

Educating the Digital Fieldwork Assistant

Nick Ryan

Computing Laboratory
University of Kent at Canterbury
Canterbury
Kent, CT2 7NF, UK

Phone: +44 1227 827699 - Fax: +44 1227 762811 - E-mail: N.S.Ryan@ukc.ac.uk

Martijn van Leusen

Groningen Institute of Archaeology
Poststraat 6, 9712 ER Groningen, The Netherlands
Phone: +31 50 3636717 - Fax: +31 50 3636992

Abstract: This paper describes ongoing development of the FieldNote system at the Department of Computer Science, University of Kent at Canterbury (UK). A new version of this portable system for self-location, mapping, and note-taking during archaeological fieldwork was field tested in October 2000 during a systematic survey by teams from the archaeological departments of Groningen University and the Free University of Amsterdam (NL) in the Sibaritide region of northern Calabria (Italy).

In these tests, the system was for the first time used for wide-area mapping tasks, and proved to be very useful in mapping field boundaries, highland transhumance routes, and archaeological sites to a specified accuracy and in the absence of detailed up-to-date topographic maps. It also proved useful in navigation and in re-locating archaeological sites mapped in the 1960's.

The results of the SIBA2000 field tests are presented here, followed by a discussion of their significance for future field survey design and methodology, with an emphasis on the trade-off between speed of operation and accuracy. Lines for further development of the system, including improvements to both interface and functionality, are set out as well.

Key words: Field survey methods, mobile computing, context awareness, spatial accuracy, GPS

1. Introduction

1.1 Improving the efficiency and accuracy of field work procedures

Modern field walking surveys have become increasingly labour-intensive both because a higher coverage rate (often with total collection of artefacts) is now thought to be essential, and because more stringent demands are now put on the precision and accuracy of field recording methods. The management and analysis of modern survey data within GIS requires the accurate mapping of large numbers of small collection units so that minor variations in the densities of all material categories can be detected. The processing of large numbers of, often undiagnostic, finds puts a strain on the ceramic specialists. In some recent surveys, the overall speed has slowed to as little as 1 hectare per person/day spent in the field; there is therefore a need to improve efficiency by any means available.

Modern survey practise also requires the accurate mapping of collection units, and the detailed recording of environmental variables which may influence the finds circumstances ('visibility conditions'). Collection units are usually mapped directly onto a large-scale topographic or cadastral map of the survey area, using existing landmarks for orientation, and a series of forms is normally used to record information about the collection unit and the finds made in it. Forms are also used to

track finds through the various pre-processing steps and the specialist classification stage into storage. The information is later transferred from the forms into a DBMS. In current practise, a certain number of errors, omissions, and illegal entries is unavoidable because maps may be incorrectly interpreted or outdated and hardcopy forms cannot prevent erroneous or illegible entries; further errors may (and will) arise where the procedure requires a transcription step. Procedures based on independent self-location and direct digital data entry should prevent most types of errors from being made.

Finally, modern field surveys are multidisciplinary. Typically, geopedological research and a study of historical maps and records will take place in conjunction with the field walking. In many cases it would be helpful if the information collected by each of the participants were available to the others in the field. For example, archaeologists might want to steer away from areas where the geopedologist has mapped severe erosion or deposition, and might want to have 19th century maps available in order to correlate finds distributions and landscape features to the pre-industrial landscape. In practise, this is hardly ever possible because the additional hardcopy maps, if they are available in time, are too cumbersome to carry about in the field.

1.2 Development of a digital Field-Work Assistant

A potential solution to this problem presented itself in the form

of digital Fieldwork Assistants (dFA's) based on small handheld computers linked to GPS receivers. One such system that has been developed to address the requirements of a range of field sciences is *FieldNote*. This originated in a project that set out to examine the utility of "context-aware" systems as fieldwork tools in a range of disciplines, including archaeology and ecology (Ryan *et al.* 1998). A context-aware system is one that actively monitors its working environment, or context, and adjusts its behaviour according to changes in that context. Contextual input may be supplied by the user, or derived automatically from internal or external sensors.

FieldNote includes several modules that work together to monitor context and trigger events under user-defined conditions. Essentially, they provide context-aware and communications services to support a range of applications designed to meet specific fieldwork requirements. The most frequently used modules are the *LocationTracker* and *ContextClient*. *LocationTrackers* exist in various specialised forms designed to work with different proprietary GPS receiver protocols as well as the widely used, but limited, NMEA protocol. The *ContextClient* handles network data exchange between handhelds and other machines.

Note taking and mapping modules *FieldNote* and *FieldMap* build upon this infrastructure to directly support the fieldworker's recording and navigation needs. *FieldNote* uses the context services in two ways. Firstly, when recording information, it automatically tags all records with additional context, including the current location, derived from a GPS receiver, the date and time, and the user's identity. Secondly, whenever the context of a recorded note matches the user's current context, that note will be 'triggered' and its contents displayed on-screen. Although many criteria might be used in matching recorded notes to the user's context, proximity of location is most commonly used. When the user approaches the location of some previously recorded information, it will be brought to their attention.

The notes, together with background maps and other data, may be displayed using the *FieldMap* program. This uses information from the context service to keep its display centred on the user's current location and to select which map layers (note symbols or cartography) are displayed.

This system had originally been developed for the now defunct Apple Newton, and a similar, but conceptually simpler, set of programs, the Stick-e-note suite, had been developed and tested on early Palm Pilot devices. These had been evaluated in several field trials with archaeologists from Southampton University (Ryan *et al.* 1999a) and ecologists from Manchester Metropolitan University (Pascoe *et al.* 1998). These early trials confirmed the essential utility and potential of the system and, in 1999, work began on a new version of the system based on the experience gained in these trials.

Previous versions had all been implemented using what was, at the time, the most appropriate language for the target device: NewtonScript for the Newton and C/C++ for the Palm. To ease portability between different hardware platforms, this new version was written in Java and has been successfully implemented

on a variety of handheld devices including those based on Windows CE and EPOC operating systems, as well as laptop and desktop Windows, Macintosh and Unix machines¹.

