EXAMINATION AND COMPARISON OF MOBILE GIS TECHNOLOGY FOR REAL TIME GEO-DATA ACQUISITION IN THE FIELD

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ABSTRACT

Scientific studies associated with land require large amount of data. The data is often collected during field studies with the use of pencil and paper based method. The method is labour-intensive and susceptible to recording and georeferencing errors during transcription. Recent advances in mobile computing, positioning and software now make it possible to bring field and office activities into a collaborative environment, thereby minimizing human errors and time delays. This paper assesses the use of Mobile Geographic Information Systems (MGIS) as an appropriate tool for geo-data acquisition applications. Firstly the computing, positioning, software and communication technology behind the system is presented. A Mobile Geographic Information System developed for field data acquisition based on the combination of Geographic Information Systems (GIS) and Global Positioning System (GPS) is described. Finally, the system is tested in two field studies to examine its effectiveness compared to traditional methods in terms of accuracy, cost and project completion time. The field studies demonstrate the noticeable gains in efficiency and cost saving achieved with the use of the MGIS technology. Results of the field studies verify that MGIS is very useful for georeferenced data acquisition applications.

KEYWORDS: Mobile GPS. Real-time Geodata. Georeferencing. Geo-data acquisition.

INTRODUCTION

In the developing world one of the biggest bottlenecks relates to the availability of spatial and attribute data. This problem is not only caused by the lack of a geo-spatial data infrastructure policy, but also by the high cost of conventional data collection and data processing methods which often surpasses 50% of the total Geographic Information System (GIS) implementation or maintenance expenditure [**23**]. Consequently, especially in developing countries, cost effective and rapid data collection methods need to be developed.

Improvements in computer technology have introduced mobile computers such as the pocket personal computers or personal digital assistant (PDA), tablet and notebook personal computers (PCs). These devices make it possible to capture, manipulate, analyze and visualize data in the field [**7**], [**6**], [**18**]. Moreover, over the last five years, software producers have developed several mapping and GIS software packages that can run on small mobile computers. Also, enormous advances have taken place in Global Positioning System (GPS) technology in the recent years: GPS accuracy has improved, the receivers have become smaller and cheaper and the GPS integration with mobile devices as the PDA has been made possible [**14**]. By mobilizing GIS inspection and verification of captured data can be carried out at the same time as the data is being acquired [**22**]. All of these improvements now make it possible to bring field and office activities into a collaborative environment that can further improve productivity, reduce costs and minimize projects completions timeframes [**24**].

Mobile Geographic Information Systems (MGIS) is a term that is being used more frequently within the geospatial industries. The development of technologies such as the internet, wireless communication, GPS and mobile computing devices are changing the way GIS is being used by moving GIS from the desktop into the field users' hands and making the mobile aspect of GIS a reality. MGIS makes it possible to capture, store, update, manipulate, analyze, and display geographic information in the field, the system integrates one or more of the following technologies: mobile devices, mobile GIS software, GPS and wireless communications for the Internet GIS access [**5**].

This paper assesses the use of MGIS as an appropriate tool for geo-data acquisition applications. Firstly the computing, positioning, software and communication technology behind the system is presented. A MGIS developed for field data collection based on the combination of GIS and GPS is tested in two field studies to examine its effectiveness compared to traditional methods in terms of accuracy, cost and project completion time. While the first field study focuses on agricultural data collection, the aim of the second is to survey transportation infrastructure of a rural settlement. Results of the field studies are compared to traditional acquisition methods and advantages of the MGIS technology are identified.

TECHNOLOGY REVIEW

Mobile Computing

Mobile computers have two main and contrasting characteristics: portability and capacity (memory, processing speed, display size and autonomy). On one hand, users want smaller and lighter devices, but on the other hand, graphical applications need wide displays and high processing capacity to process all the information. Basic models that can be used in applications are [**2**], [**5**], [**9**], [**19**]:

- *PDAs (Pocket PCs)*: PDAs were originally conceived as small devices with the basic functions of organizers, providing management of contact lists, calendars, diaries, calculators, etc. PDAs first appeared in the market in 1993, shipped by Amstrad, Apple and Sharp. Since 1996, when they were pioneered by Palm, the category has exploded with products from most of the major players of the sector: Compaq, Hewlett-Packard, Casio and Handspring. Technical features are similar to those of the PDA-based smartphones, but they have more memory (up to 192 Mbytes) and more processing capabilities (up to 520 MHz); multi media capabilities and greater connectivity possibilities through WLAN and through the Bluetooth protocol; and more expansion slots. In the early stages, PDA operating systems were completely controlled by the device maker and closed to third party applications. In recent years, open systems have appeared and applications can be executed from different sources. There are, at present, three major PDA operating system platforms: Palm OS, Windows CE and EPOC OS.
- *Tablet PCs*: Tablet PCs have high-speed processors (up to 1.5 GHz), large internal disk drives (up to 40 GB), industry-standard interface ports, extended battery life, good display resolution (up to 1050x1400 pixels), handwriting recognition software, a large memory capacity (512 Mbytes), expansion capabilities and WLAN access. These devices generally run one of the standard Microsoft Windows variants, though other possibilities, such as Linux platforms, are available.
- *Notebooks*: These can be divided into several categories: full-size, thin-and-light, mini and sub notebooks. Most of them are almost indistinguishable from one another within the categories. Some notebooks are built to withstand more damage than a standard consumer product. For example, some of them are ruggedized or even water resistant. Others include special features needed for specific jobs. The notebooks' processing capabilities, as well as their size and weight, are the highest among the mobile devices presented in this section. There are models available with

processing speeds of 2.4 GHz and storage capacities of 1 GB of RAM and 80 GB hard disks.

