3D MODEL MEASURING SYSTEM

H.Otani, H.Aoki, M.Yamada, T.Ito, N.Kochi

Topcon Corporation, 75-1, Hasunuma-cho, Itabashi-ku, Tokyo 174-8580, Japan
(h.otani, h_aoki, m.yamada, t.ito, n.kochi)@topcon.co.jp

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ABSTRACT:

With the rapid development of digital technology, we can now obtain easily the image with high resolution capability or the detailed 3D (Three-dimensional) data of the object by the technique of laser scanner or digital photogrammetry. And as we can now make a 3D model with real texture from these data by using the CG (Computer Graphics) technology, new business chance is expanding in the domain of CG and GIS as regard to city planning, architecture, maintenance, cultural assets. However, to do all this, a lot of time and work is required as we have to deal with enormous amount of data. To solve this problem, therefore, we have now developed and added a new function to our PC-based Digital Photogrammetry System which can produce a 3D model from digital camera's image. This new function can handle all the photo-image data obtained from high altitude (above 1000m) and low altitude (above 100m) aerial as well as the ground photography and can produce a 3D model incorporating simultaneously all these data altogether. Furthermore, in order to simplify the operation, we have succeeded to develop a new photo- guiding system to guide the photo-shooting and make simulation on the display in which the object is shown in real time. Here we superimpose on the display the data of plan, the data of the position of the control points on the object as seen from the shooting position of camera or the data of 3D obtained from aerial photograph so that the computer can guide and simulate the shooting position for the best possible result. In this way, even if we change the shooting position, we can always show the CG of such thing as control points at the most desired place on the display. In the following presentation, therefore, we are going to demonstrate how we have confirmed the validity of our system by making 3D measurement and 3D model out of the digital pictures taken by high altitude airplane, low altitude aircraft (e.g. powered paraglider) and the pictures taken on the ground.

1. INTRODUCTION

With the rapid development of digital technology, we can now obtain easily the image data of high resolution or the detailed 3D data of the object by using laser scanner or digital photo measurement (Kadobayashi et al. 2004). For example, such instrument as digital camera and laser scanner used on the ground enable us to measure in great detail the object seen from the side, but can not provide the measurement seen from above, e.g., the roof of the building or the road. So, the camera or scanner adapted for airplane or helicopter has been recently developed (Murai et al. 2003). With all this development in technology, the need for 3D model with real texture of the total object is growing especially in GIS as well as in such areas as city planning, architecture, maintenance, cultural assets etc. And new business is actively growing in this domain.

However, to create a necessary high quality 3D model a lot of time and work is required presently. It is imperative, therefore, to produce a new system which can create 3D model in a most efficient way. We have already developed PI-3000, the system for digital photogrammetry based on PC (Kochi et al. 2003). But now in order to integrate aerial and terrestrial 3D measurement data and to create its 3D model out of them, we have developed a new system which can make 3D measurement and modelling by using the images of different resolution capability and which can display at the same time the 3D model by using CG technology. Thus we can now coordinate the measuring data of all images obtained through various cameras with different resolution through bundle adjustment. And we can also produce a 3D model with texture by DSM data obtained through highly efficient stereo-matching and we can show it on display from all angles in all sorts of resolution.

We have also created a Virtual Guiding System (hereafter VGS) which combined digital camera, GPS and 3 Axes angle sensor in order to produce efficiently a 3D model out of the pictures taken from the air and on the ground. VGS is the device to guide ourselves visually to the best possible camera position. This is made possible by imposing or overlapping the control points measured in advance and the 3D model already produced on to the camera's view (displayed image). In this way we can make stereo-shooting on the very site of survey while checking on the display the control point position as well as missing or defective parts of 3D model. At the same time we can also check the overlapping of photographs and the accuracy of measuring. All this not only simplifies the photo-taking process, but also assures the certainty of the works after taking photographs and keeps away possible failure.

2. MEASURING SYSTEM

For measuring and modelling more than two stereo images, we are using PI-3000, a 3D measuring system based on PC. This is a system which can make 3D measuring and modelling simultaneously in one integrated operation out of all the images including aerial film photographs and the images of digital camera.
And for guiding to the proper position to take picture on the ground, we are using VGS we have recently developed. This enables us to measure in details the missing parts or sections of

the 3D model of aerial photo. VGS is a combined system of digital SLR camera with GPS, angle sensor and host PC. The outline and flow of these systems are as follows.

