MOBILE GEOGRAPHIC INFORMATION SYSTEMS (GIS)

FOR HUMANITARIAN DEMINING

by

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Doctor of Philosophy

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Abstract

The threat of landmines and other explosive remnants of war is a serious concern around the world. While landmines demand attention due to the thousands of civilian casualties they cause each year, perhaps even more shocking is the fear they instill in local populations, inhibiting movement and denying access to thousands of square kilometers of land in more than 80 countries. Humanitarian demining seeks to rid the world of landmines and return local populations to their displaced land. To meet this goal, surveys of hazardous areas, describing their location and contents, are used to produce threat maps for a given location and secure adequate funding from donor organizations for clearance operations. The focus of this study is a mobile GIS system, developed by the Geneva International Centre for Humanitarian Demining (GICHD), which allows rapid, accurate, and completely digital collection of these demining surveys. Using data collected during local evaluations of the demining Survey Tool at the University of Kansas campus and on foreign field deployments in Chile (2004), Albania (2004), Ecuador (2004), and Lebanon (2006), a fit-for-use analysis was performed on each component of the Survey Tool. Experiments were conducted to evaluate the accuracy of its GPS and laser rangefinder mapping devices, and methods for improving that accuracy were investigated.

The system was well received by all of its users and gauged to be twice as fast, require half the personnel, and provide higher levels of accuracy than traditional methods for collecting demining surveys. Even though the system was deemed fit for use, suggestions for improving all components of the device resulted from user feedback and observations of the system in the field. The system’s GPS receiver was predicted to provide 5 m accuracy 50 % of the time and 10 m accuracy 95 % of the time. If GPS positions were averaged for 1 minute, the 95% accuracy improved to 7.5 m, and if positions were averaged for 4 minutes, the 95% accuracy improved to 5.6 m. The two types of laser rangefinders used by the system were found to have a mean accuracy of 2.7 m when shooting at a location on the horizontal bare earth and a mean accuracy of 1.1 m when shooting at a well defined vertical target. Rangefinder accuracy varied due to level of user experience with rangefinders or other sighting equipment, and thus proved the value of training with these devices. Also, significant errors in bearing measurements with the rangefinders caused by magnetic interference from one user's eye glasses indicated that this issue requires considerable attention by all users of laser rangefinder devices. General themes that were found to be extremely important to the success of the demining system, such as the value of training, the need for system flexibility to match traditional field methods, and the complexities of GIS data collection in the field, should be a focus of any mobile GIS field program.

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Chapter 1

Introduction

Landmines and other lingering remnants of war inhibit movement by instilling fear in local populations, deny access to thousands of square kilometers of land in more than 80 countries, and cause thousands of civilian causalities each year. Humanitarian demining seeks to rid the world of landmines and return local populations to their displaced land. While most humanitarian demining is performed by personnel with a military background or by the affected country's military, humanitarian demining should not be confused with military demining, which generally serves a strategic purpose rather than focusing on civilian safety. At the core of any humanitarian demining program is the information describing and mapping these hazardous areas and all activities associated with them. Traditionally, the initial field surveys of these areas have been conducted with paper forms, using compass and tape or basic commercial grade GPS receivers for mapping. Recent developments in mobile computing devices, positional mapping technologies, and scaled-down versions of Geographic Information Systems (GIS) software, now provide the potential for rapid, highly accurate, and completely digital field data collection for humanitarian demining.

The goal of this research was to assess the fitness for use of a mobile GIS designed to collect humanitarian demining field surveys. This goal was pursued by examining the observations and feedback collected during a multi-year international evaluation of this mobile GIS, by conducting experiments to determine the spatial accuracy of resulting data, and by investigating methods for improving the accuracy of the mapping technologies used by such systems. By extrapolating these findings related to the demining system to mobile GIS in general, the results of this research have a broader significance such that any mobile

GIS system user, designer, or trainer could benefit from the lessons learned. This introductory chapter will present a framework, background, and literature review of the research questions investigated. The chapter concludes with an overview of the specific research goals and objectives addressed by the remaining chapters.

Humanitarian Demining

While it is impossible to know exactly how many millions of landmines are in the ground today, commonly stated estimates range from 10,000,000 to 50,000,000. Whatever the number may be, landmines and other unexploded ordnance (UXO) profoundly affect sizable populations in more than 80 countries around the world including thousands of civilian casualties each year (International Campaign to Ban Landmines, 2008). The goal of humanitarian demining is to remove these lingering remnants of war and return the cleared land to civilians and local governments. The process of humanitarian demining is generally organized into five steps: 1) Initial identification and assessment of suspected threat, 2) Survey of the suspected mined area to target clearance, 3) Clearance operation and marking, 4) Post-clearance inspection and documentation, and 5) Handover of cleared land and community notification (UNMAS 2003).

The Geneva International Centre for Humanitarian Demining (GICHD) is a widely recognized independent and impartial organization that supports humanitarian demining efforts. GICHD holds observer status on the Anti-Personnel Mine Ban Convention (AP MBC or “Ottawa Convention”) and hosts the meetings of its Standing Committees, provides expert advice to the AP MBC States Parties on mine clearance, mine risk education, and stockpile destruction, and, on behalf of the UN Mine Action Service (UNMAS), GICHD promulgates the International Standards for Mine Action (IMAS). Information management is a large component of GICHD's support for ongoing and emerging demining operations. In this area GICHD has directed the development of the Information Management System for Mine Action (IMSMA) computer software package, which is used to record, display and analyze data that catalog all stages in the humanitarian demining process (GICHD, 2008). GICHD provides IMSMA, at no charge, to the national authority set up by a country to manage demining operations. Generally speaking, IMSMA’s most common operational uses are to: 1) provide a country/region-wide overview of the demining situation including threat maps, 2) estimate operational costs for clearance of each area, and 3) serve as the foundation for clearance job bids and contracts (S. Berger, former GICHD Latin America regional coordinator, pers. comm., Sept. 14, 2009). In all of these use cases, comprehensive and accurate field surveys form the foundation for the success of IMSMA.

Early in 2003, GICHD initiated the development of a small, field-portable tool to support humanitarian demining data collection. This tool was intended to map and collect demining Technical Surveys (detailed investigations of a known or suspected hazardous area, usually occurring during step 2 of the aforementioned process of humanitarian demining) in the form of digital field reports for integration with the IMSMA computer software package. This handheld system was called Explosive Ordnance Disposal Information System-Survey (EOD IS-Survey) and was developed by the Swedish EOD and Demining Centre (SWEDEC) under the guidance of GICHD. In 2007 the handheld system was renamed IMSMA Mobile when development switched to the U.S. company FGM, Inc, which had also developed the most recent version of the IMSMA desktop software. EOD IS-Survey and IMSMA Mobile are not mine detection tools, but rather management tools for mapping areas known to be or assumed to be at risk due to landmines or unexploded ordnance.

The software component of EOD IS-Survey and IMSMA Mobile (hereafter referred to as the Survey Tool) is a stand-alone English-language application running on the Windows Mobile operating system that provides mapping functionality via a customized applet running inside the ESRI mobile GIS software ArcPad. The central hardware component running the Survey Tool is a touch-screen pocket PC, the Hewlett Packard iPAQ h5550 or hx2700. The pocket PC communicates wirelessly using the Bluetooth protocol with three other data collection devices. First, a consumer grade Socket GP0804-405 GPS receiver is used to collect the surveyor's position. Second, either the Leica/Vectronix Vector 1500 GMD laser rangefinder binoculars or the Laser Technologies TruPulse 360B laser rangefinder is used to measure distance, bearing, and inclination to a target location up to 1000 m away. By combining the surveyor's GPS position and the measurements collected by the rangefinder, the mobile GIS software can calculate the distant location's position. Finally, a Sony DSC-FX77 digital camera can be used to visually document the survey location.

As mentioned above, the purpose of the Survey Tool is collecting Technical Surveys, which confirm the existence of and document a known or suspected hazardous area. Technical Surveys are not used for the actual clearance activity or even for navigating back to the perimeter of a mine field. Rather, they provide the general extent for producing threat maps of the hazardous area and to help estimate the cost for clearance. Thomas Gilbert, of the US Dept. of Defense Humanitarian Demining Training Center (HDTC), indicated that in most humanitarian demining operations today, Technical Survey’s are performed using commercial grade GPS receivers and paper forms (pers. comm., Sept. 15, 2009). For the Technical Survey application, extremely high (sub-centimeter) levels of accuracy are not necessary, as long as the accuracy is of the measurement tool is reasonable (<10 m), understood, and documented. Gilbert also stressed that the Technical Survey occurs before the actual Clearance Survey, which, for safety reasons, requires higher levels of accuracy. Typically, Clearance Surveys use compass, measuring tape, and fixed survey markers that remain in the ground for the duration of the clearance operation.

Most demining operations are run on very limited resources of funding, personnel, and time. Hence, improvements in Technical Survey mapping accuracy when using the Survey Tool may not be as valuable for demining operations as increased speed, efficiency and safety. However, donors who fund clearance operations certainly would value accurate assessments of the size of hazard areas. It is difficult to characterize the exact operational situation for which the Survey Tool may be best suited, as humanitarian demining efforts around the world vary widely in their specific needs, methods, and resources. Indeed, one of the Survey Tool's main benefits may simply be providing a standard system of procedures, training and equipment, with a known level of performance and accuracy.

Mobile GIS

Background

Geographers have a long tradition of utilizing field observation in their work due to the simple fact that, the "collection of data on geographic phenomena is often best conducted in the presence of the phenomena, where more information is available to be sensed" (Goodchild et al., 2004). Merging technology with this need for direct study in the field led to the early development of transportable geographic information tools, such as the "Field-Station" system described by Dobson (1994a; 1994b; 2001). This desire to take GIS where it is needed most is one driving factor in the overall progression of GIS, highly influenced by developments in Information Technology (IT), from a mainframe, to a desktop, and more recently to a distributed model (Peng and Tsou, 2003).

Distributed GIS refers to those geographic information systems that do not have all of their hardware, software, or data components in the same physical location. Distributed GIS encompasses Enterprise GIS (integrated geographic data and software across multiple departments, serving a whole organization), as well as the more recent technologies of Internet GIS and Mobile GIS. Mobile GIS has been defined as "an integrated software/hardware framework for the access of geospatial data and services through mobile devices via wireline or wireless networks" (Tsou, 2004). The application areas of mobile GIS have been broken down into field-based GIS, focusing on the collection, validation and update of GIS data in the field, and location based services (LBS), concerned mainly with location management and logistics functions. As hardware and software continue to develop, the mapping accuracy and capabilities of mobile GIS have progressed along with its widespread adoption (Li, 2006).

Application and Assessment of Mobile GIS

The widespread adoption of mobile GIS in various disciplines suggests the perceived utility of this technology. In the natural sciences, mobile GIS has been used for geologic fieldwork (Clegg et al., 2006), hydrologic studies (Wagtendonk and De Jeu, 2005), and monitoring forest conservation easements (Willams et al., 2006) and invasive plants (Mau-Crimmins and Orr, 2005). Other field-intensive disciplines, such as archaeology, are conducting surveys implementing mobile GIS solutions (Tripcevich, 2004; Wagtendonk and De Jeu, 2007). Health related studies have used handheld computers for collecting survey data (Missinou et al., 2005; Shirima et al., 2007), and are more frequently including geographic coordinates from GPS into their workflow (Aviles et al., 2007; Vanden Eng et al., 2007).

Specific noteworthy improvements over traditional field data collection are often highlighted in studies of mobile GIS. Carver et al.'s (1995) early work stressed that the interactive data collection and mapping offered by mobile GIS significantly enhanced the scientific discovery process and decision making in the field. Clarke's (2004) summary of mobile mapping provided several commonly mentioned advantages, such as the improved accuracy, collection efficiency, and reliability of field data. Drawbacks to mobile GIS systems have been expressed as well. Common concerns include cost of equipment and stability of hardware and software, as well as the lack of flexibility to perform more complex field tasks (McCaffrey, 2005).

The prevalent use and apparent overall utility of mobile GIS raises the question, “What factors lead to a successful mobile GIS and a successful mobile GIS-based field program?” As Clarke (2004) noted in the introduction to a special issue of *Cartography and Geographic Information Science* dealing with the topic of mobile GIS, the research literature has yet to demonstrate how well these modern tools meet the actual needs of end-users. Some have suggested examining the whole system life-cycle, beginning with the initial design and following through to collect feedback from end-users (Wagtendonk and De Jeu, 2007). Others have suggested either utilizing a cost benefit framework (McCaffrey et al., 2005) or looking at how well individual components of the system meet their intended task in a fit-for-use analysis (Clegg et al., 2006), where the judgment of fitness for use is made by the end-user (Chrisman, 1986). Experimental testing has been performed on mobile GIS to evaluate the overall usability of the system for its intended geographic application (Nusser, 2005). These past studies suggest that the most effective way to assess the various aspects of a successful mobile GIS is to analyze a system with a well-defined purpose through extensive field trials by exploring, one component at a time, whether the system is fit for use both technologically and functionally. The system's functionality must be assessed from the perspective of end-users, examining both their ability to operate the system and their confidence in the resulting data.

Mapping Technologies

At the heart of field-based GIS are the mapping technologies, such as the Global Positioning System (GPS) and laser rangefinders, which make GIS feature collection possible. GPS has been widely accepted in commercial and research applications as a powerful satellite-based tool for determining location on and above the earth's surface. There are several grades of GPS receivers distinguished by their measurement accuracies: recreation or consumer-grade receivers provide an accuracy of 5-20 m and can cost under $100; mapping-grade receivers provide accuracies from sub-meter to 5 m and cost between $500 and $5000; and survey-grade receivers can provide sub-centimeter accuracies at costs of up to $20,000 or more (Rizos, 2002). The three main sources of GPS error affecting all grades of receivers are atmospheric refraction of GPS signals (slowing their transmission speeds), multipathing (detecting reflected GPS signals from various surfaces), and dynamically changing qualities of satellite geometry (Misra and Enge, 2001).

Higher grade GPS receivers are designed to correct for these errors using dual-frequencies to all but eliminate ionospheric effects and using signal processing to reduce multipathing. Poor satellite geometry can be overcome by using better satellite tracking, listening to more satellites, and multiple GPS systems. Differential correction can further remove errors by comparing the surveyed GPS data to that of a local reference station at a known location. Due to their lower cost, consumer-grade receivers do not have such integrated accuracy enhancement features. They are designed less for precise mapping and more for user productivity, or the ability to constantly provide a useable position. There are several methods that consumer grade GPS users can utilize to reduce errors, but they require more of the user's time to collect additional data.

The first approach filters GPS data according to the dilution of precision (DOP) measure calculated by the receiver. DOP is based on the geometry of the satellites being used. Higher DOP values indicate less certainty in the overall position and are caused when fewer and/or tightly clustered satellites are used by the GPS to calculate its position. DOP values generally range from 1-10, but may reach values >20 under very poor conditions. DOP values and can be viewed as multiples of the minimum uncertainty/accuracy level of the GPS (Hofmann-Wellenhof et al., 2001). To implement DOP filtering, a DOP mask or threshold is set, beyond which GPS data, of assumed lower accuracy, will not be recorded (Rempel and Rodgers, 1997). DOP filtering will have the most benefit in poor satellite conditions, such as under heavy tree canopy, but it can also benefit collection in open-sky conditions when few satellites are in view from the operator's position.

GPS averaging has also been shown to be a powerful way to diminish positional error (Sigrist et al., 1999). By taking the average of repeated GPS positions at a fixed location, the expected accuracy of a GPS receiver can be increased by smoothing out the fluctuations in GPS errors (Deckert and Bolstad, 1996). The important question to answer for the most efficient use of GPS averaging is, "how long is long enough?" While GPS user manuals and technical reports provide a generic starting point, and studies have been performed comparing various grades receivers (Devlin et al., 2007), the specific GPS unit in question should be tested to establish the most appropriate guidelines.

Laser rangefinder devices measure the distance, bearing and inclination to a target. Mobile GIS software uses these three pieces of information along with a known reference coordinate (operator location, usually collected from a GPS) to calculate the coordinates of the target location. These laser rangefinders, which collect measurements one-at-a-time, are frequently used in forestry applications (Wing and Kellog, 2001) and ecological field studies (Aspbury and Gibson, 2004). More expensive laser scanning technologies, also known as ground-based Light Detection and Ranging (LIDAR), can be used to collect larger quantities of point measurements at an even greater level of precision. This type of equipment is more commonly used in the fields of geology (Alfarhan et al., 2008) and archaeology (Brusco et al., 2006).

Improving Mobile GIS

A significant body of work has explored what can be done to improve the experience and accuracy of users employing mobile GIS. Unfortunately, training is an often overlooked component of emerging technologies. Without it users can quickly become frustrated and lose interest in adopting a new way of working. Unlike, say, pen and paper or compass and tape, a fair amount of background knowledge is required to effectively operate mobile GIS. Carlson (2007) suggests a short curriculum for introducing this technology to new users, which would include: 1) Theory and applications of GIS, 2) GPS fundamentals and best practices, 3) Handheld computer systems, and 4) Handheld GIS software. The overall goal of training is not about the handheld GIS technology itself, but how it relates to the work or research that will be conducted with it in the field (Mau-Crimmins and Orr, 2005). Research specifically dealing with the use of mobile computing for geographic education provides a good foundation for understanding how students use this new tool to collect spatial data and generate knowledge about their area of study (Armstrong and Bennett, 2005).

Ensuring data quality is an essential and frequently discussed topic surrounding digital field data collection. Most field GIS data errors occur on site, and thus should be identified and corrected in the field whenever possible (Wang and Reinhardt, 2006). Simple logical rules can be established by designing an intelligent data entry system to avoid common errors and mistakes with text and data input (Pundt, 2002). When systems are spatially enabled using GPS receivers, additional rule sets can be hard-coded to enforce best data collection practices. Estimates of GPS signal quality can also be calculated in advance from known satellite orbits to predict optimal data collection strategies (Karimi and Grejner-Brzezinska, 2004).

