Mobile GIS in Archaeology:
Current Possibilities, Future Needs. Position Paper

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Abstract

Ever since field survey has become an important method in researching ancient communities we can observe improvement of its technological and theoretical aspects. Nowadays, rapid urban sprawl and intensified agriculture lead to the increasing destruction of sites and archaeological landscapes throughout the globe. Thus, an adequate low budget strategies is needed, that will able help to document, preserve, study and manage all what is left. The introduction of GIS and GNSS mobile applications opened a such possibility. At the 2017 CAA meetings in Atlanta, the authors organized a session entitled "Mobile GIS in archaeology – current possibilities, future needs", at which the current issues and possibilities were discussed. The session resulted in this summary paper. The main aim of the paper is to re-evaluate the contemporary concept of the survey that was introduced due to a rapid increase of GPS accuracy and development of mobile technology.

Introduction

Ever since field survey became an important method in researching ancient communities (Adams 1965; Ford and Willey 1949; Wedel 1953), the methodology has been adapted based on the constant increase of theoretical and technical aspects of the discipline. Surveys were gradually augmented with technological innovations (Wilkinson 2003: 33–40). Nowadays, field survey is relying on remote sensing and constantly developing GNSS systems. During the CAA conference held in Atlanta, USA in 2017, the authors had the opportunity to lead the session, during which new technological innovations and problems of the field survey were discussed. The session was titled "Mobile GIS and field survey - current possibilities, future needs".

During the session, six papers were presented. Each paper discussed case studies followed by a discussion about current possibilities of implementing mobile GIS. The first paper was presented by Peter Knoop and was titled "Best practices for mobile GIS and information technology in the field". The author presented different case studies of mobile GIS applications used on tablets and emphasized technical details that one must be aware of and problems that might occur during the survey. The second paper was presented by Austin Hill entitled "High accuracy drone survey methods". The paper discussed possibilities of using photogrammetric models created from UAV photos, and the possibility of using mobile GIS in this process.

The third paper was presented by Julia M. Chyla, Miłosz Giersz, Wiesław Więckowski, Patrycja Prządka-Giersz and Roberto Pimentel Nita, titled "One step further beyond field survey". The paper discussed the use of mobile GIS applications on PDAs in a regional survey of Huarmey Valley in Peru, and the methodological challenges of creating similar surveys. The fourth paper was presented by Łukasz Miszk, Wojciech Ostrowski, Weronika Winiarska, and was titled "Urban sprawl vs. archaeological site:

a view from Paphos". The presentation focused on the uses of GIS in the site management of Paphos on Cyprus. The paper emphasized the influence of the urban landscape on the preservation of the heritage in the region, which was one of the topics of the session. The fifth paper was presented by Hannah Pethen and was titled "Accessing the inaccessible: detailed 'offsite' archaeological survey using satellite imagery and GIS at the Hatnub travertine quarries, Egypt". The presentation focused on the preparation of field prospection in Egypt preceded by analysis of satellite images and the results of archival research. The paper emphasized the need of having efficient way to verify large amount of sites located with use of remote sensing. The last paper was presented by Nazarij Buławka and was titled: "Ancient landscapes and present-day agriculture – on the example of Tejen River (Turkmenistan)". The presentation discussed the efficacy of mobile GIS applications during field prospection at the Serakhs oasis in Turkmenistan. It focused on methodology from the perspective of mapping sites in the region. The ground truth of the collected data on site extent was discussed as well.

The session finished with a discussion about the future development of mobile GIS: why its application is needed in archaeological research, and what functions researchers hope that those tools might have in the future. During the session and the discussion, participants pointed out that the emergence of Mobile GIS is closely linked with developments in navigation technology (GNSS). The discussion prompted the writing of this position paper, in order to present the current state of knowledge about GNSS technology and the use of mobile GIS applications in archaeological research.