2.1 3D Image Surveying Station PI-3000

While we have already developed 3D Image Surveying Station PI-3000 (Table 1), and now we have also developed the bundle adjustment software, which can process simultaneously all images from aerial film camera to ground digital camera. Now we can process altogether not only the image of film camera but also of that of digital camera with all the differences in resolution.

In addition, we have developed a special technique to display 3D model on monitor. By using Open GL capability of PC, this system can display in different angle and resolution the image reconstructed through 3D measurement with wire-frame or texture-mapping model in real time on PC monitor.

Image/Coordinate Input	DXF,CSV,TXT,SIM,TIN,JPG,TIFF,BMP
Orientation	Single Photo Orientation, Bundle Adjustment ,Relative Orientation, Connecting with Total Station
3D Measurement / Plotting	Making Rectified Image, 3D Plotting / Editing (point, line), DSM Automatic Measurement, Making TIN / Editing
Display	Model Display on PC (OpenGL), Stereo Monitor
Re-construction Image	Making Ortho-Birds Eye Image, Contour-lines, Cross section, 3D Modelling
Outputs	DXF,CSV,SIM,TXT,TIN,WRL,JPG

Table 1. Function of PI-3000

2.2 Photo-shooting Guiding system VGS

VGS is the device which guides the photo-shooting position on the ground, using the 3D model produced by PI-3000, or using the control points measured with Total Station (TS) or GPS. VGS is the system in which are combined and integrated digital camera, GPS, angle sensor, and the host computer (e.g. PDA). In future, we can make a handy photo measuring system by putting whole system together within a single digital camera. At this time, however, we made a pilot experiment to confirm the feasibility of the VGS system by using the devices available at hand. The Figure 1 shows its block structure and Figure 2 shows how it looks.

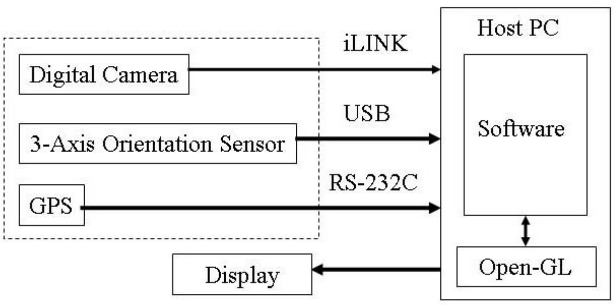

Figure 1. Block Structure

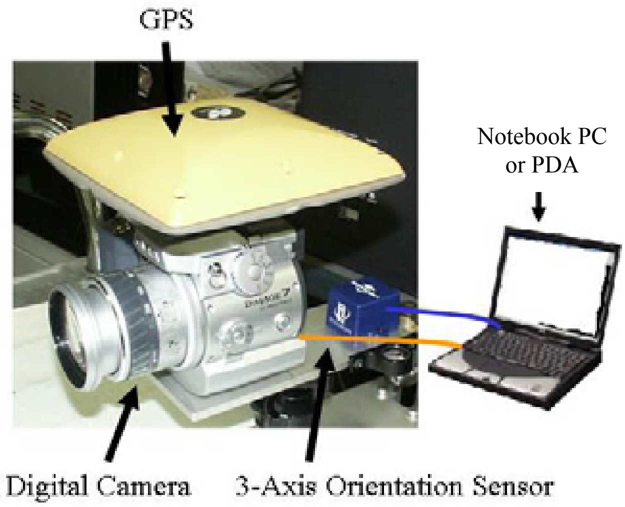

Figure 2. VGS

The digital camera we used was SLR type sold in market, which shows finder image in LCD of camera as moving image and in which the image comes out as iLINK (IEEE1394). For the host PC we used a notebook PC. We made the display of block figure the display of notebook PC, which can display the finder image in real time.

3-Axis angle sensor is not so accurate, for it shows 1 degree. It's market price is low (about $ 1700). We connected it with USB of PC. As for GPS, we used LEGACY-E/GD compatible to RTK of Topcon. The specification of other devices than PC is on Table 2. The main functions of VGS are shown in Table 3 and its displayed image is in Figure 3.