Evaluating Humanitarian Demining Mobile GIS

In late 2003, the University of Kansas was contracted by GICHD and asked to conduct an independent evaluation of the demining Survey Tool, examining its fitness for use in a variety of field conditions. Work on the evaluation began with a site visit and training by the EOD IS team from SWEDEC as well as representatives from GICHD and FGM, Inc. Following the site visit, team members at the University of Kansas began to evaluate the Survey Tool locally and to design methods to evaluate it at foreign locations. Subsequently, members of the University of Kansas evaluation team traveled to Chile (March 2004), Albania (May 2004), Ecuador (October 2004), and Lebanon (February 2006) to witness deployments of the Survey Tool. A final report, entitled "Evaluation of the EOD IS-Survey Handheld Tool for Technical Surveys," was delivered by the University of Kansas team to GICHD in June 2006.

The evaluation team consisted of the author and three additional members: Dr. Jerry Dobson, Professor of Geography at the University of Kansas and President of the American

Geographical Society; Dr. Stephen Egbert, Associate Professor of Geography at the University of Kansas and Associate Scientist at the Kansas Applied Remote Sensing Program; and Dr. John Kostelnick, then a graduate student in the Department of Geography at the University of Kansas and now Assistant Professor of Geography-Geology at Illinois State University.

Chapter Summaries

The evaluation of the demining mobile GIS, EOD IS-Survey, conducted by a team of researchers at the University of Kansas, collected a significant amount of practical information about a field-tested mobile GIS with a well defined purpose. The goal of Chapter 2 is to utilize the user feedback, interviews, and field notes collected for the demining Survey Tool evaluation to draw conclusions about what makes a successful mobile GIS system and mobile GIS-based field campaign. To accomplish this goal, the fitness for use of the demining Survey Tool is assessed by examining each aspect of the tested mobile GIS (software, hardware, training, and local factors), paying particular attention to users' feedback. Where possible, the findings related to the demining Survey Tool are extrapolated to mobile GIS in general so that any mobile GIS system user, designer, or trainer can benefit from the lessons learned.

Following the system-wide overview from Chapter 2, the next two chapters describe focused experiments designed to assess the mapping accuracy of the GPS and laser rangefinder technologies employed by the demining survey tool. The goal of Chapter 3 is to determine the expected horizontal positional accuracy of the consumer grade Socket Bluetooth GPS and to investigate DOP filtering and GPS averaging as methods for improving the expected accuracy of the GPS receiver. Chapter 4 explores the expected horizontal positional accuracy of the Vector 1500 GMD and TruePulse 360B laser rangefinders. The accuracy of point and area measurements collected with the rangefinders is determined with respect to the variables of equipment, target distance, and user. The choice of target type and the use of a monopod with the rangefinders are also investigated as methods for improving accuracy. Finally, Chapter 5 presents a summary of the conclusions drawn across this entire study and provides a series of future research areas suggested by this work.

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Chapter 2

Evaluating Mobile GIS for Humanitarian Demining

Abstract

A combination of mobile computing devices, positional mapping technologies, and scaled-down versions of GIS desktop software now provides the potential for rapid, highly accurate, and completely digital geographic field data collection. These noteworthy benefits and the widespread adoption of this mobile geographic information technology raise the following question: "What factors lead to a successful mobile GIS and a successful mobile GIS-based field program?" Beginning in 2003, researchers at the University of Kansas were invited to take part in a multi-year evaluation of a mobile GIS designed for humanitarian demining field surveys. This international effort consisted of four two-week-long field tests of this system in, respectively, Chile, Albania, Ecuador, and Lebanon. This paper summarizes the observations and feedback collected during that evaluation, paying particular attention to users' comments, in order to assess the fitness for use of each component of the demining survey tool. Where possible, these findings related to the demining system are extrapolated to mobile GIS in general. Along with a variety of specific recommendations, I conclude that in order to effectively facilitate the transition from traditional field methods, a mobile GIS must be designed with flexibility as a core concept and adaptability as an overarching theme in user training.

This chapter draws from data collected for an earlier technical report:

Egbert, S., M. Dunbar, J. Dobson, and J. Kostelnick. 2006. *Evaluation of the EOD IS-Survey Handheld Tool for Technical Surveys: Final Report*. Submitted to the Geneva International Centre for Humanitarian Demining. (Submitted April, 2006). 57p.

Introduction

With recent developments in technology, computing has become available in more places worldwide, is now small enough to move with its users even to highly remote places, and can provide access to a wide array of distributed resources. It has been noted that these changes in the "where" aspects of computing have already made significant impacts on the way geographers and GIS professionals conduct their work (Goodchild et al., 2004). Take for example, how mobile computing technology and the need for direct study in the field led to the early development of transportable geographic information tools, such as the "Field-Station" system described by Dobson (1994a; 1994b; 2001). This and other deviations from the traditional desktop GIS framework have been termed ‘Distributed GIS,’ which encompasses both mobile GIS and the broad array of enterprise and internet GIS technologies (Peng and Tsou, 2003). Mobile GIS has been defined as “an integrated software/hardware framework for the access of geospatial data and services through mobile devices via wireline or wireless networks” (Tsou, 2004). The application areas of mobile GIS have been broken down into field-based GIS, focusing on the collection, validation and update of GIS data in the field, and location based services (LBS), concerned mainly with location management and logistics functions.

The widespread adoption of mobile GIS in various disciplines is a reflection of the perceived utility of this technology. In the natural sciences, mobile GIS has been used for geologic fieldwork (Clegg et al., 2006), hydrologic studies (Wagtendonk and De Jeu, 2005), and monitoring forest conservation easements (Willams et al., 2006) and invasive plants (Mau-Crimmins and Orr, 2005). Other field-oriented disciplines, such as archaeology, are conducting surveys implementing mobile GIS solutions (Tripcevich, 2004; Wagtendonk and De Jeu, 2007). Health related studies have used handheld computers for collecting survey data (Missinou et al., 2005; Shirima et al., 2007), and are more frequently including geographic coordinates from GPS into their workflow (Aviles et al., 2007; Vanden Eng et al., 2007).

Specific noteworthy improvements over traditional field data collection are often highlighted in studies of handheld systems. Carver et al.'s (1995) early work stressed that the interactive data collection and mapping offered by field GIS significantly enhanced the scientific discovery process and decision making in the field. Clarke's (2004) summary of mobile mapping provided several commonly mentioned advantages, such as the improved accuracy, collection efficiency, and reliability of field data. Drawbacks to mobile GIS systems have been expressed as well. Common concerns include cost of equipment and stability of hardware and software, as well as the lack of flexibility to perform more complex field tasks (McCaffrey, 2005).

The prevalent use and apparent overall utility of mobile GIS raises the question, "What factors lead to a successful mobile GIS and a successful mobile GIS-based field program?" As Clarke (2004) noted in the introduction to a special issue of *Cartography and Geographic Information Science* dealing with the topic of mobile GIS, the research literature has yet to demonstrate how well these modern tools meet the actual needs of end-users. Some have suggested examining the whole system life-cycle, beginning with the initial design and following through to collect feedback from end-users (Wagtendonk and De Jeu, 2007). Others have suggested either utilizing a cost benefit framework (McCaffrey et al., 2005) or looking at how well individual components of the system meet their intended task in a fit-for-use analysis (Clegg et al., 2006), where the judgment of fitness for use is made by the end-user (Chrisman, 1986). Experimental testing has been performed on mobile GIS to evaluate the overall usability of the system for its intended geographic application (Nusser, 2005).

These past studies suggest that the most effective way to assess the various aspects of a successful mobile GIS is to analyze a system with a well-defined purpose through extensive field trials by exploring, one component at a time, whether the system is fit for use both technologically and functionally. The system's functionality must be assessed from the perspective of end-users, examining both their ability to operate the system and their confidence in the resulting data.

Evaluating Mobile GIS for Humanitarian Demining

Early in 2003, the Geneva International Centre for Humanitarian Demining (GICHD) initiated the development of a small, field-portable tool to support humanitarian demining data collection. This tool was intended to map and collect demining Technical Surveys (detailed investigations of a known or suspected hazardous area) in the form of digital field reports for integration with the GICHD Information Management System for Mine Action (IMSMA) computer software package. This handheld system was called Explosive Ordnance Disposal Information System-Survey (EOD IS-Survey) and was developed by the Swedish EOD and Demining Centre (SWEDEC) under the guidance of GICHD. In 2007 the handheld system was renamed IMSMA Mobile when development switched to the U.S. company FGM, Inc, which has also developed the most recent version of the IMSMA desktop software. However, this paper is only concerned with the earlier EOD IS-Survey system. EOD IS-Survey is not a mine detection tool, but rather a management tool for mapping areas known to be or assumed to be at risk due to landmines or unexploded ordnance.

The software component of EOD IS-Survey (hereafter referred to as the Survey Tool) is a stand-alone English-language application running on the Windows Mobile operating system that provides mapping functionality via a customized applet running inside the ESRI mobile GIS software ArcPad. The central hardware component running the Survey Tool is a touch-screen pocket PC, the Hewlett Packard iPAQ h5550. The pocket PC communicates wirelessly using the Bluetooth protocol with three other data collection devices. First, a consumer grade Socket GP0804-405 GPS receiver is used to collect the surveyor's position. Second, Leica/Vectronix Vector 1500 GMD laser rangefinder binoculars are used to measure distance, bearing, and inclination to a target location up to 1,000 m away. By combining the surveyor's GPS position and the three measurements collected by the binoculars, the mobile GIS software can calculate the distant location's position. Finally, a Sony DSC-FX77 digital camera can be used to document visual observations of the survey location (Figure 1).

In late 2003, the University of Kansas was contracted by GICHD and asked to conduct an independent evaluation of the Survey Tool, examining its fitness for use in a variety of field conditions. Work on the evaluation began with a visit to Kansas by the EOD IS team from SWEDEC as well as representatives from GICHD and FGM, Inc. Following this training on our campus, team members at the University of Kansas began to evaluate the Survey Tool locally and to design methods to evaluate it at international locations. Subsequently, members of the University of Kansas evaluation team traveled to Chile (March 2004), Albania (May 2004), Ecuador (October 2004), and Lebanon (February 2006) to witness deployments of the Survey Tool. A final report, entitled "Evaluation of the EOD IS-Survey Handheld Tool for Technical Surveys," was delivered by the University of Kansas team to GICHD in June 2006.

The evaluation team consisted of the author and three additional members: Dr. Jerry Dobson, Professor of Geography at the University of Kansas and President of the American Geographical Society; Dr. Stephen Egbert, Associate Professor of Geography at the University of Kansas and Associate Scientist at the Kansas Applied Remote Sensing

Figure 1. Mobile GIS system for humanitarian demining. Data are transfered via USB between PocketPC and IMSMA desktop software. The PocketPC recieves data wirelessly via Bluetooth from the GPS, Laser Rangefinder Binoculars, and Camera data collection devices.

Program; and Dr. John Kostelnick, then a graduate student in the Department of Geography at the University of Kansas and now Assistant Professor of Geography-Geology at Illinois State University.

Objectives

The evaluation of the demining mobile GIS, EOD IS-Survey, conducted by a team of researchers at the University of Kansas, collected a significant amount of practical information about a field-tested mobile GIS with a well defined purpose. The goal of this paper is to utilize the user feedback, interviews, and field notes collected for the demining Survey Tool evaluation to draw conclusions about what makes a successful mobile GIS system and mobile GIS-based field campaign. To accomplish this goal, two specific objectives are addressed here:

- Assess the fitness for use of the demining Survey Tool by examining each aspect of the tested mobile GIS (software, hardware, training, and local factors), paying particular attention to users' feedback.
- Where possible, extrapolate the findings related to the demining Survey Tool to mobile GIS in general so that any mobile GIS system user, designer, or trainer can benefit from the lessons learned.

Methods

Study Areas

Testing of the EOD IS-Survey mobile GIS system began on the campus of the University of Kansas. Following this initial evaluation, the Survey Tool was field tested with mine action personnel in four countries: Chile, Albania, Ecuador, and Lebanon. For each deployment, one or more members of the University of Kansas evaluation team accompanied the personnel of the Geneva Centre and their affiliates to observe the training and gather data for evaluations and recommendations. Each deployment consisted of approximately one week of classroom training and outdoor exercises (Figure 2) followed by one week of field testing at or near mined locations (Figure 3).

The deployment locations for the survey tool evaluation were chosen to test the system under diverse conditions. For each study site, three broad categories of characteristics were considered: environment, infrastructure, and culture. During the first week of each deployment there was minimal variability between study areas in terms of environment or infrastructure. This time was spent near well-equipped facilities with outdoor training sites that provided clear views of the sky for GPS reliability and elevated sighting positions with no visual obstructions for easy use of the binocular. However, the second week of practical exercises in mine affected areas varied widely by site to fully test the system's field readiness and mapping capabilities. Noted categories of differences in the natural environment included climate, land cover, and terrain (Figure 4). Infrastructure at the study areas was classified in terms of accessibility to roads, power sources, and communication networks. Finally, cultural factors that were considered throughout the deployments included the trainee's organizational structure, level of education (especially GIS, GPS, and rangefinder or sighting equipment experience), native language, and English fluency. This section provides a summary of the testing structure and conditions at the University of Kansas and each of the four foreign field deployments

University of Kansas

The first user testing of the Survey Tool was conducted between 19 February and 5 March, 2004 on the University of Kansas campus with professional staff at the Kansas

Figure 2. Classroom training the demining mobile GIS Survey Tool: A) Chile, B) Albania, C) Ecuador, and D) Lebanon.

Figure 3. Field testing the demining mobile GIS Survey Tool: A) Chile, B) Lebanon, C) Ecuador, and D) Albania.

Figure 4. Physical environments of demining mobile GIS field trials: A) Chilean Altiplano, B) Northern Albania C) Ecuador, Amazon Basin, and D) Lebanon.

Applied Remote Sensing Program. These staff consisted of ten “expert users,” meaning individuals familiar with computer technologies, GIS, remote sensing, and geography. For the test, four small groups of two or three participants were given approximately one hour of classroom training and demonstration, led by Dunbar. This instruction was followed by one hour of field testing observed by Dunbar and Egbert. Fieldwork focused primarily on collecting spatial data defining the perimeters of simulated mined areas in a park-like environment (extensive mowed lawns with scattered deciduous and coniferous trees), thoroughly characteristic of actual minefields.

Chile

The EOD IS-Survey Tool was introduced to a group of mine action personnel in Chile, 15-26 March 2004. All participants were members of the Chilean armed forces. The first week consisted of classroom training at the Army Engineer Central Command in Santiago, Chile, with field exercises in a nearby city park. The second week consisted of field testing of the Survey Tool at minefields in northern Chile, near the city of Arica along the northern Chilean border with Peru in the Atacama Desert; a one-day trip was also made to the Altiplano (Andean high plateau) by a few participants to test the system at high elevations. In contrast to the other three foreign deployments, the University of Kansas evaluation team, consisting of Dunbar and Egbert, arrived at mid-week in the first week of training and therefore did not observe most of the first week’s training activities.

The natural environment in Chile was a coastal desert with sparse vegetation. Minefields were mapped in mostly flat terrain, with occasional topographic features such as sand dunes and arroyos. Climate at the Chilean field site was warm and dry throughout the testing, with cold temperatures experienced at the high elevations of the Altiplano. All mined areas were accessed by road and, with the exception of the Altiplano, none were more than an hour's drive from a local army base. Most test sites had cellular phone access due to their proximity to the city of Arica. The armed forces personnel who took part in the Chilean training were well educated and formed a very structured organization. Training was conducted in the native language, Spanish, but several personnel spoke English and served as translators for the instructors. A number of the Chilean army officers and enlisted personnel were skilled GIS users, and nearly all had prior experience with GPS technologies.

Albania

The EOD IS-Survey Tool was introduced to a group of mine action personnel in Albania, 10-21 May 2004. The first week (10-14 May) consisted of classroom training and field exercises in and around the Albania Mine Action Executive (AMAE) headquarters in Tirana, while the second week took place at several sites on and near the Albanian border with Kosovo (accessed by coming from the Kosovo side of the border). Egbert observed the entire training.

The land cover surrounding the field sties in Albania was mostly temperate forest. Several sites contained very dense vegetation, brush, and shrubby trees, mostly 3-5 m tall. At these locations, sightlines using the binoculars were only possible along existing roads and paths. Mild temperatures were experienced through the field training, including several days with precipitation and light fog. Infrastructure during the first week of training was the least reliable at this site, where periodic power failures required the use of uninterruptible power supplies (UPS) and generators. During the second week of field testing most sites were accessible by vehicle, despite often rough roads. The training group in Albania was less structured and more diverse in background than at any other location. One participant had experience with mapping-grade GPS and laser rangefinders, several had used consumer-grade GPS and compass, while the rest had no experience with mapping technologies. This often led to inconsistent levels of comprehension during training. The native language of all participants was Albanian, with highly variable English language skills. This was an important factor since the training was conducted entirely in English.

Ecuador

The EOD IS-Survey Tool was introduced to a group of mine action personnel, including teams from both Peru and Ecuador during the period 18-29 October 2004. Egbert observed classroom training and field exercises during the first week in Quito. Then, in the second week, Egbert and Dobson observed field training in Teniente Ortiz in the Amazon rainforest.

The physical environment in Ecuador was a remote rainforest. Field testing was performed in thick forest canopy with occasional openings, including fairly dense undergrowth. Temperatures were warm, with high humidity and some precipitation. This study area was far from power or communications networks. The nearest small town and army base, Rio Santiago, was a muddy 5 mile hike followed by a 30-40 minute boat ride. The multinational trainees in Ecuador were made up of military personnel and participants from various NGOs. It was noted early in this training that, unlike other deployments, none of the participants would actually be using the tool. Instead, they would manage or facilitate programs using the equipment. Individuals had varying experience with geographic technologies. Some came from Information Management and GIS backgrounds while others were administrators of mine action programs. Training was conducted in Spanish, the native language of all participants.