The aim of the paper is to re-evaluate the development of the surface surveys caused by the increase of GPS accuracy and practices of crowd collection. Mobile GIS is becoming increasingly popular in large-scale, field archaeological prospection nowadays. Thus, it is important to step back and see what this technology brought to archaeology. We have not encountered such reflexion in other papers that would sufficiently show the parallel changes within GNSS and field survey. Available articles describe only the rapid development of the technology and admire new possibilities for archaeology (Joglekar and Sushama 2008). The scholars also do not put contemporary Mobile GIS tools in the context of other

GNSS techniques (i.e., Tripcevich and Wernke 2010; Wagtendonk and De Jeu 2007; Tzvetkova et al. 2012). There are only few successful attempts of analysing the methodological problems or indicating pitfalls that may occur if a good practice of Mobile GIS is not used (Campana 2016).

We think such a summary is needed, because the regional field prospection, in the form as we know it, might change in the near future in parallel with changes in GNSS technology. By the comparison of current possibilities, we would like to point out the quality of this technique, new tools, and would like to discuss the role of professional GIS analysts in it. We are convinced that current developments in GNSS, equipment and characteristics of mobile GIS applications have to be discussed to place the current field survey techniques in their broader context and shed light on their future development.

Past Field Surveying Techniques

The history of settlement pattern research has been summarized many times, so there is no need for detailed discussion (e.g., Alcock and Cherry 2004; Banning 2002; Campana 2016; Keller and Rupp 1983; Layton and Ucko 1999; Sanders 1999). The beginning of regional field survey in archaeology goes back to 18th century (Banning 2002: 2). As a separate research method, it appeared in the early 20th century (ex. Huntington 1908; Williams-Freeman 1915). Since the 1930s, great interest was placed on the settlement pattern studies (Adams 1965; Ford and Willey 1949; Wedel 1953). For the purposes of this article, it is relevant to mention that, in the 1950s, Gordon R. Willey working in Virú Valley proposed a workflow that is still recognized and utilized today. It included: analysing the aerial photography previous to fieldwork; mapping sites with the help of an epidiascope, with pencil and paper; field checking and measuring features not visible on aerial photos, and mapping them on previously prepared maps with the use of a compass (Willey 1953: 3–5). Similar approaches were developed in other regions (e.g., Adams 1965; Tolstov and Orlov 1948).

Through 1960s the processual paradigm shaped what could be learned from settlement pattern studies (ex. Binford 1964), which resulted in post-processual criticism (Wilkinson 2003: 4–7). Starting from

1970s, the so called "Second Wave" of prospection, proposed a methodology in which the improvement of reliability of data collection was the main focus (Campana 2016: 115). In 1990s and 2000s, a critique of the "Second Wave" in field prospection started (Campana 2016: 115). It seems that the technological development of non-invasive documentation tools was an answer to some of the limitations confronted by archaeologists. In 1998, the first use of mobile, computer applications deployed in the field was presented by N. Ryan and colleagues (1999), followed by other field researchers (i.e. Pundt 2002; Tripcevich 2004). Recently S. Campana (2016: 118) has argued that a "Third Wave" of field surveys should be distinguished.

Nowadays a majority of projects include GIS in the research, while almost all field prospection projects use mobile GIS during their surveys in some degree. Their main focus is to find new sites, verify areas of interests found through remote sensing, study the landscape, and also document archaeological features and artefacts visible on the surface in endangered areas (i.e., Bogacki et al. 2010; Buławka 2018; Buławka and Kaim 2016; Ejsmond et al. 2015; Tripcevich and Wernke 2010; Tzvetkova et al. 2012). There are many examples of research projects entirely relying on Mobile GIS techniques. Thus, there is a need to re-evaluate the development of GNSS in order to check how GPS accuracy has changed since the "Third Wave" has begun (Campana 2016).

In many areas of the world, the major problem is looting of archaeological sites or their rapid destruction due to urban sprawl (e.g., Brodie and Renfrew 2005; Casana 2015; Chyla 2017; Contreras 2010; Lauricella et al. 2017; Tapete et al. 2016). This has led to development of workflows that incorporate remote sensing, in which several thousand possible sites can be discovered (e.g., Campana 2009; Casana 2014; Hritz 2013; Lambers and Zingman 2013; Menze and Ur 2012; Sonnemann et al. 2017; Traviglia and Torsello 2017).

