DEVELOPMENT OF THE GPS SITE PATROL SYSTEM

- Shape Measurement by Close-Range Remote Sensing -

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ABSTRACT - The Global Positioning System (GPS) is a satellite positioning system developed in the U.S.A. The GPS sensors may be classified into the geodetic sensors and the navigation sensors used in the navigation of motor vehicles and marine vessels. The positioning accuracy of these navigation sensors is only around 20m, but they allow output of realtime measurement results. The authors have developed a site patrol system , in which these navigation sensors are mounted on patrol vehicles at large engineering sites for simultaneous detection of the positional information with the information relating to the safety , quality and finished shape of the structures , as well as display and recording of the information collected on the monitoring system at the site offices. The use of this system allows efficient collection , display and recording of various items of information on the construction site.

The recently developed digital still cameras , with their extremely high resolution and ability to make digital records, were also used in the system , for automatic measurement of the progress of work, for example, on embankments from the stereo pictures of the construction site and for application of the realtime images of the construction conditions to safety and quality control.

Keywords - GPS ; Cartographical Information System ; Electronic Still Camera ; Photogrammetry; Quality and Progress Control

1. INTRODUCTION

The civilian use of the Global Positioning System(GPS), an electronic positioning system using satellites, which was developed in the U.S.A., has been on the increase in Japan with the launch of new satellites and the consequent increase in the number of hours during which the system can be used. A number of motorcar makers have applied the GPS to practical use in navigation systems and portable sensors are now available for leisure purposes. The geodetic sensors , too , have now passed the test stage and are beginning to see application in construction work.

The authors have been conducting investigations on the applicability of the GPS to engineering work and have developed various support system for construction work with the application of the GPS to construction control surveying and to navigation of construction vehicles. Work is now under way for developing these systems further into a comprehensive system for construction support using various types of satellites, for what has been termed "SAC" (Satellite Aided Construction), a system that will be in line with the needs of the 21st century. This will be an information processing system using , besides the GPS, such satellites and techniques as the Landsat earth observation satellites and close-range remote sensing with electronic still cameras, providing a comprehensive construction support system with functions ranging from construction control surveying to safety, quality and vehicle control , disaster prevention and environmental monitoring (Fig. 1).

Reports are made in this paper on the development of the GPS Site Patrol System, designed for use in safety, quality and progress control, and a shape measurement system using close-range remote sensing.

2. Summary

2.1 Outline of System

This system is aimed at the provision of efficient , speedy and appropriate support for the work at construction sites through a combination of the positioning information obtained through GPS navigation sensors and various types of information concerning safety , quality and progress of work in the field, together with the parallel processing of the image information from the electronic still cameras