The note taking software had previously used either plain text or HTML formats for storage and exchange between handheld and desktop. Although some experiments in using XML based formats for data exchange had been carried out, this aspect of the system was not extensively developed (Ryan *et al.* 1999b). The new version provided an opportunity to fully implement these areas with the aim of simplifying the process of exchanging data between handheld field computers and either a remote server, or a laptop or desktop machine at the survey team's base.

One of the main strengths of *FieldNote* is that the user can carry their own and other researchers' georeferenced data around in the field. Their current location is always available, either as raw coordinates or as a moving cursor on a map display. This facility becomes particularly useful when there is a need to confirm earlier work or to re-examine an area of interest located by another member of the team. Potentially, this might be exploited to provide continuity between successive seasons of work in the same area.

An opportunity to test the new version of *FieldNote* came when, in the spring of 2000, a survey team composed of staff and students from two Dutch universities (University of Groningen and the Free University of Amsterdam) prepared to conduct a three week survey campaign in October of that year, near the village of Francavilla Marittima in the Sibaritide region, province of Calabria, in Italy.

1.3 The SIBA2000 campaign

The Sibaritide is a small alluvial plain on the Ionian seacoast, named after the Archaic and Classical Greek colonial town of Sybaris. It is surrounded by the limestone massifs of the Pollino and Sila ranges, and its margins are formed by a series of terraces of marine and fluvial origin mostly composed of pebbly sands and conglomerates, dissected by the wide pebble beds of several seasonal rivers. Early archaeological research in the area concentrated on the rediscovery of the Greek colony of Sybaris and its Pan-Hellenic and Roman successors (Thurioi and Copia), which are now covered by up to 6 meters of alluvium. Later, archaeological interest expanded to include the larger indigenous settlements and sanctuaries surrounding the plain, and the University of Groningen became involved in research at the indigenous hilltop sanctuary of Timpone della Motta and its nearby necropolis (Kleibrink 1993, 2000). Next to the small number of sites being excavated over the decades, the wider regional archaeological record was mainly created by in a large-scale survey conducted by Lorenzo Quilici and his teams in the late 1960s. These surveys, mapped at scale 1:10,000 but available only at the published scale of 1:200,000 (De Rossi *et al.* 1969), were intended to provide the context for the ongoing excavations at Sybaris and its successors. Largely targeted at the Hellenistic-Roman landscape, these data were more recently complemented by a regional compilation of pre- and protohistoric sites supervised by Renato Peroni (eg, Peroni & Trucco 1994).

The SIBA2000 fieldwork campaign forms part of the wider Regional Pathways to Complexity (RPC) project running at the University of Groningen and the Free University of Amsterdam (for an overview, see Attema et al. 1998). Its main objective was to assess the quality of the existing archaeological record in preparation for an analysis of the regional settlement history in the light of processes of centralisation, urbanisation and colonisation occurring from the Iron Age onwards. Specifically, it was unknown which fields and areas had been visited by the Quilici teams, and whether the large-scale clustering of sites visible in the Quilici maps might be related to differences in the accessibility and surface visibility of agricultural fields in the 1960s. It was decided to approach this objective through a systematic survey of a representative section of the transitional landscape unit (see figure 1) using both intensive and extensive methods. This would allow us, on the one hand, to check the recorded size, location, and interpretation of the sites mapped by the Quilici teams (plus one site mapped by Peroni) and, on the other, to collect the distributional data needed to establish the presence and nature of any spatial patterning in the extant archaeological record. A preliminary report on the campaign is in preparation (Van Leusen in prep).

As in previous RPC project surveys, an important objective of the fieldwork was to develop appropriate and efficient survey methodology for the local circumstances. The Sibaritide was known to be relatively poorly mapped in a series of 1:10,000 scale map sheets produced in the 1950s, and parts of the survey zone were expected to contain few if any topographical reference points by which collection units might be located and sites relocated. Hence the decision to experiment with the *FieldNote* system developed by Ryan and his team for efficient and accurate relocating and mapping of fields and features. The system was expected to be particularly useful in a subsidiary project being carried out at the same time as the main survey. This aimed to relocate and accurately map protohistoric settlements and caves in the hinterland and to map subrecent transhumance routes from Francavilla Marittima into the mountains of the Pollino massif (see figure 2). This project was carried out by a small team under the guidance of local speleologist/archaeologist Nino Larocca.

Prior to the SIBA2000 campaign, the new version of the *FieldNote* system had received only limited testing in familiar environments and by users who were experienced with its predecessors. The XML-based mechanisms for exchange of data between the handheld devices and base system had yet to be tested with large volumes of data. Experiments with the archaeological use of earlier versions had all taken place in relatively well mapped areas and within clearly constrained areas, typically within, or very close to, the boundaries of large urban sites. The SIBA2000 project provided an opportunity to evaluate the new system on a significantly larger geographical scale under poorer map control, and with a group of users who were not familiar with the system or its predecessors.

This campaign also provided an opportunity for the first significant testing of the system following the decision by the US military to remove the deliberate degradation of GPS accuracy known as Selective Availability (SA). This change took place on May 1st 2000 with the effect that even simple handheld GPS

receivers improved their apparent accuracy from around +/- 80m to better than +/- 10m. Previously we had needed either to use an additional receiver for live differential correction, or to record raw satellite range data and to post-process all GPS measurements against data from fixed base stations in order to remove the effects of SA. There was a need to evaluate whether the recently improved accuracy obtainable with simple equipment was sufficient for a range of fieldwork needs.

2. The Field Tests

Field tests of the dFA during the SIBA2000 campaign were conducted in a range of conditions, from extremely mobile recording of movements and observations during a survey of highland transhumance routes, to the detailed recording of grids during intensive survey. The results of these tests are described and evaluated in the following sections.