The review of the papers published recently indicates that one of the major challenges of current and future regional surveys is the possibility to verify in the field new archaeological sites identified through remote sensing. It is clear that in order to achieve this, greater speed and accuracy are required than ever before. Field survey is time consuming and that has always been a big challenge for archaeologists

(Willey 1953: 2). We think that this could be solved by an implementation of fast surveying techniques and workflows. The problem is, however, what are those "fast surveying techniques" in regard to the state of the art of current GNSS and how reliable are they? In order to answer these questions, we should evaluate how the development of GNSS articulates with our need for speed and accuracy.

The Brief GNSS History

The first Global Navigation Satellite System (GNSS) available in the world is Global Positioning System (GPS NAVSTAR). Following its deployment, some other satellite navigation systems have been developed (Hofmann-Wellenhof et al. 2008). The performance of the above-mentioned systems is augmented by national ground-based and satellite-based systems (van Diggelen 2009: 218, 297, Tab. 10.1). Since this paper is mainly concerned on the development of GNSS for archaeological purposes, the detailed analysis of all navigation systems is unnecessary. Analysing the topic from the perspective of GPS should be enough to give the reader a good understanding of development of the technology. The detailed history of GNSS could be found in several authors (i.e. Hofmann-Wellenhof et al. 1992, 1993, 1994, 1997, 2008; Madry 2015; Seeber 2003; Teunissen and Montenbruck 2017; van Diggelen 2009; Xu and Xu 2016).

The Early Civilian GPS Capabilities

GPS was a military project of the Joint Program Office, which was directed by the US Department of Defense to establish a positioning system in 1973 (Hofmann-Wellenhof et al. 2008). In 1978 the first satellite was launched (van Diggelen 2009: 229). After 1983, due to an incident with the Korean Airlines Flight 007, GPS was allowed to be used for civilian purposes (Hofmann-Wellenhof et al. 2008: 311, 332-333, Table 9.6, 9.7). In 1993 the initial 24 operational satellites were launched and two years later full operational capability was reached, but the general accuracy of positioning was low. Only one civilian GPS signal was available. It was broadcasted as L1 C/A signal (L1 Coarse Acquisition) within the 1575.42 MHz frequency. The low performance, how-

ever, was caused not by technological barriers of that time but by a "Selective Availability." It was an intentional data error on ephemeris and the clock of the satellites (Hofmann-Wellenhof et al. 2008: 311, 319-322). In the 1990s, the main problem in professional equipment was to achieve precise measurements in the shortest possible time. This, alongside with the low GPS accuracy caused the development of different ground-based and satellite-based augmentation systems.

First, the assisted GPS (A-GPS) or assisted GNSS (A-GNSS) should be mentioned. It is a ground-based augmentation system, in which the receiver gets its general location from the network of cell towers. Also, most of the information required for GPS positioning is sent by the cellular network: almanac, ephemeris, frequency and precise time. Using A-GPS the only missing ingredient to measure a position of the receiver are the signals sent by satellites themselves (van Diggelen 2009: 1–2, Figures 1.2).

A more precise augmentation system already available in the 1990s was differential GPS (DGPS). It relies on two or more receivers. First, one has to have a known static geographic location. It constantly measures new coordinates and then compares them to the known position, calculates corrections and sends them to the other receiver (the rover). This technology was implemented for aircraft and other fields requiring precision (Hofmann-Wellenhof et al. 2001: 136-141, 186-189; 2008: 415-416, 436). In archaeology, however, there were also a number of successful attempts to use this technology (Colosi et al. 2001; Hoelzmann et al. 2001; Vlahakis et al. 2002).

There were different methods relying on the above-described concept, which could be described as relative positioning (Mezera and Hothem 1995; Hofmann-Wellenhof et al. 1992, 2001, 1992, 2008; Hofmann-Wellenhof and Remondi 1988; Remondi 1985). Initially, the data had to be uploaded to the computer. On-the-fly (OTF) techniques were developed later (Hofmann-Wellenhof et al. 1994: 161, 168). Nowadays, online postprocessing services are available, which rely on the International GPS Service for Geodynamics (IGS, currently International GNSS Service) developed since 1990 (Beutler et al. 1996; Hofmann-Wellenhof et al. 1994: 69).

