years, digital close range photogrammetry has matured to the extent that it can now serve as a precise and reliable technique for non-contact three-dimensional measurement. The ease and speed of data acquisition, the inherent on-line and even real time capabilities, the high degree of automation and the adaptability to varying the requests have made it a viable measurement tool for a great number of different applications in science, art and industry. (Akinson,1996)

The position of a point in space is commonly defined by a three dimensional Cartesian coordinate system, the origin, scale and orientation of which can be arbitrarily defined. It is often necessary to convert between coordinates in systems having different origins, orientations and possibly scale (Akinson,1996). In other words, it is needed to define coordinate of points with reference to a coordinate datum related to features on the object itself, it may then necessary to define the points to a new datum.

MMS is capable of observing the objects at closer range, thus giving greater details. Land-based MMS uses digital cameras as imaging sensors. This was possible because of the much smaller camera-to-object distance in land-based MMS when compared to air-borne systems. The poor resolution of CCD chips

meant that they could not be used in aerial applications without noticeable accuracy degradation (El-Sheimy, 1999). The use of digital camera is advantageous because they eliminate the requirement to scan photographs. Consequently they substantially reduce the period from raw data collection to extracted data dissemination.

MMS integrates navigation sensors and algorithms together with sensors that can be used to determine the positions of points remotely. All the sensors are rigidly mounted together on a platform. The navigation sensors are used to determine the position and orientation of the platform and the algorithms determine the position of points external to the platform. The sensors that are used for remote position determination are predominantly photographic sensors and thus they are typically referred to as imaging sensor (El-Sheimy, 1999).

Land vehicle based mobile mapping systems result in, among others, a) close distances between the systems and the objects to be surveyed, b) no ground control and no triangulations across images exposed at different times, and c) completely digital processing. These systems are designed mainly for mapping purposes. Different approaches to the system design and implementation have been used. (R. Li, 1999)

The strength of MMS lies in their ability to directly georeference their mapping sensors. A mapping sensor is georeferenced when its position and orientation relative to the mapping coordinate frame is known. Once georeferenced, the mapping sensor can be used to determine the position of points external to the platform in the same mapping coordinate frame. The MMS is fundamentally different from the traditional indirect georeferencing where the position and orientation of the platform are determined using measurements made to control points. These control points are established through a field survey prior to or after the data acquisition. This is typically time consuming. (Joao Fernandes, C. Da Silva 2003)

The system operation can be divided into three components: raw data acquisition, georeferencing of the digital images, and 3D feature extraction. Data acquisition begins by supplying power to the system while it is stationary. The IMU uses this time to "warm up", while the GPS receiver uses this time to resolve integer ambiguities. After this warm up period, which lasts several minutes, it's then free to capture images of points or objects of interest - ensuring that each point or feature of interest is captured in at least two images.

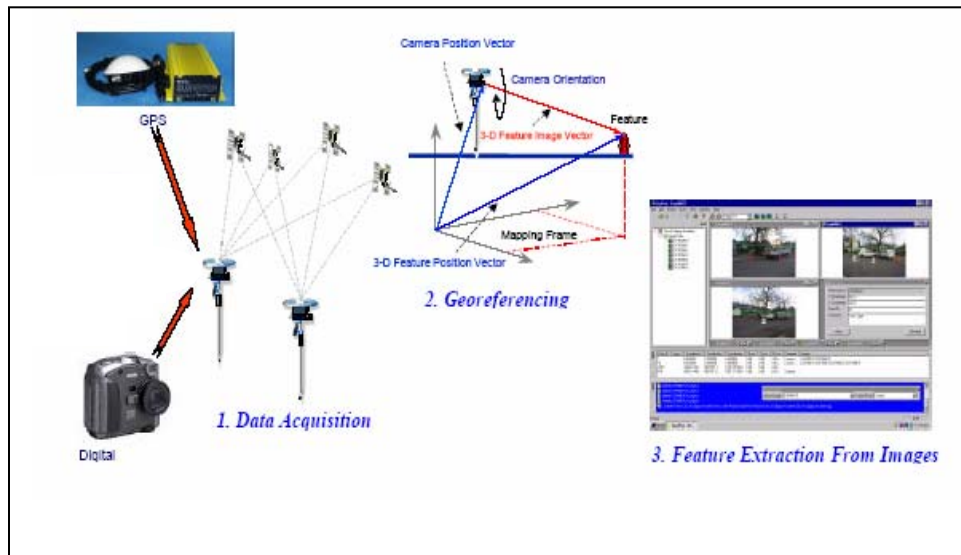
Once the data collection is completed, the images and navigation data from the INS and GPS sensor are downloaded to a personal computer. Then the INS and GPS data is processed and the digital images are georeferenced using particular software. Finally, using photogrammetric principles, two or more georeferenced digital images, 2D and 3D positions of any point or object that is visible in two or more images can be determined.

