Smart Environments for Cultural Heritage

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Abstract

This paper outlines a vision of Smart Environments for Cultural Heritage. The concept draws on research in an area variously known as Ubiquitous Computing, Pervasive Computing or Ambient Intelligence, which is recognized as one of the current grand challenges for computer science. Smart environments depend on communication and cooperation between numerous devices, sensor networks, servers in the fixed infrastructure and the increasing number of mobile devices carried by people. By adapting their behaviour to shared contextual information, applications may provide information and services tailored to their users' immediate needs.

Location is a key ingredient and many potential applications will rely on the fusion of multiple spatial models based on containment, proximity or relative positioning, as well as conventional absolute positioning. Applications in the Cultural Heritage domain range from field survey and excavation, through analysis and interpretation, conservation and preservation, to public presentation. Indeed, the domain has already proved to be a popular test bed for several experimental systems.

The approach is illustrated using FieldMap, a tool designed primarily for capturing and sharing archaeological and other data in the field, but which contains components that are applicable to a wider range of CH uses. This wider applicability arises because FieldMap is an application of the MobiComp ubiquitous computing infrastructure. MobiComp has been designed to support the capture, sharing and re-use of contextual information across a wide range of mobile and networked devices.

1. Introduction

The research area variously known as Ubiquitous Computing, Pervasive Computing or Ambient Intelligence derives much of its inspiration from Weiser's vision [1] of a third age of computing beyond the current 'Personal Computing' paradigm and the growth of the Internet. The vision is characterised by the ubiquitous presence of networked computing devices, on the person, in vehicles, in the fabric of buildings, in consumer products, etc. We are already some way towards this with embedded processors and mobile phones greatly outnumbering conventional computing devices but, in our present environment, only a minority of these devices are networked and even fewer are more than minimally interoperable.

In this imagined future, we will interact directly with only a small proportion of the devices around us. Unlike today, where the computer is often the centre of attraction, many of these devices will be peripheral and will disappear into the environment where they will provide information, services and control functions as and when they are needed.

In the ubiquitous paradigm, a personal computing environment should be truly personal in that it accompanies the individual wherever they go and whatever they are doing. It should not, however, be limited to the capabilities of our conventional desktop or laptop machines. Instead, it should also be able to adapt to its immediate environment and to make use of location-specific services. Equally, the environment should be able to adapt to its occupants by offering services that most closely correlate with their needs.

In this paper, the research background of adaptation through context-awareness is discussed in Section 2. In order to adapt their behaviour, devices must have access to appropriate contextual information. MobiComp, an experimental support infrastructure for storing, managing and retrieving contextual information is described in Section 3. The infrastructure has many potential applications in the cultural heritage domain ranging from initial data capture through to public presentation. One such application, FieldMap, is a simple handheld GIS intended for rapid data collection in the field and is discussed in Section 4. Section 5 outlines several possibilities for cultural heritage applications of MobiComp, FieldMap and related software. Conclusions are presented in Section 6.

2. Context-aware computing

Context-aware computing is an important aspect of ubiquitous computing in which the interaction with a computer is driven by externally derived or implicit context. There has been a broad scope of topics in context-aware computing, such as understanding of context, software architecture, interface design, infrastructure, sharing context, and privacy and security [2]. Technologies and applications focus on the sensing, capturing, presenting and modelling of context [3].

The notion of context-aware computing was first proposed in the early 1990s. The Active Badge system [4], probably the first context-aware application, was published in 1992 and Schilit [5] introduced the term "context-aware" in 1994. Dey's definition and discussion of context remains widely accepted today:

Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the *interaction between a user and an application, including the user and applications themselves.* [6], [7].

In practice, context includes a spectrum of information from the relatively static user preferences and device capabilities through to dynamic input from environmental sensors. Anhalt *et al.* [8] argue that a ubiquitous or pervasive computing environment must be context-aware. Brown [9] discusses software design to ease the creation of context-aware applications. Other early works defining context and the development of context-aware applications can be found in several surveys [11], [12], [13], [5].

Location-awareness has been an especially popular sub-area in context-aware computing. The technologies used are mainly short-range infrared, ultrasonic or radio signals for indoor applications, and Global Positioning System (GPS) receivers outdoors.

Many examples using location as a key aspect of context illustrate the idea of smart environments in which information and services applicable to immediate local needs are emphasised. Examples include services such as Conference Assistant [13] which sought to provide timely information suited to an attendee's interests, or tourist and visitor guides, such as Guide [14], Cyberguide [15] and C-MAP [16]. There have also been interesting developments in smart houses [17], particularly applications targeted at elder care [18], and of more direct relevance to cultural heritage, smart museums and cultural sites [19], [20], [21].

A key ingredient in building context and location-aware services for smart environments is an infrastructure for managing and disseminating contextual information. The next section describes the MobiComp infrastructure developed at the University of Kent.

3. MobiComp

Building on earlier work in context-aware field recording tools [22], [23], the MobiComp infrastructure was developed to support context sharing in a range of mobile applications [24], [25]. The current version provides a simple Java API for building distributed ubiquitous computing and context-aware applications.