Lebanon

The EOD IS-Survey Tool was introduced to a group of mine action personnel in Lebanon, including representatives from the National Demining Office (NDO) and the Mine Action Coordination Centre, Southern Lebanon (MACCSL). Egbert observed the training and field testing of the EOD IS-Survey Tool 15-24 February 2006 in and around the city of Beirut. In addition to the four standard EOD IS-Survey kits (iPAQ pocket PC, Vector binoculars, Socket Bluetooth GPS, and Sony Bluetooth camera) used during the training, an additional four Garmin iQue pocket PC systems already in-country were loaded and tested with the EOD IS-Survey software (these were not able to accept input from the Vector binoculars and were therefore used in GPS-only mode).

All testing in Lebanon was conducted in urban settings, often containing dense vegetation in the form of high grass and trees. Temperatures were mild throughout the training, with almost no precipitation. In terms of infrastructure at this study site, the urban testing environments provided easy access to roads, communications networks, and electricity for recharging equipment on a daily basis. While the Lebanese training was conducted in English, Arabic language and culture was an important consideration at this site. The education and training level of all the course participants was very high. Nearly all of the personnel were engineer officers in the Lebanese military and most had formal training and experience with computer-based geographic technologies such as GPS and GIS. All participants were multi-lingual and many had undergone training in either France or the U.S. at military engineer schools.

Evaluation

At the University of Kansas, information was gathered based on observations and verbal and written feedback from professional staff members of the Kansas Applied Remote Sensing Program. For the international deployments, four methods were used for gathering data: (1) an Initial Evaluation Form, (2) Field Observations, (3) Exit Interviews, and (4) Feedback Forms. Each of these data instruments or methods is described below and presented in Appendix A.

The emphasis of the evaluation focused almost entirely on the mapping capabilities of the Survey Tool system, as opposed to the alpha/numeric data entry or digital "forms" function of the system. This occurred for two reasons. First, the training emphasis in both the classroom and the field was primarily on mapping, and second, the mapping component was perceived by instructors and participants to be by far the most difficult part of the system to master. Therefore, the “forms” part of the Survey Tool system was not relevant to this evaluation.

Initial Evaluation Form

The Initial Evaluation Form was a two-page questionnaire filled out by all participants in the training course near the end of the first week of training. Its purpose was to give an on-the-spot assessment of how course participants viewed the mobile tool before going into the field. The form was divided into three sections. The first was designed to collect basic background information about each participant’s self-perceived level of experience in terms of computer usage and minefield mapping. The second section requested feedback about several aspects of the training, while the third asked for opinions and comments about the Survey Tool itself. As with all the information collected, the Initial

Evaluation Form was designed to be anonymous so as to encourage the frank and open exchange of opinions.

Field Observations

Field observations were collected during each of the deployments, primarily through outdoor field exercises. Written field notes routinely were taken and voice recordings of observations occasionally were made. These were usually spot observations of problems encountered in the field but also included summary comments made back in the classroom or later in the evening during review of the day's activities. These notes included visual observations as well as conversations with participants and instructors as the training and field exercises progressed. In particular, a focus was placed on repeating patterns of error conditions or problems encountered in order to focus reporting on systematic issues rather than isolated problems that related more to a particular individual or circumstance. Although all of the evaluation forms and methods provided useful input, the field observations were, without question, the most valuable part of the evaluation process.

Exit Interviews

Individual interviews were conducted with as many training participants as possible at or near the end of the two-week training period. As far as possible, the interviews were private and anonymous, permitting each participant to freely express his or her opinions without the incidental pressure that might have prevailed in a group setting, especially in the presence of a supervisor or superior officer. In Chile and Ecuador, interviews were conducted in English with Spanish translation, while in Albania and Lebanon they were conducted entirely in English. In total, 27 participants were interviewed, with the following numbers for each country: Chile 9, Albania 4, Ecuador 7, and Lebanon 7.

Questions asked during the interviews were designed to collect evaluations and recommendations regarding the training, the mobile tool's hardware and software, and the participants' general opinion of the value of the system as well as his or her level of confidence in using it and training others to use it. For Chile, Albania, and Ecuador the question sets used by the interviewers remained relatively constant. For Lebanon the questions were altered somewhat based on the knowledge gathered from previous field experiences.

In addition to these formal exit interviews with system users, extensive structured conversations with trainers and other personnel who were involved in, or who observed, the training provided additional feedback on the Survey Tool.

Feedback Forms

To set up a flow of information back from the field, a Feedback Form was distributed in each country where the Survey Tool was tested. The Feedback Form was two pages long with five sections to be filled out at the conclusion of each survey activity conducted with the system. The first section was designed to gauge the experience level of the survey team, while section two elicited basic information about the minefield, such as size, and mapping effort, such as the length of time required and the method used. Section three was a standard trouble-shooting report, asking if any problems were encountered and, if so, what steps were taken to try to solve the problem. Section four asked for information on whether any environmental factors (weather, terrain, or vegetation) impacted the survey, while section five asked for an evaluation as to whether the team considers the Survey Tool to be an improvement over other methods of mapping minefields. As with other forms and evaluation methods, the Feedback Forms were anonymous to protect both the identity of the respondent and also any sensitive information regarding the geographic location of the minefield.

In each country where the Survey Tool was field tested, each training team was asked to fill out a Feedback Form near the end of the two-week training period. This was done to familiarize each participant with the form and to solicit additional feedback from the participants in regard to their opinions about the effectiveness of the Survey Tool.

The Feedback Form was intended to be a vehicle for providing a steady stream of feedback as field teams carried out surveys using the Survey Tool. However, the actual practice turned out somewhat differently in each deployment. In Chile, it was decided locally by Major Henry Ilufi to gather feedback and submit a "summary" Feedback Form and corresponding report. In addition, the GICHD Latin American Regional Coordinator, Simon Berger, wrote a comprehensive report that summarized the experiences of the Chileans with the Survey Tool. In Albania, the Survey Tool was discontinued following the training period[1]. Therefore, no technical surveys were performed, and no feedback forms were submitted. From Ecuador, a total of five Feedback Forms were received for technical surveys performed after the training period. Some of the feedback forms represented a single minefield, while others summarized work for several minefields mapped under a single technical survey. For unknown reasons, despite the system's use in Lebanon and repeated requests, no Feedback Forms were ever received from this location.

[1] On 24 May, 2004 an accident occurred in Kukes, Albania during a training lecture (unrelated to the GICHD Survey Tool) held by Handicap International for newly recruited deminers. Training ordnance, thought to be free from explosives, detonated in the classroom killing two persons and injuring fifteen others. This accident led to a suspension of all demining activities in Albania for nearly a year while an official Board of Inquiry determined the cause of the accident.

Results and Discussion

Taking the broad view, there were two major conclusions drawn from the evaluation. First, in general, the Survey Tool performed the task for which it was designed and was a major improvement over other existing methods for performing Technical Surveys. Participants cited a two to three-fold savings in time and labor, enhanced safety, and improved accuracy and reliability. Second, the Survey Tool is a relatively complex system that needs improvement and ongoing support in order to provide the greatest utility. Specifically, it requires improvements in the form of "bullet-proofing" to protect from or warn of significant mapping or data entry errors. An effective support structure must also be in place for the Survey Tool, providing thorough training, useful instructional guides, and access to knowledgeable system specialists.

In order to more thoroughly address the Survey Tool's fitness for use, the system and its field program were broken down into their individual components. The information about the Survey Tool collected from forms, interviews, and observations most logically sorted into the following categories:

- Software: operating system, EOD IS-Survey, and mobile GIS
- Hardware: Pocket PC, rangefinder, and GPS
- Training: content, structure and training aids
- Site Specific Factors: participants, language, local standards, and geographic factors

In additional to qualitatively evaluating the observations and feedback in each of these categories, the user-indicated importance of issues was calculated by noting the frequency that a topic was mentioned in the initial evaluation form, exit interviews, and feedback forms. Any problems or suggested improvements mentioned by more than two users were integrated into the overall findings regarding the Survey Tool (Table 1).

Software

Operating System	Count
General difficulty operating handheld software	6
Minimize vs. exit program confusion	4
EOD IS-Survey	
Lockup, requiring software or handheld reset	31
System should collect additional types of data/reports	12
Reqeust for local language software	8
General software design issues	7
ArcPad	
Editing and complex feature creation	7
Missing GPS information displays (skyview, compass,etc.)	6
Importance of imagery/map layers	5

Hardware

Pocket PC	Count
Poor outdoor screen visibility	10
Handheld battery life	9
GPS	
GPS dropped Bluetooth connection	17
How long to wait for good GPS fix?	8
Integrate GPS in Handheld	4
Where to place GPS antenna?	3
Rangefinder	
Request monopod/tripod	12
Rangefinder missed transmission/dropped Bluetooth	11
Confusion over bearing errors (magnetic interference)	11
Difficulty shooting at small or no phsyical target	10
Include compass to test bearing error	6
Accidentally changed settings	3

Training

More problem solving in exercise-based training	27
Need for checklists	26
Repeated use required for profeciency	26
Request for local language training and materials	17
Train multiple mapping methods (with different hardware)	5
Provide hardware specs (battery life, accuracy, etc)	4

Table 1. Frequency of user-reported problems or requested improvements across all field trials as indicated by responses to the Initial Evaluation Form, Exit Interviews, and Feedback Form.

Software

Operating System

Almost all participants adapted well to the pocket PC operating system, Windows Mobile, very quickly. Although relatively few had previous experience with a pocket PC, all had at least some experience with the Windows operating systems on desktop or laptop PCs. It was apparent that such computer experience transferred quickly to the pocket PC and that no extensive training or documentation is required to get most participants up and running. However, small differences between the desktop and pocket PC operating system, such as the way software applications are minimized vs. completely closed, were occasionally mentioned by users as a source for minor confusion (Table 1). This suggests that a basic overview of the mobile version of the Windows operating system should be included in the training.

EOD IS-Survey

The users' most frequently mentioned problem with the Survey Tool was the EOD IS-Survey software becoming locked up during operation (Table 1). These lock-ups, while infrequent, were an ongoing source of frustration primarily because it wasn't always clear what was causing them. In most cases, the participants were able to adapt by closing down and restarting the software, by performing a soft reset (restarting the handheld), or, in some extreme cases, by performing a hard reset (re-installing all handheld software). The frequency of user comments dealing with this occasional but annoying problem suggests that, without adequate training and support, just a few occurrences of critical system failures can quickly lead to a lack of faith in the overall stability of a device.

On all deployments, numerous participants strongly requested that the Survey Tool be expanded to collect other field report types in addition to the Technical Survey, which was the focus of the original system design. Requested capabilities included reports for other standard humanitarian demining activities such as Impact Surveys, Clearance Surveys, and Mapping Dangerous/Mined Areas. Several users also asked for the ability to create customized forms that conform to their local procedures and information requirements. In addition to customizing the type of data collected, many users also stressed the need to have the software translated to their own language. Most trainees felt they could competently use the software in English, but worried about training new users on their own in the future.

There was also a variety of requests for basic changes in software design. Trainees suggested that mandatory fields should be indicated as such, and that the software should prohibit users from leaving a form until all mandatory fields are completed. Several data fields, such as the nearest town or reporting agency, allowed entry of values by hand rather than using a pull-down list. As these fields were stored in fixed lookup table within the desktop information management software, this led to database inconsistencies when importing the handheld data. Users also noted that the software mistakenly allowed multiple minefield maps to be recorded in a handheld report. This resulted in additional importing problems as the desktop software was designed to accept only one minefield map for each survey report. Both of these importing compatibility issues suggest the need for consistency between handheld, desktop, and synchronization software design. Finally, users indicated confusion with several icons and text used in the software's menus, such as the use of the terms "Add" and "Edit" rather than "New" and "Edit".

GIS Software

The evaluation team and system users indicated three areas where the modified version of ArcPad used by EOD IS-Survey could be improved: editing and creating complex features, GPS functionality, and the incorporation of base maps and imagery in the form of raster data.

Users of the Survey Tool indicated that difficulties editing existing features or creating new features using complex methods, such as collecting a minefield perimeter using the rangefinder from multiple vantage points, were their greatest concern in the mapping application. Since all feature creation and editing functionality in the Survey Tool are based on the default system used in ArcPad, this is not an issue that can be remedied with specialized code in EOD IS-Survey. Instead, editing and creating complex features requires detailed attention through training and instructional materials. Smaller numbers of requests were noted for minor feature enhancements to the mapping functionality. Participants requested that mapping capabilities be expanded to include the ability to map minefields as lines and points, in addition to the polygon feature currently allowed by the software. Some participants requested that the ability to enter a point manually using its x,y coordinates. Others suggested the additional ability to include multiple feature types, such as trees, buildings, trenches, and ponds within a minefield survey.

While it was not mentioned by users, the evaluation team immediately noticed that GPS averaging functionality was not included in the Survey Tool's ArcPad application. During deployments to Albania, Ecuador, and Lebanon, experiments were carried out using the full stand-alone implementation of ArcPad to evaluate the value of using averaged versus "raw" GPS points. Generally, ArcPad was set to average each point for approximately three minutes. In all the tests, the averaged points had a narrower range of positional values and tended to vary by less than half as much as the raw values. Participant comments also recommended that all the standard GPS information windows available in the full implementation of ArcPad (e.g., satellite view, compass view, etc.) be enabled in the Survey Tool's modified version of ArcPad.

One of the key points driven home by field testing of the Survey Tool is the importance of having high-resolution raster imagery to use as a backdrop for mapping minefield perimeters in ArcPad. Maps and satellite images on the pocket PC enable the user to visualize the goodness of fit of minefield perimeters and highlight errors at both gross and fine scales, providing an important type of field validation and feedback. In general, satellite images were used more frequently than scanned maps, presumably because they represented actual conditions on the ground rather than the generalized depiction inherent in topographic maps. It is strongly recommended that high-resolution imagery be used with the Survey Tool system at all times. Ideally, the raster data would include recent aerial photography or satellite imagery combined with 1:50,000 or finer scale digital raster maps.

Hardware

Pocket PC

The Pocket PC hardware component was found to generally meet all expectations, with the notable exceptions of its screen visibility, battery life, and Bluetooth functionality. User comments made concerning Bluetooth problems are included under the GPS and rangefinder Hardware entries in Table 1.

Many participants complained about the difficulty of reading the screen of the Pocket PC outdoors, particularly in bright sunlight. Not surprisingly, the most complaints came from Chile and Lebanon, where bright, sunny conditions were common in the test areas. Developers of future versions of the Survey Tool should be certain to evaluate specific models of candidate Pocket PCs for screen brightness, which is bound to improve with the progress of technology development. Battery life, especially for the handheld PCs, often was found to be much less than the length of a single day's fieldwork. This was a notable problem for work in isolated locations or locations without reliable electricity for recharging, and was a common complaint during exit interviews. High-capacity spare batteries should be included with all handhelds kits, along with vehicle charging adapters. Additionally, the importance of keeping all batteries fully charged should be strongly emphasized during in the training program.

In all four foreign deployments, participants experienced frequent loss of Bluetooth communications between the binoculars and the pocket PC. These unexpected events were relatively frequent and were a cause of frustration, since they necessitated interrupting the collection of data to reestablish communications. This most likely was a software issue in some component (Windows Mobile and/or ArcPad), although in one case in Albania the failure was caused by a defective Bluetooth antenna in the rangefinder binoculars. It should be noted that although the interruptions were a source of frustration, participants in most cases were quickly able to reestablish communications between devices. Because of the frequency of dropped communications, however, it would be worthwhile to investigate the use of a hardwire cable connection between the binoculars and the pocket PC or conduct tests with another model of laser rangefinders to determine if this was a hardware-specific issue.

Participants in all countries also occasionally experienced a loss in Bluetooth connection between the GPS and the pocket PC, which caused delays and frustration due to interrupted work flows. In Lebanon, where a number of participants had previous experience using integrated Garmin iQue GPS/pocket PC devices, several noted that the problem could be overcome by using a GPS integrated with a PDA (such as the Garmen iQue or Trimble Juno) or with plug-in GPS units on Compact Flash (CF) or Secure Digital (SD) flash memory cards. The potential downsides to an integrated or plug-in GPS would be increased battery drain on the pocket PC (an important consideration) and the increased hardware complexity inherent in integrated devices.

Rangefinders

It was first discovered in Chile, and subsequently verified in Albania, that the Leica Vector binoculars are highly sensitive to electromagnetic interference (EMI) from nearby electronic devices, specifically from mobile phones and GPS units. During the training in Tirana, Albania, signals generated by GPS receivers and/or their antennas located too close to the rangefinders were found to corrupt bearing readings by approximately 30º. This was further confirmed during field exercises on the Albania/Kosovo border. A GPS receiver placed directly on the Vector binoculars resulted in a bearing offset of approximately 90º. Mapping errors of this magnitude can discourage new users from adopting this technology. Worse yet, they can potentially place demining personnel in physical danger if the errors go unnoticed. Although the Vector documentation mentions the necessity of avoiding such interference, it does not (and perhaps cannot) convey an adequate warning about the dangers of EMI. It is critical to emphasize to field participants the importance of avoiding potential interference with EM signals, heavy concentrations of metal, or other local magnetic attractions. In training, a demonstration of the impact of electromagnetic interference would help to communicate this point. Several users noted that a standard magnetic compass could serve as a useful reality check to discover and avoid these errors.

One of the more common rangefinder-related requests from users was for a monopod or tripod to steady the rangefinder under difficult aiming situations. In Chile, where minefields are large and sighting distances are great, it was clear that getting good readings (distance and bearing) became increasingly difficult as distance from observer to target increased, especially if the target was small. In Chile, Albania, and Ecuador tripods and/or monopods were included with the training equipment, but not in Lebanon for logistical reasons. The Lebanese participants, however, were very outspoken in recommending that tripods be used in the future.