Composition	Model	Specifications
Digital Camera	DiMAGE7 (Minolta)	2/3-type interline CCD 4.95 million pixels (2568×1928)
GPS	LEGACY-E/GD (TOPCON)	Accuracy：Kinematic, RTK Horizontal:1Frequency±(15 mm＋1.5ppm×D)mse Vertical:1Frequency±(30m m＋1.5ppm×D)mse
3-axis orientation sensor	IneritaCube2 (INTERSENSE)	Angular Resolution 0.05 ° Accuracy 1 ° RMS(Static) 3 ° RMS(Dynamic)

Table 2. Specification of devices

Image Display	Photographed Image, Finder Image, 3D Model
Superimpose	Control Points, < Overlap Condition>
Position Information	Position（X,Y,Z） Posture（Yaw ,Pitch ,Roll） Photo-Shooting Distance, Base length
Camera Information	Focal Length、Pixel resolution
Measuring Accuracy	ΔXY、ΔZ、< Overlap ratio >

Table 3. Function of VGS（＜＞: plan for the future）

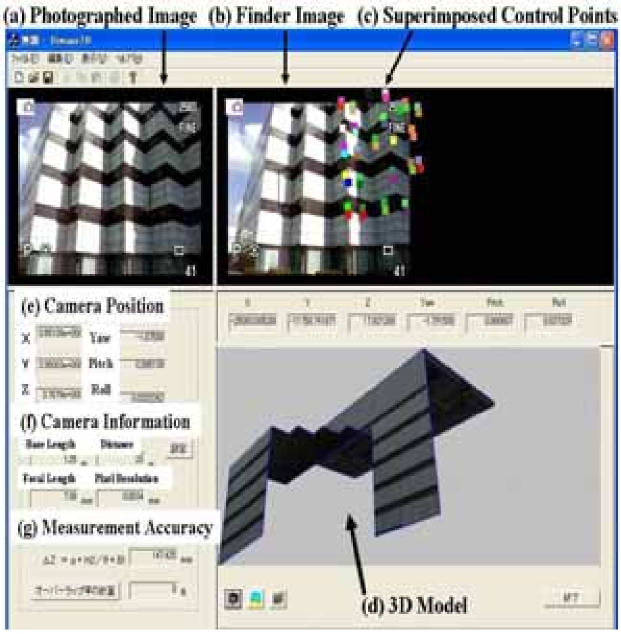

Figure 3. Displayed Image of VGS

The camera's position (X,Y,Z) is measured by GPS, and the camera's posture (Yaw, Pitch, Law) is measured by angle sensor of three axes (Figure 3(e)). From digital camera the finder image is sent to the host PC through interface and displayed on PC (Figure 3(b)). Processing the imported image data, the host PC now calculates where the control points' coordinates (which is input in advance) ought to be on the display and superimposes it on to the finder image, thus creating the real time moving image on the display (Figure 3(c)). In this way we can find how many of the control points would appear at the time of shooting. We can also display the model made in advance in accordance with the angle of camera's position and posture (Figure 3(d)). In this way we can determine the shooting position, knowing exactly what is missing or defective in the parts of the modelling. Again, the host PC, as it preserves the data of the image previously photographed and the data of shooting position, now can calculate from these data the overlapping rate and also calculate the accuracy of conformity between the finder image and the image previously obtained (Figure 3(g)).
The accuracy can be obtained in the following equations.

$$\Delta XY = H * \delta p / f$$
$$\Delta Z = H * H * \delta p / (f * B)$$

δp is the resolution capability of digital camera or scanner's reading capability. f is the focal distance which is predetermined by the type of camera.
The base length B (the distance between the cameras) is calculated from the position measured by GPS of the photographed image (Figure 3(a)) and from the position of the GPS to be photographed (Figure 3(b)). The shooting distance H can be calculated from the position of GPS, if there are control points or 3D model. If not, we input the approximate value. From these parameters we can calculate even before taking picture the accuracy of the stereo-model after measurement.

2.3 The Flow of the measuring system

The following is the explanation of the flow of the production of a 3D model by the photos taken from low altitude and on the ground as in the Figure 4.

