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An Investigation on Cost and Accuracy Analysis of Real-Time Kinematic GPS Method in Acquisition of Spatial Data for GIS

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Abstract: In this study, acquisition of spatial data for GIS with RTK-GPS and conventional survey methods have been compared in view of cost and accuracy. One of the main components of a Geographic Information System (GIS) is the formation of the database. More than 70% of the time and cost is spent on developing this database. The success of a GIS project depends on the accuracy and currentness of the obtained spatial data required for development of the GIS project. This study presents analyses of the accuracy and costs of several methods of obtaining spatial data for a GIS project in a test area selected at the Campus of Konya Selcuk University. About a 20 ha test area were established in Selcuk University Campus to compare RTK-GPS and classic methods. Detail points in the test area were measured according to polar coordinate method by using electronic tacheometry. Spatial data concerning the same area were obtained with Real Time Kinematic GPS (RTK GPS). Polar coordinate method (classical method) was accepted as a basis and compared with the spatial data obtained from RTK-GPS method in terms of accuracy and cost. As a result, it was noted that real-time kinematic GPS methods were found to be appropriate for the GIS projects requiring high accuracy (e.g., cadastral, public works, infrastructures, etc.).

Key words: Detail measurement, RTK-GPS, electronic tacheometry

INTRODUCTION

In recent years, Geographic Information Systems (GIS) have become a highly important subject in parallel with developments in computer technology. The GIS has aroused interest due to its capability for storing spatial and non-spatial data on the earth in a computer environment, performing operations and analyses using these data, presenting the results visually and so on. Therefore, the formation and effective use of GIS in many fields such as managing natural resources, public works, municipal services and environmental, sanitary, tourist, transportational and forestry activities was inevitable in today's conditions. Hence, intensive investigations and applications of studies related to GIS have been performed in public institutions, local management, private companies and universities (Yagmur, 2002; Chujiang *et al*., 2004; Işcan *et al*., 2004; Mekik and Arslanoglu, 2009).

In this study, Real-Time Kinematic GPS (RTK-GPS) method used in acquisition of spatial data for GIS projects is taken into consideration. Analyses of the accuracy and costs of the method are performed using technological hardware and up-to-date data for the test area. Finally, suggestions about the selection of a method that is appropriate for a particular GIS project are given.

GEOGRAPHIC INFORMATION SYSTEM-(GIS)

A GIS is a tool for making and using spatial information. There are many formal definitions of GIS; for example the National Centre of Geographic Information and Analysis (NCGIA) states that: A GIS is a system of hardware, software and procedures to facilitate the management, manipulation, analysis modeling, representation and display of georeferenced data to solve complex problems regarding planning and management of resources (Escobar *et al*., 2008). For practical purposes, GIS is defined as a computer-based system to aid in the collection, maintenance, storage, analysis, output and distribution of spatial data and information (Burrough and Frank, 1995).

The historical development and the methodology of GIS are described in detail by Goodchild (1985, 1992), Fritsch (1992), Curry (1998), Martin (1996), Demers (1997), Burrough and Frank (1995), Burrough (1998), Heywood *et al*. (2002), Clarke (2003) and Yomralioglu (2005).

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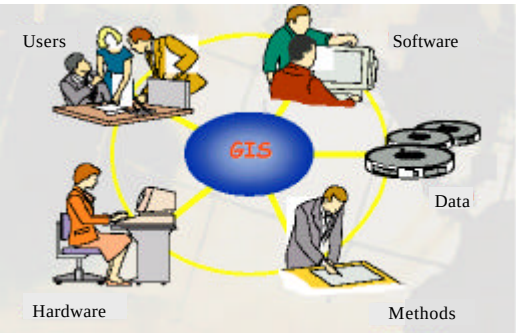

Fig. 1: The components of the geographical information system

The components of the geographical information systems: At least 5 main members must come together to make geographical information system implement its basic functions. These are called as hardware, software, data, human and methods and named as components of the GIS (Fig. 1).

Graphic information and non-graphic information in geographical information base system: The elements are known as geographical data if they quantify the geographical assets. Geographic data is expressed as two different types regarding to their properties. These are graphic and non-graphic information. Graphic information gives information about the position, size and figure of the asset. For instance, the position of A detail in space is described in cartesian coordinates (x, y, z) or geographical coordinates (φ, λ) definitely. Non-graphic information gives information about the structural properties of the asset.