### **3.0 PROBLEM STATEMENT**

The conventional method of mapping, such as aerial-photo interpretation and field surveys are coupled with the use of different remote sensing methods and all the data are integrated within a GIS environment. Limitation of traditional land-based surveying systems is the necessity to occupy each point of interest. The analysis of remote sensing data regards both optical and radar images. The processing of these conventional methods is more difficult, time consuming and cost higher. The use of digital camera is advantageous because it eliminates the requirement to scan photographs and it would substantially reduce the period from raw data collection to extracted data dissemination.

In MMS, direct georeferencing is done by using GPS and INS to determine the camera position and orientation. This is fundamentally different from traditional indirect georeferencing where the position and orientation of the platform are determined using measurements made to control points.

These control points are established through a field survey prior to or after data acquisition, and their establishment is typically expensive and time-consuming. Therefore, eliminating this step results in obvious decrease in both the cost and time requirements for data collection. The task of establishing ground control is additionally complicated since its cost and time requirement are frequently difficult to estimate. Also, for many terrestrial surveys the establishment of sufficient ground control is virtually impossible, for example; consider the control requirements to map an entire city using close range photogrammetry. The establishments of these ground controls are not practical unless direct georeferencing is performed. Figure 1 below shows the integration between GPS and photogrammetry in mobile mapping.



**Figure 1: Mobile Mapping System**

The final output is easily integrated with the Geographic Information Systems (GIS). Cartography and GIS have increased their presence in the modern days. This new situation requires spatial databases. Modern data requirements necessitate distinct solutions for acquisition of spatial information. The growing use of GIS technology and the consequent necessity to update information increases the importance of an environment to handle spatial data and information that will be even more demanding. An efficient electronic deposit of a large quantity of road images obtained by the mobile system is envisaged, whereby an image database is required to manage growing volume of data and images (Joao Fernando et al., 2003).

#### **4.0 SYSTEM CONFIGURATION**

The GPS antenna and camera are mounted on a roof rack of a van. The two GPS antenna are set parallel to 1 side of the vehicle to define the position and azimuth. The camera is located in the extension of the antenna. Figure 2 shows the system design.

In this study, the instrumentation used includes a digital camera (Kodak DC290) and Trimble GPS receiver. Also, a photogrammetry software for the close range photogrammetry known as PhotoModeler

will be used. Matlab will be use for computer programming. Figure 3 shows the digital camera, GPS receiver, Photomodeler and Matlab.