(1) Aerial photo can be anything taken by airplane, helicopter or kite balloon. In our experiment we also used a parachute-glider with engine (powered paraglider). However, in all cases the interior orientation of camera should be precognitive.
(2) On the ground we must obtain the necessary control points by TS or GPS. The measure value of TS should be harmonized with the coordinate system of GPS.
(3) We measure 3D model by PI-3000 from the image obtained in the air. We use the control points obtained in (2) as needed.
(4) We take digital pictures on the ground guided by the guiding system (VGS). For this process we input into VGS in advance the data of the control points obtained in (2) as well as 3D model data obtained in (3). In this way, when we determine the shooting position, the image as seen by camera can appear in real time on the display of VGS (Figure 3(b)). And on this image the measured control points (2) are superimposed (Figure 3(c)) and the 3D model created by (3) will be displayed as seen from the camera (Figure 3(d)). Simultaneously we can also check the measuring accuracy and overlapping precision (Figure 3(g)). With all these operations the camera position will be guided to the position most appropriate for posterior process.
(5) We create a 3D model as seen on the ground by stereo-measuring the image of VGS by PI-3000.
(6) We create a 3D model of the total object. For this purpose, we make a simultaneous bundle adjustment of all the pass-points and tie-points of the each stereo-model photographed in the air and on the ground to unify the coordinate system and produce a 3D model of the total object. Actually this process is performed automatically by bundle adjustment in (5).

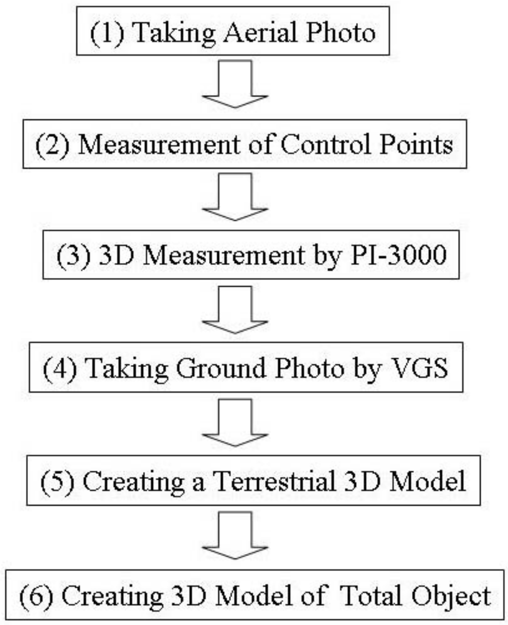

Figure 4 . Flow of Measuring System

3. THE PRODUCTION OF 3D MODEL BY HIGH AND LOW AERIAL PHOTO AND BY GROUND PHOTO

This is how we actually produced the 3D model. The object is the Topcon main building.

The pictures we used were: the aerial photo by the film camera of airplane, the photo by digital camera of powered paraglider and the lateral photo obtained by VGS on the ground. We first produced 3D model for each of them by PI-3000 and then fused them together. As for the control points, we first measured the side of the building by non-prism TS and converted the data to GPS coordinate using the points measured by GPS in the building lot. Table 4 shows the capacity of the cameras used for high, low and ground level photographs. Table 5 shows the conditions for the analysis by each camera. And Figure 5 is the display of PI-3000 showing all of the analysis of each camera. Here is how each photograph and analysis was processed.

	Airplane	Paraglider	VGS
Camera	WILD RC-20	CANON EOS Digital	Minolta Dimage7
Sensor	Film	C-MOS(22.7 ×15.1mm)	CCD (2/3inch)
Number of Pixels	6062 x 5669 (by Scanner)	3072 x 2048	2568 x 1928
Resolution	42.3 μm	7.4 μm	3.4 μm
Focal length	152.4mm	18mm	7.4mm

Table 4. Cameras used for high, law and ground level

	Airplane	Paraglider	VGS
Photographing Area	2000 x 2000	200 x 100	30 x 25
Modelling Area	300 x 300	100 x 50	20 x 20
Altitude	1609	163	26(side)
Base length	886	18	5
Resolution: ΔXY	0.89	0.06.6	0.01
Resolution: ΔZ	1.61	0.6	0.06

Table 5. Condition (unit: m)