SPATIAL DATA-ACQUISITION METHODS FOR GIS

Many technological approaches have been developed by many different disciplines to use various data sources for collecting spatial data in GIS. Since, the data-acquisition process in GIS is carried out by using more than one data source, the integration of the collected data also has great importance. The methods applied for spatial data-acquisition in GIS are listed as given in Fig. 2.

- Conventional method
- RTK-GPS method
- Photogrammetric method
- Remote sensing method
- Scanning and digitising method
- Data transfer method

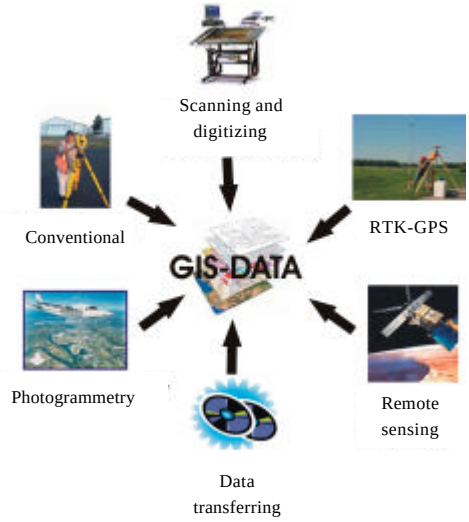

Fig. 2: Spatial-data acquisition methods

To be consistent with the aim of this study, the only classical and RTK-GPS methods were discussed.

Conventional methods: The main principle of the conventional method, also named the polar method is the determination of the horizontal and vertical position data of the detail points simultaneously with the help of the horizontal angle (β), vertical angle (Z) and horizontal distance (S) observed at the detail points with an electronic tachymeter installed at definite control points for which coordinates are known. The observations made with the electronic tachymeters are automatically recorded to the recording units and transferred to the computer environment in order to make calculations and drawings.

The accuracy of the method depends on the accuracy of the horizontal angle measurement (σ_β), the accuracy of the distance measurement (σ_S) and the accuracy of the positions of the stationary points (σ_{Y_A}, σ_{X_A}).

The point position accuracies (σ_P) can be calculated with the following formula:

$$\sigma_P^2 = \sigma_Y^2 + \sigma_X^2 = \sigma_{Y_A}^2 + \sigma_{X_A}^2 + \sigma_S^2 + S^2.\frac{\sigma_\beta^2}{\rho^2} \qquad \rho = 180°/\pi \qquad (1)$$

The point position accuracies of the conventional method were calculated and are presented in Table 1 for various distances of $\sigma_{Y_A} = \sigma_{X_A} = \pm 1$ cm, $\sigma_S = \pm 3$ mm and $\sigma_\beta = \pm 1''$ ve $\pm 2''$.

Global Positioning Systems (GPS): The Global Positioning System is a radio navigation system that uses satellite signals to determine the position, velocity and

Table 1: Point position accuracies for the conventional method (σ_P)

	S (m)					
Methods	50	100	150	200	300	400
σ_β (")	±1"	±1"	±1"	±1"	±1"	±1"
	±2"	±2"	±2"	±2"	±2"	±2"
σ_P (mm)	±14.5	±14.5	±14.5	±14.5	±14.5	±14.6
	±14.5	±14.5	±14.5	±14.6	±14.7	±15.0

time parameters economically, instantly and continuously for any place and time with high accuracy in a global coordinate system under all types of weather conditions (Kahveci and Yıldız, 2005).

Real Time Kinematic GPS (RTK-GPS): In recent years, the GPS method has been widely used to meet the need for spatial data for essential surveying, defence, navigation, transportation, energy, agriculture, tourism and environmental and natural resource management related to GIS projects. In accordance with the accuracy required of GPS methods, different measurement methods such as static, kinematic, semi-kinematic and DGPS methods are used. The disadvantages of GPS methods are the GPS signal blockage in city areas with densely packed, high buildings and the unavailability of fixed GPS receivers on building corners. On the other hand, the advantage of the GPS method is that rapid progress with hardware and software in computers creates a parallel attribution to save data at hand the point position could be obtained as a real-time and post-process. In general, the Real-Time Kinematic GPS method is preferred if a real-time position is required (Gökalp and Güngör, 2001).

