The Integration of GPS, GIS, Remote Sensing and CAD for Safeguarding Angkor Wat

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ABSTRACT

In the investigation and the restoration of ruins, new technologies are largely expected. The GIS laboratory of Keio University has acted as a member of Japanese Safeguarding Angkor Team (JSA) to support the preservation and the restoration of Angkor Wat ruins since 1995. In the project, we measured the coordinates of ground control points and the positions of ruins with RDGPS (real time differential GPS) in about 1m error and RTKGPS in about 1-3cm error. These GPS points are used for registering satellite images and locating buildings or installing the places of video cameras. Two digital video cameras are used to measure the shape of the ruins in stereo. The measured data sets of the buildings are managed as three-dimensional vector data in GIS. Finally, CAD/CG and recent VRML technology are used for the restoration simulation of ruins. This paper reports the construction methods and the experimental results of the system applied in Angkor ruins.

1. INTRODUCTION

The geographic information processing technology is entering a new generation. The traditional geographic information processing system centered its priority on the management of existing data (making databases) and the analysis, mainly using Geographic Information System (GIS). The characteristic of new technologies, on the other hand, is to combine two or more elements of technologies corresponding to various purposes. Such new technologies include remote sensing and GPS for data acquisition, object-oriented data model for multimedia database, 3D models for environmental simulations, etc.

In the investigation and the restoration of ruins, the new generation technology is largely expected. Recently, maintenance and the restoration of the Temple of Angkor ruins located in the northwest part of Cambodia have been advanced as part of the world inheritance relief plan of UNESCO. The Angkor ruins, in the chiefly, are groups of stone ruins constructed from the 9th to the 14th century by the Angkor Kingdom, where extending over the square kilometers of 310 is lined with ruins of 1000 or more. Many of them are heavily damaged and are beginning to ruin because it was left for hundreds of years in the jungle.

The GIS laboratory of Keio University has acted as a member of Japanese Safeguarding Angkor Team (JSA) to support the preservation and the restoration of Angkor Wat ruins since 1995. This team has developed and tested the applicability of the new information technologies including GIS, GPS, RS and CAD/CG for the ruins. Although many of these new elementary information technologies are still on their way to practical uses, the effectiveness of the system that we implemented have been proved through times of missions to Angkor Wat in the past two years. This paper here indicates the methods of the construction of such an integrated system and the applied results to the restoration of Angkor Wat ruins.

2. CONCEPTS OF THE SYSTEM

The Angkor ruins can be said to be considerably difficult objects from the viewpoint of surveying. The ruins containing 700 or more of buildings is widely located over 30 km all sides (*vast region*). Neither a map nor a control point exists accurately that can be used as a standard point (*lack of spatial data*). It is difficult to measure the ruins from the ground or from the air because they are covered by jungle (*characteristics of the tropical woods*), etc.

At the building level of surveying, there are the following problems:

1. The scale of individual building is large and its construction is complicated,
2. The demanded accuracy is not clear, partly because the decoration of the buildings makes the definition of accuracy difficult.

When developing a surveying system, the following policies were set up.

1. Aims to acquire the data over the large area, in 2-demention by 1m accuracy. This corresponds to the accuracy of maps in 1/3000.
2. Design data acquisition systems from the beginning because there is no enough maps or surveying data existing.
3. Try to observe the buildings in 5cm accuracy. This corresponds to the drawings of the buildings in 1/150. Moreover, it is requested to collect data about the shape of buildings in the same accuracy for three-dimensional simulation.
4. It is preferable to have the system with high portability and few troubles of breakdown in order to be used in the field.

Based on this concept, an integrated system of GPS, GIS, RS, 3-D surveying and CAD/CG are designed. The outline of the system is shown in Fig.1.