GPS and DGPS

GPS is a radio-based navigation system capable of providing an exact three-dimensional position (latitude, longitude, and altitude) anywhere on the earth, 24 hours a day, in any weather condition. GPS was originally developed by the U.S. Department of Defense (DoD) for military use. However, GPS has also proven to be a very useful tool for civilian use and is available to anyone with a GPS receiver.

GPS receivers monitor the signals from multiple satellites—at least three for a two-dimensional position and at least four for a three-dimensional position—and through a process called trilateration, they compute a position. This position is accurate from about 10 to 15 metres—now that selective availability, an intentional degradation of the satellite signals, has been turned off—down to a centimeter or less, depending on equipment and conditions [**21**].

Although GPS receivers give exact positions it is important to understand that there is some amount of uncertainty, or error, inherent in these positions. A number of factors contribute to this error including satellite clock drift, atmospheric conditions, measurement noise, and multipath. In addition, due to the satellite geometry, vertical accuracy (elevation) is generally one and a half to three times worse than horizontal accuracy [**11**]. One solution to increase precision is the use of the technique known as differential correction, or differential GPS (DGPS). The purpose of DGPS is to eliminate or reduce the inherent errors. The main idea of DGPS is that two receivers observing the same satellites will produce the same measurement errors, if the receivers are close enough. By setting one reference receiver in a well-known position and measuring the GPS position, it is possible to calculate the error and its associated correction vector. This correction vector is then sent to user receivers who use it to correct their absolute GPS position [**17**]. There are various sources of real-time DGPS signals, including Coastal beacons; Wide Area Augmentation System (WAAS, North America), and European Geostationary Navigation Overlay System (EGNOS, Europe only).

GPS receivers, which can be used for MGIS applications, are available in various configurations including Compact Flash, PC Card, specialized built-in receivers, add-on expansion packs, handheld, all-in-one antennas and GPS receivers, and backpack systems. While some GPS receivers have wirelesses communication capabilities such as bluetooth and infrared, others can be attached to a mobile computer by using cables. Fig. 1 shows the types of main GPS receivers for MGIS applications.

There are many factors that need to be considered when selecting an appropriate GPS receiver for a specific MGIS application. One of the factors is the protocols that the GPS receiver outputs. Supported protocols are especially important when GPS receivers are combined with MGIS software. Another important factor is accuracy. If the MGIS application requires higher accuracy, then the GPS receiver must have the ability to differentially correct the GPS position. It must also be taken into account whether there is an available and reliable differential correction area where applications are being performed.

In Table 1, some of available core MGIS devices that can be used in applications are grouped into mobile computing and positioning functionality. The table also shows main features of the MGIS devices [**5**].

Table 1 is just a small selection of the many different mobile computing and positioning device available on the market, and simply represents main hardware components of the MGIS technology which is best suited for the selected field studies in this paper.

HANDHELD GPS | CF GPS | RUGGED GPS | BLUETOOTH GPS | ALL-IN-ONE ANTENNAS and GPS

Fig. 1. Types of GPS receivers

Table 1. *Some of available core MGIS devices categorized into positioning and mobile computing functionality and their main features*

Functionality	Example	Cost[a]	Dimensions (mm) and weight (kg)	Battery life (h)[b]
Positioning	Magellan Handheld GPS	US$ 200	142 x 56 x 33 0.150	15
	Teletype Bluetooth GPS	US$ 150	70 x 5 0x 24 0.053	15
	Teletype Compact Flash GPS	US$ 350	140 x 84 x 41 0.064	Use PDA battery
	Trimble All-in-one antennas and GPS	US$ 515	110 x 75 x 35 0.145	10
	Trimble GEOXT Rugged GPS	US$ 6200	165 x 95 x 45 0.490	8
Mobile computing	HP iPAQ hx2400 Pocket PC	US$ 500	119 x 75 x 19 0.190	4
	HP Compaq tc4400 Tablet PC	US$ 1800	285 x 235 x 34.3 2.08	3
	Toshiba Tecra M3 Notebook	US$ 1700	282 x 213 x 24.8 1.4	3

[a] Costs are approximate.

[b] Battery life data is supplied by manufacturers and is like to change depending on usage and power management.

MGIS Software

The rising number of mobile applications and rapid developments in mobile computer technology has led to introduction of several mobile GIS and mobile mapping software packages. Some of the major MGIS software packages and producers are: ESRI ArcPad (March 2000), Autodesk OnSite (2000), Intergraph IntelliWhere (March 2000), MapInfo MapXtend (August 2000) and Trimble TerraSync (June 2000). There is also a group of mobile applications such as Datria VoCarta Field, iMedon iM:Field and iM:Collect, PointBase Mobile Edition that provide database management facilities for mobile devices. However, these latter systems do not provide any GIS functionality. Most of these packages have adopted pocket, handheld or tablet PCs as mobile platform. ArcPad and TerraSync are designed specifically to perform field data collection on a PDA, either with or without an add-on GPS [**15**].