The basic principle of the RTK-GPS method is the determination of point positions with the assistance of Navstar/GPS satellite signals by transferring the instant correction values calculated by the receiver at reference points whose positions are very well-known into mobile receivers using radio transmitters. With the RTK-GPS method, the double frequency GPS receivers are used in both reference and mobile stations. According to Mekik and Arslanoglu (2009), point position accuracies of ±2-5 cm were obtained by the RTK-GPS method.

APPLICATION

Test area: Alaeddin Keykubat campus area of Selcuk University was selected as the test area in order to compare the methods used for collecting the spatial data necessary to build the GIS formation (Fig. 3). The campus area is located 20 km North of Konya City Centre and includes ten faculties, two vocational high schools, dormitories, social facilities such as sports centres, health centres, cafeterias, shopping centres and so on.

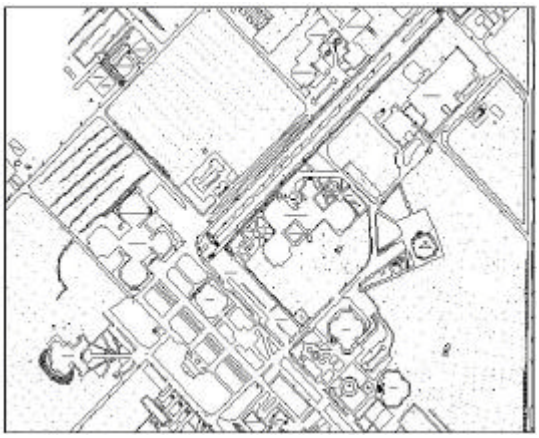

Fig. 3: Test field

Field studies and measurements

Spatial data-acquisition with the conventional method: In the conventional method, TOPCON GTS-701 electronic tachometry with ±2^{cc} angle measuring accuracy and ±2 mm + 2 ppm. D length measuring accuracy (σ_s) was used.

Evaluating the measurements obtained by the field studies with a CAD based professional computer program (NETCAD) after transferring them into the computer medium, the spatial data of the detail points were obtained and the related drawings were made. The measurement and the evaluation processes were completed in 55 h by a measuring team of one survey engineer and four survey technicians.

Spatial data-acquisition using an RTK-GPS method: Three GPS receivers with double-frequency (one stationary, two mobile receivers) manufactured by JAVAD were used in the RTK-GPS method. The manufacturer and model of the radio modem used for data transfer were SATEL and Satelline 3AS, respectively. The special frequencies used in the method were the F1 channel transmitter frequency (MHz) 443.1375 and receiver frequency (MHz) 443.1375. After loading the known coordinates of the reference points into the reference receiver, the spatial data belonging to the detail points were determined by the mobile receivers in real time. The measurements and the related evaluations were completed in approximately 3 h by a measuring team of one survey engineer and four survey technicians.

Accuracy analysis: In calculating the point position errors of the spatial data-acquisition methods, the coordinates (Y_K, X_K) obtained by the conventional method

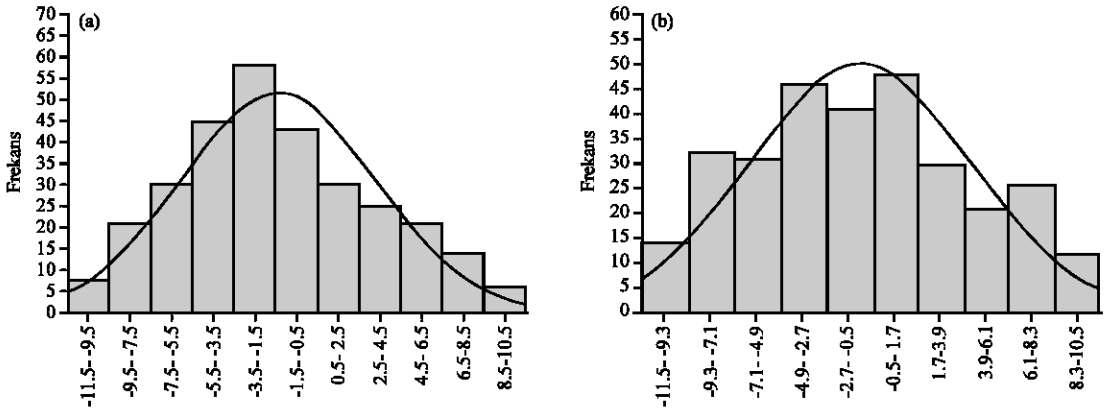

Fig. 4: (a, b) Residuals of Y and X directions

were accepted as the reference and then the point position errors of the other methods were calculated using the following equations.