Calibrating the internal compass of the binoculars at each field location is necessary before beginning mapping, but in Ecuador trainers and trainees both had trouble with the calibration procedure. Unclear instructions in the binocular documentation were the main cause of this difficulty. The documentation specifies that the user is to move the binoculars "slowly," when in fact moving too slowly causes calibration to fail. This calibration procedure should be explicitly included in training and in a checklist for binocular usage. A standard compass would also aid this procedure, as the calibration must start in a north-facing direction.

At all locations, accidental reconfiguration of the binoculars occurred on several occasions, as the procedure to establish Bluetooth communications between the binoculars and the pocket PC opens the general configuration procedure for the binoculars. If the wrong sequence of buttons on the binoculars is pressed during the process, it is possible to accidentally reconfigure other binocular settings. With the effects ranging from changing distance or bearing units to shutting off the internal display altogether, this problem was very disconcerting to several users. Since this is a hardwired characteristic of the binoculars, it should receive more emphasis in the training program.

GPS

The GPS units generally worked reliably in the field and the Socket GPS appears to have been an excellent choice for the Survey Tool, including working in the difficult GPS reception environment under a rainforest canopy in Ecuador. However, one or two GPS units failed during the test period. Because of their low cost relative to other components and the cost of fieldwork in general, a spare GPS unit should always be included for each deployment. The main user comments related to the GPS, other than the Bluetooth issue, revolved around questions of accuracy and proper use procedures. Experiments, such as those discussed in Chapter 3, should be run on the Survey Tool's GPS to determine its exact accuracy, and basic GPS best-use practices should be a part of any mobile GIS training program.

Training

While the Survey Tool system must have well-designed and reliable hardware and software components, it cannot be successfully used in the field without sound training. This subsection includes additional findings related to training content, training structure, and training aids not already mentioned under previous topics.

Content

User comments and field observations suggested a variety of specific training points that were omitted from or not covered adequately enough in the original training program. First, considering the problems experienced with Bluetooth connections of the GPS and rangefinder devices, explicit instruction should be given for dealing with Bluetooth connections timing out or losing communications between devices. Next, despite the generally strong mapping backgrounds of most participants, some of them did not readily recognize faulty binocular readings (overshoots, undershoots, crossed lines, and others) when they occurred. This could be taught effectively in the classroom by showing examples of faulty readings. Also, based on site visits, it was clear that many, perhaps most, environments will require that minefield perimeters be mapped using multiple binocular viewing points because of dense vegetation or terrain obstructions. While this skill was briefly mentioned in the original training, users' lack of comprehension indicates a strong need for more focused field exercises on this topic. Additionally, experiences in the tropical rainforests of Ecuador demonstrated that there is a need to train on navigating to and around a mapping site solely with the rangefinder binoculars from a GPS starting point (e.g., in heavy forest canopy situations, where GPS lock is lost). Although the system performs this function well, it is a complex skill, which should first be taught simply as a navigation technique, and then combined with a perimeter mapping exercise. Finally, the importance of taking rangefinder readings at the exact location of the last GPS fix, from which ArcPad calculates the rangefinder target coordinates, must be reinforced.

Structure

The general structure of the training as presented in the four test countries was successful and validated by the comments of the participants (Table 1). Practical exercises in the field proved to be invaluable in providing real-world training and feedback. These should be continued and, if possible, further strengthened by successively training in the collection of minefield perimeters in specific modes: GPS only, binoculars only, GPS and binoculars from multiple viewing points, etc. Beginning in Chile, minefield perimeters collected during a field training exercise were presented on a large display screen back in the classroom, giving the participants a visual assessment of the perimeters they collected as soon as possible after they had completed the task. Providing participants with visual feedback positively reinforced the Survey Tool's functionality and the ability of the trainees to operate the equipment, while at the same time highlighting errors and needed improvements. It is also important to ensure that each person is cross-trained and proficient in each aspect of the hardware, software, and procedures. In Lebanon, on the last day of field training each participant was required to map a minefield perimeter on his own. This type of exercise was very useful, as it revealed certain weaknesses in the proficiency of some participants but also provided for on-the-spot remedial training when needed.

Training Aids

Checklists for basic procedures were strongly recommended by participants in Chile, the first test deployment, and were subsequently developed and used in Albania, Ecuador, and Lebanon. These canned "cookbook" procedures were enthusiastically received and were overwhelmingly successful, as indicated by the requests for these materials from system users (Table 1). To ensure the continued success of the Survey Tool, the existing checklists should be refined and formalized and other checklists developed based on recommendations from participants in the post-training interviews.

In Ecuador and Albania in particular, it became clear that train-the-trainer materials would be extremely valuable as few or none of the participants in the training would be the ones doing the actual minefield surveys. Suggested topics for these leave-behind training materials include:

- Teacher manuals, lesson plans, and instruction modules
- Student handouts, training schedule

- Full set of checklists
- Additional documentation: EOD IS-Survey User Guide, Pocket PC user guide, GPS and Rangefinder manuals, and ESRI ArcPad documentation
- Quizzes and evaluations
- Teaching aids (exercises, PowerPoint presentations, etc.)

Site Specific Factors

Participants

Although this evaluation's sample size was small, it surely was no coincidence that the most successful test deployments were with programs run by well-trained, professional military organizations. In these military organizations, demining is done typically under the direction of combat engineers, many or most of whom have prior training in surveying, mapping, and geospatial technologies. In addition, the military structure tends to ensure that procedures and plans developed locally during and after the training period will be implemented.

This leaves open the question of whether the system will be as easily or successfully adopted in countries where, 1) NGOs take the lead in technical surveys and other demining operations, possibly resulting in a lower level of "command and control" responsibility and follow-through, and/or 2) the education levels of participants, particularly in geospatial technologies, are lower.

Language

In the test deployments, there were no severe problems due to language barriers or language differences. In Lebanon, as noted, all the participants were sufficiently fluent in

English to be able to adequately comprehend all the verbal and written training materials. In Chile and Ecuador, a combination of solid English language abilities on the part of key participants and/or the employment of Spanish translators provided for effective communication. Only in Albania was communication observed to be a potential problem for some participants, where instruction was in English with some translation into Albanian provided. Participants in Albania seemed to experience more problems in mastering the system during the training period; however, because the system was not employed subsequent to the training, this issue remains unresolved for Albania.

Even with the relative lack of language issues during the test deployments, interviews indicated a strong desire for future versions of manuals and other written materials to be translated into the local languages. Most participants actually felt that, if the manuals were in their own language, it would not be so important for the software to be in their language. For this reason, it is imperative that basic training materials be provided at least in languages that are widely used in mine-affected countries (e.g., Arabic, English, French, Portuguese, Russian, and Spanish).

In general, this raises the question of whether the system will be used as successfully in countries where, 1) there are few participants who speak and read English, 2) the language of the participants is not a widely spoken one, and 3) translated materials are not available in either the local language or other widely used language, such as one of the six official United Nations languages (Arabic, Chinese, English, French, Russian, and Spanish).

Local Procedures, Policies, and Terminology

Despite the promulgation of the International Mine Action Standards (IMAS) and the widespread use of IMSMA, each locale has its own procedures, policies, and even terminology regarding mine action. It became clear, for example, that the concept of what constitutes a Technical Survey differs from country to country. In some countries the Technical Survey is not performed at all. It will be important in fielding future versions of the Survey Tool to perform a pre-assessment of existing policies and procedures in each country prior to fielding the Survey Tool, adapt the training to local policies and procedures, and build flexibility into future versions of the Survey Tool system to accommodate local conditions and needs.

Geographical Factors and Environmental Influences

Other than sunlight impacting screen visibility, the environmental factor with the greatest potential impact on the use of the Survey Tool is vegetation (Figure 4). Heat, cold, humidity, and even rainfall had only minor impacts during the field deployments. Slope also was not a serious factor, except that in deep valleys the number of satellites available for a GPS fix is reduced. Vegetation, however, has two impacts. First, the presence of a dense overhead canopy, as in tropical rainforest, can effectively block incoming signals from GPS satellites. Dense canopy conditions result in highly inaccurate GPS measurements, or, more likely, the inability for the GPS to acquire a fix at all. Either outcome renders the GPS unusable for collecting a minefield perimeter on foot or for collecting the starting point of a rangefinder-based perimeter. In Ecuador, this problem was solved by taking a GPS fix in an open clearing and then navigating to a starting point for a rangefinder-based perimeter using the Vector binoculars. The second impact of vegetation on use of the Survey Tool is that dense vegetation blocks the laser signal from the Vector binoculars, limits line of sight, and therefore necessitates taking perimeter readings from multiple points. The Survey Tool system is able to handle this condition, but sufficient training is required in order for field teams to use this technique efficiently.

Conclusions

The findings presented in this paper are specific to the demining Survey Tool, but the general lessons learned have broader application for any mobile GIS user, developer, or trainer. When implemented correctly, mobile GIS can be faster, more accurate and more reliable compared to traditional methods for collecting spatial field data, such as paper forms, maps, and the stand-alone location technologies of GPS or compass and tape. However, these benefits and the promise of a "high-tech" solution to fieldwork can often lead potential users to erroneously believe that mobile GIS is an off-the-shelf solution. Just as was found with the demining Survey Tool itself, solid system development, proper training and instructional materials, and support from knowledgeable technical staff, are critical for the successful fielding of any mobile GIS.

Developers of mobile GIS should note that infrequent but significant system crashes can quickly lead users to become frustrated or, even worse, to lose confidence in a new system. This issue with the demining handheld, along with the numerous minor bugs reported during deployments, demonstrate the importance of thorough field testing by users, prior to the start of actual field data collection. A good rule is to assume that *nothing* will work in the field if it hasn't been exercised thoroughly in or near the fieldworker's home facility. As early as possible, system designers and developers should also consider the important matter of whether to develop a focused, task specific mobile GIS or a broadly scoped one-size-fits-all tool. As a rule of thumb, applications should be directed specifically at a narrow group of user needs, while remaining flexible enough to adapt to the dynamic nature and diverse challenges of field data collection.

Two major conclusions can be drawn from this evaluation concerning the use of mobile GIS software. First, editing spatial data in a mobile GIS is somewhat more complex than on the desktop due to a smaller screen size, touch-screen interface, and the often difficult conditions of fieldwork. Inevitably, errors will be made during initial data collection or updates required after the fact, and users should have received enough practical training beforehand so that editing procedures require little thought to perform. Second, efforts should be made to develop quality base map data for the most effective field experience. High spatial resolution raster data, such as aerial/satellite imagery or scanned topographic maps, were found helpful for the demining system, but detailed vector data may also be appropriate for certain applications. Detailed base map data can help users gauge the accuracy of field measurements, aid in navigation, and provide a reference source of previously gathered field data. In fact, as a direct result of this finding, early in 2005 the University of Kansas was contracted by GICHD to develop a geographic base data archive (satellite imagery, topographic maps, elevation, population, transportation, and political layers) for over 50 mine-affected countries to facilitate more effective use of the GIS capabilities in the Survey Tool and IMSMA computer software package.

The hardware components of the demining mobile GIS also warrant a set of recommendations. In general, with the high cost of fieldwork, it is worthwhile to invest in backup hardware units for all but the most expensive pieces of equipment. When choosing a mobile GIS field computer (pocket or tablet PC), extra attention should be given to outdoor screen visibility and battery life. Considering the repeated rangefinder- and GPS-related Bluetooth issues experienced during this evaluation, system complexity should be reduced by using an integrated solution or cabled versions of equipment whenever possible. Magnetic interference was shown repeatedly to have the potential to seriously impact measurements collected with rangefinder equipment. This fact should be stressed in the rangefinder training, along with the exact procedure for calibration, setting local magnetic declination, and Bluetooth configuration. Additionally, given the likely need for long-range sighting, a monopod or tripod should also be considered required equipment for the rangefinder. Simple GPS receivers were found to be well received by users in terms of their usability, leaving the project's required mapping accuracy as the key factor for selecting an appropriate unit. Whatever the accuracy desired, formal testing should be conducted on both GPS and rangefinder hardware to determine the exact accuracy users can expect to obtain under their specific field operating conditions.

Training sessions and materials related to a mobile GIS were found to be just as important as the system's hardware and software for ensuring a successful field effort. Keeping in mind all of the training concepts already mentioned, extra attention should be devoted to complex mapping tasks. All conceivable combinations of data collection methods and mapping hardware should be taught in as many practical hands-on exercises as possible, thus addressing any specific needs or gaps in the knowledge of individual field users. Users and system evaluators alike also indicated that thorough and well thought out guide materials, such as checklists, laminated for durability in the field and translated into the local language, would be nearly as valuable in the long run as a formal training program.

The most common theme encountered across all aspects of the Survey Tool evaluation was summed up nicely in a comment made by one trainee from the Chilean deployment, “Nothing will ever be exactly as we had planned, but we must be ready to deal with it anyway.” While this concept is likely known by anyone who has spent much time doing fieldwork of any sort, it needs to be incorporated throughout mobile GIS so that the free flowing nature of traditional fieldwork is not interrupted. To ensure this, every effort should be made to train for user adaptability and design for system flexibility. Training experiences and materials must provide users with the ability to make decisions on their feet in the field, both in how to collect data and how to deal with system malfunctions. The system software and hardware also must be able to operate in a variety of data collection modes, from the open-ended nature of a field notebook to the highly structured methods used for a formal site survey. Finally, adequate time must be allocated (at least a day) to work out the "kinks" in hardware and methodology on-site, under real field conditions prior to the beginning of actual data collection.

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Chapter 3

Assessing the Accuracy of a Consumer-Grade GPS for Mobile GIS Mapping

Abstract

Users of field-based mobile GIS today can select from a wide variety of location mapping technologies. An understanding of the errors associated with various types of equipment and basic methods for improving accuracy enables each user to choose the right tools and design the most appropriate field data collection strategy. This study examined the positional accuracy of the inexpensive consumer grade Socket GP0804-405 Bluetooth GPS unit used in the IMSMA Mobile humanitarian demining mobile GIS system. Four hours worth of one-second interval data collected under ideal conditions was used to calculate a 9.4 m horizontal accuracy at a 95% confidence level. An averaging time of 30-60 seconds was determined optimal for low priority points (polygon vertices or turning points) and an averaging time of 2-4 minutes was determined optimal for high priority points (landmark or reference point).

Introduction

Mobile GIS

With recent developments in technology, computing has become available in more places worldwide, is now small enough to move with its users even to highly remote places, and can provide access to a wide array of distributed resources. It has been noted that these changes in the "where" aspects of computing have already made significant impacts on the way geographers and GIS professionals conduct their work (Goodchild et al., 2004). This deviation from the traditional desktop GIS framework has been termed ‘Distributed GIS,’ which encompasses both mobile GIS and the broad array of internet GIS technologies (Peng and Tsou, 2003). Mobile GIS has been defined as “an integrated software/hardware framework for the access of geospatial data and services through mobile devices via wireline or wireless networks” (Tsou, 2004). The application areas of mobile GIS have been broken down into field-based GIS, focusing on the collection, validation and update of GIS data in the field, and location based services (LBS), concerned mainly with location management and logistics functions. At the heart of field-based GIS are the mapping technologies, such as the Global Positioning Systems (GPS), that make GIS feature collection possible.

GPS

GPS has gained widespread adoption in commercial and research applications as a powerful satellite-based tool for determining the location of points on and above the earth’s surface. There are several grades of GPS receivers distinguished by their measurement accuracies: recreation or consumer-grade receivers provide an accuracy of 5-20 m and can cost under $100; mapping-grade receivers provide accuracies from sub-meter to 5 m and cost between $500 and $5000; and survey-grade receivers can provide sub-centimeter accuracies at costs of up to $20,000 or more (Rizos, 2002). The three main sources of GPS error affecting all grades of receivers are atmospheric refraction of GPS signals (slowing their transmission speed), multipathing (detecting reflected GPS signals from various surfaces), and poor satellite geometry (Misra and Enge, 2001).

Higher grade GPS receivers are designed to correct for these errors using dual-frequencies to all but eliminate ionospheric effects and using signal processing to reduce multipathing. Poor satellite geometry can be overcome by using better satellite tracking, listening to more satellites, and multiple GPS systems. Differential correction can further remove errors by comparing the surveyed GPS data to that of a local reference station at a known location. Due to their lower cost, consumer-grade receivers do not have such integrated accuracy enhancement features. They are designed less for precise mapping and more for user productivity, or the ability to constantly provide a useable position. There are several methods that consumer-grade GPS users can utilize to reduce errors, but they require more of the user's time to collect additional data.

The first approach for reducing errors in consumer-grade receivers deals with the filtering of GPS data based on the dilution of precision (DOP) measure calculated by the receiver. DOP is based on the geometry of the satellites being used. Higher DOP values indicate less certainty in the overall position and are caused when fewer and/or tightly clustered satellites are used to by the GPS receiver to calculate its position. DOP values generally range from 1-10, but may reach values >20 under very poor conditions. DOP values and can be viewed as multiples of the minimum uncertainty/accuracy level of the GPS (Hofmann-Wellenhof et al., 2001). For a stationary observer, there are three different DOP measures to select from based on the desired type of GPS mapping: 2D horizontal DOP (HDOP), vertical DOP (VDOP), and 3D position DOP (PDOP). To implement DOP filtering, a DOP mask or threshold is set, beyond which GPS data, of assumed lower accuracy, will not be recorded (Rempel and Rodgers, 1997). Very few consumer-grade GPS receivers provide DOP filtering on their own, but DOP filtering is a standard function in most Mobile GIS software. DOP filtering will have the most benefit in poor satellite conditions, such as under heavy tree canopy, but it can also benefit collection in open-sky conditions when few satellites are in view from the operator's particular location.

GPS averaging has also been shown as a powerful way to diminish positional error (Sigrist et al., 1999). By taking the average of repeated GPS measurements at a fixed location, the expected accuracy and precision of a GPS receiver can be increased by smoothing out the fluctuations in GPS errors (Deckert and Bolstad, 1996). GPS averaging is available as a built-in function on some consumer-grade GPS receivers and a standard function in Mobile GIS software. The important question to answer for the most efficient use of GPS averaging is, "how long is long enough?" While GPS user manuals and technical reports provide a generic starting point, and studies have been performed comparing various grades of receivers (Devlin et al., 2007), for the most appropriate guidelines the specific GPS unit in question should be tested.