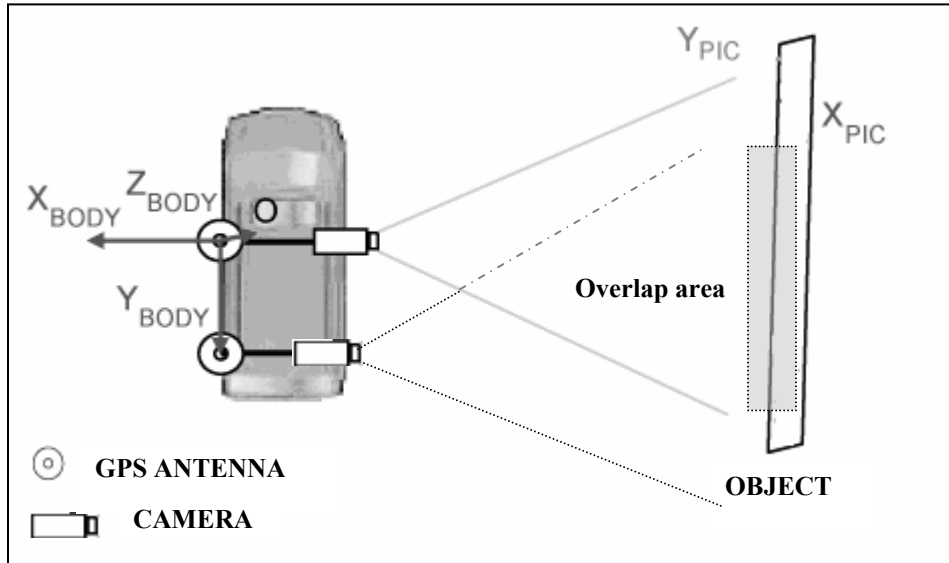


Figure 2: System Design



Figure 3: Photomodeler, digital camera, Trimble Receiver and Matlab

#### 4.1 Mapping sensor

Kodak DC290 zoom digital camera will be used in this research. The resolution of the camera is 1792 x 2100 mega pixels.

#### 4.2 GPS Positioning

GPS Trimble 4800 is use in determine the position of the camera station. Stop And GO technique is applied to shorten the field measurement period. The data is process using TGO (Trimble Geomatic Office).

### 4.3 PhotoModeler

PhotoModeler is one of the close range photogrammetry software produces by Eos System. It is a windows program which is good in extract measurements and 3D models from photographs. By using a camera as an input device, the mapping scenes are captured. It then organizes the model building process as trace over photos on the screen.

To use PhotoModeler, one or more photographs of a scene or an object are taken. The photographs are displayed on screen and each photograph is mark with the mouse, tracing and tagging features of interest. PhotoModeler then combines the data and locates the marked features in three dimensions. The result is a 3D model that can be transferred to any graphics or CAD program. In this research, Photomodeler is used to determine the object position in local coordinate system.

### 4.4 Matlab

MATLAB is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numerical computation. It can also display information graphically. The photographs apply with photo coordinates are process using collinearity equation with MATLAB. The outputs of the program are object coordinates of the selected mapping object.

## 5.0 CAMERA CALIBRATION

Before carrying out survey on sites, the camera calibration has to be performed. Camera calibration is the process of determining the characteristic of a camera so it can be used as a measurement device. Figure 4 shows the calibration grid provided in PhotoModeler. To obtain the required data of camera calibration, six or more photographs taken from different angles of a dense point grid are needed. Figure 5, shows the photographs of the grid taken at different positions.