2.1 Highland Survey: the Recording of Transhumance Routes

Since the indigenous societies of southern Italy are assumed to have had largely pastoral lifestyles into the early Iron Age, the presence of late prehistoric and early protohistoric remains was to be expected both in the foothills and in the mountainous hinterland of the Sibaritide, and possibly correlating with sub-recent transhumance corridors. In preparation for the design of an appropriate research proposal, the team decided to test the kit by walking along some of these routes (see figure 2), making digital notes of archaeological material found along the way while at the same time recording accurate locations for a number of known highland prehistoric settlements and cave sites. The equipment functioned as expected, and a large number of observations, including georeferenced photographs, were recorded along routes running from the foothills near Francavilla Marittima toward the highland villages of Alessandria Carreta and San Lorenzo Bellizi. These included observations of Hellenistic farmsteads (up to 1000m asl), junctions of transhumance routes, subrecent structures relating to pastoralism, natural springs, potential locations for pollen cores, cave sites, and even individual sherds. The GPS trails of these surveys are depicted in figure 3; figure 4 gives examples of notes taken at such observation points.

2.2 (Re-) location and Recording of Sites

The capabilities of the dFA system for wide-area mapping tasks were tested during the SIBA2000 campaign by using it to relocate sites mapped in the 1960s by the Quilici teams, and by tracing agricultural field boundaries and centroids and circumferences of archaeological sites to a specified accuracy. In the absence of detailed up-to-date topographic maps for the area, the latter test was of direct practical utility to the survey team, as it turned out that the infrastructure of roads and tracks had changed considerably over the years and changes in land use and ownership had resulted in the removal of microrelief and old field boundaries.

Thus, in many cases it was no longer possible to relocate sites mapped more than 30 years earlier by reference to mapped landmarks only. In contrast, the use of the dFA as a navigation

instrument allowed existing sites (the positions and identities of which had been pre-loaded onto the kit) to be relocated in a straightforward manner. Both the map layer containing the Quilici sites and the operator's current position were marked on the display, and with the kit set to respond to the operator's current geographical position, nearby sites were brought to our attention by a beep followed by a display of the site's database record.

Only a few field and site boundaries were digitally recorded, but this was enough to show that the system functioned well. However, it was noted that the current procedure for tracing field boundaries on foot is inefficient, and alternative methods should be explored (see section 3). The digital recording of the centroids of ceramic scatters using a single GPS reading with an attached note, which only involved previously tested functionality of the dFA, again was a trivial exercise.

It should be noted parenthetically that the criterion used to draw site boundaries during the SIBA2000 survey was a simple finds density drop-off, and the reason for recording these boundaries was not analytical but practical, enabling easy and reliable relocation at a later stage. It is recognised that the concept of 'site' has come under attack from many quarters in recent years, and that future surveys may choose to ignore it altogether, preferring instead to record collection units at higher resolutions and accuracies.

2.3 Recording of topographic reference points and collection units

Doubts about the quality of the available topographic maps and about the possibility of accurately mapping gridded collection units were the main reason for including measurements of topographic reference points in the SIBA2000 fieldwork. Separate measurement grids, consisting of square units approximately 50 by 50 m (0.25 hectare) in size, were set up in preparation to surveying (groups of) agricultural fields, and cardinal points in each grid were located in reference to these topographic landmarks. As the survey grids were established using a combination of sighting and pacing methods in sometimes difficult terrain, we felt it would be a good idea to obtain additional GPS measurements of the grids; accordingly, in some cases the locations of the canes used to mark the corners of collection units were also recorded using the dFA. All grids, landmarks, and GPS positions were mapped on field maps at a scale of 1:2000. Each of these field maps was later digitised along with its GPS points, and the latter were used to calculate a simple 1st order georeferencing transformation².

Although having a large number of GPS points, with attached notes, available during GIS processing did allow us to resolve some mapping problems, it was found that the procedures described above were insufficient for obtaining the desired mapping accuracy for many of the collection units. Where a large number of corners of collection units had been measured by GPS, the collection units could be mapped directly, without having recourse to transformations of the field maps. But for most field maps only a small number (from 3 to 8) of GPS points had been taken, and it proved impossible to 'rubber sheet' some of these onto the relevant GPS points in a satisfactory manner

– apparently because there were too many internal distortions to the survey grids. Figure 6 gives an example of the problems encountered.

The georeferencing of the field maps brought to light other problems as well; in a few cases GPS points were so poorly placed for georeferencing transformations that additional points had to be constructed using plane geometry. In others, the inherent (standard) locational error of the GPS points confounded our attempts at georeferencing. Clearly, we have to rethink our approach in this regard (see discussion in sections 2.4, 2.5 and 3.1).

2.4 GPS Accuracy

During the SIBA2000 survey, we experimented with three types of GPS measurements at different levels of accuracy:

1. For most readings (eg, field boundaries) speed is more important than accuracy, so we took the readings on the move or even set the equipment to continuous logging, which typically yields positions with a standard error better than 7m.
2. For field reference points (topographical landmarks, cardinal survey grid points) our experience suggests that the accuracy should be increased to 2 to 3m by taking several minutes for each reading.
3. For base reference points the accuracy can be increased even further to about 1 to 2m by leaving the equipment to record a position for several hours.

Figure 6 shows a plot of GPS measured points collected over a period of nearly six hours at the Francavilla Marittima museum on the morning of 26th October 2000. The antenna was fixed to the top of a ranging rod which was then attached to the south-west corner of the railing at the front of the museum. Measurements were collected at approximately 10 second intervals for a period of about three hours. The antenna was then moved to the south-east corner of the railing and a further three hour sequence of measurements was recorded.

The observations at the western point were made at a time when the geometry of the visible satellite constellation was near-optimal, and are probably indicative of the best that can be achieved with a stand-alone single-frequency receiver. Those at the eastern point include a period of poor geometry and the re-establishment of position following a failure of the GPS receiver battery. They are probably more typical of average reception conditions. However, the introduction over the next few years of additional satellites to provide Wide Area Augmentation Systems (WAAS), primarily to support improved aircraft navigation, can be expected to bring typical performance into line with the better results seen here from the western point. Although a single receiver can be now used to obtain the level of spatial accuracy required for archaeological surveys, it comes at the price of reduced measurement speed. It is also clear that "mission planning" software, which predicts the number of visible satellites and the quality of their geometry, still has an important role to play. However, the combination of extended point occupation times and the need to avoid periods of poor geometry, which may amount to one or two hours of the working day, hardly contribute to streamlining the fieldwork process.