IMSMA Mobile – Mobile GIS for Humanitarian Demining

Early in 2003, the Geneva International Centre for Humanitarian Demining (GICHD) initiated the development of a small, pocket-sized tool to support humanitarian demining data collection in the field. This tool was intended to map and collect demining related data in the form of digital field reports for integration with the GICHD Information Management System for Mine Action (IMSMA) desktop software. This handheld system was called Explosive Ordnance Disposal Information System-Survey (EOD IS-Survey) and was developed by the Swedish EOD and Demining Centre (SWEDEC) under the guidance of GICHD. In 2007 the handheld system was renamed IMSMA Mobile when development switched to the U.S. company FGM, Inc, which has also developed the most recent version of the IMSMA desktop software. IMSMA Mobile is not a mine detection tool, but rather a management tool for mapping areas known to be or assumed to be at risk due to landmines or unexploded ordinance.

The software component of IMSMA Mobile is a stand-alone application running on the Windows Mobile operating system that provides mapping functionality via a customized applet running inside the ESRI mobile GIS Software ArcPad. The central hardware component running IMSMA Mobile is a touch-screen pocket PC. The mapping components of the IMSMA Mobile hardware include a consumer grade Socket GP0804-405 Bluetooth GPS receiver and Bluetooth laser rangefinders, either the Leica/Vectronix Vector 1500 GMD or the Laser Technologies TruPulse 360B.

User studies conducted with field operators of IMSMA Mobile found overall acceptance of the system due to its improved mapping accuracy, ease of use, increased productivity, and safety (especially relevant in demining) when compared to traditional methods. While each of these benefits should be studied and tested, a more complete understanding of the mapping accuracy component would provide the most immediate benefit to the system users. Because the accuracy of the system's two mapping components, GPS and rangefinder, are cumulative, it is desirable to evaluate their accuracies independently, allowing users to determine the specific accuracy range for their expected use scenario. This concept of independent evaluation of accuracy components was employed by the author in a previous study comparing GPS accuracy to compass and tape measurements for demining applications (Berger and Dunbar, 2006). Despite the need for a better understanding of the errors associated with the IMSMA Mobile mapping hardware, to date no thorough accuracy assessment of the system's GPS receiver had previously been performed.

Objectives

The goal of this study was to determine the expected horizontal positional accuracy of the Socket Bluetooth GPS used in the IMSMA Mobile field-based GIS for humanitarian demining. In order to meet this goal, the following two objectives were addressed:

- Determine the positional error of the Socket GPS and calculate its predicted accuracy.

- Investigate DOP filtering and GPS averaging as methods for improving the expected accuracy of the Socket receiver.

Methods and Materials

Reference Data Acquisition

A Javad Maxor survey grade GPS was used to precisely calculate a reference point location to serve as "ground truth." The Javad Maxor is a 20-channel dual frequency (L1 and L2) GPS/GLONASS receiver that provides sub-centimeter level post-processed accuracy. The reference point was surveyed with the Javad GPS for a collection period of two hours. The Javad unit was placed on top of a Leica Geosystems HDS Twin-Target Pole (2.15m tall) to avoid operator obstruction of GPS satellites (Figure 1). The surveyed location was in open sky conditions, free of overhead obstacles such as trees and buildings. These near-ideal sky view conditions were chosen to provide the most accurate reference data possible and to permit the GPS experiment to determine accuracy under a best use-case scenario.

The reference data were post-processed using Javad's Pinnacle software to perform differential correction. The base station data used for this correction were collected from the NOAA Continuously Operating Reference Station (CORS) located in Seattle, WA (ID: SEAI). The base line to the CORS location was 5.5 km away from the surveyed point. The differential correction produced a solution located at 5278001.97 m Northing and 552005.76 m Easting (UTM Zone 10 NAD83), with an orthometric height of 35.82 m, and a root-mean-square (RMS) error of .44 cm.

Figure 1. Leica Geosystems HDS Twin-Target Pole shown with a) Javad Maxor Global Positioning System (GPS) unit attached at top for recording reference data (GPS center at 2.15 m height).

GPS Data Acquisition

This experiment examined the positional accuracy of the Socket GP0804-405 Bluetooth GPS receiver, and investigated methods for improving its accuracy. This inexpensive (<$100) 12-channel L1 frequency GPS uses a Sirf Star IIe/LP chipset, and has a manufacturer stated horizontal positional accuracy of 10 m RMS error. One reference point location surveyed with the Javad Maxor unit was used to conduct the GPS accuracy experiment. After completion of the data logging session using the Javad reference unit, the Socket receiver was placed at the same location on the same target pole (Figure 1). An HP iPaq PocketPC hx2490b, paired to the Socket GPS, was used to collect the GPS data using ESRI's ArcPad 7.1.1 software. Over four hours worth of GPS positions were collected at a one-second-interval, totaling 14,462 readings. An average number of 8 satellites was used across all GPS points (minimum 4 and maximum 11 satellites), with an average PDOP of 2.0 and an average HDOP of 1.2. During data collection, an efficiency (number of points recorded/number of seconds logged) of 99.8% was achieved. This high efficiency confirms the nearly optimal GPS data collection conditions desired for this accuracy assessment, as the GPS was only rarely unable to calculate a position. These ideal conditions allowed the experiment to set a baseline of accuracy for this equipment, demonstrating for users the maximum performance to be expected from the GPS.

GPS Data Processing and Analysis

The instantaneous accuracy of the raw one-second interval GPS data was derived using a variety of statistical methods. First, the minimum, maximum, mean and standard deviation of the error of all horizontal positions were calculated, as they are familiar and often used measures for studies of GPS accuracy (Wing and Eklund, 2007). The minimum and maximum indicate the best and worst case instantaneous measurements provided by the GPS during the sampling period. The mean provides a measure of the average error in the recorded GPS data, while the standard deviation suggests the data's variability about that mean.

An even more common statistic for assessing the predicted GPS horizontal positional accuracy is the root-mean-square error (RMSE or RMS error). When assessing horizontal positional accuracy the RMS error is equal to the square root of the mean of the set of squared differences between measured coordinate values (Socket GPS) and coordinate values from a source of higher accuracy (Javad "ground truth"). RMSE is also equal to the square root of the sum of the mean of all errors squared plus the standard deviation of all errors squared. The RMSE value represents the radial horizontal distance from the reference position within which an estimated 63% of the position errors will fall (Greenwalt and Schultz, 1968). Comparing the accuracy reported by the mean and standard deviation to the accuracy reported by RMSE, Sigrist et al. point out that RMSE "…depicts the deviation from the truth (reference) and not from the mean error, as is the case with the standard deviation….(RMSE) is a measure of the repeatability of the observations" (1999). In other words, while the mean and standard deviation describe the error of the actual data collected during a particular GPS sample, RMS error attempts to statistically describe the anticipated receiver performance under the conditions used to collect the GPS samples.

In addition to the mean and standard deviation, a variety of horizontal RMSE-derived confidence intervals were calculated and then compared to the percentage of the collected data distribution within those same intervals. First, the Circular Error Probable (CEP) or median (50% error distance) was calculated as 0.83 x RMSE. Second, the mean (54% error distance) was calculated as 0.89 x RMSE. Finally, the 95% confidence interval was calculated as 1.7308 x RMSE. This 95% confidence interval is a good measure for comparison across GPS units since it is recommended by the National Standard for Spatial Data Accuracy (NSSDA), published by the Federal Geographic Data Committee (1998). NSSDA is an effort to provide a unified approach to assessing the accuracy of digital geospatial data. The NSSDA 95 percent accuracy standard and many other RMSE GPS accuracy standards are based, in whole or part, on the early work of Greenwalt and Schultz (1968).

DOP Filtering Processing and Analysis

Since this experiment was only concerned with horizontal or 2D GPS accuracy, DOP filtering was only performed on the horizontal dilution of precision or HDOP values. While DOP filtering is normally implemented using Mobile GIS software in the field, the same results can be simulated by sub-setting the raw one-second-interval data set, which contains HDOP values for every position recorded, and examining the improvements in accuracy measures. The narrow HDOP distribution of the collected GPS data, with a low average value of 1.2, only permitted exploration of two subsets of the original data: HDOP <= 2 and HDOP <= 1.5. The mean, standard deviation, and NSSDA 95% confidence error of the horizontal error were calculated for both subsets.

GPS Averaging Processing and Analysis

The original one-second-interval GPS data collected from the Socket Bluetooth receiver (14,492 points) was used to investigate the impact of GPS averaging. To simulate the effect of averaging on the Socket GPS data, a running window was passed over the original coordinates, averaging every x longitudes and x latitudes, to derive a new set of

(14,492 – x + 1) coordinates. This averaging procedure was run to simulate the following time intervals: 15 and 30 seconds, as well as 1, 2, 4, 8, 16, 32, 64, and 128 minutes.

The original and average coordinate sets were plotted to visually show the impact of averaging on data dispersion. The mean, standard deviation, and NSSDA 95% confidence interval were calculated for the original and averaged data to quantify the changes in accuracy as average time increased. An accuracy improvement rate was derived by comparing the change in the NSSDA 95% confidence level to the number of seconds in the time interval between averaging periods (1 sec to 15 sec, 15 sec to 30 sec, etc.).

Results and Discussion

One histogram and several statistics were generated to provide a complete picture of the horizontal accuracy of the raw GPS data collected from the Socket device. Figure 2 presents the positively-skewed distribution of error in the GPS data, with the majority of error values less than 5 m. Note that the histogram only presents data to an error distance of 25 m because only 0.1% of the data falls beyond this threshold. Table 1 shows that the minimum error during the collection period was 3 cm, while the maximum error was 34.42 m. The mean horizontal error for the dataset was 4.37 m, encompassing 62% of the data, with a standard deviation of 3.23 m. In contrast, the RMS error deviation from the reference position indicated a 5.43 m radius at a confidence level of 63%. This RMS value is far better than the 10 m RMS specified by the manufacturer, perhaps due to a conservative or non-ideal GPS condition used by the manufacturer to rate the device. Also noteworthy is the fact that all RMS derived confidence intervals contain more of the actual GPS data (74%) than the statistics theoretically predicts (63%). This was likely due to a more elliptical distribution of

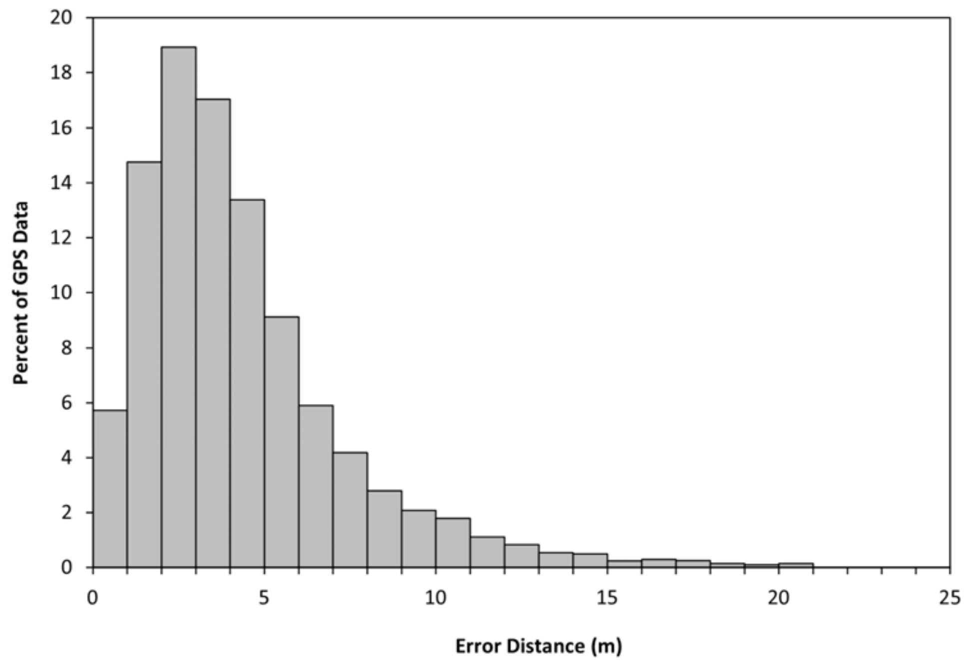

Figure 2. Histogram of horizontal error distance in the original one-second interval GPS data (14,462 positions).

Statistic	Calculated Error Distance	Points Closer than Distance
Minimum	0.03 m	0%
Maximum	34.42 m	100%
Mean	4.37 m	62%
Standard Deviation	3.23 m	n/a
RMS (63%)	5.43 m	74%
CEP/Median (50%)	4.56 m	65%
RMS Mean (54%)	4.83 m	68%
NSSDA 95%	9.40 m	93%

Table 1. Horizontal accuracy statistics calculated from Socket Global Positioning System (GPS) data and the percentage of the actual data distribution within that distance. All statistics in the bottom half of the table are derived from root mean square (RMS) error.

the collected GPS point positions, since the RMS theoretical intervals are calculated based on a spherical distribution. Finally, the FGDC standard supported 95% RMS level of 9.40 m provides a fairly close approximation of the actual data distribution (93%). These findings suggest that, under good GPS conditions (clear skyview and adequate satellite coverage), the Socket GPS delivers an accuracy of less than 4.56 m 50% of the time or less than 9.40 m 95% of the time.

Due to the extremely favorable sky view conditions of the GPS experiment, DOP filtering showed only minor improvements in GPS accuracy. Table 2 indicates that setting HDOP <= 2.0 filtered out just 55 points and only slightly improved the mean (2 cm) and 95% confidence interval (3cm). Setting HDOP <=1.5 filtered out 1299 points and provided a greater improvement in the mean accuracy (14 cm) and the 95% confidence interval (32 cm). While the lower HDOP filter (<= 1.5) did improve both the mean and 95% confidence accuracy by approximately 3% each, this improvement is small compared to that of the averaging results presented next. However, for fieldwork conducted in less than ideal sky view conditions, such as under tree canopy, this accuracy improvement method may prove beneficial.

The more detailed results of the averaged GPS data analysis are presented in Figure 3 both visually and quantitatively. In the upper left corner, the legend indicates how many samples in the averaged datasets are represented by each colored dot on the plots, while the graph presents a summary of the 95% confidence and mean statistics over the averaging periods. The rest of the figure is divided into eleven sections presenting the original one-second interval GPS data and the results of the ten averaging periods investigated by this study. The numerical results in each section show the mean and standard deviation (in the lower left), 95% confidence interval (in the upper right), and the rate of improvement of the

Statistic	Complete GPS Dataset	Filtered HDOP <= 2.0	Filtered HDOP <= 1.5
Number of Points	14,462	14,407	13,161
Mean	4.37 m	4.35 m	4.23 m
Standard Deviation	3.23 m	3.22 m	3.10 m
RMS (63%)	5.43 m	5.41 m	5.24 m
NSSDA 95%	9.40 m	9.37 m	9.08 m

Table 2. Results of horizontal dilution of precision (HDOP) filtering on the horizontal accuracy of Socket Global Positioning System (GPS) data. All statistics in the bottom half of the table are derived from root mean square (RMS) error.

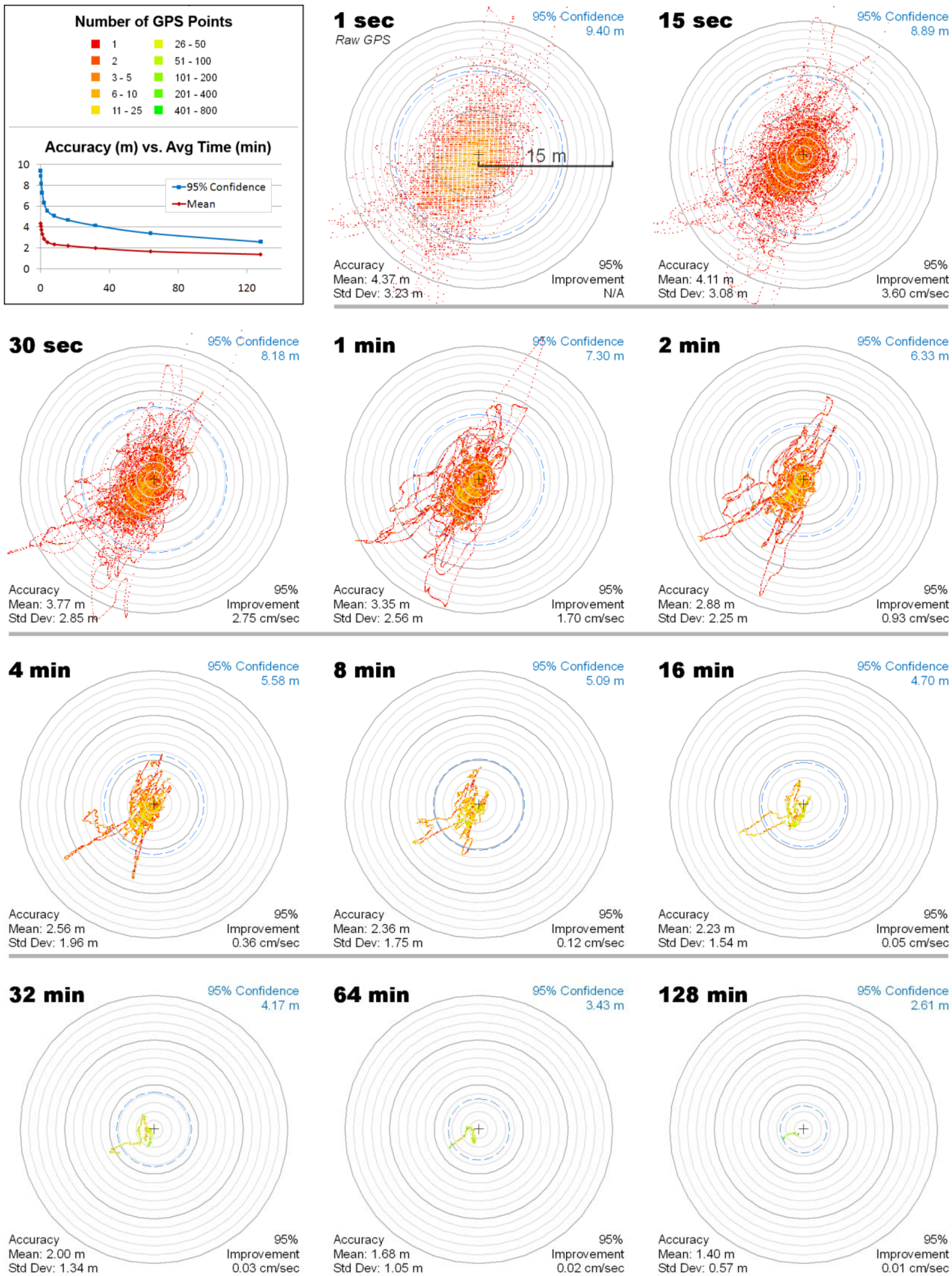

Figure 3. Visual and analytical description of the impact of averaging on GPS accuracy.