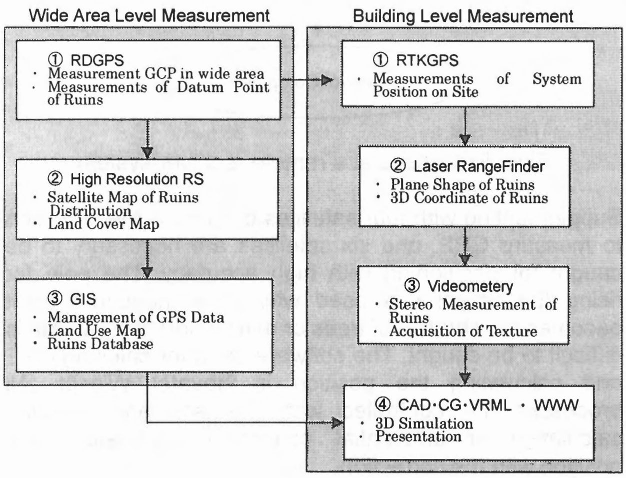


Fig.1 Modules of the system

By this system, we measured the coordinates of control points and the positions of ruins in high accuracy with RDGPS (real time differential GPS) concerning the large area data. Using RDGPS, the position can be absolutely acquired in an accuracy of about 1-2m. These GPS points are used for a precise correction of satellite images. As to building level data, the required accuracy is about 1/200 scales for the ruin restorations in about 1-3cm accuracy. A highly accurate, high-speed instrumentation system is necessary for that. We adopt RTKGPS (real time kinematic GPS) for 3D measurement of buildings.

The structure of a building is measured by stereo videometry. An absolute position of the installation place of video camera is obtained by RTKGPS. A Total Station surveying instrument is introduced in order to collect three-dimensional GCP of ruins. The measured data about the shape of buildings is managed as three dimensional vector data by GIS including plane map data etc. Finally, CAD/CG and recent VRML technology was used and the restoration simulation of ruins had been done.

3. POSITIONING BY RDGPS

GPS is a system that calculates an absolute position on the earth using satellites, differing from the past method of surveying. It can be said that this is an effective technology to the measurement in a region where control points do not exist or the accuracy of them is not enough, such as in Cambodia. However, because it is developed by military purposes, some limitations are installed on private use. It is difficult to have accurate positions just using simple GPS(C/A code). Usually the accuracy of simple GPS (SGPS) is about 100m. Here we try to use RDGPS (Real time Differential GPS) to survey the coordinates of points in high accuracy at first.

3.1 Basic Principle of RDGPS

DGPS (Differential GPS) uses two or more GPS receivers. With a base station whose accurate position has already been known, we make any new GPS measurement. Then the difference means the error in the new observed data. This error information is then transmitted to a remote GPS receiver as calibration (RTCM) to the observed position there. The remote receiver uses it to correct the directly observed position for the enhancement of accuracy. This technology is called differential GPS (DGPS).
RDGPS means that the transmission of correction information and the calibration of the position in the remote receiver are done in real time. It is necessary to transmit and receive the correction data every minute in RDGPS through communication such as radio. Because the transmission of correction information is one-way traffic and a signal speed with 1200bps will be enough. At this extent, we can select number of communication modes such as portable telephone, beacon wave, FM multiple broadcasting, and Internet, etc. As the result of experiment and examination, radio was adopted in this project because it is the most applicable in Cambodia.

3.2 Construction and Operation of RDGPS System

The system of RDGPS is composed of a base station and remote receivers as shown in Fig.2. However, a relay station was set up in our system that is located in Phnom Baken, one of the temples in Angkor ruins with the elevation of 95m. The Base station is located in Siem Reap City, and the remote receivers are mobile surveying points in Angkor ruins during the investigation here. Because tropical woods, which can be trouble of transmitting and receiving electric wave, extends between these two points, the relay station receives calibration data from the base station, amplifies information, and transmits to the remote receiver again.

