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Full Length Research Paper

Accuracy and cost comparison of spatial data-acquisition methods for the development of geographical information systems

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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. The conventional and Real Time Kinematic Global Positioning System methods were found to be appropriate for GIS projects requiring high accuracy (e.g. cadastral, public work, or infrastructure projects). On the other hand, photogrammetric methods, digitising and scanning, and high resolution satellite images (remote sensing) were determined to be the most suitable methods for GIS projects requiring lower accuracy over large areas (e.g. in environmental management, highways, railways, forestry, disaster management, land consolidation).

Key words: Geographic Information System (GIS), Global Positioning System (GPS), detail measurements, remote sensing, digital orthophotograph.

INTRODUCTION

In recent years, Geographic Information Systems (GIS) have become a highly important subject in parallel with developments in computer technology. 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 (Pierre, 1994; Garal- Nabi, 1997; Yagmur, 2002; Arslanoglu ve Mekik, 2003; Chujiang et al., 2004; Iscan et al., 2004). Most of these studies have considered only one spatial-data acquisition method used for GIS projects and the results obtained by this method.

In this study, the spatial data acquisition methods used for GIS projects are taken into consideration. Analyses of the accuracy and costs of the methods 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.

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GEOGRAPHIC INFORMATION SYSTEMS (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 modelling, representation and display of georeferenced data to solve com-plex 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

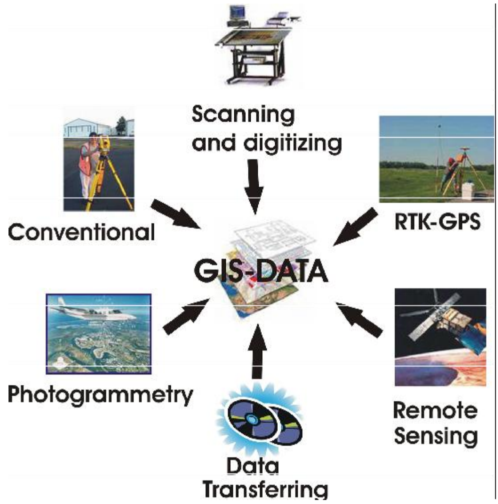

Figure 1. Spatial-data acquisition methods.

Table 1. Point position accuracies for the conventional method (σ_p).

S (m)	50 m		100 m		150 m		200 m		300 m		400 m	
σ_β ($''$)	± 1”	± 2”	± 1”	± 2”	± 1”	± 2”	± 1”	± 2”	± 1”	± 2”	± 1”	± 2”
σ_p(mm)	± 14.5	± 14.5	± 14.5	± 14.5	± 14.5	± 14.5	± 14.5	± 14.6	± 14.5	± 14.7	± 14.6	± 15.0

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 (Coppock, 1992; Goodchild, 1985; Goodchild, 1992; Tomlinson, 1972; Fritsch, 1992; Curry, 1998; Martin, 1996; Demers, 1997; Burrough and Frank, 1995; Burrough, 1998; Garal-Nabi, 1997; Heywood et al., 2002) and (Clarke, 2003).

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 GISs. Since the data-acquisition process in GISs 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 in Figure 1.

1.) Conventional method
2.) RTK-GPS method
3.) Photogrammetric method
4.) Remote sensing method
5.) Scanning and digitising method
6.) Data transfer method.

Conventional method

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 install-ed 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_{YA} , σ_{XA}).

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

$$\sigma^2_P = \sigma^2_Y + \sigma^2_X = \sigma^2_{YA} + \sigma^2_{XA} + \sigma_S^2 + S^2 \cdot \frac{\sigma^2_\beta}{\rho^2}$$

$$(\ =180/\ \ =57.2958^o) \qquad (1)$$

The point position accuracies of the conventional method were calculated and are presented in Table 1 for various distances of

$\sigma_{YA} = \sigma_{XA} = 1$ cm , $\sigma_S = 3$ mm and $\sigma_\beta = 1''$ ve $2''$.

Real-time kinematic GPS (RTK-GPS)

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

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.

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 Arslanoglu ve Mekik, 2003, point position accuracies of ± 2 - 5 cm were obtained by the RTK-GPS method.

Photogrammetric method

Photogrammetry is the art, science, and technology of collecting reliable information about the physical properties and the positions of the physical bodies in the environment by measuring, discussing, and evaluating photographs (Wolf, 1974).