95% confidence interval from the last averaging period (in the lower right). The 15 m radius plots in each section indicate the reference location with a cross, 5 m intervals in dark grey, and 1 m intervals in light grey, and they define the 95% confidence limit boundary with a dashed blue circle.

The visual distribution shown in these plots provides several insights into the impact of GPS averaging. First, by stepping through these plots over the time intervals, it is clear that averaging GPS data helps to smooth away the short term errors caused by various sources of GPS error since the point data become more clustered about the reference location. Next, while the majority of points in the original and averaged GPS data are clustered near the reference location, these plots clearly indicate the ability for a GPS position to "wander" away from and back toward the reference location. Multipath errors are usually the cause of these noticeable short-term movements in GPS position, as reflected GPS signals have to travel farther to the receiver. Averaging the GPS readings can certainly help smooth out these errors, but plots like these can help to clearly communicate to users the real-world fluctuation expected from a particular GPS device. Finally, a binning or clumping of the raw one-second-interval GPS data can be seen when compared to the 15 second data. The regular pattern in the original data is an artifact from the Socket GPS' NMEA data stream, which outputs to only 6 decimal places in decimal degrees (equal to 0.185 m N/S and 0.125 m E/W at this latitude). Although not directly related to accuracy, averaging allows the GPS to achieve a finer spatial resolution.

The quantitative data contained in Figure 3 are summarized in the graph of accuracy vs. average time (upper-left). This graph shows that there is a rapid decrease in error, regardless of statistic, over the short term when averaging, but that this improvement rate quickly slows as the longer averaging periods are reached. This suggests a favorable cost to benefit (average time to accuracy increase) ratio within the first averaging periods, which can be investigated in more detail by looking at the 95% confidence interval and the 95% confidence improvement rates provided for each averaging period. Although the greatest improvement rate was measured during the first 15 seconds of averaging (3.60 cm/sec), given a small investment in time, the 30 second to 1 minute averaging period provides a 1-2 m accuracy improvement (from 9.40 m to 8.18-7.30 m). If slightly more time can be allotted to a point survey, the 2-4 minute averaging period should provide an additional 1-2 m improvement in accuracy (from 9.40 m to 6.33-5.58 m). A "point of diminishing returns" is reached at 4 minutes of averaging beyond which the accuracy improvement rate decreases substantially compared to the time investment required for each point survey. Considering long-term costs, if positional mapping accuracy greater than 5.58 m at 95% confidence is desired, a higher grade GPS receiver should be investigated. Finally, presenting the accuracy statistics with the data plots provides a tangible tool for users to understand the implications of both GPS averaging and the various measures of accuracy and confidence intervals.

Conclusions

The Socket GP0804-405 Bluetooth GPS Receiver was predicted to deliver a horizontal accuracy of less than 5 m at least 50% of the time and less than 10 m at least 95% of the time. It is important to note that these accuracies are only applicable under the relatively ideal GPS conditions used for this study, including the particular surroundings, ionosphere conditions, and satellite constellation status. HDOP filtering was shown to provide only minor accuracy improvement under the GPS conditions of this experiment, but this technique may be relevant for this device when conducting GPS surveys with poor satellite conditions or under vegetation cover. Simulations showed that up to four minutes of

GPS averaging with the Socket device can provide a useful increase in expected accuracy. As a rule-of-thumb, 30-60 seconds should be spent averaging for lower quality data needs (perimeter vertices or sample points) and 2-4 minutes should be spent averaging for high quality data needs (benchmark or rangefinder reference points).

In order to more completely describe the expected performance of a GPS, future studies should investigate accuracy over a longer sampling period, under non-ideal sky view conditions (i.e. different levels of canopy closure), and on different days at different times under various non-ideal satellite configurations as reported by mission planning software (Johnson and Barton, 2004). Because the Socket GPS is no longer "cutting-edge" technology, newer consumer-grade devices using more modern GPS chipsets should be examined and compared against one another. Just as this experiment produced suggestions for averaging times, it also suggests the importance of appropriate wait times prior to data collection to ensure that the GPS position has stabilized after movement. To determine the appropriate wait time, an experiment could be developed in which wait time would be simulated in a similar manner to the averaging times of this experiment: 1) move the GPS to a new location, 2) immediately start logging GPS data, and 3) explore the accuracy improvement of different wait times on raw data.

Finally, this work also suggests the need for more general investigations of the accuracy expected with Mobile GIS systems. This experiment was designed to focus on the error component introduced with mapping equipment. However, operator error of Mobile GIS systems often can lead to even larger problems. Operator-based studies should investigate the ways in which users interact with software to assess the accuracy of collected measurements, when they choose to correct/not correct errors and why, and if there are methods for encoding best-use practices in the Mobile GIS software to systematically avoid these errors in the future.

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Chapter 4

Assessing the Accuracy of Laser Rangefinders for Mobile GIS Mapping

Abstract

Users of field-based mobile GIS today can select from a wide variety of location mapping technologies. An understanding of the errors associated with various types of equipment and basic methods for improving accuracy enables each user to choose the right tools and design the most appropriate field data collection strategy. This study examined the positional accuracy of two laser rangefinder units, the Leica/Vectronix Vector 1500 GMD and the Laser Technologies TruPulse 360B, used in the IMSMA Mobile humanitarian demining mobile GIS system. Across a variety of testing conditions, the Vector rangefinder was found to have a slightly higher mean accuracy (2.4 m) in collecting point locations compared to the TruPulse (3.0 m). However, when shooting at well defined vertical physical targets rather than a point on the horizontal bare earth overall point and area measurement accuracy improved greatly and the difference between equipment accuracy all but disappeared (Vector 1.0 m and TruPulse 1.2 m). Significant variation in accuracy among users, corresponding to level of rangefinder experience, was found, suggesting the positive impact of training and practice on expected accuracy. Finally, magnetic interference, caused by the metal content of one user's eye glasses, led to highly irregular bearing measurements with the TruPulse rangefinders. Users of rangefinder equipment should be alert to the potential for this type of bearing measurement error and aware of methods for testing and preventing it.

Introduction

Mobile GIS

With recent developments in technology, computing has become available in more places worldwide, is now small enough to move with its users even to highly remote places, and can provide access to a wide array of distributed resources. It has been noted that these changes in the "where" aspects of computing have already made significant impacts on the way geographers and GIS professionals conduct their work (Goodchild et al., 2004). This deviation from the traditional desktop GIS framework has been termed ‘Distributed GIS,’ which encompasses both mobile GIS and the broad array of internet GIS technologies (Peng and Tsou, 2003). Mobile GIS has been defined as “an integrated software/hardware framework for the access of geospatial data and services through mobile devices via wireline or wireless networks” (Tsou, 2004). The application areas of mobile GIS have been broken down into field-based GIS, focusing on the collection, validation and update of GIS data in the field, and location based services (LBS), concerned mainly with location management and logistics functions. At the heart of field-based GIS are the mapping technologies, such as the Global Positioning Systems (GPS), that make GIS feature collection possible.

Laser Rangefinders

Laser rangefinder devices measure the distance, bearing and inclination to a target. Mobile GIS software uses these three pieces of information along with known reference coordinates (operator location, usually collected from a GPS) to calculate the coordinates of the target location. These laser rangefinders, which collect measurements one at a time, are frequently used in forestry applications (Wing and Kellog, 2001) and ecological field studies (Aspbury and Gibson, 2004). More expensive laser scanning technologies, also known as ground based Light Detection and Ranging (LIDAR), can be used to collect larger quantities of point measurements at an even greater level of precision. This type of equipment is more commonly used in the fields of geology (Alfarhan et al., 2008) and archaeology (Brusco et al., 2006).

IMSMA Mobile – Mobile GIS for Humanitarian Demining

Early in 2003, the Geneva International Centre for Humanitarian Demining (GICHD) initiated the development of a small, pocket-sized tool to support humanitarian demining data collection in the field. This tool was intended to map and collect demining related data in the form of digital field reports for integration with the GICHD Information Management System for Mine Action (IMSMA) desktop software. This handheld system was called Explosive Ordnance Disposal Information System-Survey (EOD IS-Survey) and was developed by the Swedish EOD and Demining Centre (SWEDEC) under the guidance of GICHD. In 2007 the handheld system was renamed IMSMA Mobile when development switched to the U.S. company FGM, Inc, which has also developed the most recent version of the IMSMA desktop software. It is important to note that IMSMA Mobile is not a mine detection tool, but rather a management tool for mapping areas known to be or assumed to be at risk due to by landmines or unexploded ordinance.

The software component of IMSMA Mobile is a stand-alone application running on the Windows Mobile operating system that provides mapping functionality with a customized applet running inside the ESRI Mobile GIS Software ArcPad. The central hardware component running IMSMA mobile is a touch-screen pocket PC, the Hewlett Packard iPAQ h5550 or hx2700. The mapping components of the IMSMA Mobile hardware include a consumer grade Socket GP0804-405 Bluetooth GPS receiver and Bluetooth laser rangefinders, either the Leica/Vectronix Vector 1500 GMD or the Laser Technologies TruPulse 360B.

User studies conducted with field operators of EOD IS-Survey in Chile (2004), Albania (2004), Ecuador (2004), and Lebanon (2006) as well as IMSMA Mobile in Chile (2007) found overall acceptance of the system due to its improved mapping accuracy, ease of use, increased productivity, and safety (especially relevant in demining) when compared to traditional methods. While each of these benefits should be studied and tested, a more complete understanding of the component of mapping accuracy would provide the most immediate benefit to the system users. Because the accuracy of the system's two mapping components, GPS and rangefinder, are cumulative, it is desirable to evaluate their accuracies independently, allowing users to determine the specific accuracy range for their expected use scenario. This concept of independent evaluation of accuracy components was employed by the author in a previous study comparing GPS accuracy to compass and tape measurements for demining applications (Berger and Dunbar, 2006). Despite the need for a better understanding of the errors associated with the IMSMA Mobile mapping hardware, to date no thorough accuracy assessment of the system's laser rangefinders had previously been performed.

As few generic studies have examined the positional accuracy of laser rangefinder measurements, experiments must be designed based on first-hand experiences using these devices in a specific application area. The user studies conducted with field operators of EOD IS-Survey and IMSMA Mobile revealed several important factors that appear to influence laser rangefinder measurement accuracy and deserve further investigation: the type of equipment, the distance to the targeted object, the user operating the equipment, the type of targeted object, and whether a monopod is used to steady the equipment.

Objectives

The goal of this study was to determine the expected horizontal positional accuracy of the Vector 1500 GMD and TruePulse 360B Laser Rangefinders used in the IMSMA Mobile field-based GIS for humanitarian demining. In order to meet this goal, the following two objectives were addressed:

- Determine the accuracy of point and area measurements collected with the rangefinders given the variables of equipment, target distance, and user
- Explore the impact of target type and the use of a monopod with the rangefinders as methods for improving this accuracy

Methods and Materials

Reference Data Acquisition

To evaluate the accuracy of rangefinder devices, some form of reference data or ground truth is required. Previously surveyed monuments were not appropriate for this study since the experiments required multiple target locations within a 100 m radius. Instead, a Javad Maxor survey-grade GPS was used in this study to precisely calculate five point-locations on the University of Washington, Seattle campus. The Javad Maxor is a 20-channel dual frequency (L1 and L2) GPS/GLONASS receiver that provides sub-centimeter level post-processed accuracy. All reference points were surveyed with the Javad GPS for a collection period of at least two hours. The Javad unit was placed on top of a Leica Geosystems HDS Twin-Target Pole (2.15m tall) to avoid operator obstruction of GPS satellites (Figure 1). All point locations were in open sky conditions, free of overhead obstacles such as trees and buildings. These near-ideal sky view conditions were chosen to provide the most accurate reference data possible.

Figure 1. One of four Leica Geosystems HDS Twin-Target Poles used in this study. Shown with a) Javad Maxor Global Positioning System (GPS) unit attached at top for recording reference data (GPS center at 2.15 m height), and b) White board with black crosshair target used for rangefinder experiment (target center at 1.75 height).

All reference data were post-processed using Javad's Pinnacle software to perform differential correction. The base station data were collected from the NOAA Continuously Operating Reference Station (CORS) located in Seattle, WA (ID: SEAI). The base lines to the CORS location were no more than 5.2 km away from any point surveyed for these experiments. The results of the differential correction showed an RMS error no larger than 0.66 cm for any reference point solution.

Rangefinder Testing and Data Acquisition

This experiment was designed to assess the accuracy of measurements collected with laser rangefinders given the variables of equipment, distance to target and user. The first rangefinder device examined was Vectronix/Leica's Vector 1500 GMD, which costs $11,900 and has a manufacturer stated distance accuracy of ±1 m at distances <500m or ±2m at distances >500m, with a maximum range of 2 km. The second rangefinder device tested was Laser Technology's TruPulse 360B, which costs $1,700 and has a manufacturer stated distance accuracy of ±30 cm to high quality targets (survey reflectors) or ±1 m to low quality targets, with a 1 km typical maximum range or 2 km maximum range to reflective targets.

This experiment was based on a test course surveyed with the Javad GPS, composed of a reference point where the rangefinder and operator were located, and four target locations, to be measured by the rangefinders (Table 1). The targets locations were situated at approximately 25, 50, 75 and 100 m from the reference point in an arc-shaped pattern creating a perimeter with a polygonal area of 851.7 m^2 (Figure 2). This arrangement allowed the accuracy of both point-locations and area measurements to be evaluated.

Point Type	Northing (m)	Easting (m)	Height (m)	Distance to Reference (m)
Rangefinder Ref.	5278427.53	551731.69	49.85	0
Target 1	5278451.06	551721.98	50.27	25.45
Target 2	5278476.27	551719.37	51.29	50.27
Target 3	5278502.52	551733.34	53.27	75.01
Target 4	5278522.26	551762.62	55.97	99.65

Table 1. Reference locations surveyed by Javad Maxor (northing and easting in UTM Zone 10 NAD83, height orthometric).

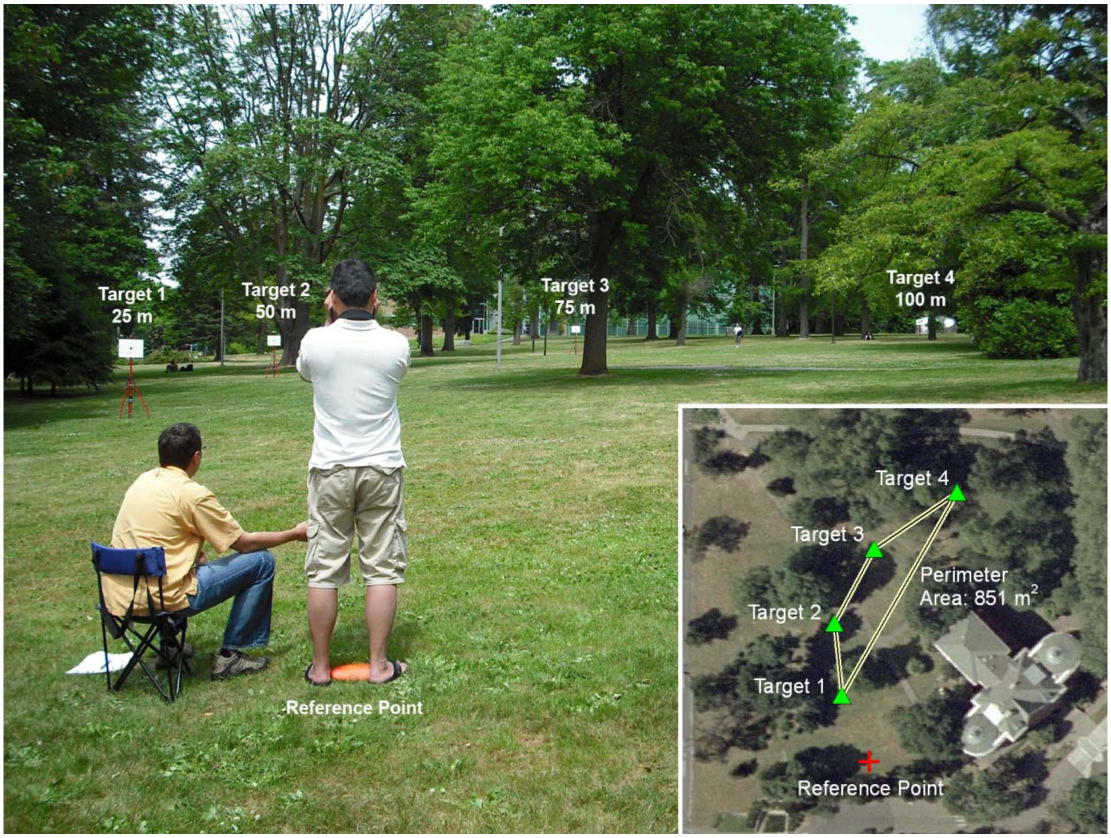

Figure 2. Rangefinder experiment test course from ground and overhead views. Test participant (standing) measuring Target 2 location, while test administrator (seated) collects data on PocketPC.