In the 1990s new types of relative positioning were also developed - real-time kinematic relative positioning (RTK) and wide-area RTK (Hofmann-Wel-

lenhof et al.1997: 137, 138, 144; 2001: 135; 2008: 431-439). In these methods, the precise coordinates could be measured OTF with use of corrections transmitted from the continuously operating reference stations (CORS) (at first via radio). This technology evolved with time in parallel to changes in GNSS and other technologies.

GNSS and the Geospatial Revolution

A new era of satellite navigation began in early 2000s. First, in the May 2000 thanks to the presidential order of Bill Clinton, a "Selective Availability" (SA) was turned off (van Diggelen 2009: 229). This was the first and the largest leap in increasing GPS accuracy. The removal of SA was crucial, because previously the increase of accuracy could only be done with specialized equipment. Ever since, a regular GPS user with basic skills could enjoy 10 to 25 meter accuracy. This event had a serious impact on the GIS community in archaeology and other disciplines.

Three years later GPS appeared in the first palmtops and mobile phones. A rapid growth of the number of GPS receivers available in smartphones was observed (Schreiner 2007). In 2007, over 70 million of them were sold. Since many of them were programmed with the Android system (Lee 2012; Rogers et al. 2009: 3), new navigation and mapping applications were created, some of them available at no cost.

Simultaneously, there were improvements in professional equipment. First of all, in 2003, GPS Wide Area Augmentation System (WAAS) started to be available for the GPS users. WAAS is an example of a regional Satellite Based Augmentation System working in the North America (Hofmann-Wellenhof et al. 1997: 347-347; 2008: 348). Also, new civilian signals were introduced. In 2005, satellites equipped with the second civilian signal (L2C) were launched (van Diggelen 2009: 310; Hofmann-Wellenhof et al. 2008: 334-335), but the signal was not broadcasted until 2010 (Doberstein 2012: 244). Currently, civil L2 signal has pre-operational status, it is broadcasted on a 1227.6 MHz carrier frequency (Hofmann-Wellenhof et al. 2008, 334-335, Table 9.6, 9.7). It provides greater position accuracy even in partly covered areas, also when used together with another signal, it enables the user to eliminate the ionospheric errors (van

Diggelen 2009, 24, 310). A gradual slow increase in precision of GPS was visible until 2013 (Madry 2015: fig. 3.19). In 2014, the third signal (L5) appeared. It is broadcasted on 1176.45 MHz carrier frequency (Hofmann-Wellenhof et al. 2008: 335-336, Table 9.6, 9.7). Its initial testing was conducted in 2009 (GPS 2014), and the current status is still pre-operational.

Current GNSS Trends and Future Possibilities

In 2009, it was announced that a fourth civilian signal will be broadcast in GPS III generation satellites – L1C. It will be broadcast on the same frequency as L1 C/A (1575.42 MHz carrier), but it will be different. It is planned that Galileo and other civilian constellations will broadcast the L1C code, which will enable greater interoperability (GPS 2014; Hofmann-Wellenhof et al. 2008: 336, Tab. 9.5; Madry 2015: 55). In the last decade other GNSS systems have been developed, such as a European Galileo (since 1994) (Hofmann-Wellenhof et al. 2008: 365-395), Russian GLONASS (Hofmann-Wellenhof et al. 2008: 344), a Chinese BeiDou 2/Compass (since the 1970s) (Hofmann-Wellenhof et al. 2008: 401-403), a Japanese QZSS (Hofmann-Wellenhof et al. 2008: 409-413), and an Indian IRNSS (Hofmann-Wellenhof et al. 2008: 414). The accessibility of different constellations create an opportunity for GPS receivers to integrate all the systems together. Recently, several teams have argued that the development of triple frequency GNSS or availability of different constellations will cause the Real-time Precise Point Positioning (RT-PPP) to be an alternative to RTK (Choy et al. 2015; Rizos et al. 2012; Ye et al. 2016). This method of positioning is not new; however, its development was possible due new capabilities.

After 2020, we are expecting gradual changes. The recently published 2017 Federal Radionavigation Plan confirms that when L2C and L5 signals are available in 24 satellites the transmission of the codeless/semi-codeless signal will be gradually stopped. It is planned that L2C signal will be coded in 2023. In 2024, the full constellation carrying L5 signal will be achieved, which will be followed by transition to coded signal. The L1C will be also coded (DoD / DHS / DOT 2017: 58-59, 105). According to published data, it will force equipment to be changed to receive these new coded signals (Hegarty 2017: 217).