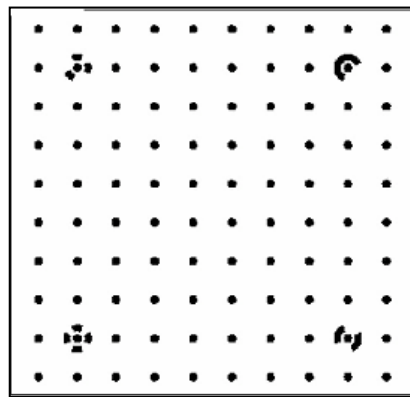


Figure 4: Calibration grid

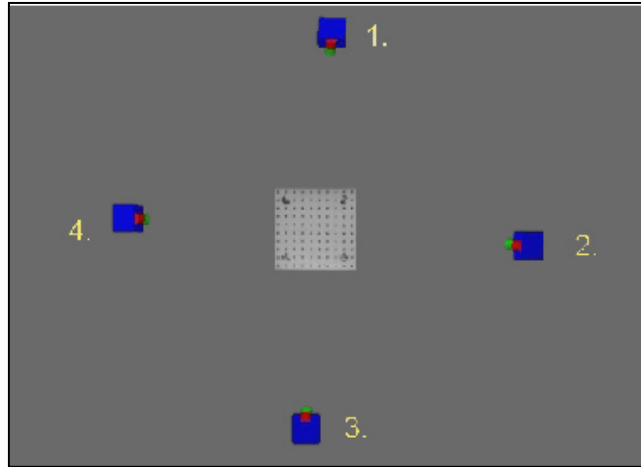


Figure 5: Photograph taken at different position

The purpose of camera calibration is to determine numerical estimates of the interior orientation parameter of the implemented camera. The interior orientation parameter comprises the focal length(c), location of the principle point (xp,yp) and lens distortion (K1,K2,K3,P1,P2). Figure 6 shows the information of the calibrated camera.

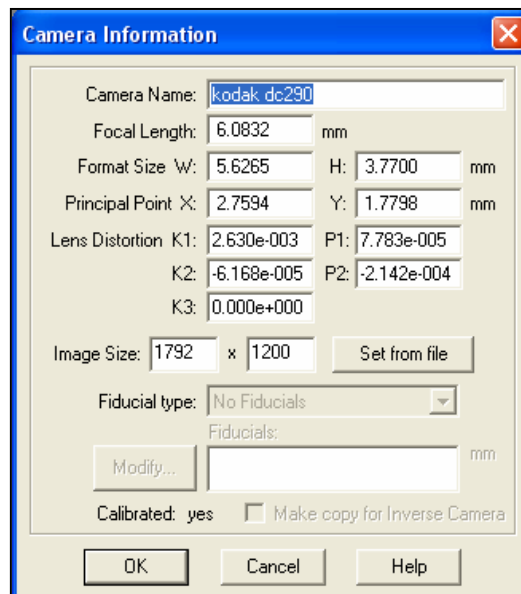


Figure 6: Camera Information

## 6.0 MATHEMATICAL PROCESSING

The object coordinate is established by the collinearity equation. In accordance to the collinearity condition, every object point, its image and the projection center, should belong to a straight line. A distortion in the image signifies that there is a deviation from collinearity. The collinearity equation, which define the relationship between the image and ground coordinates of a point in the image are as follow:

$$F_x = x_i - x_0 + f \frac{m_{11}(X_i - X_0) + m_{12}(Z_i - Z_0) + m_{13}(Y_i - Y_0)}{m_{31}(X_i - X_0) + m_{32}(Z_i - Z_0) + m_{33}(Y_i - Y_0)} = 0$$

$$F_y = y_i - y_0 + f \frac{m_{21}(X_i - X_0) + m_{22}(Z_i - Z_0) + m_{23}(Y_i - Y_0)}{m_{31}(X_i - X_0) + m_{32}(Z_i - Z_0) + m_{33}(Y_i - Y_0)} = 0$$

- $m_{11} = \cos \phi \cos \kappa$
- $m_{12} = \sin \omega \sin \phi \cos \kappa + \cos \omega \sin \kappa$
- $m_{13} = -\cos \omega \sin \phi \cos \kappa + \sin \omega \sin \kappa$
- $m_{21} = -\cos \phi \sin \kappa$
- $m_{22} = -\sin \omega \sin \phi \sin \kappa + \cos \omega \cos \kappa$
- $m_{23} = \cos \omega \sin \phi \sin \kappa + \sin \omega \cos \kappa$
- $m_{31} = \sin \phi$
- $m_{32} = -\sin \omega \cos \phi$
- $m_{33} = \cos \omega \cos \phi$

- $x_i, y_i$  = image coordinates of points
- $x_0, y_0$  = principle points
- $f$  = focal length
- $X_0, Y_0, Z_0$  = camera positions
- $X_i, Y_i, Z_i$  = geodetic coordinate of object point

### 6.1 Exterior Orientation

The exterior orientation consist of camera positions ( $X_c, Y_c, Z_c$ ) and the exterior orientations of the camera, which are rotation through x-axis ( $\omega, \omega$ ), rotation through y-axis ( $\phi, \phi$ ), rotation through z-axis ( $\kappa, \kappa$ ). The camera position is determined by GPS and checking with the processed camera's coordinates in PhotoModeler, the camera orientation parameters ( $\omega, \phi, \kappa$ ) are determined using the PhotoModeler.