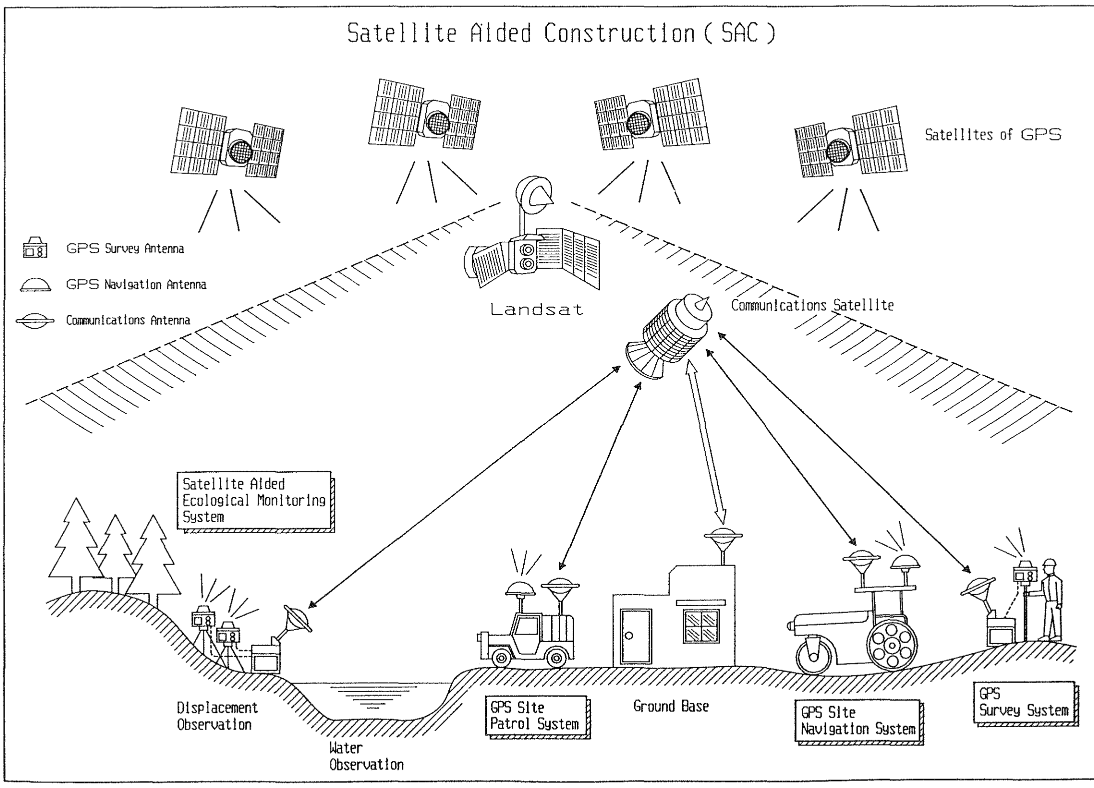


Fig. 1 Final System Composition SAC

The system as a whole is comprised of the following (Fig. 2).

①System for collection of site information using patrol vehicles

②Monitoring system at the site office

③System for shape measurement by close-range remote sensing using still cameras

2.2 Site Information Collection System

GPS navigation sensors are installed on vehicles patrolling engineering sites and information relating to the safety, quality and progress of the work is collected together with the positional information. By stationing the vehicle at the site at which the information is to be collected and inputting the item of information, the information sought is automatically recorded on the floppy disk together with the positional information (latitude, longitude and elevation) concerning the site as outputted from the GPS navigation sensor. The site conditions and the embankment configuration are photographed at the same time by the electronic still camera and the picture number recorded on the floppy disk.

2.3 Office Monitoring System

Upon completion of the patrol, the patrol results recorded on the floppy disk are displayed in the site office on the map of the site prepared using image scanners. The information obtained are displayed at the relevant positions on the map in different colours according to items , together with the picture numbers. Speedy and accurate display of the position and conditions of the site can be obtained by displaying on the video screen at the same time the pictures taken by the electronic still camera.

2.4 Close-Range Remote Sensing Shape Measurement

The stereo pictures of the construction site obtained by close-range remote sensing (photographed from two points by digital still cameras) are automatically put through processes such as orientation calculations and matching processing on general-purpose EWS to provide three-dimensional information. The processing is carried out in the five steps of relative orientation, absolute orientation, rectification, matching and calculation of three-dimensional information. Each of these processes are outlined below.

(1) Relative Orientation The relative angles of the stereo pictures taken (from two points) by digital still cameras are obtained form the pass points for model preparation(Photo.1 original photo).

(2) Absolute Orientation The positional relationship between the models prepared in the relative orientation and the ground surface is determined from the control points obtained from the GPS positional information.

(3) Rectification The orientation elements obtained by relative orientation are used for the preparation of vertical pictures. Stereo pictures free of vertical parallax can be obtained through this rectification, leaving only the lateral(x-axis) positional deviation between the left and right pictures