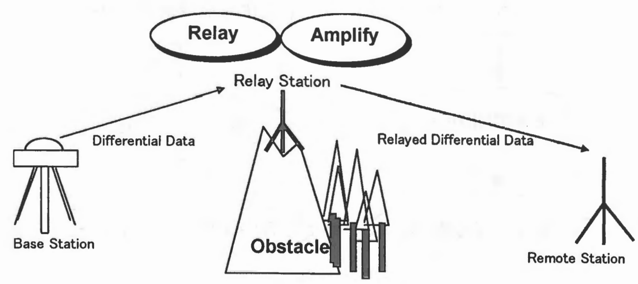


Fig.2 RDGPS system with a relay station

The GPS unit at the base station, as shown in Fig.3, calculates the error included in the GPS code by comparing the already known position. Calculated error information is transmitted from the GPS control terminal to the transmission modem with the code of the industrial standard, which is called correction signal (RTCM104).

Then it is amplified with preamplifier and the linear amplifier and sent it to the relay station and the remote receivers.

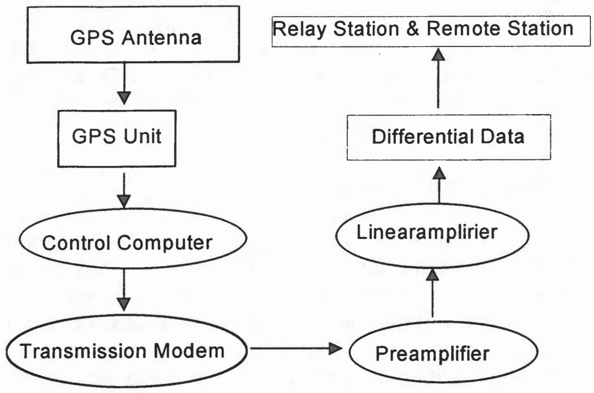


Fig.3 Processes at the base station system

In this project, the GPS antenna at the basic station was set up on the rooftop of JSA office in Siem Reap City. The position of the base station was measured with non-differential mode of positioning for an hour and then an average was taken.

Calibration information from the base station is sent off in the wavelength of 429MHZ and the output is about 10W. Considering of the electric power circumstances in Cambodia, the electric wave was transmitted by the output electric power within the capability of GPS itself when blacked out.

At the relay station, as shown in Fig.4, calibration information transmitted from the base station is received with a receive antenna same as remote receivers and the noise is removed with the filter. After amplifying it with the preamplifier, forwarding to the receive modem, amplifying again with the preamplifier and the linear amplifier, and it is transmitted from the antenna to the remote receiver.

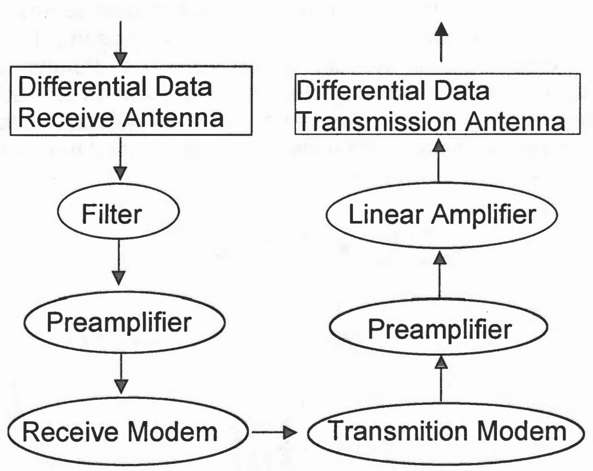


Fig.4 Processes at the relay station

At a remote receiver, as shown in Fig.5, the position is measured with calibration information from the relay station and the base station. After the noise is removed with the filter, calibration information is sent from preamplifier to the receive modem and then to the GPS unit. The GPS unit records correction information and the position of general GPS is corrected. The position information is recorded in the GPS control terminal.