Figure 7 shows the exterior orientation of the camera can be retrieved after processing the photographs in PhotoModeler. Figure 8 shows the relations between object points and camera positions in 3D model.

Photo #	Description	Center X (m)	Center Y (m)	Center Z (m)	Omega (deg.)	Phi (deg.)	Kappa (deg.)
1	p0003276	626919.23	172520.265	35.6	99.606816	-3.862796	0.319833
2	p0003277	626909.8032...	172521.07576	35.272304	106.322253	-33.629443	6.923125
3	p0003278	626932.9665...	172522.0142...	35.889796	105.089829	34.382877	-6.179192
5	P0003250	626919.4576...	172520.2789...	35.62432	102.559417	-14.123419	0.196709
6	P0003251	626919.4260...	172520.3318...	35.537712	110.055688	-15.666979	0.417708

Figure 7: The exterior orientation of the camera



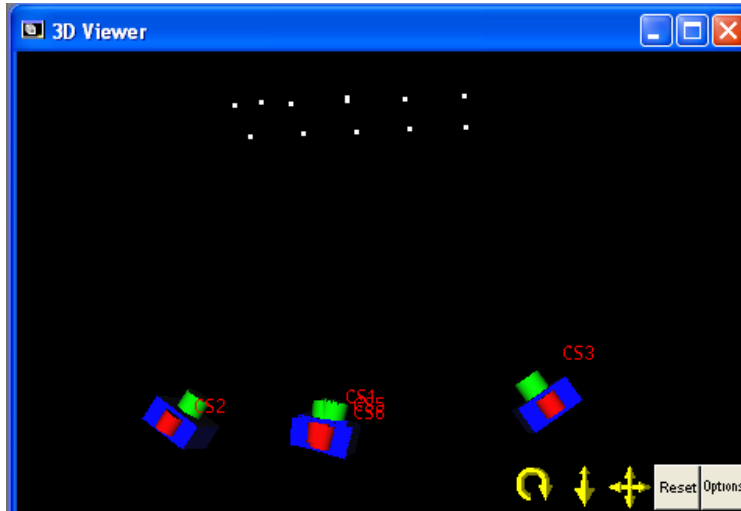


Figure 8: The relations between object points and camera positions

## 7.0 SIMULATION TEST 1

A simulation test has been conducted, aiming to determine the accuracy maybe reached at close range photogrammetry when using the exterior orientation parameter provided in PhotoModeler, GPS positioning and consumer camera Kodak DC290.

The simulation test located at building C05, Faculty of Geoinformation Science and Engineering, UTM. Two GPS stations have been established approximately 20m from the building. Then the building has been surveyed by a total station, which was set up at the known GPS station. On the building, eleven points have been surveyed using intersection method. The error of their location is within the range of +/- 0.5cm. The same frontage has been survey photogrammetrically with digital camera Kodak DC290 at the established GPS stations. The main camera optical rays are approximately parallel and inclining towards the vertical plane.

The digital images were processed using PhotoModeler. The calibration with this software is done during the processing. For the purpose of this experiment, the orientation of the building has been processed by mean of three control points (3 Point). The coordinates of eleven geodetically determined checkpoints have been measured and compare with the ones, which have been process using 3 Point method in PhotoModeler. Figure 9 is the digital image that process with 3-Point method in PhotoModeler. The points in red are set as control points (Point 14,19,25).