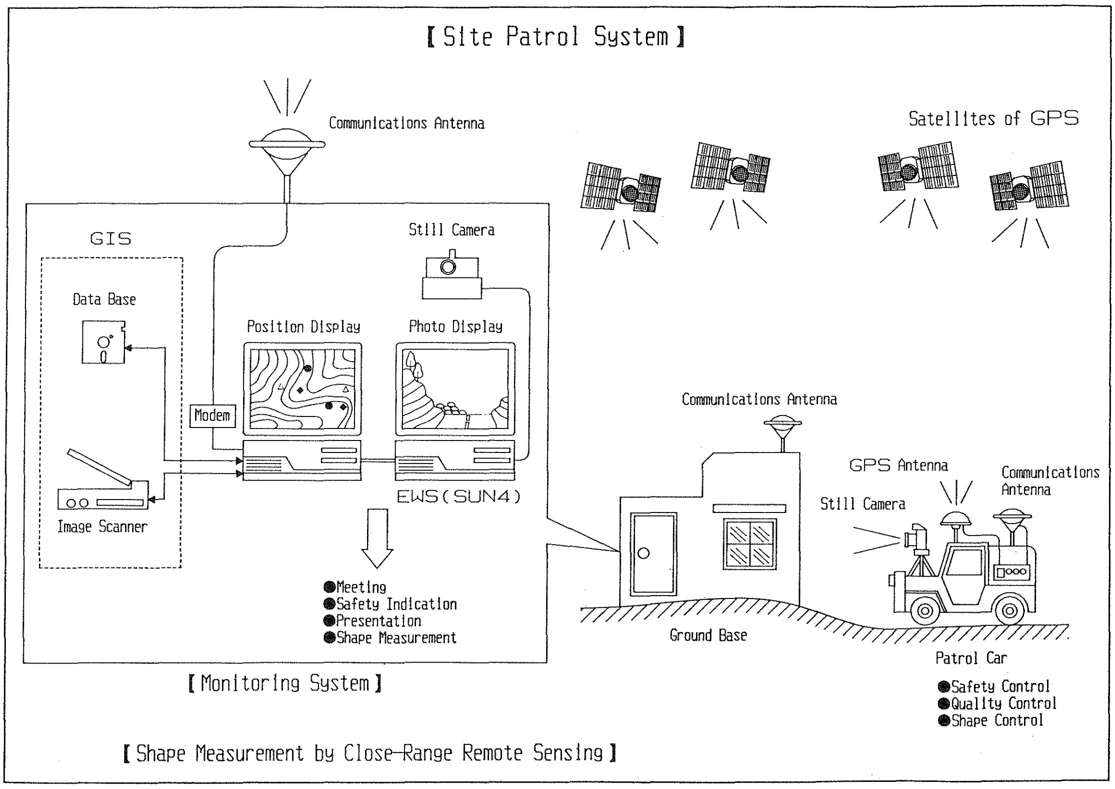


Fig.2 Outline of Site Patorol System

due to relative height differences and so allowing the search range in the matching processing to be limited to a single dimension(Photo.2 Rectification process).

(4) Matching The rectified stereo pictures are subjected to matching processing in which the corresponding points in the two pictures are sought for the whole of the area in question. The area correlation method is used for this purpose. Bearing in mind the large relative angles that result between the two pictures when stereo pictures are taken on ground, the correlation windows used in the area correlation method, a widely-used automatic matching method , were deformed in accordance with the inclination angles of the two pictures (Photo.3 stereo matching process).

(5) Calculation of Three-Dimensional Information The elevations of the matching points are calculated from the results of absolute orientation and matching processing and the elevation data irregularly laid out on the ground surface are rearranged into a regular pattern for the preparation of the digital topographical models (DTM).

In this method, all the steps in the analytical processing after the taking of the pictures to the calculation of the three-dimensional information are carried out automatically, except for the selection of the pass points.

3. SYSTEM COMPOSITION

3.1 GPS Sensors

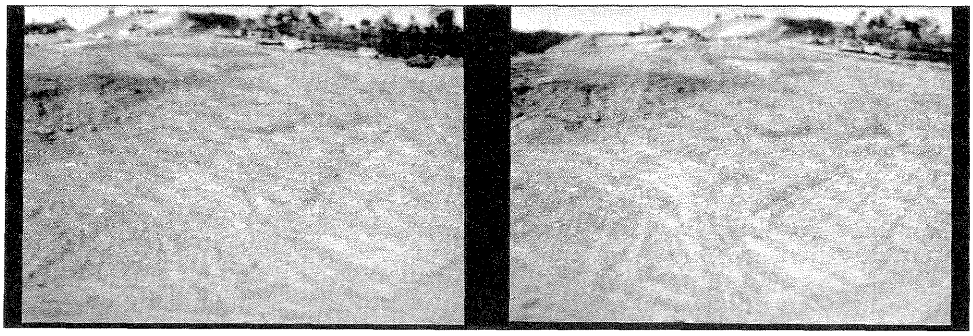
Sensors produced by Trimble Navigation (U.S.) were used for the GPS sensors.