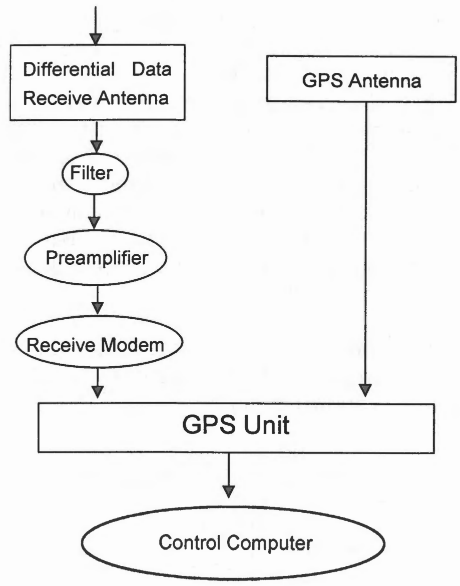


Fig.5 Processes at a remote receiver system

Supplementing with four satellites or more is the condition to measure GPS, and six satellites are necessary to be caught for positioning with high accuracy. The pole for rising the antenna is used when the measured point becomes the shadow of trees or ruins where the satellite is difficult to be caught. The software used for catching GPS and calculating the position is Novatel Winsat. All processes are controlled with this software including calculation of differential correction information and position with the correction.

3.3 Examination of Accuracy

As we mentioned before, an accuracy of 1m is necessary for the measurement of ruins or as a control point for mapping with high-resolution satellite images. The positioning accuracy has been improved by the following two methods in this research.

3.3.1 Accuracy improvement by average: An original program was coded to calculate the average value. This program reads the log of the GPGGA format of NMEA (National Marine Electronics Association) to calculate the average position. When the average value is obtained, we removed the value that comes off twice or more than the standard deviation of latitude, the longitude and the elevation respectively. It is considered that this method is efficient when a supplementation numbers of satellites are few, or extremely big errors are sometimes contained. In September and November 1996, totally 113 GCPs (Ground Control Point) were observed (53 points in September and 60 points in November) and 106 points of them were with 1-2m errors.

3.3.2 Accuracy improvement by real-time differential GPS (RDGPS): Even if the number of satellites which can be caught is four or more, we found that the accuracy of positioning using RDGPS changes largely depending on the number of satellites.

(1) A case with enough numbers of satellites caught:
Take the point in front of Siem Reap Airport as an example. Supplements with 8-9 satellites are caught at this time. The maximum error in each direction of X, Y, and Z, the longitude is 6.08m, latitude is 5.26m, and the height is 8.6m respectively. In the standard deviation, longitude is 0.0000118 ° (1.27m), latitude 0.0000089 ° (0.99m). Therefore, the accuracy of positioning in this case is very high.

(2) A case when few of satellites caught
This is the case at the Northern Gate of Angkor Thom. This place covered with trees and the sky was hardly to be seen. The number of satellite supplementation averages at this position was one of the worst place (We caught average number of 4.2 satellites). Therefore, a very big error occurred in maximum: the longitude 134.39m, latitude 19.95m, the height 580.8m. Different from general GPS, which constantly had 10m of error, RGPS only has extremely big error sometimes. We used the antenna attached to the pole of about 10m. Therefore, difficulty in catching the satellite has decreased. When the antenna is raised to 7.5m at the same place, the average of catching the satellite is 5.6, the error lessen to that of longitude 12.86m, latitude 15.52, height 105.62m.

4. INTEGRATION WITH GIS·RS OF GPS MEASUREMENT

Up to now, not enough investigation and nor the management of information on the whole of Angkor Wat ruins have been performed. It is necessary to make a unified database in order to share the data on safeguarding among different teams. Collecting the GPS data, the map information data of the region of ruins and geographic information from satellite image, etc. a prototype of geographic information system (GIS) of the Angkor ruins was made. All GIS data were stored in Arc/Info format.

