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Development of Earthwork Progress Measurement System Using Global Positioning System (GPS)

Mikio Okano /Akimasa Waku /Akira Fujioka/ Katuyuki Kikuta

Technical Research Institute of Fujita Corporation
74 Ohdana-cho kouhokuku Yokohama-City Kanagawa JAPAN 223

ABSTRACT

In this study, a new system for earthwork measurements using the Global Positioning System(GPS) has been developed. This paper describes the development of a device to automatically hold an antenna level and a computer program developed for the transformation of coordinates obtained by GPS surveying to the ordinary plane coordinates.

This paper gives a report on the earthwork progress measurement system, including its effectiveness. This effectiveness was verified a comparison between this new system and the traditional surveying system.

1. INTRODUCTION

In Japan, it is general practice in the carrying out of earthwork, the well balanced cutting and filling of soil is performed at the construction site. This is done in a way that does not generate any surplus or shortage of soil. Therefore, surveying must be executed periodically in correspondence to the progress of the work, in order to control the earth volume.

In many cases, field surveying involves extensive areas that need measurement, therefore surveying methods need to be outstanding in the execution of surveying rapidly, economically, as well as with work-performance ease, including a high-level of accuracy. An Electric Distance Meter (hereafter referred to as EDM surveying) and an aerial photogrammetry are generally used for the field surveying. However, EDM surveying takes time, as well as lack promptness, sometimes failing to follow earthwork progress, while an aerial photogrammetry enables measurement in a very short time, but is inferior to EDM surveying in accuracy. Also, frequent measurement using an aerial photogrammetry is not economical.

On the contrary, in recent years, the Global Positioning System(GPS)[1)~3)], a surveying system that takes advantage of artificial satellites, has attracted attention. The GPS is a system that receives radio wave transmitted from artificial satellites in order to attain three-dimensional coordinates of observation points.

The GPS has led the authors to assume the feasibility of creating such as a system that can perform measurement faster and more economically than the traditional measurement system. On the basis of this concept, earthwork progress control system using the GPS has been developed, for application to large-scale civil engineering projects.

2. OVERVIEW OF GPS SURVEYING

GPS surveying is largely classified into two categories, the point positioning method and the relative positioning method. The former is a surveying method aiming to assist navigation, and has been extensively used, while the latter is a surveying method that can attain the relative coordinates between observation points. The relative positioning outweighs the traditional surveying system in various ways, such as 1) enable highly accurate surveying in relation to long baseline, 2) not requiring through-vision between observation points, and 3) enabling surveying in rainy weather and at night. In this system, kinematic positioning of relative surveying is used.

The kinematic positioning is such that an antenna is fixed at the base point, and another antenna is moved from one observation point to the other successively, in order to attain the relative coordinates between the base point and the observation points. Since observation by this positioning needs only several seconds, it enables the attainment of coordinates for a large number of observation points. The only disadvantage it has, is the requirement for the continued receiving of radio waves from at least four artificial satellites.

3. EARTHWORK PROGRESS MEASUREMENT SYSTEM USING GPS

3.1. System Concept

Fig.1 illustrated the flow of the GPS earthwork progress measurement system developed through this study. This system consists of four constituents, as mentioned below.

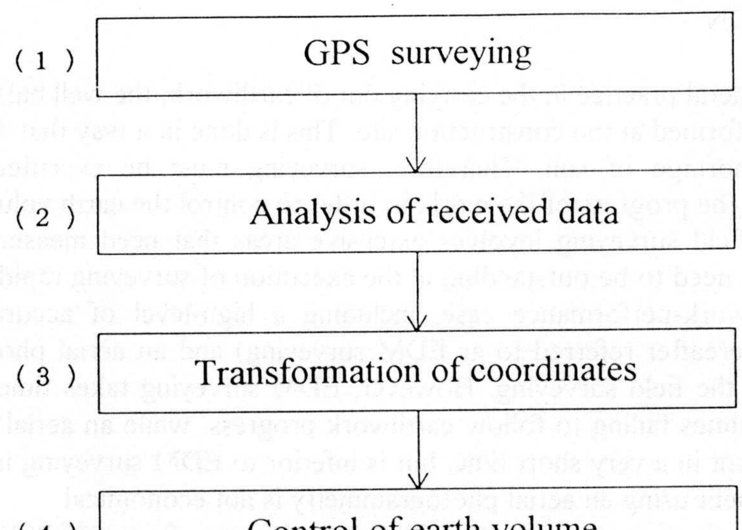


Fig. 1 System Flow

(1) GPS surveying

In earthwork progress measurement, it is necessary to survey observation points quickly in a large site. Therefore, this study used the kinematic positioning that requires only a short time for the measurement at one point. However, the important issues are how quickly the measurement can be taken without causing cycle slips. The meaning of cycle slip is as follows. As some radio waves from artificial satellites are interrupted, they are being received, due to the influence of an obstacle or a noise wave. In this instance, the phase being measured loses continuity. The occurrence of this state is known as the cycle slip.