For our second and third types of measurements there remains a case for using differential techniques to improve accuracy without sacrificing speed.

The accuracy of GPS measurements made by a single receiver can be significantly improved using differential methods (DGPS). In its simplest form, this involves using satellite-receiver distance measurements taken by another receiver at a known fixed location. Details of the orbital position of a satellite can be obtained as part of the satellite signal, so it is possible to calculate the difference between the measured and "correct" satellite-receiver distances. These differences can then be used to correct measurements made by a roving receiver. This simple technique effectively removes the measurement errors due to atmospheric effects on the propagation of satellite signals. With two receivers separated by only a few kilometres, accuracy can be improved to +/-1m or better. More complex techniques involving signal carrier-phase measurements may be used to improve this to sub-metre levels. All this can be achieved using inexpensive single-frequency GPS receivers; greater accuracy requires the use of purpose-built and much more expensive dual-frequency 'survey-quality' equipment.

Real-time differential correction services are available in many areas. These include freely available signals from coastal beacon stations, intended for maritime use but often available at a considerable distance inland. Their main benefit is as a source of reliable correction data for inexpensive GPS receivers intended primarily for navigational use. Typically, the error in individual position fixes can be reduced to around +/-3m, increasing with distance from the beacon station. Various commercial services are also available, but these usually broadcast encrypted signals for which payment of license fees and a special receiver and decoder are required.

If live correction is not required, much better results may be obtained by post-processing recorded measurements against full measurement data from a second receiver. In many parts of the world, there are stations operated as part of the International GPS Service (IGS, igsb.jpl.nasa.gov) which make records available on a daily basis. For many areas, this is an invaluable source of highly accurate data. Unfortunately, the nearest observatory to the SIBA2000 survey area is at Matera, some 100 kilometres to the north. This distance is towards the upper limit of baseline distances for reliable corrections.

In view of the limited correction quality obtainable by post-processing against data from distant observatories, a further option would be to operate our own base station at a fixed location throughout the survey. This would require a dedicated computer and GPS receiver at the project base, recording continuously whilst survey teams were in the field. Given a maximum range to the edges of the extensive survey area of no more than 5 km and to the furthest point of the highland survey of about 15 km, position accuracy relative to the base station of between one and two metres could be expected by this method. In addition, long duration observations would help to significantly improve the absolute position of the base station by comparison with data from an observatory such as Matera. Clearly, for those applications where the accuracy requirements

are higher than what can be achieved with a single receiver, the last option would give the most satisfactory results. It is, of course, still a post-processing option so would not offer any improvement in the real-time positioning in the field but, as already mentioned, this does not appear to be a high priority because *FieldMap* provides sufficient accuracy for the field-workers' location needs. Should it become necessary, corrections could be broadcast from the base station and received at the rovers by using conventional wireless-modem transceivers.

2.1 Spatial accuracy and the problem of identity

With the advent of accurate GPS location (and even before that with the increasing use of accurate field equipment) a peculiar problem has begun to haunt archaeologists: conflicts between field measurements and existing cartography. The position of topographical features as measured by GPS may not agree with their position as mapped on the most accurate available maps³. In the case of the SIBA2000 survey, this problem expressed itself in many conflicts between the GPS positions and the 1:10,000 scale topographic map; since the latter already had a bad reputation we 'resolved' the conflict by believing the GPS data to be the more accurate. On the other hand, some disagreements between paced distances on our field maps and GPS-measured distances could not be resolved at all because they were larger than could be explained by the standard GPS error. Using differential GPS or taking redundant readings suggest themselves as potential ways out of such conflicts. From this, and our problems in attempting to georeference the field maps, we learnt that field mapping methods based on estimates of distances and bearings are insufficiently precise in the kind of rolling terrain encountered in the Sibaritide foothills.

With respect to the sites mapped by the Quilici teams in the 1960s, the same problem was expressed in a more archaeologically relevant set of decisions. How much disagreement should we allow between the notional and measured locations of sites, before deciding that the two are *not* identical? Given the small scale of the published map data from which we had to work, it will not come as a surprise to learn that many Quilici sites were relocated up to 50m from their notional location. With larger disagreements it is no longer clear whether we have relocated an existing Quilici site, or have found a new one. While efforts continue to locate the Quilici's original 1:10,000 scaled field maps we may still hope that some of the remaining conflicts will be resolved.

3 Further work

Development of the dFA is ongoing; further work is needed to improve the functionality of both hardware and software components, and the user interfaces. The system should be able to deal with a range of fieldwork tasks under various field conditions, and should be to a large extent configurable by the user. In the following section we discuss plans and potential for further work on the functionality of the current dFA kit, on customising it with additional hardware and communication features for survey work, and on improvements to user and networking interfaces.

3.1 Enhancing current functionality

The functionality of the system as tested during the SIBA2000 fieldwork should be improved by some fairly straightforward changes to both hardware and software components, as outlined below.

Firstly, current systems are not well adapted to typical Mediterranean field conditions. Although monochrome screens work well, colour displays are preferred for situations where multiple map layers are displayed. Unfortunately, most colour displays are dependent on backlighting and are difficult to read in direct sunlight. Manufacturers have been slow to realise that a mobile device might be used outdoors, but a solution may be found in some newer PDA models with partially reflective screens intended for outdoor use.

Data input is typically by an on-screen virtual keyboard or character or handwriting recognition software. Although the recognition systems are much improved when compared with those available on early handheld devices, these are still relatively slow processes, particularly for users who have not had considerable practice. The main interfaces of the *FieldMap* and *FieldNote* programs have been designed to minimise the amount of written input and, with large buttons and other controls, most interaction can be performed using a fingertip, making the pen almost redundant. This facility needs to be extended to the options screens, and we anticipate further development based on the Minimal Attention User Interface (MAUI) devised in earlier work (Pascoe *et al.* 1999). This employed large input controls that could be driven by the user's thumb, thus enabling one-handed control of the software.

Simple use of voice actuation for selections from a constrained list of options is worth investigating as well. Recognition and automated transcription of voice input is not yet possible on these devices but, with rapid increases in computational power, may become available in the near future. In the meantime, we will investigate the use of the built-in voice recording capabilities of the PDA for adding voice notes as an alternative to text input.