In next seven years we are going to face a new era of GNSS. This will definitely have an effect on the GIS community. From the perspective of contemporary problems of financing archaeological projects, it could have a negative effect. In our opinion, it could trigger the bigger emphasis on the use of L1 C/A capable receivers. The discussion on the future of mobile GIS from the perspective of smartphones seems inevitable. Yet, it dangerous to speculate whether the availability of L1C signal will be beneficial in smartphone technology or not. This sector of the market will keep developing through the next decade though (European GNSS Agency 2017: 6, 7, 10-12).

It is obvious that some problems should be taken into account. First of all, the GNSS receiver is stacked together with other receivers in smartphones (Bluetooth, WIFI, 3G) in one chip. The design of those chips has to face the problems of energy consumption and demand of miniaturization together with the performance of other functions (Gramegna et al. 2006; Kadoyama et al. 2004; Uvieghara et al. 2004). The review of papers indicates that currently the indoor positioning is more important than outdoor capabilities in cities. This is achieved by use of gyroscope, compass, accelerometer, A-GPS and Wi-Fi-based positioning (Hsu et al. 2016; Vaughan-Nichols 2009; Zhao 2002). For a long time, however, there was no need to develop the GPS chips in order to use different GNSS constellations or signals in smartphones. But, recently this became necessary and the chip architecture that could handle different GNSS constellations was created (Mair et al. 2015). Perhaps, the better performance of L1C signal indoors and in cities could trigger the creation of cheap smartphone chips too.

Even though the development of GNSS is still in progress, nowadays, archaeologists can use receivers with accuracies ranging from 5 m to 1-3 cm. The regular handheld GPS receivers can have the accuracy of 3 m, which with smartphones and tablets (about 5 m) (Zandbergen, 2009), fill about 99% of the market. While, cheap GIS tools with SBAS are able to reach 1.5 m, most of the sellers also provide additionally paid post-processing service, which give further improvement to sub-meter accuracy. Also, for precise measurements RTK and RT-PPP can be used. It is unclear how the future development of GNSS

will change the available accuracy or influence the preference of specific surveying methods in archaeology. It is clear, however, that less time-consuming techniques of prospection than RTK or RT-PPP are needed for the regional survey (Gill et al. 2018).

Within the spread of GPS in archaeology several factors are important when we compare the past and current possibilities. First is the price of the receiver in accordance with its accuracy. Initially, the price of a GPS receiver for civilian use was ca. 20,000 U.S. dollars (Hofmann-Wellenhof et al. 1992: 122). The price decreased, but until 2000s early survey projects had to deal with high equipment prices and low accuracy caused by SA. Nowadays, however, the 5-10 meter GPS accuracy, which is appropriate for regional surveys, can be achieved with cheap devices and can be performed by users that need very little training.

Mobile GIS Tools
in Archaeological Prospection

Nowadays for field prospection, understood here as the identification and documentation of new archaeological sites on regional scale, one can choose from a spectrum of tools and applications. Since 2013 (Google 2013) a variety of software dedicated to tablets and smartphones became a main interest of developers. The new tools and software improved on site measurements and cabinet works (Campana 2016).

In 2014, Chyla and Bryk proposed a table which analysed functions of tools used during archaeological field prospection on a regional scale. They analysed three types of tools: GPS receivers (Joglekar and Sushama 2008), smartphones with mobile GIS applications (a new trend in GIS software development), and Personal Digital Assistants (PDA) with GNSS receivers. The table described possibilities of each tool with characteristics which are mostly needed by archaeologist during their fieldwork, such as: describing documented features, documenting features as polygons; changing coordinate system of documented data; the possibility to create the workflow without the need of being connected to the internet; the possibility of different users working at the same time, editing and collecting information in the same datasets at the same time; tools' battery

life (suitability for long time data collection without charging); tools' durability in the field; the possibility of connection to reference stations that could help to increase accuracy of the measurements. Other characteristics, like using your own rasters, importing desktop created data to the tool, navigation to areas of field survey or exporting documented data to the computer are not listed, because all tools have such options.