(2) Analysis of received data

An analysis method for receiving data has been proposed, so this study utilized it[1),4)].

(3) Transformation of coordinates

Since the coordinates of the observation points attained through analysis are derived from the World Geodetic System-1984[1)] (hereafter referred to as WGS-84), using their results directly may give rise to the following problem. The coordinates based on Japanese Geodetic System[1)] are generally used on a construction site, so it is necessary to transform the coordinates attained through GPS surveying, into those in Japanese Geodetic System.

(4) Control of earth volume

Earth volume were calculated using the observation points transformed the coordinates in Japanese Geodetic System.

3.2. Development items

Description of detailed development items in this study are as follows.

1) A device to automatically hold an antenna level

To enable the quick measurement of earthwork progress at an extensive range of sites by using the kinematic positioning, the use of a vehicle that moved from one observation point to the other was contemplated. In addition, if the antenna tilted while was being moved, it might become impossible to receive radio waves from artificial satellites. If cycle slips occur then the job efficiency would drop considerably. All this led to the development of a device that can automatically hold an antenna level in order to enhance the efficiency and reliability of kinematic positioning.

2) Linkage program

The results of GPS surveying are represented in accordance with the WGS-84, so the result, when applied to general earthwork, have to be transformed into coordinates in Japanese Geodetic System. This requires a program capable of transforming of many observation points quickly and accurately. To this end, a program has been developed, that directly links the analytical results of GPS surveying to the earthwork progress program.

4. A DEVICE TO AUTOMATICALLY HOLD AN ANTENNA LEVEL

4.1. Overview of a device

Desired control accuracy of this device was designed as follows.

While vehicle moving	5 degrees
While vehicle at reset	0.5 degrees
Control limit	30 degrees

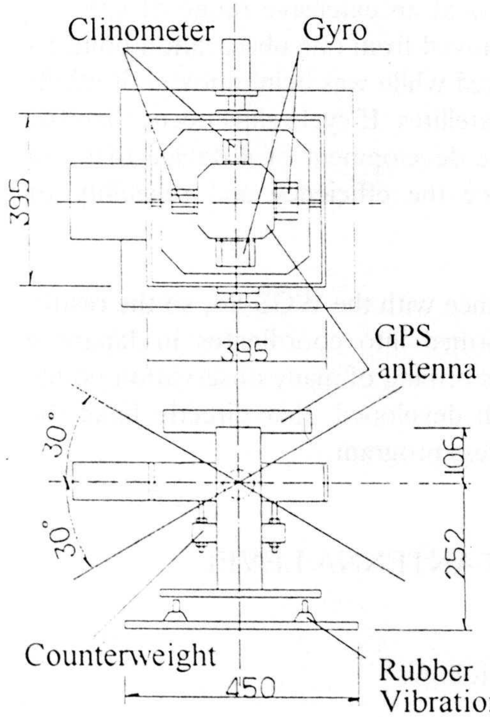
Fig.2 illustrates this device developed accordance with the target accuracy mentioned above. A clinometer to measure tilt angles of the antenna plane and a gyro to measure angular speed were installed, one each in biaxial direction (at the pitching and the rolling angles) respectively, for a total of four. A DC motor was used in the driving section to hold the antenna plane level.

This automatic device collects the data measured by the clinometers and the gyros, makes correction in an amount corresponding to the tilt angle of the antenna plane, and by driving the DC motor, holds the antenna plane level. In detail, data from the quick-responding gyros is used to control the changing angles of the antenna created by sharp ground undulations felt by the traveling vehicle, while data from the clinometers is used to accurately control the marginally changing angle of the antenna.