In this paper, the case studies, which will be mentioned later, were performed by using ArcPad. The MGIS software installed on the PDA is part of the ESRI suite of

GIS products. Although it is specifically designed to run on a PDA it can also run on any PC running Windows XP or XP Tablet. This can be adventurous if a combination of PDA's and Tablet PC's will be used during a data acquisition project. This MGIS application is designed specifically for PDAs and integrates almost seamlessly with ESRI's desktop GIS application ArcGIS as a frontend data-capture solution. It cannot be considered as a standalone MGIS software as it needs to be used in conjunction with ArcGIS and ArcPad Studio to provide the full range of GIS functionality. ArcPad Studio is a separate software development package for building custom ArcPad applications [**3**].

Wireless Communication

Applications that run on portable devices need access to GIS information. This necessity can be met with two different ways. The first one is to store the information in local memory. The second is to download cartographic information on demand. This operation must be carried out in the most transparent way for the user; for instance, when the GIS platform detects that the required map is not stored locally, it tries to download it from the server after requesting confirmation from the user [**20**].

In order to connect mobile devices to a fixed network in which the cartographic server will be set, it can be used two kinds of wireless networks: Wireless Local Area Networks (WLAN) and Wireless Wide Area Networks (WWAN). WLANs, as the name expresses, have a limited coverage, from few metres to some kilometres. Their main characteristics are that they provide high transmission rates and usually are privately owned. WLAN appeared first as office data networks, then gave coverage to university campus, hospitals or other private and public institutions, and nowadays, there are some operators that give this service in strategic areas as downtown districts. For the WLAN group, there are three basic possibilities: IEEE 802.11, bluetooth and infrared [**2**].

On the other hand, WWANs are public networks, with national coverage and provide lower transmission rates, up to 2 Mbps for the third generation cellular networks as CDMA2000, UMTS or FOMA. In these networks, the transmission bandwidth is expensive and the network design is focused on the link utilization efficiency. WWANs, or commonly named mobile telephone networks, are cellular networks that firstly appeared as voice networks and, later, due to the social requirement of data transmission have been adapted to transmit any kind of data. These networks have evolved and according to their capabilities are classified in three generations: 1, 2 and 3G [**4**], [**6**]. Basic WWAN networks are GSM (Global System for Mobile Communications), HSCSD (High Speed Circuit Switched Data), GPRS (General Packet Radio Service), EDGE (Enhanced Data rates for GSM Evolution) and IMT-2000 (International Mobile Telecommunications 2000).

METHODOLOGY FOR GROUND DATA COLLECTION WITH MGIS

GIS data consists of both graphic and related descriptive data which are also considered to be attributes. A number of techniques are used to capture graphic data, including land surveying, photogrammetric, remote sensing, digitizing. As for attributes, they are automated either separately and linked to the graphics through unique keys, populated later or simultaneously during graphic data capture. The main reason why an integrated data acquisition and maintenance tool is being investigated is that data acquisition is a costly process often surpassing 50% of GIS implementation or maintenance costs [**1**], [**8**], [**13**], [**23**], with an integrated system it is anticipated that fewer people will be required to perform the same task thereby reducing the expenditure of data acquisition.

Field surveys require a number of processing phases to be performed (capture, conversion, verification) before the information can be used within a GIS environment. Typically each phase is the responsibility of a different individual. With the use of MGIS technology, the field operator takes ownership of the whole data acquisition process, thus improving workflow by removing both duplicated effort and the need to communicate difficulties that may have been encountered in the field, but may not be obvious to office based colleagues.

At this stage, MGIS is tested on two different cases. While the first application focuses on agricultural field data collection, the second is developed to survey a transportation network of a rural settlement. The methodology hereby discussed for each application consists of three main phases: examination of current method to evaluate the needs for the MGIS technoloy, pre-field studies and field data capture.

Agricultural Field Data Acquisition with MGIS

In 2001, Turkey started the implementation of a new project titled Agricultural Reform Implementation Project (ARIP). This project is financed by the World Bank. Its implementation period starts in June 2001 and ends in December 2005. The loan amount of the project is $600 million. One of the components of the projects is the Direct Income Support (DIS). The objective of this component is to set up a National Registry of Farmers (NRF) capable of identifying farmers who are eligible for payments under the DIS and delivering those payments. This component is at the heart of the whole program [**10**].

DIS applications have been implemented by Ministry of Agricultural and Rural Affairs (MARA). Since cadastral works have not yet been completed in some rural areas, MARA workers have to go field to determine the owners of the agricultural lands and to collect data about the lands. When the verification of the owner is completed, field data collection is started. In the traditional approach, field data collection has been performed using sketches and notes on paper maps and forms. In addition, geometric descriptions of the lands have been determined by using either handheld GPS receivers or topographic paper maps. Once back in the office field edits have been deciphered and manually entered into a database. Fig. 2 shows a flow chart for current method of agricultural data collection.

The pre-field studies include three stages: preparation of spatial data sets for the field study, combination of the GPS unit with the pocket PC and software development. The first stage was carried out with the help of GIS technology. Two georeferenced data sets were used. The first one was high resolution IKONOS satellite imagery; the second was a digital topographic map at a scale of 1:25,000. It should be note that these raster data sets were big in size and the field application platform –pocket PC- have limited memory capacity (128 MB). Hence, only particular parts of the georeferenced spatial data sets which cover the application site were used instead of full data.