In parallel with technological developments, scanning systems providing aerial photograph digitalisation, graphical screens displaying these photographs, and automatic drawing systems, and methods for data compaction and storage have been invented. As a result of these developments, digital orthophotograph maps, the products of digital valuation, have been accepted as the indispensable graphical basis of the GIS and as the standard product of planning and management disciplines related to spatial subjects. Digital orthophotographs can be used directly as the map layer of the GIS and in computer aided data processes including data operations, displays, analyses, updates, and so on.

Digital orthophotographs that can be presented faster and easier electronically give flexible, cheap, and high quality outputs whose image quality is not lost as it is by the analogue methods.

The point position accuracy of digital orthophotographs can be calculated by the following formula (Gürbüz, 2006):

$$\sigma P = \sqrt{B}.m_r.m_{px} \qquad (2)$$

Where:

B = an empirical number (B = 3 for 1/5000 or greater scales),

m_r = picture scale, and

m_{px} = pixel size.

The point position errors for orthophotographs of various scales are given in Table 2.

Remote sensing method

Remote sensing is “the art and science of getting information about a research event, area or object by making analyses with the present data obtained by using a device or without any direct contact with the researched object” (Lillesand and Kiefer, 1994).

There are satellite systems with different technical properties and resolutions around the world which are used for various purposes. The Geos, Sesat, Landsat, Spot, Ikonos and Quickbird satellites have satellite display systems with 0.5 m to 1 km resolutions which are intensively used in the fields of cartography and remote sensing.

Point position accuracies in the ± 0.5 to ± 1.0 m range were determined by studies performed using high resolution satellite images taken using analogue camera systems with panchromatic and multi-spectral sensors of 0.5 to 5.0 m spatial resolutions (Eisenbeiss et al., 2004).

Resolution information for some currently used satellite systems is given in Table 3.

Scanning and digitising method

It is essential to digitise non-digital maps, plans, statistical data in tables, and other text data recorded at various locations in order to use them in GIS projects.

The traditional paper map can be called a real map. The computer, in contrast, has forced us to reconsider this simple definition of a map. In the digital era, and especially within GIS, a map can be both real and virtual. Using maps within GIS means that they have already been turned from real into virtual maps.

Another way to say this is that a paper map has gone through a conversion from a paper or analogue form to a digital form (Clarke, 2003).

Scanning and digitising are widely used for the conversion from analogue to digital form. The accuracy of this method depends on the currentness of the maps and plans used the accuracy of the drawings, the resolutions of the scanners and the digitalisation accuracy of the operators. The point position accuracy of the method can be given as ± 10 cm for 1/1000 scale maps and ± 2 m for 1/5000 scale maps (Ceylan et al., 2005).

Data transference

It is also possible to carry out the data-acquisition process in GIS by transferring the data recorded by various people or institutions in the past. Today, there are many service sectors presenting these data to meet the needs of users by generating digital data sets. While some are performing this service by demanding some payment from the users (Map General Directorate, US Geological Survey, etc.), most of them conduct their services using the Internet and similar technological tools without asking for any money. The use of digital data is a kind of electronic data transfer (Yomralıoglu, 2005) and the cheapest method of data-acquisition for GIS is to record previously produced geographical information files onto CD, DVD or any other offline environment and to transfer the data recorded in the past using online network systems.

In general, each GIS has a distinctive operating format and a geographical information data set can only be read by the same GIS software. Interchange formats are described for the ex-change of geographical information data sets between different GIS software applications. Mostly standardised formats have almost been introduced by manufacturing companies. In recent years, intensive standardisation of the transfer format by international institutions has been observed. Then GIS software applications will have to include private transfer programs for each format.

APPLICATIONS

Test area

Alaeddin Keykubat campus area of Selcuk University was selected

Table 2. Point position accuracies in orthophotograph maps.

Orthophoto Map Scale	Picture Scale ($1/m_r$)	Pixel size $m_{px\,(\mu)}$	σ_p (mm)
1/1000	1/3500	7	± 42
1/2000	1/7000	15	± 182
1/5000	1/16000	21	± 582

Table 3. Satellite systems and their resolutions.