**Figure 9: Photo 1 processed with 3 Point method**

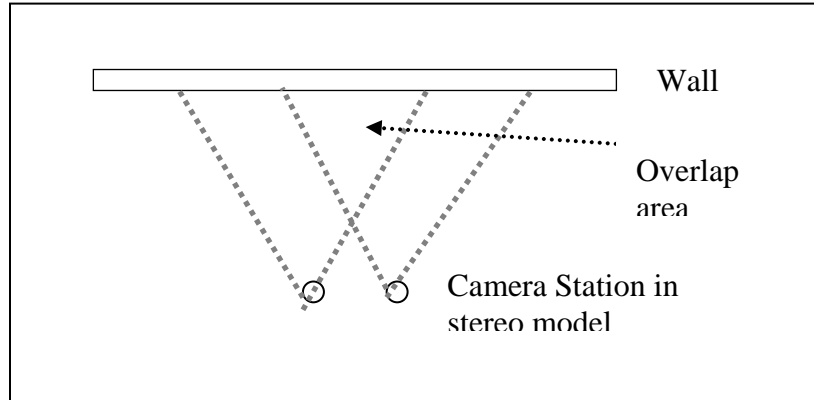
The accuracy of the checkpoints is then compared. Table 1 shows the accuracy of some geodetic coordinate checkpoints that were processed using PhotoModeler. The processed z coordinate in PhotoModeler for point 28 and 29 are not satisfactory because of some bugs in the software that cause the changing of the coordinate-z in fix control Point 14 after the processing.

**Table 1: Accuracy Assessment Test 1**

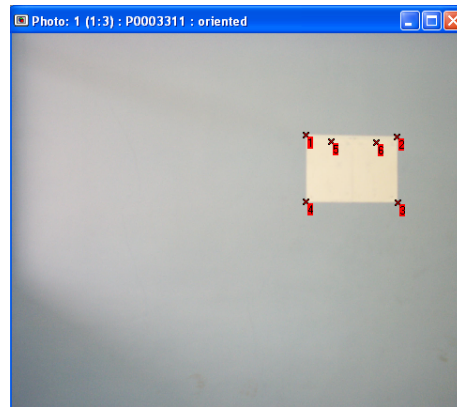
Check Point	Geodetic Coordinate (Total Station) (metres)			Geodetic Coordinate (PhotoModeler) (metres)			Differents (metres)		
	x	Y	z	x	y	z	$\Delta dx$	$\Delta dy$	$\Delta dz$
5	626908.564	172535.477	39.935	626908.577	172535.499	39.926	<b>0.01</b>	<b>0.02</b>	<b>0.01</b>
23	626911.743	172537.322	39.914	626911.747	172537.347	39.923	<b>0.004</b>	<b>0.02</b>	<b>0.01</b>
28	626908.573	172535.496	43.311	626908.584	172535.486	43.653	<b>0.01</b>	<b>0.01</b>	<b>0.3</b>
29	626911.792	172537.272	43.220	626911.770	172537.315	43.629	<b>0.02</b>	<b>0.04</b>	<b>0.4</b>

## 8.0 SIMULATION TEST 2

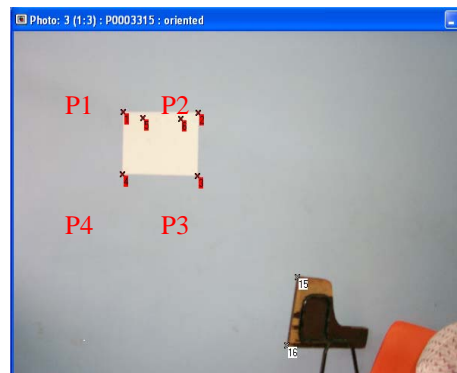
The second simulation test has been conducted in November 2004. This experiment was conducted aiming to determine the accuracy of the checkpoint in digital image without setting up the control points during processing with the developed program. The simulation test conducted in a room. Total Station used to measure the coordinate of the object on the wall. The photographs were taken in stereo. The distance between the object and camera station is approximately 3m. Figure 13 shows the left image and figure 14 shows the right image. Both images are capture in stereo.