Combination of the GPS unit and the mobile computer required the MGIS application software and the GPS receiver to be configured for transmission of the positional data. This configuration included definition of the standard protocol, e.g. NMEA, and communication parameters such as parity, data bits, and stop bits. Finally, the combination stage was completed with defining the reference system. Data both come from the GPS unit and exist in the PDA must be in the same reference system. Field studies were implemented based on the Turkey’s national coordinate system. Since the MGIS software does not support the national system by default, a projection file was created so that the GPS data can be transformed to the national reference system during the field study (Fig. 3).

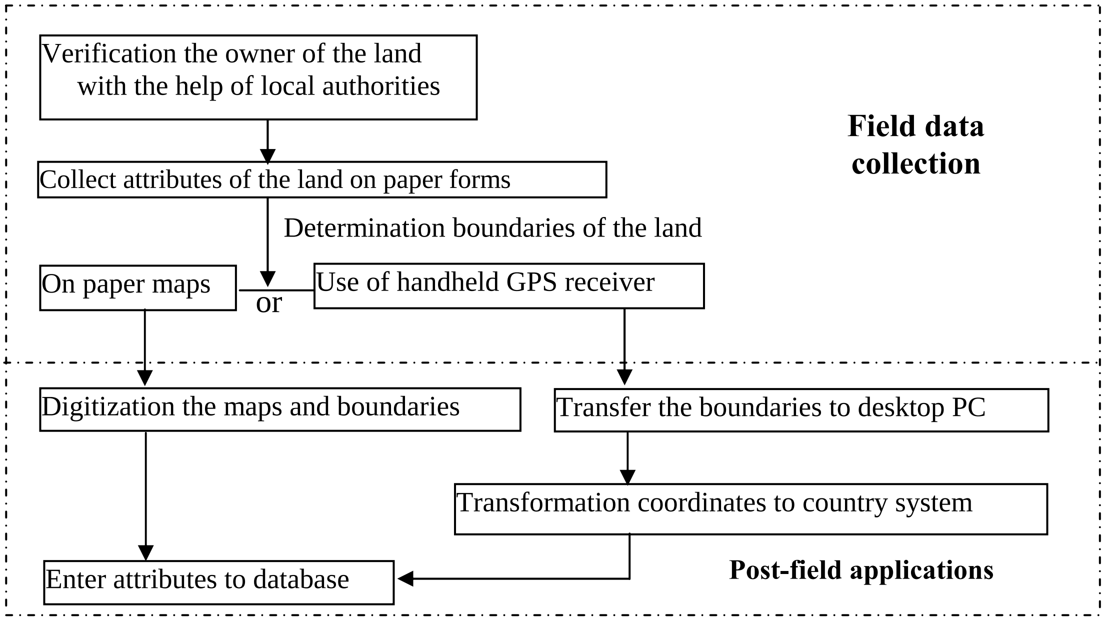


Fig. 2. Flow chart of traditional agricultural field data collection

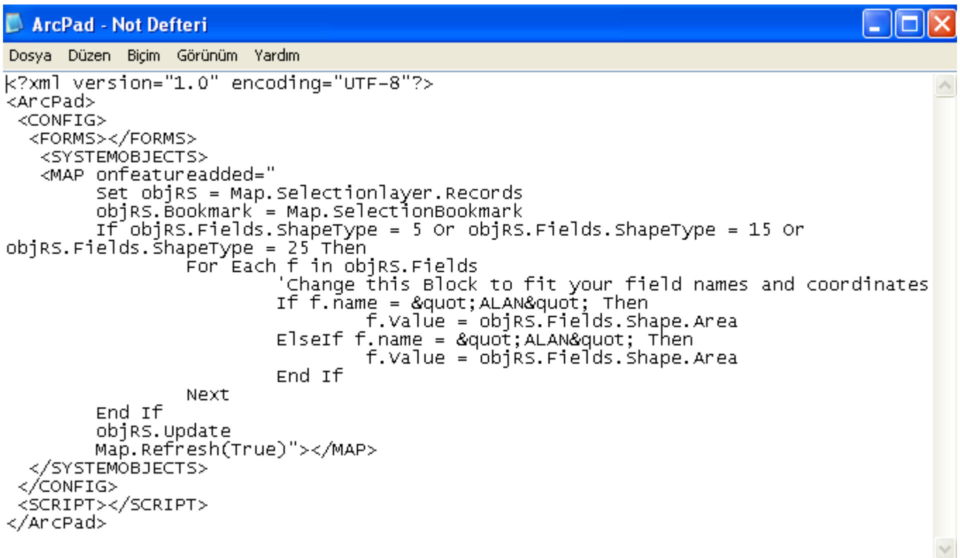
In software development stage, customizations were performed to improve the accuracy of collected data and to speed up the data acquisition process. All customization was performed on the desktop and deployed on the mobile device. One of the customizations was creation of a script that interacts with the MGIS software's internal objects. Fig. 4 shows the content of a configuration file developed for calculating areas of agricultural lands and populating related item with the data in database during the field study.

```
PROJCS["ED_50_1950_UTM_Zone_37N",
     GEOGCS["ED_50",
        DATUM["ED_50",
           SPHEROID["INTERNATIONAL_1924",6378388,297]],
        PRIMEM["Greenwich",0],
        UNIT["Degree",0.0174532925199433]],
     PROJECTION["Transverse_Mercator"],
     PARAMETER["False_Easting",500000.0],
     PARAMETER["False_Northing",0.0],
     PARAMETER["Central_Meridian",39],
     PARAMETER["Scale_Factor",1],
     PARAMETER["Latitude_of_Origin",0.0],
     UNIT["Meter",1.0]]
```

Fig. 3. Content of projection file defined in MGIS application software

The method for agricultural field data capture began with verification of the owner of the land. When the verification was completed, field data acquisition was started. GPS integrated MGIS platform was opened and the MGIS software was run. In the next stage, the field worker activated the GPS to understand current location and to determine if there were available digital maps or images in local memory. Field worker could use the data to digitalize boundaries of the agricultural lands. The georeferenced background images were useful because they provided the field operator a more comprehensive understanding of the outdoor situation and orientation capabilities.