Satellite Systems	Landsat 7 Etm	Landsat 7 Pan	IRSI-C Liss3	IRSI-C Pan	IKONOS Ms	IKONOS Pan
Resolution	30m	15m	23m	5.8m	4.0m	1.0m
Number of Bands	7	1	4	1	4	1

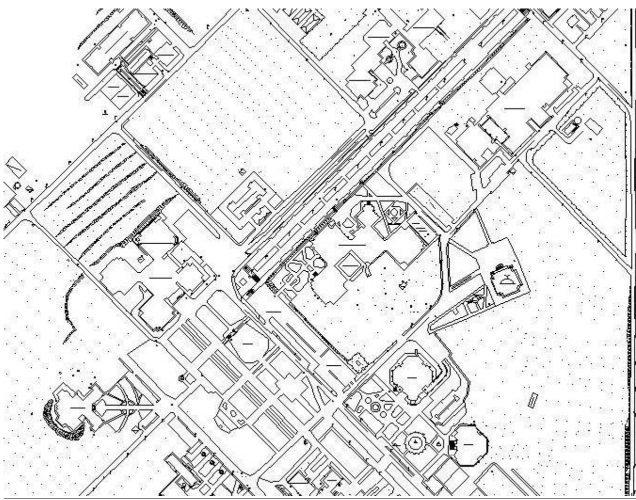

Figure 2. Test area.

as the test area in order to compare the methods used for collecting the spatial data necessary to build the GIS formation (Figure 2).

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.

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 (m_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 evalua-tions were completed in approximately three hours by a measuring team of one survey engineer and four survey technicians.

Spatial data-acquisition using a photogrammetric method (orthophotography)

In this study, a photograph block formed from eight black and white aerial photographs including the test area and taken at 1/16000 scale with 60% longitudinal and 20% transversal ratios was used. Since the photographs used in the study were analogue photographs, they were digitised by scanning with a precise SCAI (Scanner with Auto Winder Interface) photograph scanner. Eventually, a digitised orthophotograph map of the cam-pus area at 1/5000 scale was produced after treating the photo-graphs using PCI OrthoEngine software (Yagmur, 2002).

The spatial data for the test area's detail points were determined by using the digitised orthophotophic maps produced by Ortho Base Erdas Imagine software. The measurements and the related evaluations were completed in a total of 30 h by one survey engineer.

Spatial data-acquisition with remote sensing (high resolution satellite images)

In this study, a mono satellite image taken on 3rd May, 2003 by IKONOS and covering an approximate area of 5 × 5 km with 1 m resolution was used (Figure 3).

Orthorectification of the image was carried out to ± 0.5588 pixel accuracy with the help of the OrthoBase Erdas Imagine software using the digital elevation model (DEM) and the assigned position control points.

The spatial data of the test area's detail points were obtained by

Figure 3. IKONOS satellite image.

using the image attained through the orthorectification operation performed with the OrthoBase Erdas Imagine software. The foundation of the earth control points, GPS measurements and evaluations, the orthorectification operation and the spatial data-acquisition processes were all completed in 74 h by the team of two survey engineers and two survey technicians.

Spatial data-acquisition using scanning and digitising

The test area's 1/5000 and 1/1000 scale maps were digitised by scanning with a XEROX 8830 scanner at 400 dpi resolution. The affine transformation was applied to the scanned map after transference to the NETCAD medium. The average error of the transformation was ± 0.33 m, and the spatial data on the detail points of the test area were obtained by digitising the transformed map. The digitalisation and evaluation processes were completed in three hours by one survey engineer.

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

$$V_Y = Y_G - Y_K$$
$$V_X = X_G - X_K \qquad (3)$$

$$m_x = \pm\sqrt{\frac{V_X V_X}{n}} \qquad (4)$$

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

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

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 4 (Mutluoglu, 2004).

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 techni-cians) 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. Furthermore, in the scanning and digitising method, the costs of the 1/1000 and 1/5000 scale maps were added to the hardware cost. Similarly the cost of the orthophotographs and remotely sensed imagery are considered to be a hardware cost. 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 5 (Mutluoglu, 2004). In the calculations, the unit costs of the ministry of public works and settlement are used.

DISCUSSION

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.

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.

Photogrammetric, cartographic and remote sensing methods can be proposed for GIS projects like environmental do not need to be so accurate. Since the photogrammetric and remote sensing methods cost more for small areas, the cartographic method is preferred. However, the currentness of the map that will be used as the basis of the cartographic method should be taken into consideration. On the other hand, the photogrammetric or remote sen-sing method should be preferred for larger area GIS pro-jects (> 1000 ha).

Table 4. Methods and the point position accuracies.