**Figure 10: Simulation Test 2**



**Figure 11: Left image**



**Figure12: Right image**

Table 2 shows the accuracy of the point coordinates which processed with develop program. The results are satisfactory with no control point setting up in the digital image. The biggest different vector is Point 4, which is 0.27m. Vector for Point 2 and 3 are about 0.15m.

**Table 2 : Accuracy Assessment Test 2 using developed program**

Check Point	Geodetic Coordinate (Total Station) (metres)			Geodetic Coordinate (Develop MMS Program) (metres)			Differents (metres)		
	x	Y	z	x	y	z	$\Delta dx$	$\Delta dy$	$\Delta dz$
P2	100.973	102.67	1.56	100.89	102.46	1.73	<b>0.08</b>	<b>0.06</b>	<b>0.12</b>
P3	100.973	102.66	1.26	100.90	102.6	1.32	<b>0.07</b>	<b>0.12</b>	<b>0.06</b>
P4	100.556	102.66	1.26	100.38	102.46	1.31	<b>0.17</b>	<b>0.21</b>	<b>0.04</b>

The simulation test 1 photographs are processed using the developed program. Table 3 shows the accuracy assessment of the points coordinates.

**Table 3 : Accuracy Assessment Test 1 using developed program**

Check Point	Geodetic Coordinate (Total Station) (metres)			Geodetic Coordinate (PhotoModeler) (metres)			Differents (metres)		
	x	Y	z	x	y	z	$\Delta dx$	$\Delta dy$	$\Delta dz$
7	626905.393	172533.633	39.931	626913.446	172529.297	34.6	<b>-8.05</b>	<b>-6.6</b>	<b>5.33</b>
4	626914.898	172539.158	43.157	626919.384	172527.288	30.922	<b>-4.48</b>	<b>11.8</b>	<b>12.2</b>
28	626908.573	172535.496	43.311	626920.37	172527.416	32.8	<b>-18.8</b>	<b>8.08</b>	<b>10.5</b>
3	626914.898	172539.158	43.157	626917.085	172529.100	35.263	<b>-2.1</b>	<b>10.0</b>	<b>7.89</b>

## 9.0 ANALYSIS

The different between the two simulation tests are, test 2 was conducted in stereo-pair at the time captured the photograph and the data are processed using the developed program in MatLab. The results of the two test show big different in accuracy where the data process using Photomodeler with control point showed better accuracy compared to data of the simulation test 2. Test 2 was processed without control points in the photo using the developed program. The result of the 20meters (Simulation Test 1) are bad if compare to the 3meters length (Simulation Test 2). Therefore, distance between the camera and object affect the accuracy of the object points.

## 10.0 SIMULATION TEST 3

The third simulation test has been conducted on March2005, aiming to determine the effectiveness of PhotoModeler to provide accurate objects coordinate for longer distance. The field procedures are same like the simulation tests before. The ground coordinates are determined with two known point and the building are surveyed with total station. This simulation test is conducted in different length start with 5meters, 10meters, 15 meters and 20 meters between the camera and object (building).Local coordinate systems need to establish in photograph processing because no physical ground control point are established during the field procedure. The local coordinate are then transform to real coordinate system through the developed 2D transformation program.