Recording of geometric elements such as lines and polygons was a feature of earlier versions that was omitted from the new version because of development time constraints. Although the necessary data is recorded as part of the track log, restoring explicit user control of the geometry associated with a note is now a high priority.

Software should also be developed to facilitate conducting various types of 'gridded' surveys. The simplest option would be to record the locations of unit corners as they are being set out by the survey team, but more helpful alternatives should also be made available. For example, the system could be set to indicate the locations of unit corners at specified intervals and bearings from a given origin, or it could simply track the ground covered by teams as they work and warn them at specified intervals that a new unit is required. A major advantage of locating collection units in any of these ways, at least in rough and poorly controlled terrain, is that the spatial error is non-cumulative. Overall error can never be larger than that of an

individual GPS point – about 5 to 10 m. A second advantage of the latter option is that the time consuming stage of setting up survey grids can be largely skipped, leading to greater efficiency.

A third area in which the functionality of the system may be improved is in the ease with which data can be exchanged between kits and with the project's base computer systems. Properly defined XML-coded data formats will ensure that information can be exchanged and downloaded, stored and edited easily, and can be accessed by web servers and browsers (see section 3.3).

Lastly, a number of minor potential improvements to the functionality of the system were identified during the SIBA2000 experiments:

- Addition of several simple utility functions, to allow, among other things, on-screen measurement of distances and bearings using the pen
- The readability of the display may be further increased by the addition of line and area symbols for monochrome display (eg, dotted lines for grid edges, thick line for paths; dithering for images such as air photos), and by the use of transparency when displaying icons.

3.2 Hardware and Communications

If the paper recording trail is to be obviated altogether by the digital recording equipment proposed here, then one further step should be taken – the use of a barcode reader to link bags of finds to collection units. Handheld computers with attached barcode readers have been in use in archaeological excavation and survey since the mid-1980s, and the addition to the system of a barcode reader on a CompactFlash card is trivial.

A downside of the current system is that it can only record GPS locations of the kit itself, forcing the operator to walk along the features that are to be mapped. The mapping capabilities of the system would be clearly enhanced if it were possible to record the locations of distant features as well (eg, suitable areas for further work, caves seen in cliff faces). The time consuming and often strenuous task of following field boundaries could also be replaced by either of the following methods:

- by manual on-screen mapping as proposed in section 3.1, using a georeferenced large-scale topographic map as a reference; in this case the position of the features is estimated; or
- by attaching laser range-finder binoculars, which allow the measurement of distance and bearing. Commercially available models can be as accurate as ± 2 m at distances up to 2000 m.

As the functionality of the digital fieldwork assistant increases, more hardware components are added, leading to a shortage of ports. Many components require a serial connection so not all of them can be connected to the PDA at once without some form of intermediate switch; and even if they can, the additional cables and connectors make the system increasingly cumbersome. Even with a well-designed harness to keep these under control, there is an ever-present danger of catching cables on trees and other obstacles. We feel that the most practical solution to these problems lies in the adoption of wireless (ra-

dio) communications between system components. Ideally, each device would contain its own radio and would collaborate with the others to form a 'Piconet' or 'Body Area Network'. The long-awaited arrival of Bluetooth devices (www.bluetooth.com) which are intended to support short range (<10m) wireless networking may provide a solution.

An ever-present concern with mobile equipment is battery life. Battery technologies are improving but this is at least partly offset by increasing power demands as handheld computers become more powerful. The major limitation here is that most manufacturers design their systems for occasional and brief usage, whereas field computers are typically used more frequently and for longer periods. Many devices that are aimed at a consumer PDA market do not have adequate battery life for a full day's work in the field, particularly when heavy use is made of their serial interface to receive GPS data. Other similar machines intended for industrial/commercial use are, however, equipped with higher capacity batteries that have proved equal to our demands.

The power requirements of GPS receivers have reduced considerably in the last few years as manufacturers strive to develop receivers that can be embedded in other equipment, such as PDAs and mobile phones. At present, a few receivers are available in PC card format, and smaller CompactFlash devices may appear in the near future. Whilst these have the advantage of reducing the number of cables used in the system, they rely on the PDA as a power source and therefore put an additional strain on its batteries. Whilst we intend to experiment with integrated components such as these, it will probably remain necessary to carry spare or external battery packs to support the combined load.

Communication for data exchange between handheld and desktop machines typically uses serial or wired Ethernet connections. For those devices capable of using PC cards, local communication over a range of about 150m is possible using conventional 'Wireless Ethernet' cards. As yet, however, no such card is available in the CompactFlash format more commonly supported by PDAs. Away from the team's base, mobile phones provide a suitable communication medium, provided that there is adequate network coverage in the survey area. In uncovered areas, other devices such as wireless modems might be used.

The main limitation of current mobile phone technology as a data transfer medium is cost. At the time of the SIBA2000 campaign, data calls on GSM digital network still required the pretence of analogue transmission and hence the use of a modem. As a result, the exchange of any amount of data, no matter how small, requires a lengthy negotiation phase as the modem attempts to establish a connection with an ISP. It is this rather than the low data rates (typically 9600bps) that constitutes the main limitation. *FieldNote* transfers often involve sending and receiving only a few hundred bytes, but long connection times mean that any transfer takes a minimum of about 70 seconds.

Since the SIBA2000 campaign, several telecom networks have begun to roll-out a GPRS service. Whilst still using the basic GSM technology, this provides a fully digital connection, sim-

ilar to that of ISDN systems, albeit at a much lower data rate. The mobile phone can maintain an 'always-on' IP connection to a network server and charging is by data volume rather than usage time. Initial experiments with such a system in the UK suggest that this may become a viable communications medium for future field campaigns. Over the next few years, further developments are scheduled. The next major advance will be the so-called 'third generation' networks which will offer far higher data rates (up to 2Mbps) and the possibility of live multimedia and video links.

In parallel with infrastructure developments, a convergence of mobile phone and PDA technologies is under way. Eventually, the question of whether to add mobile communications to our field tools may become irrelevant as these will be part of the normal function of a PDA.