Methods	Number of points	Accuracies (rms)		
		m_y (cm)	m_x (cm)	m_p (cm)
RTK GPS	301	± 4.9	± 5.4	± 7.2
Photogrammetric (Ortofoto)	390	± 37.3	± 38.6	± 53.7
Remote Sensing (IKONOS)	220	±103.0	±89.6	±138.8
Scanning and digitizing (1/5000)	254	±118.2	±151.1	±191.8
Scanning and Digitizing (1/1000)	639	±11.6	±7.9	±14.0

Table 5. Cost analysis.

Methods	Cost ($/ha)
Conventional	95,86
RTK-GPS	17,22
Photogrammetric (Orthophoto)	21,93
Remote Sensing (IKONOS)	80,53
Scanning and digitizing (1/5000)	4,79
Scanning and digitizing (1/1000)	4,79

Appropriate spatial data-acquisition methods proposed for GIS applications are summarised in Table 6.

Conclusion

A test area in the campus area of Selcuk University was selected for the performance of accuracy and cost analyses of the methods used for the data-acquisition processes for GIS based spatial data. At the end of the measurements and evaluations, various accuracy and cost values were obtained for each method after carrying out the necessary and appropriate accuracy and cost analyses. As a result of the cost analyses, it was found that the conventional method has a greater cost due to the lower rate of production related to increasing measurement time, more demand to work-power, and the negative effect of meteorological conditions. However, the conventional method may be chosen with the help of RTK-GPS for the sake of high-position accuracy in cadastral work, reconstruction applications, public works, infrastructure management, and so on. For the collection of spatial data in the GIS projects mentioned above, the most suitable method is RTK-GPS if spatial accuracy, cost and time are on the agenda. However, RTK-GPS applications cannot be conducted in areas of dense and high buildings due to GPS signal blockages. In this case, spatial data for undefined detail points can be measured and completed by a conventional method.

Another finding of this study was the high cost of the remote sensing method used with 1 m resolution (IKONOS). The reason for this is the low rate of the chosen test area to the minimum satellite image area, as the cost of satellite images is the most effective factor in cost analyses. In the cost analyses of this method, the costs of full satellite images were considered. If the chosen test area were fixed, with minimum satellite images, the cost would be lower. The point position accuracy for this method was calculated as ± 138.8 cm. The remote sensing method may be preferred for GIS projects related to environmental and natural resources management, education, health and tourism, that is for projects with large construction areas, due to the fast and up-to-date spatial-data-acquisition.

In this study, the cost of the photogrammetric method was also found to be higher than expected. As with remote sensing, the reason for this was the choice of a testing area smaller than the minimum orthophotograph size. The point position accuracy of this method is ± 53.7 cm. The photogrammetric method may be preferred for large area applications in GIS projects related to public works, highways, energy and infrastructures, as it allows fast and economic collection of spatial data.

The method with the lowest cost is scanning and digitising. The accuracy of this method depends strictly on the level of deformation of the base maps used. The disadvantage of the method of using old maps is the non-current property of the data. In this method, the point position accuracies obtained by the digitisation of the 1/1000 and 1/5000 scale maps were ± 14.0 cm and ± 191. 8 cm, respectively. The ease, simplicity and lower cost of the method can be accepted as the advantages of this method, which can be proposed for studies that do not require high accuracy. Therefore, the scanning and digitizing method is widely used for spatial data collection in GIS projects.

In a GIS project, the accuracy of spatial data should be certain, depending on the aim of the work. To select a method or methods that provide the required degree of accuracy, one or more methods may be considered suitable in the light of the above explanations.

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Table 6. GIS test areas and spatial data-acquisition methods.

GIS Test Areas	Spatıal Data-Acquısıtıon Methods					
	Conventional Method	GPS (RTK)	Photogrammetric (Orthophoto)	Scanning and Digitizing 1/1000	Scanning and Digitizing 1/5000	Remote Sensing
Environmental Management			•		•	•
Natural Resource Management			•		•	•
Possession-Managerial Administration	•	•		•		
Public Works	•	•	•	•		
Education					•	•
Health Management					•	•
Municipality Activities	•	•	•	•	•	•
Transportation Planning			•		•	•
Tourism			•		•	•
Forest and Agriculture			•		•	•
Commerce and Industry			•		•	•
Defense and Security	•	•	•	•	•	•

• Spatial data-acquisition method proposed for GIS projects.

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