4.2. Accuracy Verification tests

For the purpose of verifying the level holding accuracy of this device, this device was mounted on the vehicle(Photo. 1) and tested at the site ((a)smooth gravel road, (b)asphalt-paved surface with a certain gradient, (c)graded site with sharp undulations) at the traveling speed of approximately 5km/h .

Fig. 3 plots some of the results. In the cases of the smooth gravel road and the asphalt-paved surface with a certain gradient, the antenna plane while the vehicle was traveling, was held level with the accuracy of approximately 5 degree. In the case of the roughly graded site with sharp undulations, this device was sometimes unable to follow the motions of the vehicle body. It sometimes exceeded 5 degrees, but was not over 10 degrees in any case. As the above



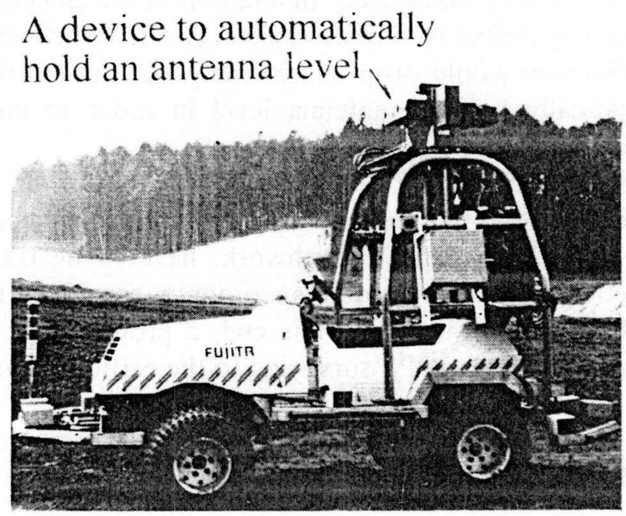


Photo. 1 The Vehicle

Fig. 2 A device to automatically hold an antenna level mentioned test results indicate, the target accuracy was able to be achieved for the most part within the range of the given limits. However, at the present stage, promptness, and an application to complex topography remain unsolved requiring future modification.