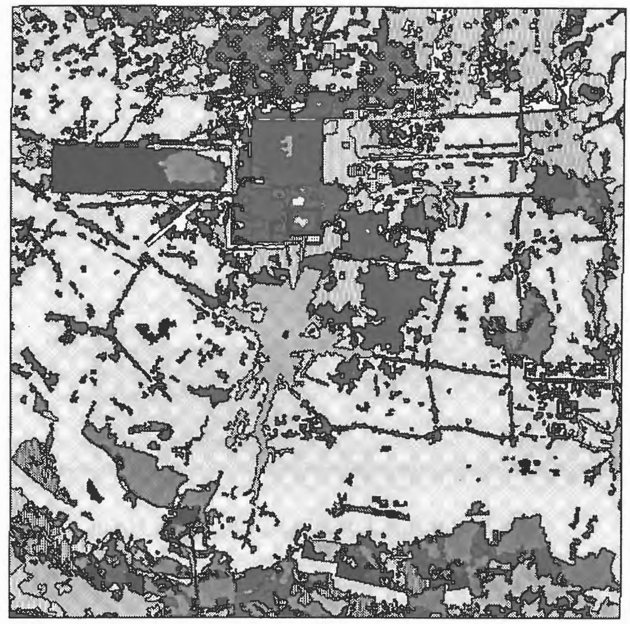
4.1 Data Processing

First, a panchromatic image of SPOT satellite was registered with the measured GPS points. The acquired GPS point was dropped on the image. Next, GIS and the data concerned to ruins were integrated by using the drawings and the photographs of ruins. For the drawings, we used the one from the JSA report of 1994 concerning Bayon and Prasat Suor Prat and also the drawings printed in "A GUIDE TO ANGKOR" . As for the photograph images, we used the ones that we actually took during the investigation there.

To make map coverage we digitized the roads, the waterways, and the reservoirs from the map of 1/10,000 and 1/50,000. These map data was also registered with GCP coordinates.

In addition, as shown in Fig.6, the latest land use, the roads, and the water networks were acquired from IRIC (Integrated Resources Information Center) of Cambodia, supported by UNESCO.

After the comparison of the accuracy about the above, the coverage on land use and roads from IRIC was finally used while the water system was from the 1/10000 map that we digitized.



(a) Land use

(b) Roads and water networks

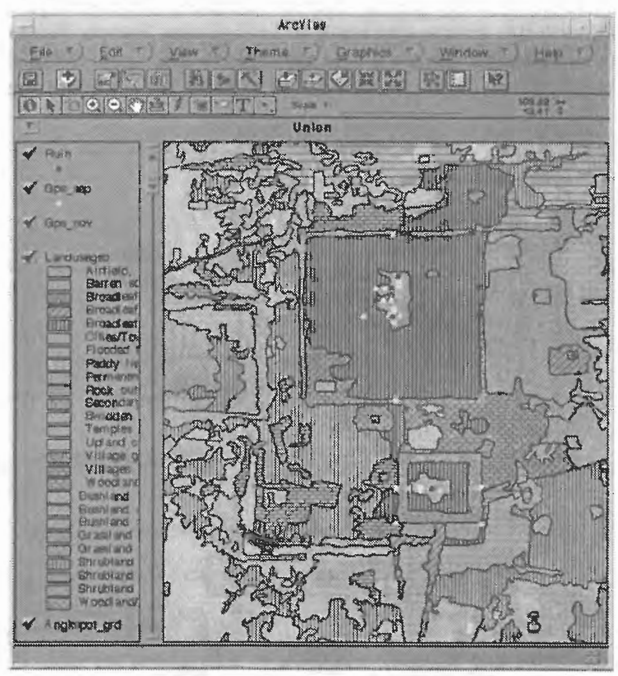


Fig.6 The data of IRIC

4.2 Integration of Data

The above data sets were integrated on Arc View (Fig.7). The display and non-display of a data set can be easily switched by a click of the mouse. Moreover, because two or more themes were registered in the same Arc View project, many GIS data can be displayed at the same time.

The image data sets are attached to the GPS points of ruins as attributes. As the result, the image of the ruins could be displayed by clicking the GPS point overlayed on other GIS data or the satellite image. Concretely, the function of Hot Link in Arc View is used.