Ten test subjects performed the experiment to examine the variation of readings among users. The subjects varied in their past exposure to this or any other sighting equipment (binoculars, gun sight, etc). A simple questionnaire administered to participants revealed that two users had no experience with any sighting equipment, five users had basic sighting equipment experience, two users had worked specifically with laser rangefinders before, and one was an expert user of the rangefinder equipment.

In addition to examining the role of equipment, distance to target, and users on rangefinder measurement accuracy, this study was organized into three specific tests to investigate the potential for improving accuracy. For the first test, users were instructed to shoot at the center of a black on white vertical target board (45 cm x 60 cm with center at 1.75 m high) affixed to four of the Leica target poles (Figure 1). For the second test, users were asked to shoot at the horizontal ground directly below the central pole of the Leica target poles. Since the bottom of the pole was elevated above the ground surface, this test simulated the scenario of shooting at an identifiable location on bare ground where no vertical object is present. For the third test, users repeated the second test with the addition of a Benro MC 91n6 monopod to steady the rangefinder. A comparison of the results between test 1 and test 2 permitted examining the impact of shooting at a well-defined vertical target rather than the horizontal bare earth. A comparison of the results of test 2 and test 3 permitted examining the impact of using a monopod when shooting at the horizontal bare earth. All ten participants used both pieces of equipment to conduct the three tests collecting five repetitions of the four target perimeter. This produced a total of 1,200 point measurements (10 test subjects x 2 rangefinders x 3 tests x 5 repetitions x 4 targets) recorded as 300 polygon perimeters.

Readings taken by the rangefinders were collected on an HP iPaq PocketPC hx2490b, paired to the rangefinders, using ESRI's ArcPad 7.1.1 software. Before testing, both rangefinders were calibrated to offset any local magnetic fields and the local magnetic declination was set. During the testing, participants were required to operate only the rangefinder. A test administrator was responsible for all interaction with ArcPad on the PocketPC system. Users were first asked to remove any cell phones or other electronic devices from the testing area due to the potential for electromagnetic interference with the rangefinder's measurement of bearing. Next, users were provided brief instructions on the operation of each device, such as which button(s) to press in order to collect a reading and what visual feedback to expect from the device. They were instructed to stand over a .25 m-diameter plastic marker disc indicating the reference location.

After this introduction, users were asked to collect one practice perimeter, shooting at the black on white target boards to become familiar with the system. Once the testing began, participants were allowed to repeat any target reading if they felt they had made an error. The test administrator asked the subject to re-collect a point if it would be obvious to any system user that an egregious misreading had been made, such as a measurement more than twice the actual distance to the target. The test administrator also let the participants know if they shifted their standing position from the reference position marker disc.

Rangefinder Data Analysis

Analysis began by calculating the difference between the area of the 300 perimeter polygons collected by users during the rangefinder experiments and the reference area meticulously surveyed using the Javad Maxor survey-grade GPS (Figure 2). Each polygon perimeter was then divided into 1,200 individual point locations, and each point was identified by the variables of equipment, target distance, user and test. For each point, the horizontal error distance to the known target location was calculated. Additionally, the individual error components in the rangefinder distance and angle measurements were derived from the reference location, known target location and measured target location.

These results were explored, by variable, to identify any irregularities in the data. One user, number 5, had unusually large errors with the TruPulse, displaying three times the horizontal distance error of any other user for many short-ranged readings. The errors in this user's readings were explored in more detail and, due to magnetic interference from the metal content of the user's eye glasses, were determined to be invalid for the purposes of this experiment (see Results and Discussion). For this reason, all measurements by this user were removed from the dataset, including the valid Vector readings to keep the sample size equal across equipment types (reduced to 540 points per equipment type or 1,080 total).

To assess the relative impact of each tested factor (equipment, target distance, user, and test) on the overall rangefinder accuracy, mean horizontal errors were calculated one factor at a time across the entire dataset. To study the variation among users, mean accuracies were computed at the individual level and also as user groups classified by experience level. An analysis of variance (ANOVA) test was performed for each factor (equipment, target distance, user, user experience level, and test) to determine if the means for each group were significantly different. In addition to these means, the individual impact of distance and angle measurement errors were examined at the equipment level to ensure that error was equally distributed between these two measurement components. The mean rangefinder area accuracy was calculated for the entire dataset to show general accuracy for a wide range of scenarios and for the subset of data collected during test one to show the expected performance under the preferred case of targeting a vertical object.

Results and Discussion

The first objective of this study was to determine the impact of equipment type, distance to target, and user on the accuracy of measurements made with rangefinder devices. A lower overall accuracy was observed using the TruPulse device (3.00 m) than with the Vector device (2.40 m) (Table 2). These mean accuracies were significantly different, with an ANOVA significance value of .009. Note that these accuracies, along with all others presented, are averaged measurements computed across all other test factors. Neither of these findings is better than the manufacturer's specified levels of accuracy (±1 m for both rangefinders at this distance), but this is largely due to using non-vertical targets for two-thirds of the tests. A closer investigation of this difference between devices revealed an equally-shared impact among the individual error components of measured distance and measured angle. Although not included in the experimental design, two other important differences were noted between the two types of equipment. First, all TruPulse tests required, on average, only one half the time required for all Vector tests as determined from time-stamps on collected data files. Second, the Vector equipment would produce, on average, five Bluetooth miscommunications per user over the course of sixty measurements, resulting in lost data and requiring a second measurement. At nearly 8 times the cost, the Vector rangefinders do not appear to provide a sound return on investment if both efficiency and accuracy are the main concerns with equipment choice.

The next factor investigated was the distance from the observer to the measured target location. As expected, there was a dramatic increase in measurement error with increasing target distance when averaged across all other factors tested. The differences among the means of all test distances were found to be significant. Users in minefield mapping scenarios will likely position themselves naturally at the safest location with a clear

Equipment	Mean (m)*
Vector	2.40
TruPulse	3.00

Distance	Mean (m)**
25 m	1.06
50 m	1.83
75 m	3.53
100 m	4.38

User	Mean (m)**
1	3.53
2	2.50
3	3.11
4	2.53
6	3.36
7	3.16
8	2.30
9	2.15
10	1.76

User Exp. Level (N)	Mean (m)*
None (2)	3.03
Basic Sighting (5)	2.86
Basic Rangefinder (1)	2.15
Expert Rangefinder (1)	1.76

Test	Mean (m)**
1- Target	1.08
2- Ground	3.87
3- Ground w/ Monopod	3.20

Table 2. Rangefinder positional accuracy experiment results summarized by factors of equipment, distance to target, user, user experience level, and test. Means within each summary category include all data points across all other variables. ANOVA results provided for the means of each factor (*$p < .01$ and ** $p < .001$).

sightline to their target(s). Understanding the impact of distance on accuracy can help with assessing the reliability of their field measurements. Finally, a comparison of the overall accuracies among different users demonstrated a highly variable and significantly different set of mean accuracies. By classifying the user results into the self-reported levels of experience (no experience, basic sighting, basic rangefinder, and expert rangefinder), it is clear that these significantly different mean accuracies improved with experience levels (3.03 m, 2.86 m, 2.15 m and 1.76 m respectively). These results make a strong case for the positive impact of training and repeated use on the expected accuracy of this equipment.

Two methods for improving accuracy were also examined in the rangefinder experiment: using vertical physical targets instead of shooting at the horizontal ground and using a monopod to stabilize the rangefinders. Table 2 presents the significantly different mean accuracies of the methods. Comparing the results of test 1 and test 2 shows that users can expect more than 3.5 times the accuracy from the rangefinder equipment when shooting at a well defined vertical target compared to a point on the horizontal bare earth. The much larger error when shooting at the ground is caused by the difficulty of the user to precisely target a point location that is not well defined, and the inability for the rangefinders to precisely measure a surface with a non-perpendicular angle to the rangefinder's measurement laser. This result demonstrates that both rangefinder devices are capable of measuring a well defined target/object to nearly 1 m accuracy. Comparing test 2 and 3 indicates that the monopod provided only a small increase in accuracy across all other variables when shooting at the ground (0.67m). Although not tested in this experiment, it is hypothesized that at longer distances the steadying effect of a monopod would provide an increased accuracy when shooting at a physical target. With a cost under $100, a monopod may be a worthwhile addition for any rangefinder-based field GIS data collection. Additional field equipment can be a burden, but a telescoping carbon fiber model, like the one used in this study, weighs only 500 grams and collapses down to 50 cm in length.

The accuracy of areas measured with the rangefinder devices was assessed by comparing the original 4-point polygons collected by the experiment to the surveyed area of 851.7 m^2 bounded by the target locations. Across all users and tests, the Vector device had a mean underestimation of 25 m^2 (std. dev. = 97 m^2), while the TruPulse had a mean underestimation of 45 m^2 (std. dev. = 107 m^2). While these errors and distributions are reasonable considering the cumulative impact of point error measurements on total surveyed area error, the actual numbers are important to communicate to users who will be collecting data in the field. Additionally, to investigate the impact of shooting only at well defined targets on area measurement accuracies, error results were computed for test 1 across both devices and all users. As noted with point measurements, the use of well defined objects as targets yielded a dramatic increase in area measurement accuracy with a mean overestimation of only 2.5 m^2 (std. dev = 25 m^2). This finding is particularly relevant given the humanitarian demining application of this system, due to the fact that mine action funding is usually based on the total area surveyed for clearance.

Finally, it was important to investigate the cause of the errors leading to the removal of one study participant’s rangefinder data. Large inaccuracies in user 5's TruPulse results, not apparent during the field data collection but discovered during analysis, led to an examination of the individual components of distance and angle measured by the rangefinder. No anomalies were found with the distance measurements; however a plot showing every user's measured angle error with both rangefinder devices clearly identified a problem with the bearing measurements of the TruPulse device for user 5 (Figure 3). This figure shows that user 5 had a much greater overall angular measurement error (user 5 mean = 5.06º, versus the

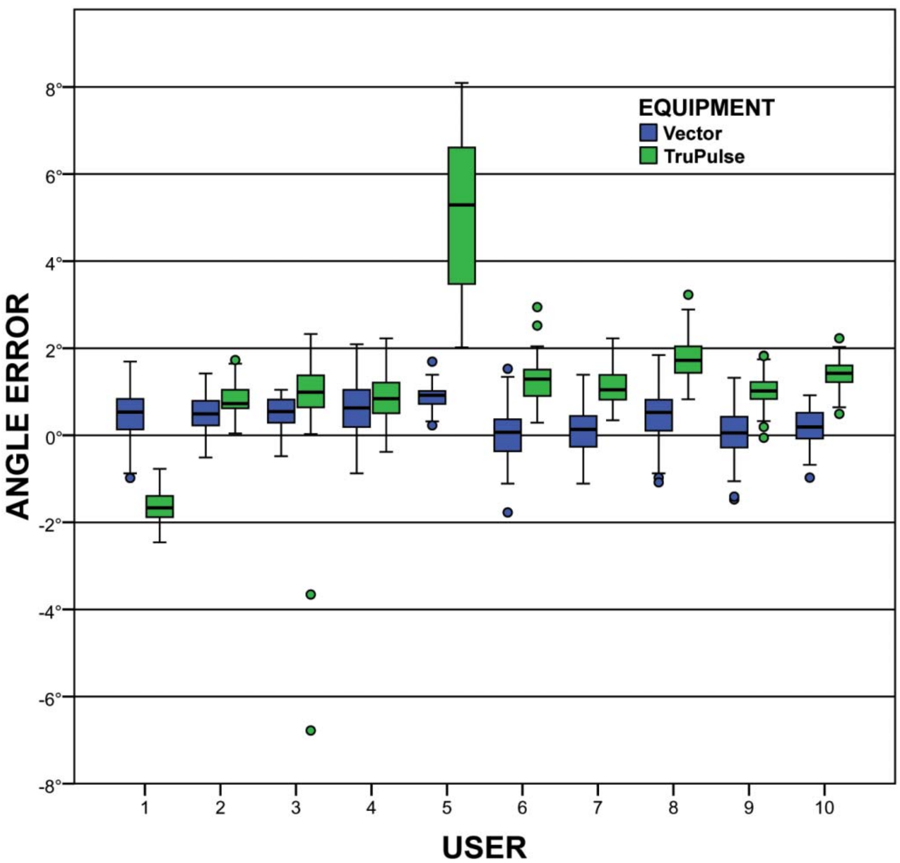

Figure 3. Error in angle/bearing measurement with rangefinders by equipment type and user (n=60 per box). Box indicates 75th and 25th quartiles, dark line indicates median, whiskers indicate max/min value within 1.5 IQR, and outliers are represented with points. The extraordinarily large angular error in user 5's TruPulse measurements led to the removal of all of this user's data in the final analysis.

mean for all other users = 0.58º) and also more variability in measurements (user 5 std. dev. = 1.70º, with the std. dev. for all other users = 0.91º) with the TruPulse device. The impact of this type of angular measurement error can be important because it increases the overall error in the measured horizontal position as the distance to the measured target increases. Given an angular error of 5 º, for every 100 m additional target distance, an error of 8.75 m is introduced in the measured horizontal distance.

Despite the author's *a priori* attempts to alleviate any magnetic interference in the testing site, it was later discovered that the errors in user 5's bearing measurements were caused by this user's glasses, which had frames made from a ferromagnetic metal. Indeed, "steel rimmed glasses" are mentioned in the TruPulse documentation as one potential source leading to errors in azimuth readings (Laser Technology, Inc., 2007). These results, confirming the susceptibility of the rangefinder devices to influence by magnetic fields, and the other findings of this experiment suggest the importance for training and operating procedures designed to ensure operator awareness of the factors leading to increased accuracy or, conversely, to potentially severe problems.

Conclusions

Among the two laser rangefinder units studied, the Leica/Vectronix Vector 1500 GMD was found to be slightly more accurate (2.4 m) than the Laser Technology TruPulse 360B (3.0 m) across a wide variety of testing scenarios. Shooting at a well defined physical target was the most effective way to improve rangefinder accuracy, resulting in 3.5 times less point measurement error and 14 times less area measurement error than shooting at the bare ground across both devices. Results showed a high degree of variability in measurement accuracy among users. Because this generally followed a trend of higher accuracy for higher levels of experience, user training can be confirmed as the second best method of improving rangefinder accuracy. Under the scenarios tested, the addition of a monopod device for steadying the rangefinders was found to improve accuracy, but only marginally. However, due to its low cost and the increased importance of stability when shooting at longer target distances, a monopod may prove useful for rangefinder applications involving long lines of sight.

In the past, the author had observed erratic bearing readings from the Vector rangefinders caused by cell phones or other mobile GIS equipment (GPS or Pocket PC) being placed too close to the rangefinders. This experiment demonstrated that even seemingly harmless items, such as eye glasses, can lead to unexpectedly high levels of error in bearing readings, especially with the TruPulse equipment. Users should be aware that even small fluctuations in bearing measurement can lead to high levels of positional error, especially when sighting large distances. To avoid such errors, multiple rangefinder measurements should be taken by multiple users and compared, or a basic compass should be carried with the rangefinders to test for magnetic interference by suspect items. In general, it is very important that users consult reference guides for equipment, because their apparent ease of use can be deceiving and can lead to inaccurate data collection that may not be immediately perceivable while in the field. The old cliché – “When all else fails read the instructions.” – certainly applies. But that may be easier said than done considering the amount of material to be covered and the vagaries of training venues.

The analysis of the rangefinder data collected in this study was intended to be very simple and straightforward, by only analyzing one variable at a time. Future experiments could use the same data, or data collected using similar testing procedures, to statistically investigate the relative importance of all variables on accuracy and model the interactions among variables.

Finally, this study also suggests the need for more general investigations of the accuracy expected with Mobile GIS systems. With the exception of examining the variability in users' rangefinder measurements, these experiments were designed to focus on the error components introduced by the actual mapping equipment. However, operator error of Mobile GIS systems can lead to even larger problems. Operator-based studies should investigate the ways in which users interact with software to assess the accuracy of collected measurements, when they chose to correct/not correct errors and why, and if there are methods for encoding best-use practices in the Mobile GIS software to avoid these errors in the future.

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Chapter 5

Conclusions

Landmines and unexploded ordnance pose a serious threat to civilians in more than 80 countries around the world. Humanitarian demining seeks to rid the world of these remnants of war and return the cleared land to local populations. One essential step in humanitarian demining is the collection of information describing and locating these hazardous areas. This research examined the fitness for use of a mobile GIS used for fields surveys to support humanitarian demining. Overall the system was found to be a success by its users, but areas in need of improvement and greater ongoing support were identified. This fit-for-use analysis calls attention to the benefits of this system while simultaneously providing a series of recommendations for best use practices concerning software, hardware, training, and user components of this mobile GIS.

As more and more academic disciplines, commercial endeavors, and technologies incorporate geographic information into applications, the demand for timely, accurate, and safely collected spatial field data will continue to rise. While the findings of this research are directly relevant to users of the humanitarian demining system, they are also generally applicable to many other mobile GIS applications.

Evaluating Mobile GIS

This study demonstrated that mobile GIS for humanitarian demining can be faster, more accurate, and more reliable compared to traditional methods for collecting spatial field data, such as paper forms, maps, and the stand-alone location technologies of GPS or compass and tape. However, these benefits and the promise of a “high-tech” solution to fieldwork can lead potential users to erroneously believe that mobile GIS is a turnkey solution. Solid system development, proper training and instructional materials, and support from knowledgeable technical staff are critical for successful use of any mobile GIS in the field.

Infrequent but significant system crashes were shown to quickly lead users to become frustrated or, even worse, to lose confidence in a new system. This issue with the demining handheld, along with the numerous minor bugs reported during deployments, demonstrate the importance of thorough field testing, prior to the start of actual field data collection. A good rule is to assume that *nothing* will work in the field if it hasn't been exercised thoroughly in or near the fieldworker's home facility.