One can also observe growing interest in working with UAV and photogrammetric data in the field (including use of the LiDAR and ALS survey results). At the same time, the quality of data acquisition stopped being the main focus for the archaeologists during regional field prospection, as the tools can connect to reference stations and add corrections to the positions during post-processing work as well. Also, an external GPS for smartphones and tablets were introduced, which can propose reliable measurements for such a type of surveying (AFS 2015).

The described characteristics of tools used in regional surveys (presented in the table 1) show the biggest differences between them.

GPS

A simple handheld GPS navigator is relatively popular tool used in archaeological field prospection. It supports single satellite frequency, but it connects with many constellations and has access to SBAS. It can position the user on previously uploaded maps and allows uploading earlier prepared points. This helps to orient users in the landscape. GPS also allows collecting new data as points in any coordinate system, with short text information. It allows to export data to *gpx format, which is possible to display in GIS. Additionally, it is possible to edit, verify and update data in the GPS while still in the field. GPS allows the user to save data as points or tracks (lines). This allows marking areas of archaeological site before or during field survey. GPS works without any internet connection, but it does not allow simultaneous work of different groups and real time, export of data to the cloud or external server. The design of the tool itself was made for fieldwork, so it has high durability and usually long battery life. GPS does not have a possibility to support documentation with UAV or with photogrammetric models (Table 1).

Tool	Attributes	Polygons	Possibility to choose coordinate system	Work without internet	Groups working at the same time	Battery life	Field durability	Connecting to reference stations	Working with UAV	Using photogrammetric data
GPS	X	◊	✓	✓	X	✓	✓	✓	X	X
Application on tablet or smartphone	✓	✓	X	◊	✓	X	X	◊	✓	✓
Mobile GIS on GNSS tool	✓	✓	✓	✓	✓	✓	✓	✓	X	X

Table 1. Table represent the most important aspects of using mobile GIS and tools most often used in archaeological field prospection (based on Bryk and Chyla 2014: 23, with changes).

Legend:
✓ – function exists
X – function is not existing
◊ – function exists under special conditions

Mobile Applications on Smartphones and Tablets

There are many smartphone or tablet tools for daily or professional design. But, even the rugged GNSS tablets, specially created for the professional topographic surveys, without the external antenna, can only use L1 C/A code. At the moment, the GPS with SBAS does not occur in non-professional equipment (except handheld GPS receivers). There are some examples of wide screen GNSS tools with dual frequency, but they have to be linked with PDAs. There are many operating systems for smartphones and tablets, as well as a large variety of mobile GIS applications, working on those OS. They are already capable of using different satellite constellations; however, their inbuilt receivers do not support many of the functions. A regular smartphone, however, can function as a RTK controller when an external receiver is used (via Bluetooth) or can be used to coordinate UAV survey (Table 1).

Applications for smartphones and tablets allow locating and navigating users thanks to an inbuilt GPS (Zandbergen 2009), but it is not recommended to start the documentation without an external antenna (AFS 2015). Several types of applications with spatial capabilities could be distinguished. It is not possible to give a comprehensive list of all mobile ap-

plications, because it is a fast-developing field. There is a vast field of non-GIS applications that collect spatial data (Twitter, Facebook, etc.). The most popular types are car navigation, tracking applications used for geocaching, compass and GPS viewers, etc. The most useful types include databases with spatial capabilities, GIS applications that can visualise different spatial data but only map points and tracks, GIS applications that allow mapping different geometries, applications supporting different geodetic calculations, applications used to configure a RTK controller, conduct UAV survey or make 3D model.

Most popular applications allow preparing the dataset beforehand, which includes all geometries with attributes. However, it is not possible to change coordinate systems in the field. As a default, applications run on prepared basemaps, satellite images, and WMS services. Many of them, in order to export the data, use cloud services. Therefore, it is obligatory for those tools to be connected to internet. On the other hand, it allows different groups of researchers to work on the same project at the same time, as data is sent in real time. This is done by Wi-Fi or cellular network data transfer, which is not problematic in places which are covered by 3G, 4G, or LTE. However, problems occur when the research area is outside such zones. In such situations the application will update the data it reconnects to the network.