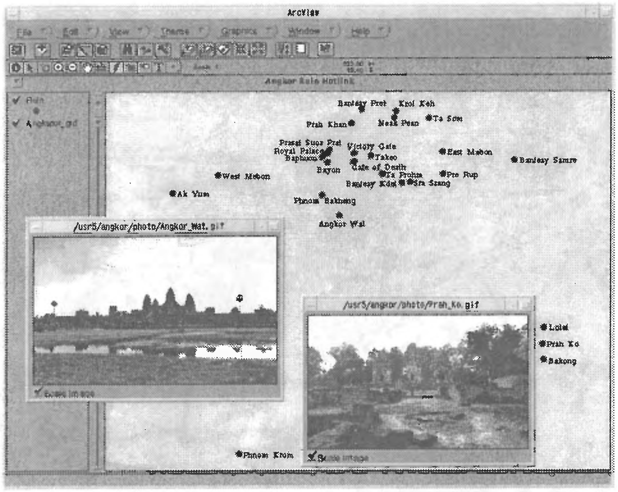


Fig.7 Integrated database of Angkor Ruins

5. 3D COORDINATES MEASUREMENT SYSTEM

5.1 System Structure

As shown in Fig.8, 3D Coordinates Measurement System consists of three parts: Stereo cameras (Videometry) to acquire the shape and texture; LRF (Laser Range Finder) to acquire the distance and azimuth to a target; RTKGPS to get an absolute position of the system in high accuracy.

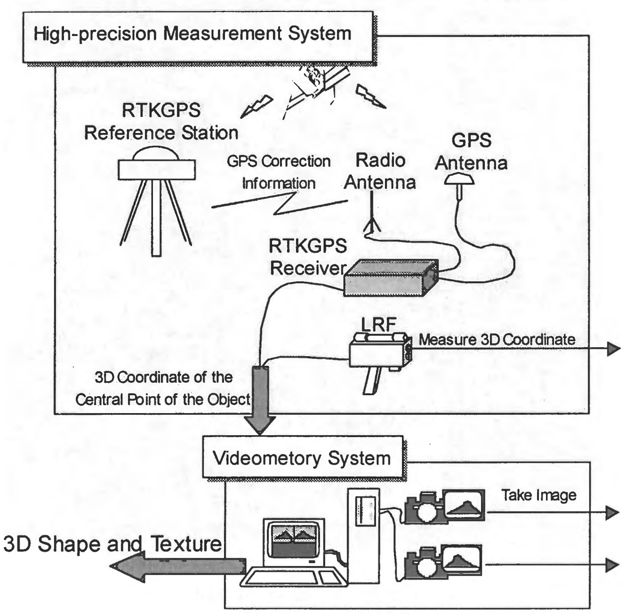


Fig.8 3D Coordinates Measurement System

These three parts was integrated in high-accurately surveying. At first, with RTKGPS we precisely observe the coordinates of a system point on the ground. Then we measuring X, Y, Z and the angles to the point on a building from the system point with RTKGPS. Therefore, the system can acquire three-dimensional absolute coordinate of a object in several cm or less accuracy. After the system acquired the coordinates of a point on an object, stereo images of the entire building with stereo cameras were taken. With the processing of video images, the texture image of objects could be obtained and 3D coordinates of the points on a building could be measured at the same.

5.2 Characteristic of the System

It is possible to measure the entire ruins including the height. The largest advantage of this 3D-measurement system is it can reduce hands compared with the traditional surveying style. In the method of current survey, it is difficult to survey an unstable place or a high place because it is necessary to use the prism at the survey point. On the other hand, this system can acquire coordinates in the entire building on the ground at one time. It can reduce work greatly. However, it is necessary to raise the system position by using scaffolding vehicle because accuracy may drop when the laser is applied up to the high place from the ground. Moreover, it is preferable to measure as near as possible because accuracy drops when object is measured from distance position.

This system can greatly decrease working hours because all processes can be done automatically from the measurement of the position to the acquisition of the image in a moment.

It is necessary to get data in the accuracy of centimeter order for the drawing of complex ruins. This system can acquire more accurate data than before because high accuracy GPS and the development of the measurement technology though work were reduced.

All data and calculations like the positions and the texture are digital. We can input them into computers. Therefore, the output data is also digit. We can restore it on the computer by CAD directly.