If there was no available digital data, boundaries of the agricultural lands were gathered through the GPS unit. That is, boundaries of the agricultural areas were captured by moving around the lands. When a polygon or an agricultural land was completed, a pre-defined user form was automatically displayed on the PDA.




```
<?xml version="1.0" encoding="UTF-8"?>
<ArcPad>
 <CONFIG>
  <FORMS></FORMS>
   <SYSTEMOBJECTS>
   <MAP onfeatureadded="
        Set objRS = Map.Selectionlayer.Records
        objRS.Bookmark = Map.SelectionBookmark
        If objRS.Fields.ShapeType = 5 Or objRS.Fields.ShapeType = 15 Or
objRS.Fields.ShapeType = 25 Then
                For Each f in objRS.Fields
                        'Change this Block to fit your field names and coordinates
                        If f.name = &quot;ALAN&quot; Then
                                f.Value = objRS.Fields.Shape.Area
                        ElseIf f.name = &quot;ALAN&quot; Then
                                f.Value = objRS.Fields.Shape.Area
                        End If
                Next
        End If
        objRS.Update
        Map.Refresh(True)"></MAP>
  </SYSTEMOBJECTS>
 </CONFIG>
 <SCRIPT></SCRIPT>
</ArcPad>
```

Fig. 4. Configuration file created in xml format to calculate areas of agricultural lands

Attributes about the land was transferred into database via this form. Some of attributes were the location of the agricultural area, the agricultural product that is being grown, the class of the agricultural land, the inspection date, owner of the land and the total area of the agricultural land. When the field data acquisition phase was completed, the collected data was transferred from the PDA to enterprise database. Fig. 5 gives a flow chart and Fig. 6 includes some interfaces for the MGIS application.

Use of MGIS Technology in Mapping Transportation Networks of Rural Settlements

There are a lot of applications of GPS technology in many scientific fields all over the world. In recent years, the rapid increase in the development of the GIS technology has led to the development of GPS/GIS applications. It is proposed to combine GPS technology with other technologies (e.g., mobile computers, cameras etc.), for the maximization of the efficiency of the system and the reduction of the application costs. In this case study, application of MGIS technology in the field of land transportation system is evaluated. Within the context of the case study, data collection and mapping of the land transportation infrastructure is emphasized.

The study area chosen for carrying out the field study was the Gumushane-Yaydemir road axis. Yaydemir is a rural settlement located about 20 km from Gumushane Province. During the field study, the mapping of the road network from Gumushane to Yaydemir (both directions) using the MGIS technology was performed.

A vehicle moving along the line at a speed of 30 km/hour was used for the survey needs. The recording of the characteristic points of the existing situation was made by using the applications software's 'capture point' option. This means, for every characteristic point, the coordinates together with the time were stored in the database. The characteristic points include electricity posts, intersections, bridges and other constructions. There were also several historical remains along the axis and these constructions were mapped with the application (Fig. 7). It must be mentioned at this point that some parts of the specific axis was covered with condense woods. In cases where the vehicle was under a woody area, measurements stopped for a period of a few minutes in order to initialize the GPS due to loss of contact with the satellites. The specific process was repeated three (3) times during the route Gumushane-Yaydemir.

In addition to mapping transportation infrastructure, the MGIS technology can be used in the situation where the accurate position of an accident is needed in the road network. Nowadays, the only available information concerning the position of a road accident, according to the police records, is the kilometer to which the specific accident is referred to. The use of MGIS technology also offers the ability to produce accurate thematic maps with ‘‘black spots’’ spots where a statistically significant number of road accidents take place in a certain time period [**12**].