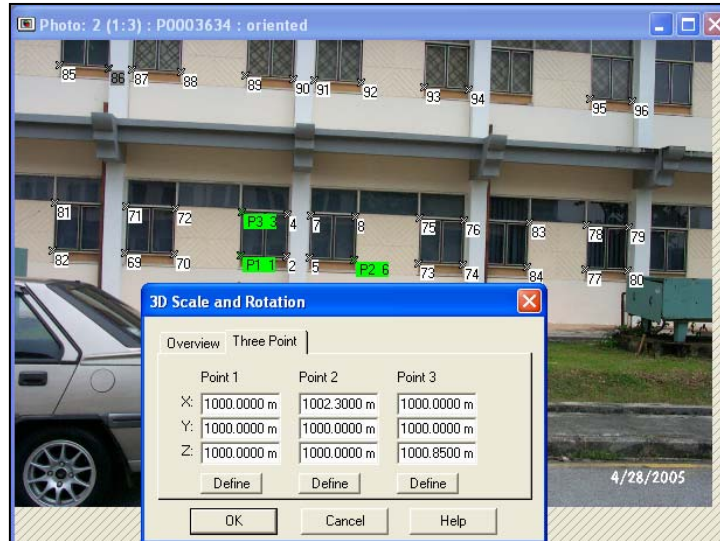


Figure 13: Set up Local Coordinate System

## 11.0 ANALYSIS

Tables below show the accuracy assessment of the simulation test in 5meters to 20 meters. P1, P2 and P3 are the object points in the photograph.

Table 4: Accuracy Assessment in 5meters

Check Point	Geodetic Coordinate		Geodetic Coordinate (Integrate PhotoModeler and developed program)		Different		
	X	Y	X	Y	$\Delta X$	$\Delta Y$	$\Delta XY$
P1	1000.31	1004.77	1000.29	1004.99	0.02	-0.22	0.22
P2	1002.60	1004.44	1002.71	1004.66	-0.09	-0.22	0.24
P3	1001.23	1004.63	1001.23	1004.87	0.00	-0.24	0.24

Table 5 : Accuracy Assessment in 10meters

Check Point	Geodetic Coordinate		Geodetic Coordinate (Integrate PhotoModeler and developed program)		Different		
	X	Y	X	Y	$\Delta X$	$\Delta Y$	$\Delta XY$
P1	1000.31	1004.77	1000.51	1004.88	-0.14	-0.11	0.17
P2	1002.60	1004.44	1002.81	1004.48	-0.19	-0.05	0.24
P3	1001.23	1004.63	1001.42	1004.74	0.26	-0.1	0.27

Table 6 : Accuracy Assessment in 15meters

Check Point	Geodetic Coordinate		Geodetic Coordinate (Integrate PhotoModeler and developed program)		Different		
	X	Y	X	Y	$\Delta X$	$\Delta Y$	$\Delta XY$
P1	1000.31	1004.77	1000.168	1003.807	0.2	0.96	0.98
P2	1002.60	1004.44	1002.32	1003.5	0.29	0.96	0.97
P3	1001.23	1004.63	1001.01	1003.69	0.67	0.95	1.16

**Table 7 : Accuracy Assessment in 20meters**

Check Point	Geodetic Coordinate		Geodetic Coordinate (Integrate PhotoModeler and developed program)		Different		
	X	Y	X	Y	$\Delta X$	$\Delta Y$	$\Delta XY$
P1	1000.31	1004.77	1000.655	1005.95	-0.28	-1.18	1.21
P2	1002.60	1004.44	1003.079	1005.53	-0.66	-1.105	1.19
P3	1001.23	1004.63	1001.609	1005.79	-0.07	-1.049	1.15

The results show that the greater the distance between the camera and object, the lower the accuracy can be obtained. The initial setup of this mobile mapping system is, captured the photograph within 10meters between the camera and object. Some processing technique that can minimized the errors and maximized the measurement accuracy is to ensure that the well calibrated camera is used for MMS, maximize the number of photographs that each point is marked on and all the points appeared on three or more photographs, and ensure the point or line marking are precise on the photograph.

## 12.0 CONCLUSION

The research is on going and concentrates in developed the mobile mapping system. There are still many uncertainties in the program that need to be solved and determined. Some aspect that need to be evaluated and examined include the true value of the exterior orientation of the camera for each photograph (in field survey), the calibration parameters, the image coordinates, the accuracy of the GPS positioning, technical problem and others. These uncertainties and unknown parameters will be figure out as more experiment and simulation test will be conducted. The outcome of this research is hoped to be useful and could be implemented in Malaysia.

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