3.3 User and network interfaces

Extending the functionality of the PDA in all the directions suggested above will require some rethinking of its user interfaces, which will have to allow full configuration of task and display options and efficient ad hoc switching between tasks and displays. As more intelligent use of the system will require the simultaneous display of more different types of information and the availability of more options on a limited screen size, the design of intuitive and effective user interfaces will become essential.

A complex multi-component system will also require extensive configuration. Here we envisage that the design phase of a typical fieldwork project would include the preparation of configuration scripts which are uploaded onto each individual kit. An on-screen menu will then give access, firstly, to the list of available configurations (tasks such as 'create new grid' or 're-locate features'), and secondly, to a list of the configurable variables for that task (e.g., 'set grid size' or 'set alert distance'). The configuration data can also specify which options will be available as on-screen buttons and/or as voice actuated options. Given that the system already contains components for handling data exchange in XML format, and that XML techniques for managing software configuration are becoming widespread elsewhere (see, for example, Austin *et al.* this volume), it is likely that this approach will be used to provide these configuration scripts.

At present, we see on-line communications between field crews as something of a luxury, but it has the potential to significantly improve the reliability of the system. If newly recorded data is rapidly mirrored on a remote server, we can overcome the ever-present fear of losses arising from device failures in the field. There may also be benefits in making preliminary environmental and archaeological maps available to crews as they are produced. As the costs of use and features offered by the mobile networks become more favourable, we anticipate exploring ways in which such connectivity might be exploited, particularly as the field teams are already carrying mobile phones for voice communications.

Work is also under way to provide a mechanism for automatically generating a web interface to notes, maps and photographs

recorded in the field. This has the obvious benefit of making the field data accessible in a widely used form but, with on-line field communications, it would enable all participants in the field, at the campaign base, and at their home institutions to have direct, near real-time, access to the progress of the campaign. This opens up the possibility of 'remote' specialists taking part in the field work, for example providing determinations of enigmatic finds.

Further development of the desktop data management tools developed for the current and earlier versions of the *FieldNote* system is required. At present, these tools support conversion to and from appropriate GIS data formats and simple display and editing of data collected in the field. A revised version of the desktop component should include facilities for managing the configuration scripts discussed above. We envisage that responsibility for the dFA will become part of the Data Manager's task, and that procedures for the acquisition and distribution of data on dFA's will need to be fully integrated with the broader survey design.

4 Conclusions

The experiments described here have confirmed the potential of the dFA system for both speeding up field recording procedures and reducing the number and size of errors made during the recording process. The system's potential for easing navigation and the sharing of information during surveys has not been fully explored, but our experience in (re-)locating archaeological sites mapped in the 1960's indicates that it will also prove useful in that area.

With the limited enhancements to functionality discussed in section 3.1, and the further improvements to the standard accuracy discussed in section 2.4, the system can profitably be used in any type of archaeological survey. With full technical and procedural integration of a professional version of the kit into fieldwork methodology, along the lines suggested in sections 3.2 and 3.3, dFAs will begin to transform fieldwork practise. This will require further extensive testing of system components, software, and field procedures.

In recent years, the use of professional GPS surveying equipment in archaeological fieldwork has become much more popular (cf. De Wulf *et al.* 2000a,b), and some teams are adapting commercially available products in order to obtain GIS-like capabilities in combination with GPS (Johnson & Wilson n.d.). These high-powered approaches, while providing very high accuracy and versatility, require considerable expense and highly skilled personnel, and cannot provide a true field information system⁴. The advantages of the digital Field Assistant system described here over such alternative approaches can be summarised as follows:

- Inexpensive - it is possible to fully equip a fifteen to twenty person team for the price of one typical professional survey kit;
- Immediate feedback - the data collected in the field are made available for use straightaway in a process contributing to and enhancing the available pre-loaded data, rather than being taken away for later processing

and use. They can also be made context-aware, presenting themselves actively rather than passively as in field GIS;

- Portability and unobtrusiveness - the equipment weighs very little, will fit in your trouser or vest pockets, and requires very little training. It is designed to avoid distracting the user from the tasks at hand;
- Utility - the equipment, as envisaged, performs typical and frequently occurring archaeological fieldwork tasks such as setting out grids, mapping collection units and points of interest, and recording finds information.

With respect to the GPS component of the system, the availability of a good location device is a crucial feature in the recent shift in emphasis of archaeological survey work away from the well-mapped and well-controlled coastal zones of Italy, to the more rugged and less well-mapped inland zones. For archaeological applications where the accuracy requirements are higher than what can be achieved with a single receiver, the addition of a GPS base station for differential correction would give the most satisfactory results. Post-processing, of course, would not offer any improvement in real-time positioning in the field but so far we have not identified any reason why this should be a high priority. Should it become necessary, corrections could be broadcast from the base station and received at the rovers by using conventional wireless-modems.

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End notes

1 In practice, we have not achieved the full platform independence potentially offered by Java. The WindowsCE version of FieldNote used in this campaign was in fact written in *waba* (see www.wabasoft.com), a Java-like language with its own libraries and independently developed virtual machine. Despite these differences, a high proportion of the code is common to this and the pure Java versions.

2 For these operations, we used PC Arc/Info; all other processing took place under GRASS 4.1.

3 This was noted, for example, when geophysical survey grids were very accurately positioned with the help of differential GPS at the buried Roman town of Wroxeter (Van Leusen 1998).

4 ESRI offer the field mapping system ArcPad (which runs under Windows CE); Trimble offer the Pro XRS system with Asset Surveyor and Pathfinder Office software for use on notebook computers. This will view and edit pre-loaded maps and interface to ArcView for subsequent query, analysis and presentation. Total cost for this system, used by the Australian Paliochora-Kythera Project APKAS to map survey units and landscape/archaeological features and to upload and correct the data in ArcView at the end of each day, is \$12K. De Wulf et al. (2000a,b) investigated the use of survey quality GPS in an archaeological topographical survey of the Thorikos region in Greece, concluding that it is more than twice as efficient as a total station (EDM) survey but also twice as expensive at the highest accuracy class; moreover, the processing, quality control, and interpretation of GPS measurements required a higher degree of skill than was needed with a total station.