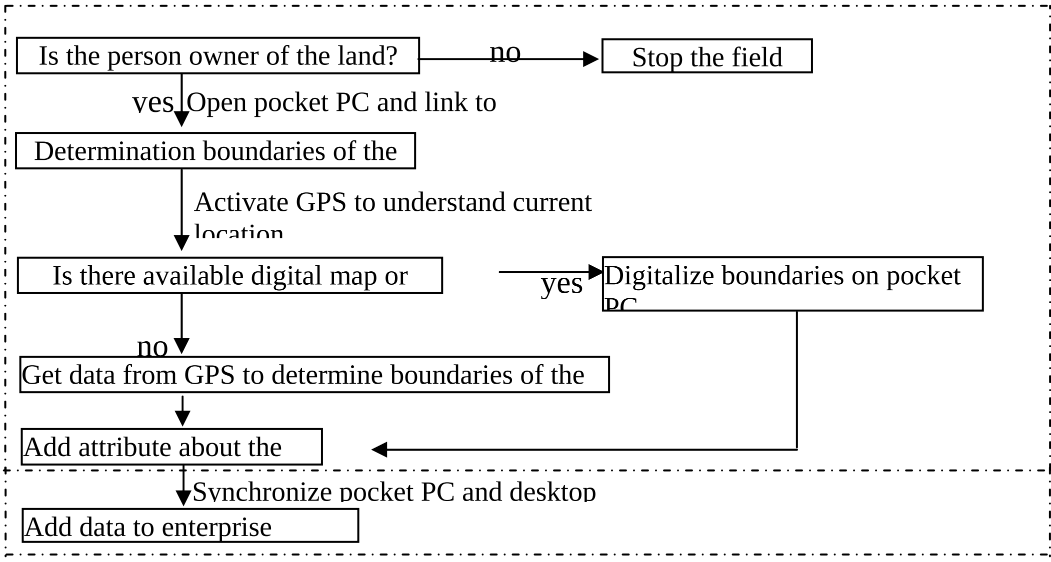


Fig. 5. Flow chart of MGIS application for agricultural data acquisition

Accuracy Comparison

Accuracy of spatial data acquired with MGIS technologies differs depending on mainly the digital bases used on mobile computers and the GPS units integrated. In this study, a MGIS system based on integration of PDA and GPS was examined. Two bases were evaluated in the first MGIS application: one-meter resolution IKONOS satellite imagery and digital topographic map at a scale of 1:25,000. Before the field study, geometrical corrections of the IKONOS satellite imagery were performed based on the data gathered from a map at scale of 1:1,000 which produced with terrestrial survey. Accuracy of the IKONOS satellite imagery used in the field study was determined as ± 1 meter. The other data set, digital topographic map at a scale of 1:25,000 was produced with photogrammetric method by General Command of Mapping. Horizontal accuracy of the topographic map is ± 5 metres while vertical accuracy (elevation) is ± 2.5 metres.

Apart from the digital data sets available on the PDA, throughout the second MGIS application and also in some part of the first MGIS application (if there were no available digital bases) a GPS unit was employed by integrating to the PDA in order to acquire spatial data. The choice of the GPS unit was determined by the mapping task to be undertaken and the levels of accuracy required.

The GPS receiver used in the MGIS applications is a Magellan SporTrack Map, which is capable of receiving real time differential corrections using WASS and EGNOS and has a specified accuracy of 1–5m (DGPS). Due to integration with MGIS software, accuracy of GPS data was able to be estimated during field studies. The application software recorded a log file includes data about accuracy of GPS position. In addition, variety of information about GPS satellites, position quality, GPS mode (2D, 3D, DGPS 3D) and coordinates were displayed on the PDA screen during the MGIS applications (Fig. 6). Based on the data recorded in the log file it was determined that the GPS unit received real time differential correction from EGNOS system and the accuracy of spatial data acquired was about ± 3 metres in the first MGIS application.

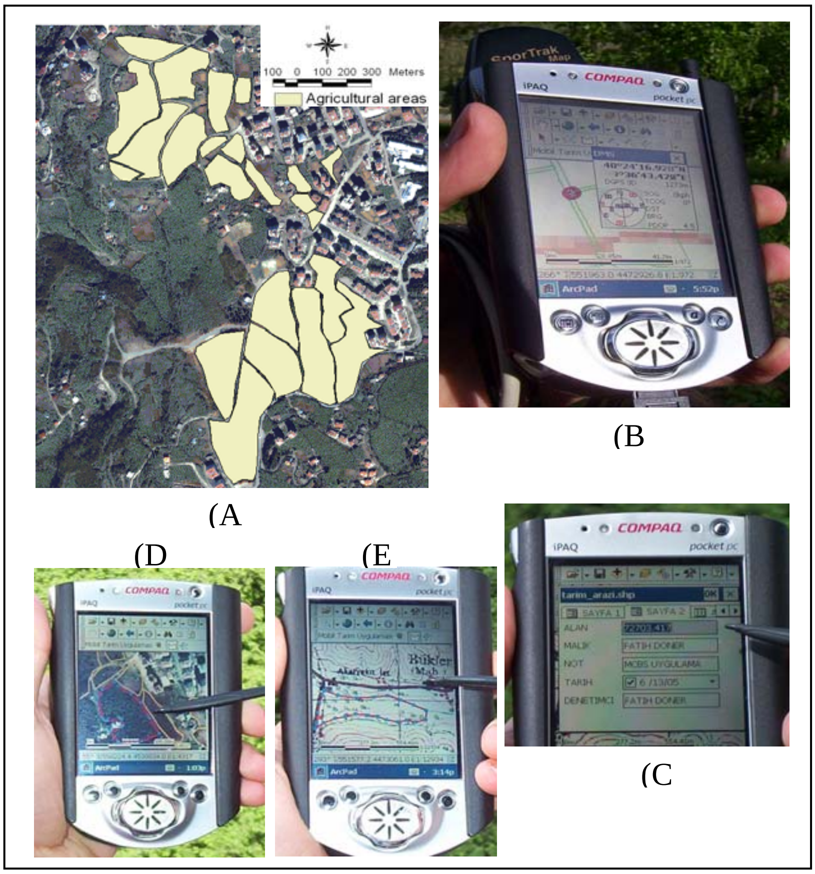


Fig. 6. Agricultural data collection with MGIS: (A) agricultural areas mapped with GPS integrated PDA; (B) application software interface on PDA while the agricultural areas are being captured with GPS; (C) a customized user form developed for transferring attributes to GIS database; (D) and (E) use of raster images on PDA during first field study