Editing spatial data in a mobile GIS was found to be somewhat more complex than on the desktop due to a smaller screen size, touch-screen interface, and the often difficult conditions of fieldwork. Inevitably, errors will be made during initial data collection or updates required after the fact, and users should have received enough practical training beforehand so that editing procedures require little thought.

Efforts should be made to develop quality base map data for the most effective field experience. High spatial resolution raster data, such as aerial/satellite imagery or scanned topographic maps, were found helpful for the demining system trials, but detailed vector data may also be appropriate for certain applications. Detailed base map data can help users gauge the accuracy of field measurements, aid in navigation, and provide a reference source of previously gathered field data.

The hardware components of the demining mobile GIS also warrant a set of recommendations. In general, with the high cost of fieldwork, it is worthwhile to invest in backup hardware units for all but the most expensive pieces of equipment. When choosing a mobile GIS field computer (pocket or tablet PC), extra attention should be given to outdoor screen visibility and battery life. Considering the repeated rangefinder- and GPS-related Bluetooth issues experienced during this evaluation, system complexity should be reduced by using an integrated solution or cabled versions of equipment whenever possible.

Magnetic interference was shown repeatedly to have the potential to seriously impact measurements collected with rangefinder equipment. This fact should be stressed during the rangefinder training, along with the exact procedure for calibration, setting local magnetic declination, and Bluetooth configuration. Additionally, given the likely need for long-range sighting, a monopod or tripod should also be considered for the rangefinder.

Simple GPS receivers were found to be well received by users in terms of their usability, leaving the project's required mapping accuracy as the key factor for selecting an appropriate unit. Whatever the accuracy desired, formal testing, as described in Chapters 3 and 4 of this study, should be performed on both GPS and rangefinder hardware to determine the exact accuracy users can expect to obtain under their specific field operating conditions.

Training sessions and materials related to a mobile GIS were found to be just as important as the system’s hardware and software for ensuring a successful field effort. Extra attention should be devoted to complex mapping tasks. All conceivable combinations of data collection methods and mapping hardware should be taught in as many practical hands-on exercises as possible, thus addressing any specific needs or gaps in the knowledge of individual field users. Users and system evaluators alike also indicated that thorough and well thought out guide materials, such as checklists, laminated for durability in the field, would be nearly as valuable in the long run as a formal training program.

While many of the findings presented in this study were specific to the demining Survey Tool, the general lessons learned during this evaluation have broader application for any mobile GIS user, developer, or trainer. Take, for example, a theme encountered across all aspects of the Survey Tool evaluation, which was summed up nicely in a comment made by one trainee from the Chilean deployment, “Nothing will ever be exactly as we had planned, but we must be ready to deal with it anyway.” While this concept is likely known by anyone who has spent much time doing fieldwork of any sort, it needs to be incorporated throughout mobile GIS so that the free flowing nature of traditional fieldwork is not interrupted. To ensure this, every effort should be made to train for user adaptability and design for system flexibility. Training experiences and materials must provide users with the ability to make decisions on their feet in the field, both in how to collect data and how to deal with system malfunctions. The system software and hardware also must be able to operate in a variety of data collection modes, from the open-ended nature of a field notebook to the highly structured methods used for a formal site survey. Finally, adequate time must be allocated (at least a day) to work out the "kinks" in hardware and methodology on-site, under real field conditions prior to the beginning of actual data collection.

As early as possible, mobile GIS system designers and developers should consider whether to develop a focused, task specific mobile GIS or a broadly scoped one-size-fits-all tool. Using the lessons learned from observations and user feedback related to the demining system, applications should be directed specifically at a narrow group of user needs, while remaining flexible enough to adapt to the dynamic nature of field data collection.

GPS Accuracy for Mobile GIS

Based on 14,462 readings, the Socket GP0804-405 Bluetooth GPS Receiver was predicted to deliver a horizontal accuracy of better than 5 m at least 50% of the time and better than 10 m at least 95% of the time. These accuracies should be considered the best-case scenario for this equipment considering the relatively ideal GPS conditions used for this study, including a completely open sky-view and deliberate selection of conditions for extremely low dilution of precision (DOP) values. This study also investigated horizontal DOP (HDOP) filtering, but found that this technique provided no accuracy improvement under the GPS conditions of this experiment. However, DOP filtering may still be relevant for this device when conducting GPS surveys under poor satellite conditions or more dense vegetation cover. The readings collected from the GPS also were used to simulate the effects of GPS averaging. These results indicated that a reasonable increase in expected accuracy can be achieved with up to four minutes of GPS averaging using the Socket device. As a set of best-use practices, 30-60 seconds should be spent averaging for low quality data needs (perimeter vertices or sample points) and 2-4 minutes should be spent averaging for high quality data needs (benchmark or rangefinder reference point).

Rangefinder Accuracy for Mobile GIS

This study investigated the accuracies of two laser rangefinders, the Leica/Vectronix Vector 1500 GMD and the Laser Technology TruPulse 360B. Across all testing scenarios, the Vector 1500 was found to be slightly more accurate (2.4 m) than the Laser Technology TruPulse 360B (3.0 m). However, when shooting at well defined vertical physical targets, rather than a point on the horizontal bare earth, overall point measurement accuracy improved greatly and the difference between equipment accuracy all but disappeared (Vector 1.0 m and

TruPulse 1.2 m). The same results were found for the accuracy of areas measured with the rangefinder devices. Surveys of an 851.7 m^2 area yielded a dramatic increase in measurement accuracy across both devices from a mean underestimation of 35.5 m^2 (std. dev = 102.9 m^2) when shooting at the bare horizontal ground to a mean overestimation of only 2.5 m^2 (std. dev = 25 m^2) when shooting at a well defined vertical target.

Results of the rangefinder testing also showed a high degree of variability in measurement accuracy among users. Since this generally followed a trend of higher accuracy for higher levels of experience, user training can be confirmed as the second best method of improving rangefinder accuracy after target selection. Under the scenarios tested, the addition of a monopod device for steadying the rangefinders was found to marginally improve accuracy. However, due to the low cost and the increased importance of stability when shooting at longer target distances, a monopod or tripod should be used for most rangefinder applications, especially those with long lines of sight.

Throughout the foreign field deployments of the demining mobile GIS, users experienced erratic bearing readings from the Vector rangefinders caused by cell phones or other mobile GIS equipment (GPS or Pocket PC) being placed too close to the rangefinders. Despite an attempt to safeguard against such interference, this experiment confirmed that even seemingly harmless items, such as eye glasses, can lead to unexpectedly high levels of error in bearing readings, especially with the TruPulse equipment. Users should be aware that even small fluctuations in bearing measurement can lead to high levels of positional error when sighting large distances. To avoid such errors, multiple rangefinder measurements should be taken by multiple users and compared, or a basic compass should be carried with the rangefinders to test for magnetic interference by suspect items.

Significance of Findings

Although generally unmentioned by users, one of the significant benefits offered to humanitarian demining by the Survey Tool is a standardized set of equipment, software, and training for conducting field surveys. As the system becomes more widely adopted, any improvements that are made to the system, training developed for it, and lessons learned using it, will have the potential to benefit many users throughout the larger humanitarian demining community. For example, due to the findings of experiments conducted in this study, all users of the system can now be confident in the known accuracy of measurements collected with both the GPS and rangefinders. While the accuracy levels of the GPS and rangefinders are not as precise as top-of-the-line equipment, the accuracies fit the requirements of demining Technical Surveys, and the costs of the equipment fit the price-point of most humanitarian demining operations. If users choose to expand the application areas beyond Technical Surveys and require higher levels of accuracy, mapping or survey grade GPS and rangefinders can be added to the current system.

The various components of the demining Survey Tool were well received by its users, and the system was considered an improvement over existing approaches and technologies. This provides a sound indication that this mobile GIS was fit for use in its intended purpose. Although areas for improving every component of the system were indentified, when these modifications are introduced over time, they will build on a solid foundation. As long as system designers and administrators continue to focus on refining both the usability and training of the system it likely will continue to receive high praise from users. The user's evaluation of the system indicated that it provides a 2 to 3 fold increase in survey speed, can be used with teams of half the size, and offers more accurate and reliable results than traditional methods. These results should be considered just as revolutionary for humanitarian demining as the same improvement would be for a manufacturing process, farming practice, or construction activity.

Future Research

Beginning with technical issues, future studies examining expected GPS performance should investigate accuracy over a longer sampling period than this study, under non-ideal sky view conditions (i.e. different levels of canopy closure), and on different days at different times under various non-ideal satellite configurations as reported by mission planning software (Johnson and Barton, 2004). Because the Socket GPS is no longer "cutting-edge" technology, newer consumer-grade devices using more modern GPS chipsets should be examined and compared against one another. Just as this experiment produced suggestions for averaging times, it also indicates the need for appropriate wait times prior to data collection to ensure that the GPS position has stabilized after movement. An experiment could be developed in which wait times would be simulated in a similar manner to the averaging times of this experiment: 1) Move the GPS to a new location, 2) Immediately start logging GPS data, and 3) Explore the accuracy improvement of different wait times on raw data.

The analysis of the rangefinder data collected in this study was intended to be simple and straightforward, analyzing changes in mean measurement accuracy one independent variable at a time. Future experiments could use the same data, or data collected using similar testing procedures, to statistically investigate the relative importance of all variables on accuracy and model the interactions among variables.

In additional to the individual mapping components of a mobile GIS, this study suggests the need for more general investigations of the accuracy expected from the system as a whole. Except for examining the variability in users’ rangefinder measurements, these experiments were designed to focus on the error components introduced by the actual mapping equipment. However, operator error of Mobile GIS systems can lead to even more significant errors. Operator-based studies should investigate the ways in which users interact with software to assess the accuracy of collected measurements, when and why they chose to correct/not correct errors, and if there are methods for encoding best-use practices in the Mobile GIS software to avoid such errors in the future.

Mobile GIS has made significant progress over the last decade, and its development will certainly continue. One highly studied emerging area of research in mobile GIS computing involves the increased potential of handheld devices that are wirelessly networked, either to one another or to a central server. Early prototype studies have used close-range wireless local area networking to stream data from handhelds to a mobile data server (Tsou, 2004) or cellular communications to transmit from the field back to a remote location (Vivoni and Camilli, 2003). Along with field based GIS, attention should be paid to developments in the other sub-field of mobile GIS, Location Based Services (LBS). LBS deals primarily with commercial applications at the convergence of mobile computing, cellular data transmission and GIS. Raper et al. (2007) presents a comprehensive introduction to the field in the recently formed *Journal of Location Based Services*, while Dobson and Fisher (2007) address ethical concerns of privacy and control in LBS’ growing subfield of human tracking.

The de facto standard of software used by most mobile GIS devices, ESRI's ArcPad, is also undergoing noteworthy changes in networking functionality. At the 2008 User Conference, ESRI (2008) introduced ArcGIS Mobile as a new application development framework for designing "sometimes-connected" mobile GIS devices (via a cellular network). As a programming framework, ArcGIS Mobile can be designed to meet a specific field data collection task rather than appearing like a scaled down version of a desktop GIS. ESRI's addition of a network capable mobile GIS product also suggests their interest in a server-based architecture for field data collection, much like LBS. Finally, along with the previously mentioned variations in GPS and laser rangefinder technology, developers of mobile GIS systems should also be aware of other mobile computing platforms. There are a wide variety of netbook-style laptops, tablet PCs, such as the recently announced iPad, and Smart Phones that may suit the needs of specific mobile GIS applications (Maguire, 2007; Clegg et al., 2006).

On a more theoretical note, one striking thread throughout this work was the role that users play in determining not only the accuracy of the data collected, but also the content of that information. There has been a recent interest in the use of the Internet to create, assemble, and disseminate geographic information offered up voluntarily by users, termed volunteered geographic information (Goodchild, 2007). As interest in this process grows, volunteers will likely expand their geographic data creation activities from the desktop into the field and vice versa. When this occurs, research should be conducted on the role of mobile GIS technologies in this process. Community-based GIS, known in different research circles as participatory GIS (PGIS), public participation GIS (PPGIS), or participatory mapping, is another research area that stresses the need for a bottom-up or user-based approach to GIS data collection (Talen, 2000). There is an active dialogue on the ability for PGIS to respond to the criticism of GIS as an undemocratic and divisive technology, most evident in settings where financial and skills-based resources are limited. (Elwood, 2007). Mobile GIS certainly has applicability to the PGIS effort, and research should explore how this technology might respond to critical geographers’ concerns.

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Appendix A

Evaluation Forms and Interview Questions

Initial Evaluation Form

1 - Personal Background

	(Circle One) None - Expert
Rate your level of computer experience:	1 2 3 4 5

Please describe what you use a computer for and how frequently:

What method(s) have you used previously for mapping minefields?

2 - Training Evaluation

	Low-Medium-High
How confident do you feel using the Pocket PC device?	1 2 3 4 5

Comments?

How well do you understand the process of data entry in EODIS?	1 2 3 4 5

Comments?

How easily could you collect a minefield perimeter sketch using EODIS on your own?	1 2 3 4 5

Comments?

Initial Evaluation Form page 1.

Would you have liked more training time in the classroom? Ye s / No
If yes, what specific areas needed more emphasis?

Would you have liked more training exercises in the field? Yes / No
If yes, what types of field exercises?

What other recommendations do you have for improving the training?

3 - EOD IS-Survey Evaluation

After your training with EODIS Survey, how do you feel that this tool will be an improvement over your previous methods of surveying minefields?

Rate each of the following qualities of the EODIS Survey tool (1 = low & 5 = high):

Improved safety	1 2 3 4 5	Accuracy	1 2 3 4 5
Time savings	1 2 3 4 5	Ease of Use	1 2 3 4 5
Reliability	1 2 3 4 5		

Please provide any other feedback about EODIS Survey that you have at this time (problems encountered, recommendations for improvement):

Initial Evaluation Form page 2.

EOD IS-SURVEY Post Training Interview Questions

This has been mentioned before, but we wanted to let you know that this system will be tested around the world. To get ready for the other tests, we have two general questions that we would like to get answer to during this interview: does it work and are there changes that we need to make?

We would like to start with the different devices that make up the system. Starting with the Pocket PC, how well did you think it worked?

The lockups on the Pocket PC were a big concern with everyone at our first interview. Do you feel comfortable handling those now?

Moving on to the binoculars, we would like to know how well you think they worked?

After the two weeks of using the device, do you feel confident with the measurements they were returning to you?

The last device we wanted to ask you about is the GPS. How well did you feel it worked?

After you training over the past few weeks, did you feel that it was communicated that you need to keep the GPS antenna in clear view of the sky?

In general, if you had to collect a minefield tomorrow without any assistance, could you?

Do you feel comfortable enough with it to teach others?

How important would it be for you to have materials in (local language): software, manuals or (local language) speaking instructors?

In the first interviews that we did, many people said that making a small mistake could lead to very big problems. Can you think of any examples of how this might still be the case?

Another thing that we thought would be very helpful are checklists. (show example checklist for ArcPad) These are for ArcPad, but would something like this be helpful for you to have to carry in the field?

Can you think of specific things that would be good to have on the checklists?

Now that you have finished a full week of training plus a week of fieldwork, how would improve the training process for our next training in (next training location)?

Did you feel that the training was long enough or would you like more time?

Do you think you will continue to use the system in (testing country) for minefields in (other known mined areas)?

After your two weeks with the device, what are the most important one or two things we should try to fix before our next training exercise?

The last question is, after using the device for two weeks, do you feel it is an improvement over how you would have done this job in the past?

How confident are you in the results?

Interview questions for Chile, Albania, and Ecuador.

EOD IS-SURVEY Post Training Interview Questions

1. Background

What is your role in demining in Lebanon?

What experience have you had mapping minefields?

What methods have you used for mapping minefields?

2. Training

How helpful was the training?

What recommendations do you have for future training?

Should more time be spent in the classroom?

What recommendations do you have to improve field/outdoor training?

3. Documentation

Many participants have said that the checklists, which were developed during training in other countries, were helpful. Do you agree?

What suggestions do you have for modifying the current two checklists?

What other checklists would you like to see developed?

How helpful would it be to have user manuals during the training?

4. Mapping

How confident are you that you could now map a minefield on your own using the Survey Tool?

How confident are you that you could teach others how to use the Survey Tool?

Do you have any comments on the individual hardware components (GPS, Pocket PC, Vector binoculars)?

5. Overall Evaluation

What are the most important strengths or advantages of the Survey Tool?

What is the biggest weakness in the system?

What improvements do you recommend?

What would be an ideal system (for mapping minefields and collecting related data)?

Do you have any other comments or suggestions?

Interview questions for Lebanon.

Feedback Form – Field Team DATE: ____________

Evaluate EOD IS-Survey after each Minefield Report

1 - Total Minefield Surveys previously completed using EOD IS-Survey:

1-5 6-10 11-20 21-30 More than 30

2 - For this minefield report:

What hardware did you use to collect the minefield perimeter points?

GPS only Binoculars only GPS and Binoculars together

How long did it take you to complete the survey?

Data entry: ___ hours ___ minutes

Minefield mapping/sketching: ___ hours ___ minutes

a. How large was the minefield? (to find the area and perimeter, choose the identify button in ArcPad (Blue button with white "i") and click on the minefield)
Perimeter ________(m) Area ____________(m2) Number of points _____

3 - Did you encounter any problems with the following components of EOD IS-Survey?

Component	*yes* *no*	Component	*yes* *no*	Component	*yes* *no*
EOD IS-Survey Program		Binoculars		GPS	
Pocket PC		Camera			

For each component you found a problem with answer the following (be specific):

Describe the problem:

Describe what you were doing when the problem occurred:

Feedback Form page 1.

Describe what you did to fix the problem:

4 - Did any of the following environmental factors impact your use of the device?

Weather	*yes no*	Vegetation	*yes no*	Terrain	*yes no*

For each yes marked, describe how the environmental factor impacted your survey:

5 - After using EOD IS-Survey to complete this minefield report, do you feel the tool is an improvement over previous methods of mapping and recording minefield reports?

YES NO

Please comment on why you marked Yes or No:

Feedback Form page 2.