Figures

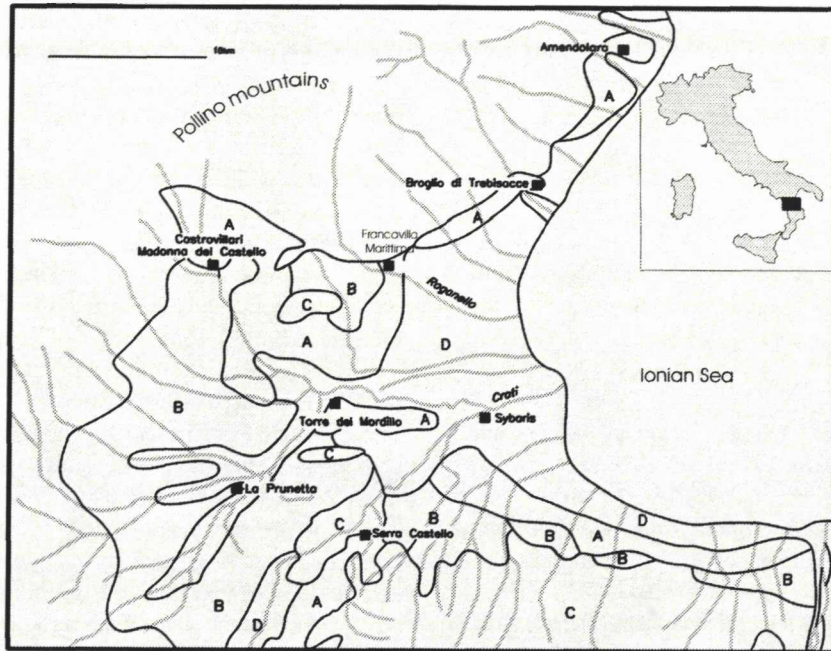


Figure 1: Major landscape units of the Sibaritide. The coastal and alluvial plain (D) is surrounded by a series of marine and fluvial terraces (A) which merge into the lower slopes of the Pollino and Sila ranges (B).

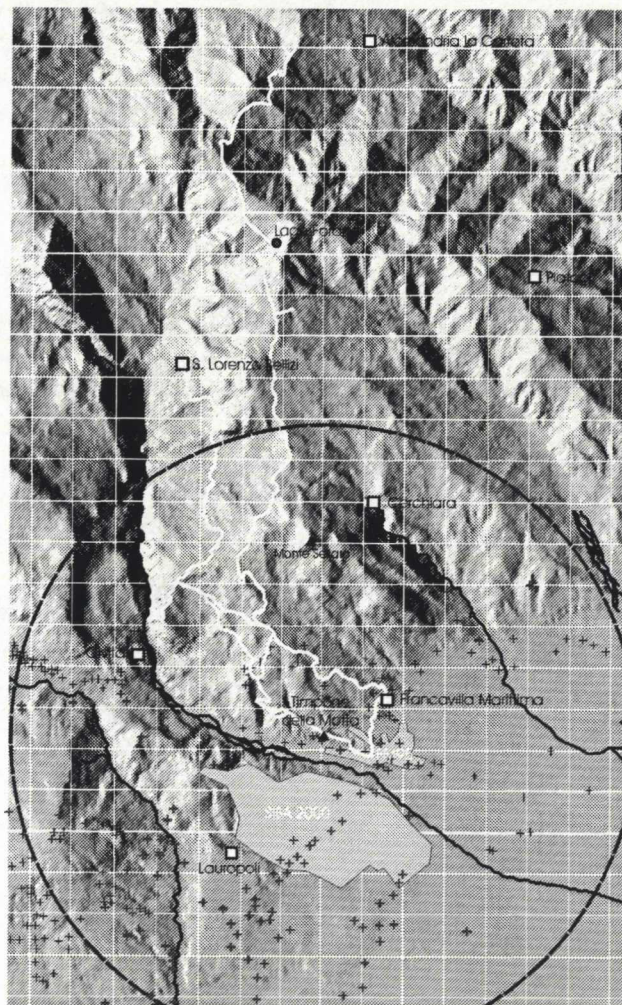


Figure 2: The SIBA2000 survey zone centres on the Late Iron Age to Hellenistic hilltop sanctuary at the Timpone della Motta de Francavilla Marittima, under excavation by the Groningen Institute of Archaeology since 1991. The locations of the survey areas, GPS tracks of highland survey, and Quilici sites are indicated. Grid size: 1 km.

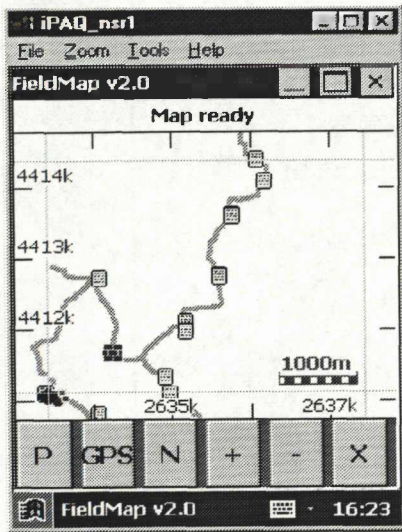


Figure 3: PDA window with GPS trace and observation points for exploratory highland survey along a transhumance route.

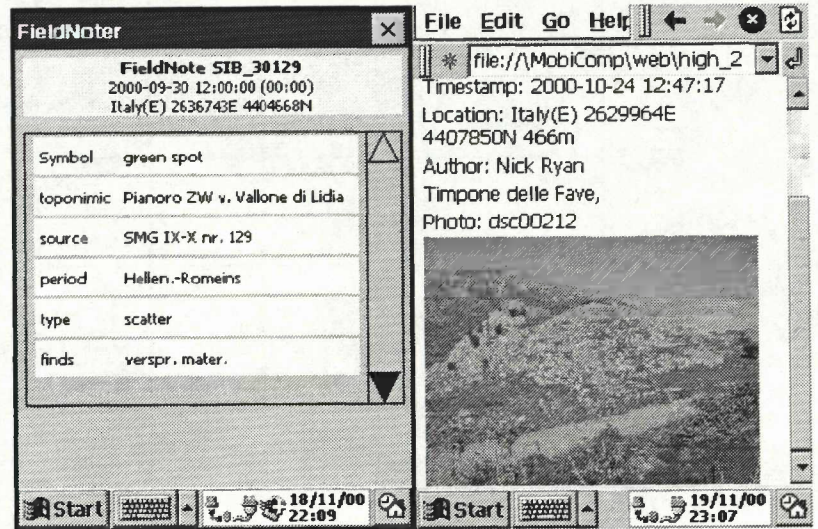


Figure 4: Examples of archaeological FieldNotes: (a) popup note for Quilici record no. 129; (b) a georeferenced photographic note.