5.3 Characteristic of RTKGPS

The allowable margin of error is about 1m when we measure the distribution of ruins in a wide region. On the other hand, 1/200(6cm in the error) high level accuracy is demanded in the building scale. For this, we must use RTKGPS which accuracy is higher than RDGPS.

The amount of work and accuracy are important elements when we integrate a system. Generally, if we try to improve the accuracy, the amount of work will increase. A survey of ruin has different problems from a general survey. The buildings of ruins are not composed of a simple geometry object such as the straight line, the circular arc or plane. Moreover, because each user has different interest, they demand different accuracy. It also makes a ruin survey difficult.

RTKGPS is better accuracy than RDGPS and can obtain the accuracy of 1-2cm in about five minutes. However, to obtain the accuracy of 1-2cm, we needs the initialization time of 70 seconds + 1.5 sec./km according to the distance from the base station.

Moreover, there is a problem that accuracy drop when the distance between the base and the rover is far. Therefore, the RTKGPS base station must be set on site. It means that RTKGPS is not suitable to know the distribution of ruins in wide area.

The largest advantage that we use GPS for building level 3D measurement is that we are able to survey a reference point without the base line. Therefore, works on site are greatly reduced. Moreover, GPS keeps centimeter accuracy independent of distance from base station in a building level measurement unlike a current survey system. However, it means that the accuracy is worse than a current survey method because GPS includes 1cm or more error even just near base station. GPS also has a fault that it is impossible to get position if the sky does not open because of the tree or the buildings, etc.

5.4 Characteristic of LRF

Non prism type total station (LRF) is able to measure range, azimuth and inclination using the laser beam and built-in compass. It enable measurement of X, Y, Z coordinates, heights, diameters and so on. The reflection board such as prisms is not necessary.

It can acquire 3D coordinates at 300m apart in the 2cm accuracy. The advantage of LRF is also the simplification of work. It can acquire 3D coordinates including high position for oneself because of no prism type. Moreover, LRF data match well GPS data. We can add an absolute position acquired by GPS and a relative coordinate to object acquired by LRF. It means that the system can get absolute coordinate of the object in one time without base line.

However, it has following problems mainly about accuracy. First, there is a problem that it is difficult to specify where the system is measuring. Especially, it is difficult to recognize the exact point of a Buddhist image or the corner of ruins. Because each operator takes different position of the corner at same object, it causes error. There is a limit in the accuracy of the terrestrial magnetism sensor and it causes azimuth error. Moreover, it is difficult to use LRF, because it is still expensive.

6. THREE-DIMENSIONAL MEASUREMENT OF THE RUINS BY VIDEOMETRY

It is impossible to measure the detail of a building by GPS. To make 3D CG of ruins, we must make 3D modeling and rendering based on the shape data of constructions. Usually, to make complicated 3D CG quite lots of coordinate values are needed. It is impossible to measure each point of each building in detail on the site. Therefore, we developed videometry technology by stereo video pictures.

6.1 Integration of system

The principle of stereo measurement with video pictures is fundamentally the same as the photogrammetry. That is, we take two pictures with two parallel cameras and the distance between two points is obtained by the paradox. Here two digital video cameras (SONY DCR VX-1000) are used. Moreover, in order to be carried by one person in field, the system must be light. The total composition of the system we installed is shown in Fig.9.

Because the image is used to measure an accurate position of objects in three dimensions, a very high resolution is required. Time codes are automatically recorded in a digital video (DV) tape so that is possible to handle the recorded images by frame. This is also a great advantage for a 3D measurement using DV. In addition, we can control two cameras by one remote control because same cameras are used. This method was especially effective on the site. The visor type liquid crystal monitor named SONY GLASSTRON was adopted to decide the direction of two cameras.