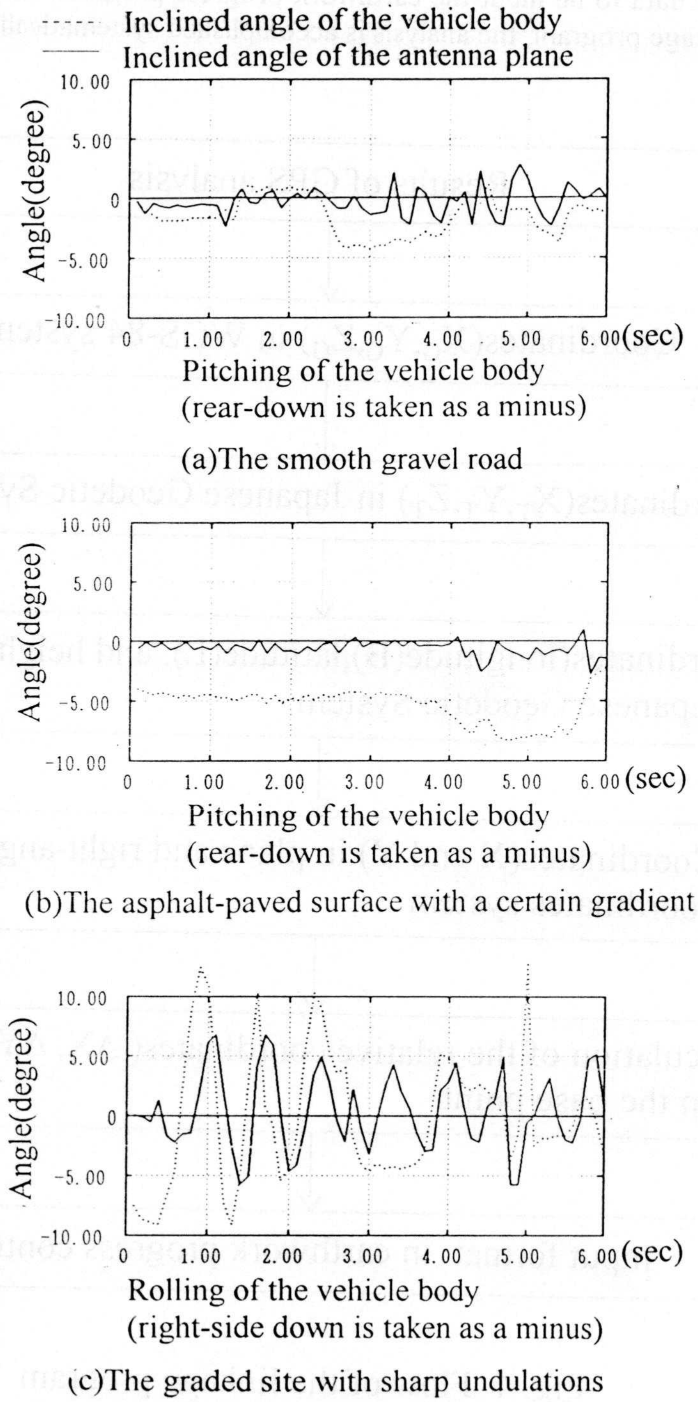


Fig. 3 The results of the accuracy of verification tests

5. DEVELOPMENT OF LINKAGE PROGRAM

A linkage program has been developed to transform coordinates attained through GPS surveying, into plane coordinates in according with the Japanese geodetic system, and to offer the easy attainment of data to be input the earthwork progress program. Its flow is shown in Fig. 4[5]. Using the linkage program, the analysis is accomplished systematically and efficiently.