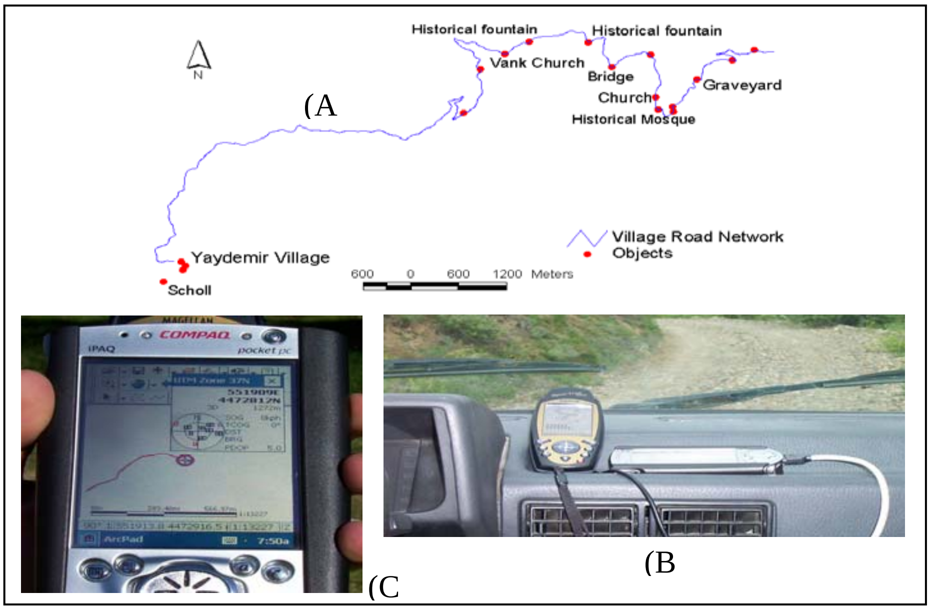


Fig. 7. Field data collection within Yaydemir Village: (A) transportation network mapped with MGIS application and distribution of some of collected data; (B) application of MGIS; (C) ArcPad interface on PDA while the transportation network is being detected in a moving vehicle

Real time differential corrections from WASS/EGNOS systems offered an improved accuracy for the first MGIS application. In the second application, however, this was not case. The reason is that these systems don't provide global coverage like GPS. To make a conclusion about accuracy, the digital map of the road line was produced and was compared to the output produced by the digitization of the map at a scale of 1:25,000. In Fig. 8, digitized road line is presented at a scale of 1: 60,000, together with the same road axis line as resulted from the use of the MGIS technology during the field study. As shown in the figure, there are differences in the road tracks using the two approaches (digitization and MGIS). The thick line represents the road line as resulted from the digitization while the thin line represents the road line as resulted from the use of MGIS technology.

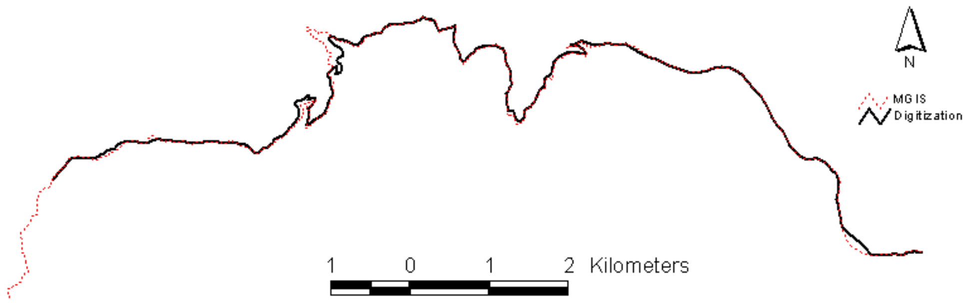


Fig. 8. Representation of the track of the road line using MGIS

It should be mentioned that the large part of the detected discrepancies can be attributed to the fact that the MGIS application covers the most recent road alignment while the digitization was based in older edition of the map including previous alignments. It must be mentioned at this point that it is a costly and time consuming process to produce and to keep the maps up to date at a scale of 1:25,000 throughout the country so these maps are often far from adequate when compared to GPS data [**25**].

In conclusion, the spatial accuracy observed for the selected MGIS technology is sufficient for applications performed in this study. The MGIS technology can also meet survey needs for wide range of application which spatial data is acquired traditionally from small scale maps by digitizing. In this paper, a PDA based system comprising a Magellan GPS receiver, Compaq pocket PC, and ArcPad mobile mapping software was selected. Of course, different technologies can be preferable for an improved geo-referencing. For example, there are ruggedised systems which permit differential corrections via post-processing software to achieve an accuracy of 10–20 cm. However, this is a relatively costly alternative (Table 1). In selection of the appreciate MGIS technology, purpose and price should be fit accordingly. In addition, the MGIS technology selected improved the accuracy of spatial data by using high resolution digital images in the field which is impossible with traditional acquisition methods. In the first MGIS application, it was possible to bring one-meter resolution satellite imagery into the field and to digitize or acquire necessary spatial data on it. Because of small screen size and slow processing power of the selected MGIS system, some difficulties (lots of scrolling and slow fresh rate) can arise while working with the high resolution data. However, these can be overcome by employing other MGIS technologies like built around a tablet PC. Finally, accuracy of the attribute data was improved by using customization tools of the application software permitting defining mandatory attribute fields and using rich set of form controls to streamline data collection in the field. One drawback should be mention at this stage that although use of the MGIS technology is easy particularly to those familiar with GIS, customization for better accuracy of attribute data requires high level of information technology (IT) skill.