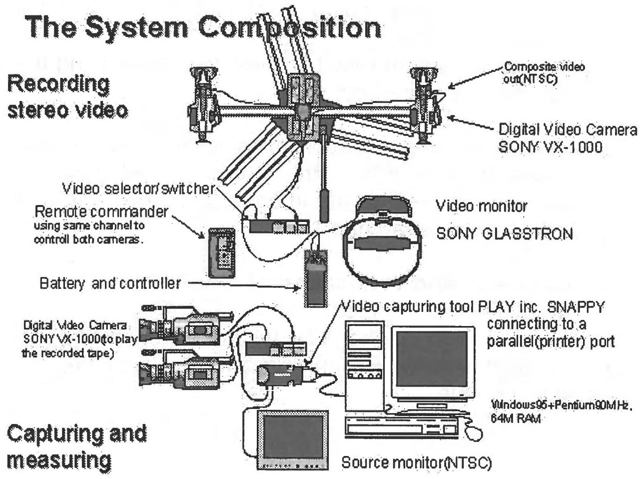


Fig.9 The system configuration of videometry

Concerning the installation of a video camera, it is preferable to take the interval of two cameras, that is, the base line length as long as possible. However, for the convenience of carrying, the system must be small and the base line should not be too long. Two cameras were installed at both ends of the aluminum pipe on the tripod. The length of the pipe here is 1.5m.

It is basic to put the measured object on one scene as much as possible for obtaining three-dimensional coordinates, especially when you want measure a length between two vertexes. However, usually more than three or four of images are needed for a big ruin, we can only take stereo images with one-third or more overlap.

It is general to use a video capture board etc. as a device to input video pictures into a computer. In this system high quality and high resolution is needed as a static picture more than images for animation. So we adopt not usual video capture board but a capture adapt called SNAPPY. With SNAPPY, a video image can be taken with 1500× 1125 pixel resolution. The picture input is NTSC composite.

6.2 Stereo measurement

The pictures are inputted into a computer by the procedure shown in the following and the stereo measurement is done. It is necessary to specify each vertex that wants to be measured in a pair of image in the algorithm for obtaining three dimensions coordinate by the stereo method.

Procedures of three dimensional measurement with video pictures:

1) Connect SNAPPY to a parallel port of the PC.
2) Connect two VX-1000 cameras to the video selector.
3) Connect the selector and SNAPPY, SNAPPY and a monitor with cables.

4) Start the measurement application software 3DV.
5) Retrieve two images in both cameras with the same time code.
6) Stop a left picture and push the CAPTURE button of 3DV.
7) Capture a right picture in similar.
8) Point the corresponding point in the right and left picture by mouse.
9) The measurement result is displayed by pushing the distance measurement button.

The stereo measurement application originally developed is semi-automated. When the measurement point is specified once by one on the images, the other side of a line is alternatively searched.

6.3 Experiment and verification of result

The ruin chosen in Angkor Wat for the experiment of 3D measurement is called Bakong because the structure of it is relatively simple.

Fig.10 Video image for the measurement of Bakong

Fig.10 is one scene of a video image for the measurement taken in Bakong. The stereo measurement is based on this kind of images. As you can see, the brightness and contract of images are quite different. Usually, latitude of the video is narrower than that of the photograph. In addition, brightness and darkness could be easily over exceeded in a video image. Therefore, not only the performance of a video recorder but also that of the capture strongly influences this.

Based on the 3-dimensional measurement, 3D CG simulation was created about Bakong ruins as shown in Fig.11. Modeler and renderer that we used are included in formZ (V2.7) for Apple Power Macintosh 8500. Texture mapping technique was used here to make the CG more reality, rather than the detail of the shape of each stone.

Fig.11 Three dimensional CG of Bakong

7. CONCLUSION

We were able to obtain fruit of results by bringing GPS, GIS, RS and CAD/CG together through the activities for safeguarding Angkor Wat. First, the positions of control point and ruins could be measured using RDGPS with 1-2 meter error and RTKGPS with 1-2 cm. These measurements were used to register SPOT satellite images with 10meter resolution and a satellite image map with the distribution of ruins has been made. Moreover, the GPS were applied to old maps so that an integrated database with maps, images, photos and plans of ruins become possible. In addition, 3D simulation of ruins restoration was made based on a digital video reflection. With this system, three-dimensional CG could be made in low-cost. These results could greatly contribute to the preservation and the restoration activities of Angkor Wat ruins.

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