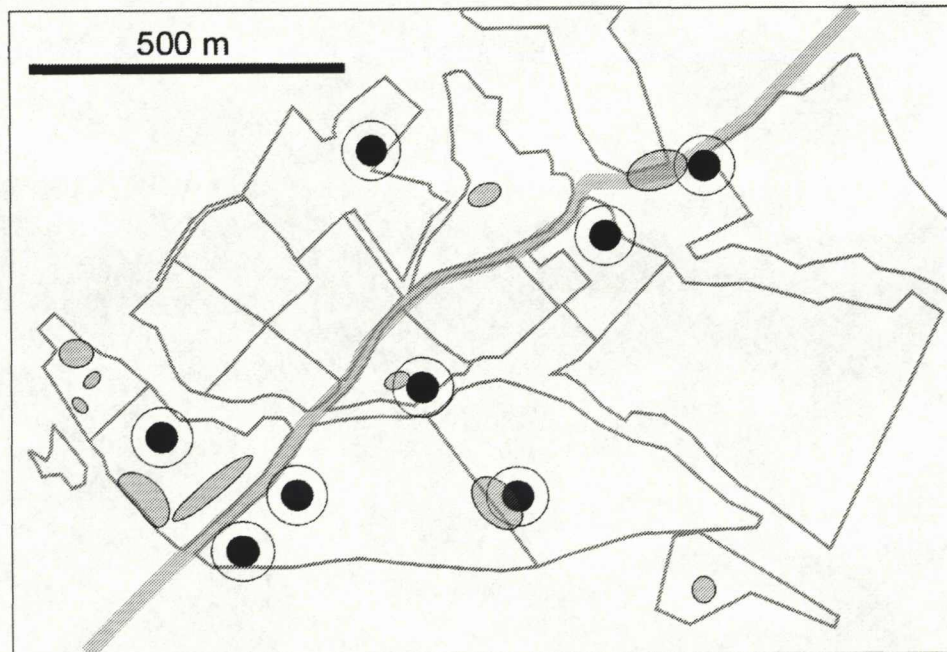


Figure 5: Detail, showing disagreements between notional and actual positions of sites. Quilici site locations as derived from De Rossi et al. 1969 are indicated with 25m and 50m radius; approximate shape and location of RPC surface scatters is indicated by grey ellipses.

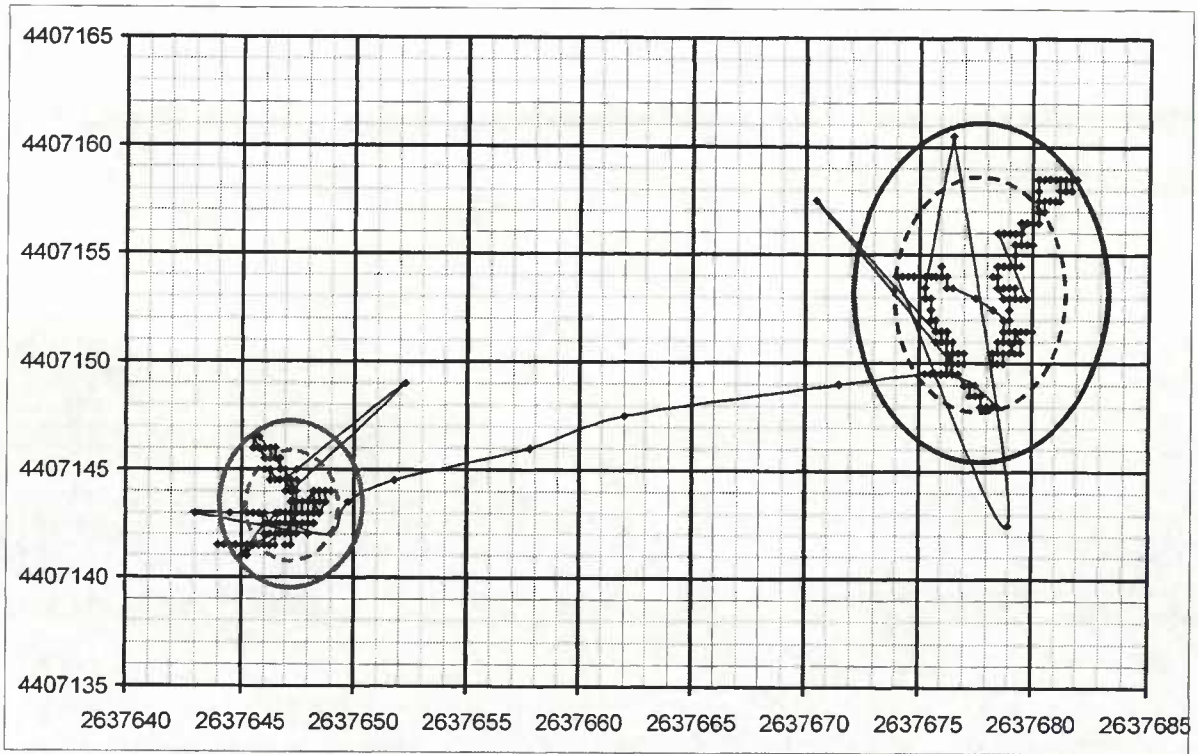


Figure 6: GPS measurements of the two ends of the Timpone della Motta site museum balcony, illustrating the accuracy obtainable with a single receiver (Trimble SK8). Ellipses indicate 1 and 2 SD of location. Interval: 10 seconds, duration: 6 hours.