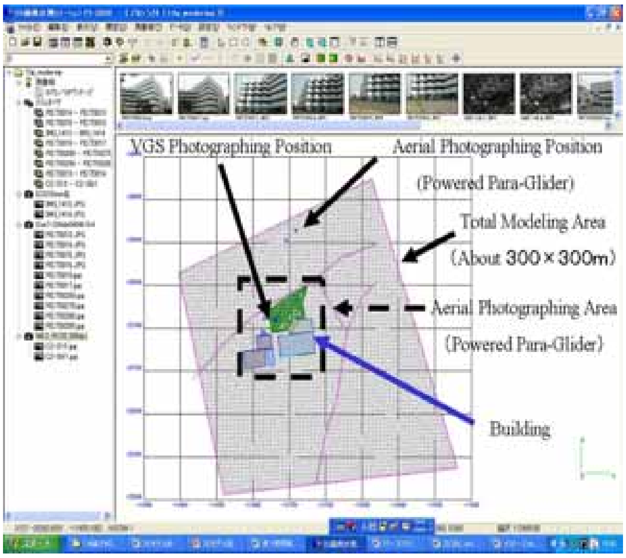

Figure 5. All of the analysis of each camera

3.1 Making of the base by the analysis of high altitude aerial photo

For aerial photo, we used the photo which shows 4 kilo-meter square around Topcon in Itabashi ward of Tokyo. The camera was WILD RC-20 with focal distance of 150mm. The altitude was 1609m. Out of the base length (distance between cameras) 886m we picked out the area 300m × 300m for modelling (Figure 6). Since we used the photo of the high altitude, which was taken by film, we got its analyzed data by a scanner with 600dpi and put them into PI-3000 for inner orientation. The Figure 7 is the modelled image processed by PI-3000 to be used as the base of all operation. This time we did not make stereo-matching but made simple 3D modelling. However, if there is such thing as mountain, we have to make stereo-matching on that area and produce a 3D model.

Figure 6. Aerial Photo

Figure 7. Modelled Aerial Image (300m x 300m)

3.2 The production of a 3D model from the photo taken by lower altitude Powered Paraglider

This time we used what we call Powered Paraglider or parachute glider with engine (Figure 8) and took photo with digital camera (Figure 9). This type of airplane has advantage in that it can take bird view photo safely and with low price and is not legally restricted in its flying height.

The camera we used was Canon EOS Digital SLR type. The sensor of Camera is C-MOS type with the size 22.7mm × 15.1mm, the pixel number 6.5M (3072×2048) and the focal length 18mm. The area of the photo we used for modelling was 100m×50m.

The analysis we worked out was the following.
We made orientation on PI-3000 with the control points measured by non-prism TS. We measured the building edge and foreground with poly-line measurement (both manual and automatic DSM: Figure 10(a)). And then we made mesh of the plane (Figure 10(b)) and pasted texture (Figure 10(C)). And finally we fused all with high altitude aerial photo (Figure 10(d)).