(1) Detection of Patrol Vehicle Position TANS, produced by Trimble Navigation , were used as the sensors for the positioning of the vehicles. These are two-channel sequential reception sensors, receiving L1 band, C/A code data from the GPS satellites. The measurement accuracy is 25m(SEP) in the horizontal direction and 35m(SEP)in the vertical direction. They have softwares capable of automatically recording on floppy disks the position(latitude, longitude and elevation) of the vehicles at the time and the patrol items , together with the picture numbers on the electronic still camera , upon selection of the patrol items and input of the picture numbers.

As shown in Photo.4, the hardware consists of the sensor, aerial and note-book personal computer, with the sensor and the personal computer made into a unit. Table.1 shows the principal specifications of TANS.

(2) Control Point Survey for Absolute Orientation The absolute orientation (survey of ground control points)in the close-range remote sensing was carried out by the continuous kinematic method using 4000ST (shown in Photo.5), produced by Trimble Navigation. This sensor has an accuracy of 2 cm + 2 ppm and measurement time of 5 seconds.

left camera



right camera

Photo. 1 original photo

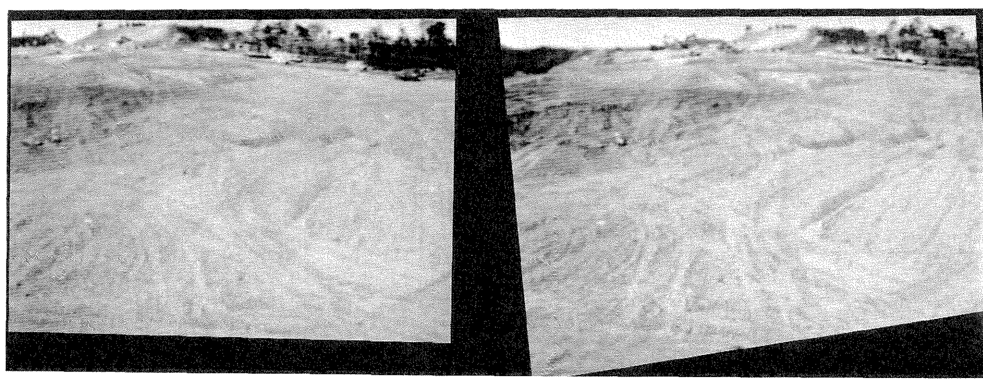


Photo. 2 Rectification process

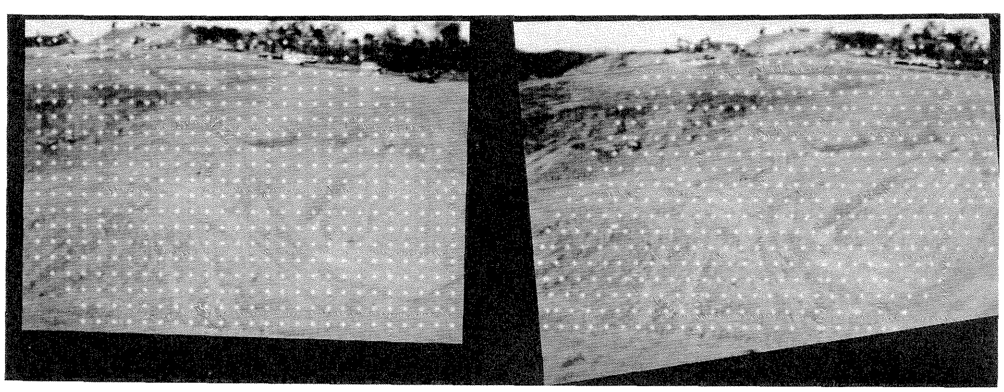


Photo. 3 stereo matching process

3.2 Electronic Still Camera

The digital still cameras are high-resolution cameras capable of recording the pictures taken in the form of digital data. In comparison with conventional cameras they have advantages such as that 1) there is no need to process the films, 2) there is no need for A/D conversion, 3) the picture quality does not deteriorate with time, and 4) there is no deterioration of the picture quality due to copying. The actual procedure for taking pictures with the digital still cameras is the same as with conventional cameras. The pictures can be reproduced instantaneously by connecting the camera to a CRT, allowing the patrol results to be used immediately for holding consultations and giving instructions. The specifications of the cameras used in the study reported here are given in Table. 2.