Data is saved in many different formats, depending on the application and is available for cabinetwork through a browser or GIS program connected to the Internet. Also, it is possible to download the data and add it to a desktop GIS. Smartphones and tablets are not durable in the field and their battery life is usually low. There is a need of additional external power bank and accessories to protect the machines. New applications for smartphones and tablets allow connecting to cameras on the UAV in real time or pre-program flight paths (i.e. DJI GO, Litchi). Also, they allow doing 3-D scanning and collecting photogrammetric data (i.e. 123D Catch).

As for software which could be used by archaeologist on smartphones or tablets, one could choose a variety of them (i.e. GoogleEarth, ArcCollector, Survey123, QField, Locus, WolfGIS, SW Maps, Mappt, to name just a few) (Sikora 2013). There are also many applications created by archaeologists (i.e. FAIMS Mobile, Archeotracker) (Ross et al. 2013; Sobotkova et al. 2015). The goal of such applications is to make field documentation workflow easier, however very often such applications are not updated. In the time when phones and tablets systems are upgrading at least every half a year, there is a danger that not regularly updated archaeological applications could become outdated. Additionally, for the same reasons, it is very difficult to describe specific applications. What we write today might not even be valid tomorrow.

Personal Digital Assistants with GNSS Receivers

This category of equipment is variously described by different vendors. The name examples include handheld GIS data collectors, handheld computers with GPS/GNSS, handheld GNSS systems, PDAs, or controllers (used in RTK). In general, they are professional rugged portable handheld devices with GNSS or GIS capabilities. Currently PDAs differ in capability within frequencies, augmentation systems, satellite constellations, CPU performance, and size. Some have single frequency and SBAS augmentation systems, others could have dual frequency. PDAs are also used as RTK controllers. This enables the user to achieve different accuracy from 5 meters through 1.5 meters to several decimetres and all the way to < 1 cm. Mobile GIS Applications

designed for PDAs seem to combine good accuracy of GPS measurements with the capabilities and comfort of use of smartphone/tablet applications. They allow the user to pre-program the interface and databases with attributes before the fieldwork but also to change them during the process. Applications like this, work the same as desktop GIS software, and they allow uploading and documenting field data as points, lines, or polygons with attributes. Additionally, it is possible to define attributes to create fast and accurate descriptions of documented sites, features or artefacts from regional or detailed scales (Chyla 2015). The coordinate systems can be chosen by the user, also the software can propose basic coordinate transformations if needed. PDAs do not have to be connected to the Internet. However, such an option allows different groups to work simultaneously on the same project (the same as applications on smartphones and tablets) or can allow working with WMS basemaps. PDAs, similar to handheld GPS, are dedicated for field work and therefore they are resistant to atmospheric conditions and their battery life is long. They can be connected to reference stations in real-time, or it is possible to post-process data after. For PDAs, UAV and photogrammetric software has not been developed; however it is possible to upload results of their work to mobile GIS applications. There are, however, PDAs working on phone/tablets dedicated systems (i.e. Trimble TDC100, Leica Zeno 20), which make it possible to use such applications if the performance of the PDA is adequate. Additionally, quality of the measurements done by such tools might allow one to support the creation of photogrammetric models or to register aerial photos (Table 1).

Summary

The table compares various tools used by archaeologists and their characteristics which are, or probably will be, most often used in the regional scale field prospection (Table 1). All of the above-mentioned tools share the need to prepare the data before starting fieldwork. The workflow focuses on proper preparation of the datasets and attributes in the office. One can notice that the workflow connected to field work with GPS, PDAs, or smartphones/tablets might differ quite a lot. Fieldwork with the use of

handheld GPS for example, seems to be still based on paperwork. PDAs and smartphones/tablets workflow is based on digital data and proposing automatic, easy workflows.

All described tools fit the current needs of archaeological fieldwork. Although smartphones/tablets and PDAs have more options for accuracy and enable one to create full descriptions of documented features

In the near future, it seems that mobile GIS software on smartphones and tablets will dominate large scale field surveying thanks to possibility of multi-user cooperation (crowd collection of data), the variability of applications, and the flexibility of workflows. Crowd data collection might make prospections faster; however, it is required to properly prepare datasets and attributes by a manager/administrator, as any changes during the work might be problematic. It is important to stress that the use of mobile GIS on smartphones separates the role of data creator and data collector. This allows archaeologists who are not GIS specialists to use applications dedicated just for their needs.