Figure 8. Powered Paraglider

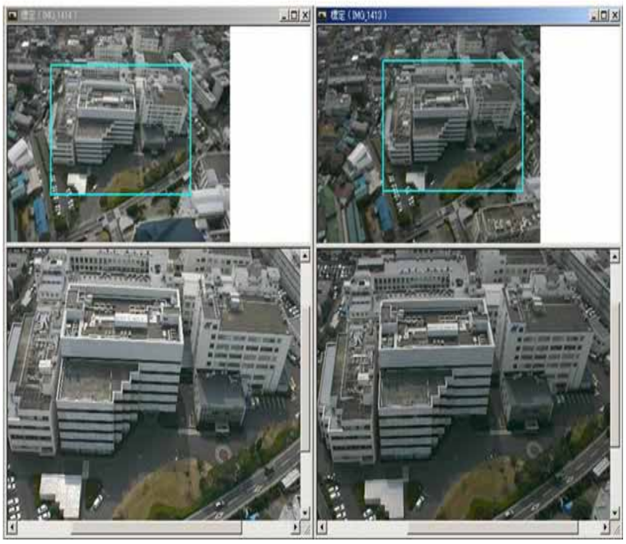

Figure 9. Digital Photograph by Powered Paraglider

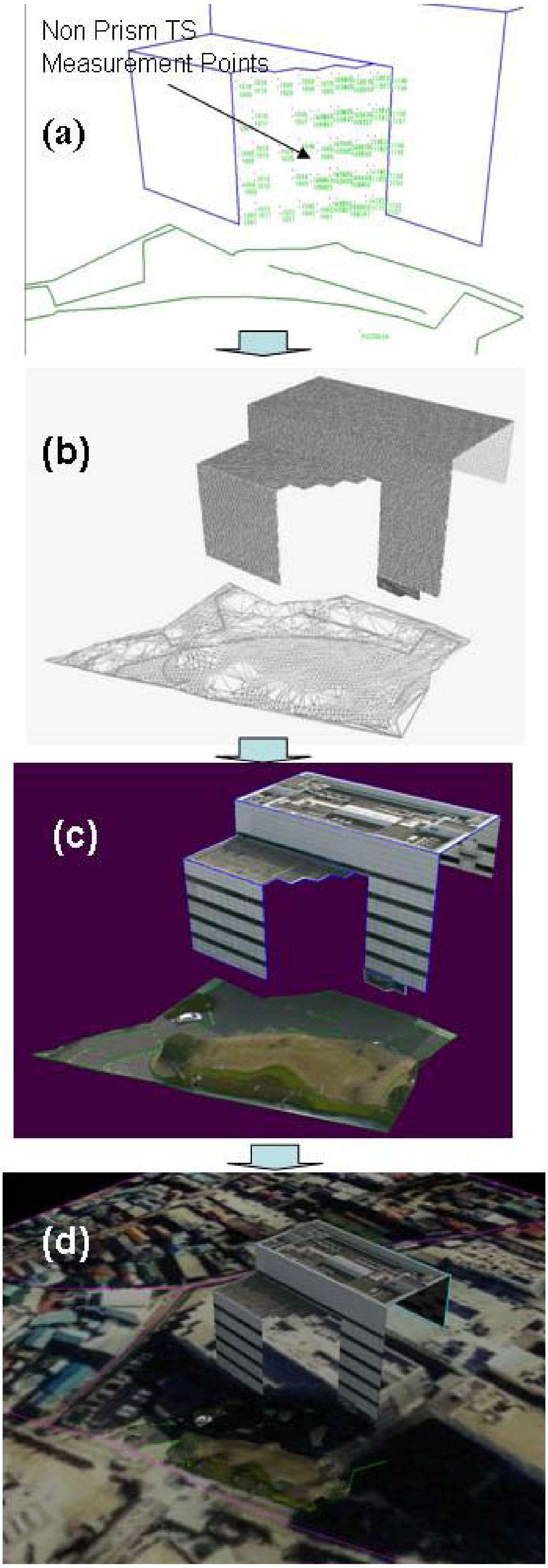

Figure 10. 3D Modelling of Aerial Photo

3.3 Adding the 3D model made by ground photo

The Figure 11 shows how we were taking photo of the defective parts by experimental VGS and the image thus produced and added. The display of VGS for this operation is as shown in Figure.3. Figure 12 and 13 show the result of 3D measuring and modelling of the defective parts by PI-3000. Figure 12 shows the wire-frame model after the added parts have been added and Figure 13 shows the image pasted with texture-mapping model. In this way we can always patch up accurately the defective parts.

Furthermore, Figure 14 shows the 3D model added with another building. The addition was made by the photo obtained by low altitude powered paraglider.
In this way the missing parts can be reproduced by VGS and also by the analysis of the low or high altitude aerial photo.

4. CONCLUSION

We have developed and successfully experimented a new total system which fuses and integrates altogether the various instruments or their functions and which can make up satisfactorily for the missing or defective parts in 3D model.

And we have shown how the new system integrated with digital camera can fuse together the images of various resolution (e.g. photo of film camera of high altitude airplane, photo of digital camera of low altitude airplane and photo of the ground) to create a 3D model from all of them together.

Furthermore, the system's efficiency is greatly enhanced with its capability to display the 3D images in real time while the pictures are actually taken on the very site of survey and to guide the operations and process the data in the most efficient way. Especially when we make bundle adjustment of film photo of airplane and digital photo, it is imperative to allocate properly and perceive accurately the control points or tie-points. But the VGS of the new system makes it possible to display these orientating points in real time. And this is the secret of its great capability.

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Figure 11. Taking Building Photo (right) by VGS (left)

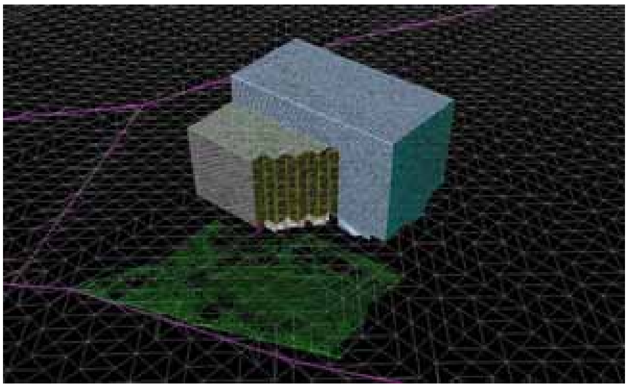

Figure 12. Wire-Frame Model after the added parts

Figure 13. Texture-Mapping Model after the added parts

Figure 14. 3D Model added with another building