$$V_Y = Y_G - Y_K \quad (2)$$

$$V_X = X_G - X_K \quad (3)$$

$$m_x = \pm\sqrt{\frac{[V_X V_X]}{n}} \quad (4)$$

$$m_Y = \pm\sqrt{\frac{[V_Y V_Y]}{n}} \quad (5)$$

$$m_p = \pm\sqrt{\frac{[V_X V_X + V_Y V_Y]}{n}} \quad (6)$$

where, Y_G and X_G are coordinates obtained by other methods and n is the number of points.

The point position accuracies of the methods are given in Table 2 (Mutluoglu, 2004).

Histogram belongs to coordinate differences in X and Y directions are given in Fig. 4a and b.

Cost analysis: The cost analysis of the spatial data capture methods for GIS took the following factors into consideration: personnel, hardware, software and the profit of the contractor. In the calculation of personnel costs, the optimal number of staff (engineers and technicians) required for the implementation of the methods in the field and in the office, time, salary, taxes and other administrative costs were taken into account. In the calculation of hardware and software costs, the usage time for surveying instruments, computer scanner, plotter and other instruments and unit costs were considered.

Table 2: The point position accuracies of RTK-GPS method

		Accuracies (rms)		
Methods	No. of points	m_y	m_x (cm)	m_p
RTK GPS	301	±4.9	±5.4	±7.2

Table 3: Cost analysis of conventional method

Processes	Unit	Cost ($)
Point plant measurements and calculations	28 items	752.57
Detail intake measurement		
Hardware (rent)	20 h	169.90
Personel expenditures	5 person	621.16
Auto (rent)	10 h	37.50
Other expenditures		336.08
Total		1917.21
Unit cost (1 ha)		95.86 $ ha^{-1}

Table 4: Cost analysis of RTK-GPS method

Processes	Unit	Cost ($)
GPS (rent)	3 h	123.07
Personel expenditures	5 person	140.62
Auto (rent)	3 h	11.25
Other expenditures		68.89
Total		344.45
Unit cost (1 ha)		17.22 $ ha^{-1}

The profit of the contractor is taken to be 25%. Considering all the costs mentioned above, the unit costs for each method were calculated and are given in Table 3 and 4 (Mutluoglu, 2004). In the calculations, the unit costs of the ministry of public works and settlement are used.

CONCLUSION AND RECOMMENDATIONS

At the implementation part of the GIS, the data collection is one of the important stages and requires highest time duration and cost between stages. Different accuracies and costs were determined for each spatial data-acquisition method used for the development of the GIS projects. The success of a GIS project primarily

depends on having spatial data of an appropriate accuracy and currentness for the goal of the project. Therefore, the most appropriate method or methods for the goal should be determined before starting a GIS project.

In this study, accuracy and cost analysis of the positional data by electronic tachometer and RTK-GPS methods were done. Positional data by RTK-GPS with mean square error of ±7.2 cm.

The cost of the data obtained from unit (1 ha) field by RTK-GPS method is (17.22 $ ha^{-1} (USA). When the cost of the data obtained from unit (1 ha) field by polar intake method considered (99.77 $ ha^{-1}).

RTK-GPS measurement method can be thought as an alternative to the polar intake method.Conventional and RTK-GPS methods can be proposed for GIS projects like cadastral studies, public works and infrastructure projects requiring high spatial accuracies. The RTK-GPS method is especially preferred for open areas due to the higher cost of conventional methods, lower production rates and dependence on the meteorological conditions.

When the accuracy and cost values by RTK-GPS, it can be seen that RTK-GPS method can be used in the Geographical Information System works which need high accuracy.

But, this method offers better results in measurements in open field because of its known inconveniences. In the region, with tree densities or residential, since satellite signals are interrupted no efficient results can be got. So that, in residential place and coppice, detail measurements must be supported with other classical methods.

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