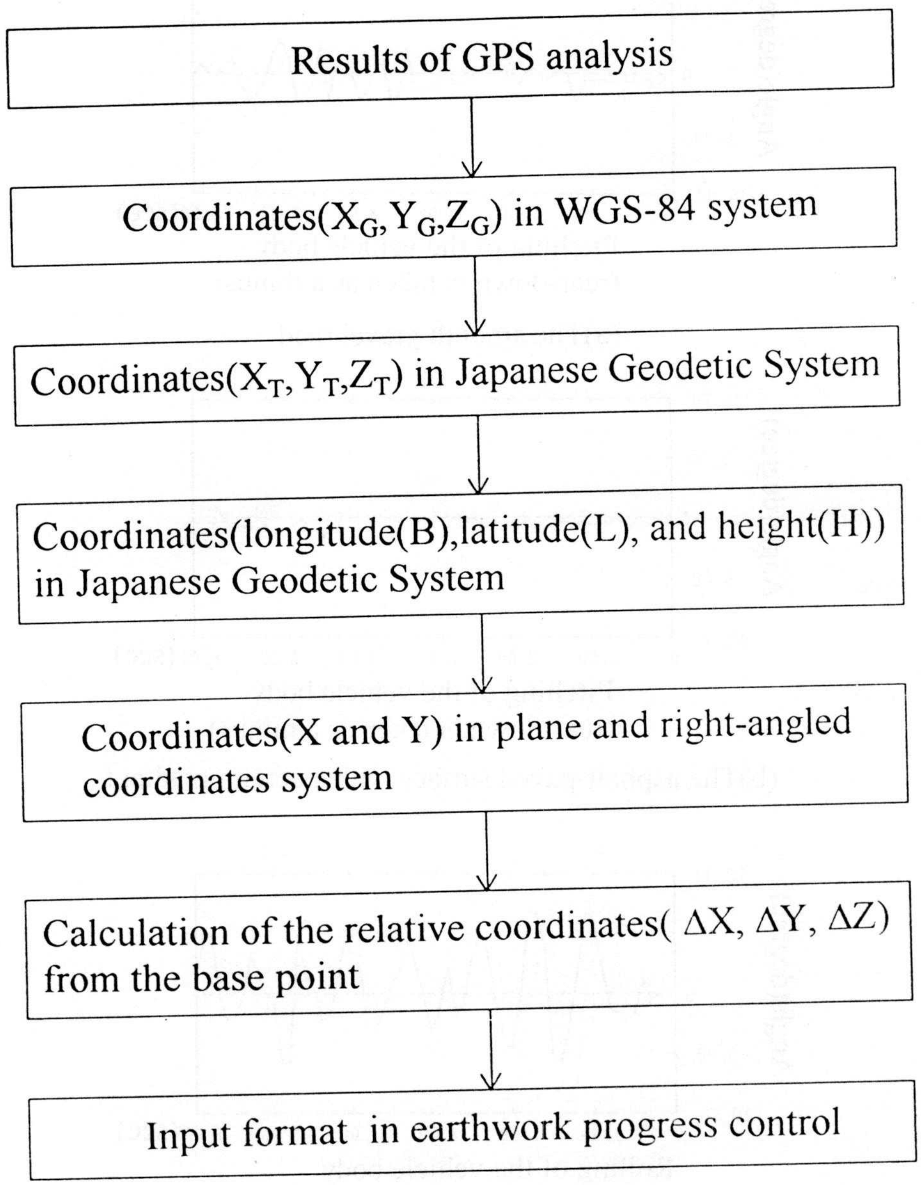


Fig. 4 Flow of the linkage program

6. DEMONSTRATION FIELD TESTS

6.1. Overview

Field tests are done in this study to verify the adequacy of the system developed, after its application to the measurement of earth volume.

The area of test yard was approximately 1 hectare. The earth volume of this site was measured using the system developed through this study and EDM surveying, and both results were compared.

6.2. Measurement result

Fig. 5 is the planar view of the observation points. Table 1 shows the calculated results. The results indicated that the earth volume calculated by this system was merely 0.6% less than that calculated by EDM surveying. This difference would not be a particular problem in the calculation of earth volume.

These tests revealed that the system can offer approximately the same accuracy as the EDM surveying, and that the use of the device to automatically hold an antenna level mounted vehicle was able to facilitate field GPS surveying.

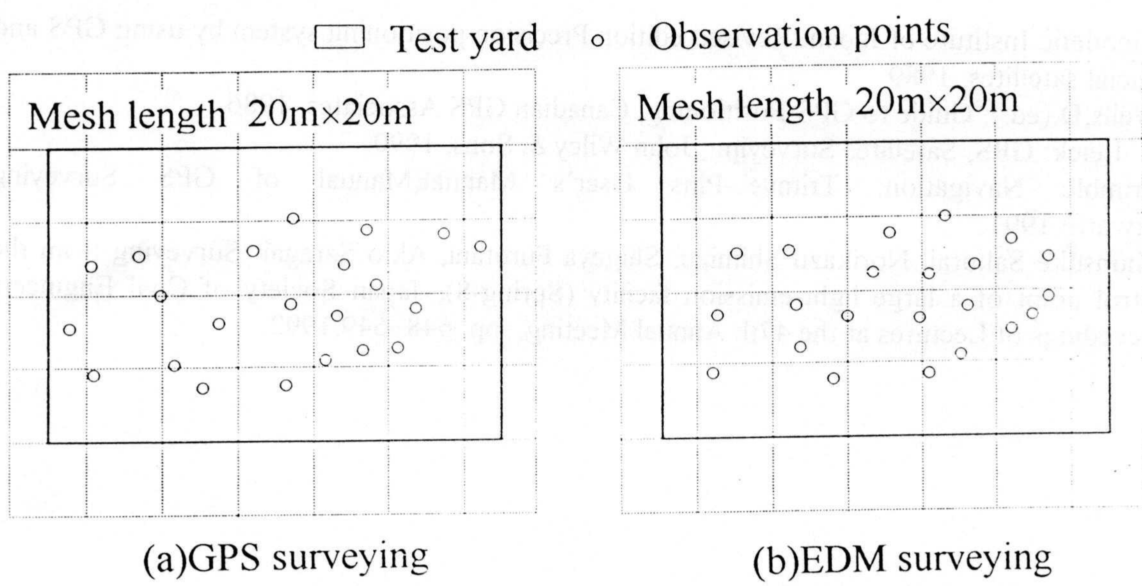


Fig. 5. Observations ground plane

Table 1 Measurement results

	Electric Distance Meter	GPS surveying
Observation points	22	22
Accuracy	31,495m^3	31,672m^3 (0.6%)

7. CONCLUSION

Through this study, the earthwork progress measurement system is developed using the GPS. This system consists of (1)GPS surveying, (2)Analysis of received data,(3)Transformation of coordinates, and (4)Control of earth volume. This basic study specifically focuses on (1) and (3), the development of a device to automatically hold an antenna level mounted vehicle, and a linkage program that links analysis results to the earthwork progress control program.

Field tests conducted at a roughly graded site indicated that the device to automatically hold an antenna level was able to achieve the required accuracy to hold the antenna level. A linkage software is created to link the transformed coordinates with the earthwork progress control program. This was followed by an application of the system to earth volume. The results proved the capability of the system to calculate as the EDM surveying, as well as its excellent features to facilitate the execution of the work.

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