Characteristics such as battery life and field durability and precision of measurements speak in favour of GIS applications on PDAs. On the other hand, as mentioned above, tablets dedicated for topographic surveys are also available on the market, although their cost makes them less accessible. Additionally, it seems that the software developed for smartphones and tablets will become the main working tools in field surveys in general (SAMSUNG 2017; GPS World Staff 2014; Trimble 2014), as developers withdraw from upgrading software dedicated for PDAs (see Windows Mobile Life Cycle - Microsoft 2017; ArcPad Life Cycle – ESRI 2017). PDAs also have one, very important advantage. They allow full access and control over collected data, the place where it is exported and where (and with whom) it is shared. There is no need to upload data to the server. It is possible to access the data directly in the tool memory from the PC. This is available also on the tablets and smartphones; however, the process is not intuitive and automatic. This might change when smartphones become more commonly used than laptops or desktop PCs.

However, many questions arise from the analysis of the table. The most important is: are archaeologists using the full capabilities of described tools?

Conclusion and the Discussion About Current Possibilities and Future Needs

One of the main tasks of the archaeologists – localisation and mapping of archaeological heritage based on observations – has always been a challenge, especially in light of landscapes' dynamic change. Tools with inbuilt GPS become a convenience, which not only helps to position the user in the landscape but also allows for increasing measurement accuracy. They allow the user to integrate digitized archival paper documentation, marking areas of interests, documenting and mapping features in the field (Bryk and Chyla 2014: 25).

Mobile GIS allows one to document and map new archaeological sites and artefacts' distribution. It also gives the possibility of editing previously updated data. The variety of data types that can be collected is limitless. Thanks to such solutions results can be displayed immediately, analysed, and presented in final reports.

As we demonstrated, the recent developments in archaeological field survey clearly correspond with changes in GNSS technology. During the Second Wave of archaeological field survey a variety of measuring techniques were used. The problem, however, was to connect collected data with geographical coordinates. The presence of GPS was not associated with the increase of the measurement's accuracy; the main subject of the 1990s discussion among field surveying archaeologists. Since 2000, the Third Wave was connected with the geospatial revolution and the increase of positioning accuracy. As a result, the availability of data and the access to different sensors re-defined the surface survey.

With the arrival of the Fourth Wave, the main focus will be on the possibility of mapping higher number of new archaeological sites in shorter amounts of time with methods such as crowd data collection and remote sensing with the use of satellite images or drones.

So far, in our opinion, there is no Mobile GIS application that is able to meet all expectations of the archaeologists. However, there are applications created by archaeologist and for archaeologist, which are fulfilling many needs of fieldwork. Such applications do not necessarily have to have the possibility of sub-centimetre accuracy in measurement, but mostly should be flexible enough to support the different

types of data that archaeologist document, create, or use. Software should also allow for modification of database schema. New directions indicate that such tools should provide possibility for simulation works with UAVs, photogrammetric data, analyse collected information in 3D and also to display archaeological data not only for researchers but also to the public.

If the combining of multiple signals from the different satellite constellations become an everyday practise, then the smartphones will exceed the PDAs with the available capabilities. In addition to that, the ability for multiple users to collect data on the cloud simultaneously will become a common solution for large, regional scale field surveys, which are time limited. Especially if it can be done using the tool that most of us have - smartphones or tablets, there will be no need to expand budget with high cost, specialized tools. We predict that these characteristics will change not only field prospection methodology but also the data collection process. Our current work already raises questions about the roles, skills and abilities needed for not only data managers, who creates field projects as applications, but also data collectors, who will be responsible for filling out field information.

Conclusions of the session "Mobile GIS and field survey - current possibilities, future needs", as mentioned at the beginning of the paper, are strong-ly suggesting that regional field prospection will change in the near future, in connection to changes in GNSS technology. The paper broadened the topics discussed during the session. Presented comparison of available tools and their characteristics, together with current trends in GNSS technology not only shows what are current possibilities, but possible direction that archaeologist are heading to. This direction seems to lead to the fast, low cost techniques, in which role of professional GIS specialist is a manager not a data collector. The questions still need to be asked out loud, whether it is a right direction.

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