3.3 Site Graphical Information System

A system has been developed with which the plan views of the site can be displayed on the personal computer screen by simply reading the maps with image scanners and inputting the latitude and longitude of the control points and the reduction scale. The GPS positional measurement results can be overlaid on these plan views. Since this system facilitates the input of local cartographical information, allowing the site patrol systems to be put immediately into operation at any given site, it is hoped that the system will see general-purpose application at each office. On the personal computer screen, it is possible to also divide the plan views into 16 sections and to obtain enlarged pictures of each of these sections.

Photo. 4 System Hardware Composition

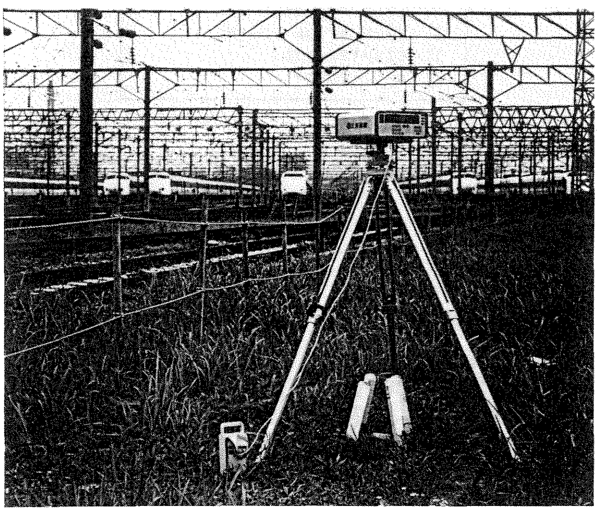


Photo. 5 GPS Surveyor 4000st

Table. 1 Principal Specifications of TANS

Item	Specifications
Sensor	L1 frequency, C/A code reception
Positioning Mode	1) 4 satellites, 3D positioning 2) 3 satellites, 2D positioning 3) automatic switching according to number of satellites
Horizontal Positioning Accuracy Vertical Positioning Accuracy	25 m (SEP) 35 m (SEP)
Velocity Accuracy	0.2 m/s (RMS) at constant speed
Time Accuracy	within 1 microsecond of UTC
Positioning Dispersion	less than 5 m (RMS) per 10 minutes at PDOP < 8
Positioning Interval	1 second
Digital Interface	two-way RS-422, 9,600 baud
Dimensions	127 mm x 241 mm x 50 mm
Weight	1.27 kg
Power Consumption	9 to 32 VDC, less than 4 W

3.4 Data Base

Since the patrol results obtained by this system, such as the patrol time, position, item and picture number, are stored in floppy disks, they can easily be made into a data base. Similarly, the picture images, analysis results and earthfill configurations are recorded on floppy disks, allowing immediate visual presentation as the need arises.

4. APPLICATION RESULTS

4.1 Information Collection and Monitoring System

The system was put into operation at a large land development site on the outskirts of Tokyo. Up to 99 patrol items(Table. 3) relating to safety, quality and progresscontrol can be set as required according to the site conditions. In Photo. 6, the aerial has been fixed to the roof of the patrol vehicle with a magnet, the sensor/personal computer unit has been installed on the assistant driver's seat, and pictures are being taken with the electronic still cameras.

The information on the patrol items can be recorded automatically with the positional information by inputting the patrol item and picture number via the keyboard once the vehicle has reached the patrol site. Photo. 7 and 8 show the monitoring screen in the office after the patrol , the conditions at the patrol site being shown on the screen (Photo. 7) and the picturetaken by the electronic still camera in Photo. 8.