Time Comparison

One of the important factors for the success of the MGIS technology applied to cases is the reduction of the project completion time. To evaluate this, a time comparison was carried out for the first field study. The graph in Fig. 9 presents project completion times obtained for the MGIS technology and the traditional field data collection in minutes.

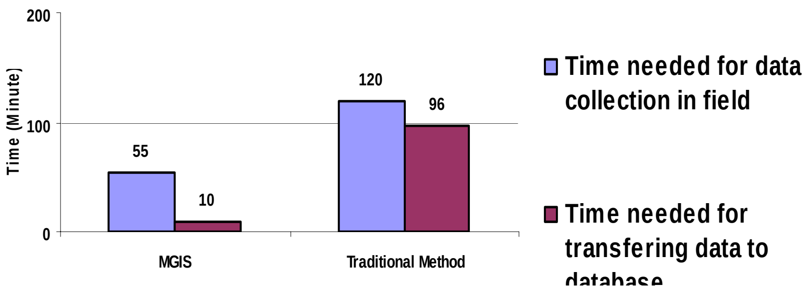


Fig. 9. Time comparison between MGIS technology and traditional data acquisition method for first field study

With the traditional field data collection, it took two hours to be completed the field stage of the study by the field team while total time required for completing the whole acquisition process (Fig. 2) was about 3.5 hours needed before the data was used in GIS environment. With the use of the MGIS technology, on the other hand, the same data was able to be acquired three times faster than the traditional method. A great amount of time saving was achieved through customization of the MGIS application which enabled many post-field studies including coordinate transformation (Fig. 3) and area calculation (Fig. 4) to be performed at the same time while the data was being acquired in the field. Besides, because the data in MGIS is always in digital format, it took relatively short time to incorporate the data into spatial analyses. This means that, the MGIS technology can accelerate not only the process of data acquisition but also the process of decision making.

Cost comparison

One critical factor, which may be the greatest influence on preferring the MGIS technology for users, is cost. Therefore, a comparison was performed for the second field study to evaluate the success of the MGIS technology over other data acquisition methods in terms of cost. Table 2 presents costs obtained for the selected MGIS technology and other acquisition methods.

Table 2. *Cost comparison between MGIS technology and other data acquisition techniques for second field study*

Technique	**Terrestrial ground survey**	**Remote sensing**	**Mobile GIS**
Unit Price ($)	2750 / per kilometre[a]	150 / per square kilometre[b]	3500 / software and hardware cost[c]
Application cost ($) (for 20 km-length road network)	55000	7200 / the road network mapped with application covers a 48-square kilometer area	3500

[a] Supplied by Union of Chambers of Turkish Engineers and Architects - Chamber of Survey and Cadastre Engineers

[b] Supplied by companies provide satellite image

[c] Represents total cost of hardware and software components of MGIS listed in Table 2

Total cost of the field study for a 20.5-kilometre road line axis was about US$3,500. Half of this cost was made up by the software components of the MGIS technology while the remaining half was made up by equipment used. Table 3 also presents detailed components of the MGIS technology selected for the second field study. It was possible to use different hardware options such as a more accurate GPS receiver and a tablet PC. However, the cost of equipment has to be carefully weighed against the accuracy requirements of the project. Results achieved with the use of the MGIS technology were satisfactory for the field study.

Table 3. *Components of MGIS technology selected for field study*

Functionality	**Generic product**	**Manufacturer**	**Model**
Computing	Pocket PC	Compaq Corp.	IPAQ 3600 Series
Positioning	GPS receiver	Magellan Inc.	SporTrack Map
GIS mapping	Mobile mapping	ESRI Inc.	ArcPad 6.0.3
Software development	Software customization	ESRI Inc.	ArcPad Application Builder
Field deployment	Field power supply	Magellan Inc.	Cig. Ltr. Adapter
System connection	PC serial cable	Magellan Inc.	PC cable
System connection	Pocket PC serial cable	Magellan Inc.	Serial Autosync Cable 191008-B21
Picture taking	Digital camera	Kodak Inc.	CX6230

CONCLUSIONS

MGIS is a growing technology and mainly focuses on integrating of existing techniques, equipment and data. Development of the technology opens the possibility of increasing accuracy and speed of the data collection process. In this paper, a MGIS system based around a palm sized PDA was evaluated on two geo-data acquisition studies in field. Results of the field studies verified a lot of benefits of the MGIS technology such as improved accuracy of spatial data, speed of data collection and low cost compared to traditional geo-data acquisition methods. Since the MGIS technology provides a streamlined workflow from data collection to final map production, it was possible to collect and to transform the geo-data without need for disparate and separate data processing. In addition, in terms of project completion time, the application results verified that geo-data acquisition with the MGIS can be completed in half the time than required for a traditional method. This is mainly due to the digital format of the data which can be directly saved thus eliminating the time needed for data transfer. Furthermore, from a cost–benefit point of view, the MGIS technology is a sensible alternative as it not only cuts down on the time necessary for the data collection process, but the equipment involved is widely available and can be purchased at affordable prices.

The MGIS technology applied to the traditional field data acquisition studies was a selection which most matches the requirements of the selected field studies. The technology can also be advantageous for wide range of geo-data acquisition projects which consider power supply and total weight of equipment as important factors. However, some applications which require further accuracy, functionality and customization to user specifications may need more powerful equipment and more experienced staff. It should also be state that developments in MGIS technology advance at rapid pace. Therefore, the information and conclusions presented here are just a snapshot in the continuing development of the technology.

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