4.2 Shape Measurement System

Verification was conducted on the accuracy of the system regarding 1) the errors in the control points along the X, Y and Z axes, 2) the accuracy of the elevation at all measurement points, 3) the error in soil volume and 4) the effect of the intervals between search points in the matching processing on the measurement accuracy, using the measurement results from the total station as the real values. The shape measurement accuracy obtained by this system in an area 40 m by 40 m is shown in Table 4. More than one value is given for the soil volumes as obtained on the total station in the table showing the shape measurement accuracy. This is to indicate the errors that result in the soil volumes when large intervals are used. A comparison was also made in the work efficiency between when the system reported here was used and when the total station, generally used in shape measurement at construction sites at present, was used. The investigation items here were

① measurement time and

② processing time.

The results of the comparative study are given in Table 5.

Table. 2 Digital Still Camera

Recording Method	frame digital recording
Data Compression	subsampling and ADPCM
Image Sensor	2/3inch, 400,000 picture element FIT-CCD
Image Sensor Size	8.96 mm x 6.64 mm
Image Data	RGB, 8bit/picture element
Image Composition	640 x 475
Picture Element Size	0.0135 mm
Lens	F 2.0 f: 9 to 27 mm

Table. 3 Examples of Patrol Items

a. Safety Control 1. work area 2. base course conditions 3. road shoulder conditions 4. drainage conditions 5. safety indication 6. directional signs 7. safety fences
b. Quality Control 1. compaction tests 2. bearing strength tests 3. boring 4. settlement measurement 5. displacement measurement 6. water level measurement 7. concrete strengths
c. Shape Control 1. fill volume 2. excavation volume 3. displacement 4. settlement

Photo. 6-1 System Installed on Patorol Vehicle

Photo. 6-2 Photographing with Electronic Still Camera

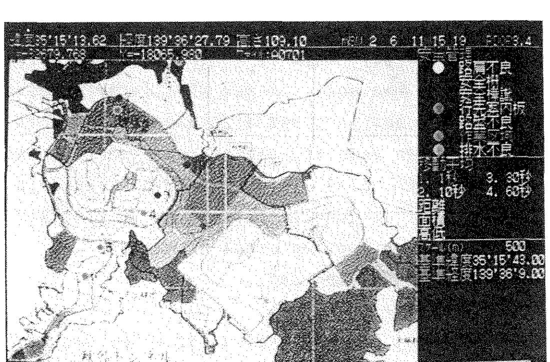


Photo. 7 Screen Showing Conditions at Patorol Site

Photo. 8 Parallel Display with Photograph

Table.4 Accuracy of Measurement

Measuring area 40m×40m

mesh		Total Station 10m	20m	B = 12.8 m D = 44.6 m h = 14.9 m	
a mesh length on matching(m)	x	---	---	10	5
	y	---	---	10	5
RMS error of standard point (m)	x	---	---	0.213	0.213
	y	---	---	0.698	0.698
	z	---	---	0.170	0.170
RMS error of hight		---	---	0.206	0.257
volume of cutting (m^3)		0.000 0%	165.52 15.3%	-20.531 1.9%	-75.65 7.0%
volume of embankment (m^3)		0.000 0%	71.367 7.8%	18.128 2.0%	-111.59 12.3%
error of volume		0.000	250.90	21.028	-24.788

Table.5 investigation of surveying efficiency

Time (min)	measurment	analysis
measurment by still camera	4	20
measurment of Range Finder	54	half day

5. CONCLUSION

The results of the research and development work for the system may be summarised as follows.

1) The system curtails the time and personnel required for conducting patrols for safety control and other purposes on construction sites,while the patrol results, which can be reproduced instantaneously at the site office, can be used immediately for consultations and giving instructions.

2) Since the patrol positions are recorded automatically using GPS in the site information collection system, there is no need for confirmation of the positions using markers and other devices. This means that those conducting the patrols need not be familiar with the site and that even on sites where the landscape is changing constantly those conducting the patrols can confirm their positions on maps and are not likely to be misled.

3) On the site office monitoring system, the information can easily be displayed on maps on the CRT , facilitating explanation to newcomers and visitors unfamiliar with the site.

4) The instant display of the site conditions using electronic still cameras facilitates consultations and giving of instructions.

5) A level of accuracy adequate for practical purpose can be obtained by the three-dimensional shape measurement using digital still cameras, making great contributions to raising the efficiency in the measurement work at construction sites.

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