The core element of the infrastructure is the ContextService (figure 1). This represents a simple interface to a tuplespace [28], [29], extended with event notification. It acts as a store for context elements and enables coordination between the components of context-aware applications. The approach here is similar to that employed in several other ubiquitous computing support infrastructures, for example the Stanford Event Heap [30]. The storage components behind the ContextService interface may be configured to support different scales of context-aware applications: for simple, stand-alone, applications, for multiple applications on a single device, or for distributed storage. In the latter case, servers at well-known addresses can be employed as proxies for mobile devices where their network connections (e.g. via GSM/GPRS) prevent direct requests from the Internet to the device.

The ContextService interface provides put, get and remove methods to support the tuplespace model. Registration and notification methods support an event-based model and so avoid the need for continuous polling for interesting events. In addition, a general query interface is being developed to enable clients to enquire about the content of the store, retrieve element schemas, and to extent the simple 'get' interface with general-purpose XQuery [31] requests.

Context producers (Trackers) register their availability and capabilities by putting appropriate elements into the tuplespace. Their purpose is to collect raw context data from sensors such as GPS receivers and other dynamic sources, or static sources such as configuration files for device capabilities and user-preferences. Trackers transform their input into context elements which are then put into the tuplespace.

Context elements take the form of a subject-predicate-object triple, relating an entity identifier to a, possibly complex, named context value. Additionally, elements carry a production timestamp, a default validity period, and a privacy level indicating how they may be disseminated through the ContextService. The object part of a context element may be arbitrarily complex, and different trackers might produce elements with similar names but different semantics. Equally, similar information may be packaged in different forms. As a first step towards wider interoperability, Trackers are required to supply XML Schema fragments for each element they may produce as part of their initial registration with the ContextService.

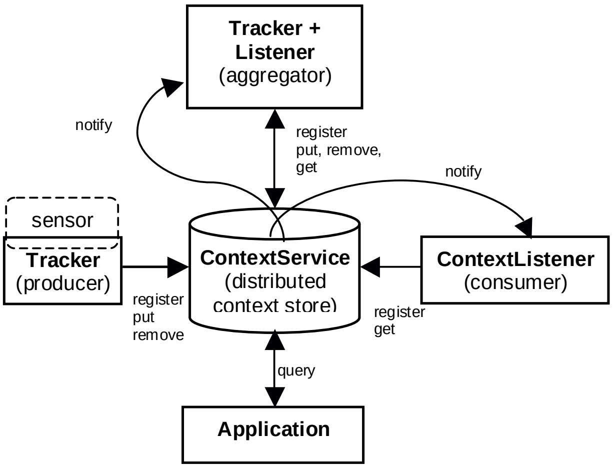

Tracker + Listener (aggregator)
notify
register put, remove, get
notify
sensor
Tracker (producer)
ContextService (distributed context store)
ContextListener (consumer)
register put remove
register get
query
Application

Figure. 1. The MobiComp infrastructure

Element communication between infrastructure components takes the form of XML documents based on the ConteXtML schema which has been developed to support the infrastructure. Typical location and velocity elements are shown in figure 2.

Treatment of privacy is extremely limited. Indeed, the privacy attribute of a ContextElement is more correctly seen as a distribution control rather than any attempt to control access to the information. Elements marked as public may be distributed throughout the context service and are therefore visible to any user of the system. Those marked as local remain on the originating device and are available to any tracker running on the device. Privacy is a pressing issue in context-aware systems that has received relatively little attention. A survey and description of work with an alternative 'privacy-aware' ubiquitous infrastructure is provided in [32].

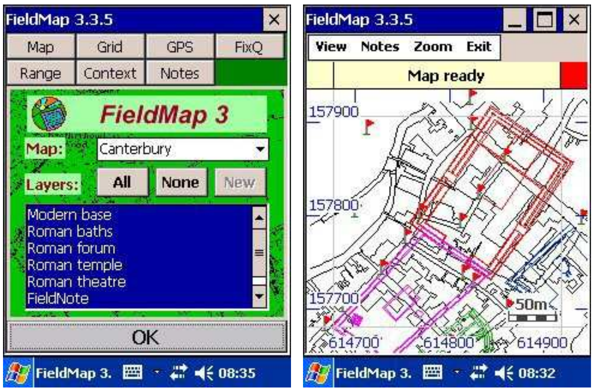
```
<?xml version="1.0" encoding="UTF-8"?>
<context
 xmlns="http://www.mobicomp.org/ConteXtML/">
 <contextElement timestamp="1074527918877"
  privacy="public" lifetime="600">
  <subject>4da941681d39c92095e73fc59f</subject>
  <predicate>location.point</predicate>
  <object type="SpatialObject">
   <spatial srs="BNG">
    <point>
     <x>614093.63</x>
     <y>159854.88</y>
     <z>75.54</z>
    </point>
   </spatial>
  </object>
 </contextElement>
 <contextElement timestamp="1074527918620"
  privacy="public" lifetime="600">
  <subject>4da941681d39c92095e73fc59f</subject>
  <predicate>velocity</predicate>
  <object type="Velocity">
   <velocity>
    <speed unit="m/s">1.4</speed>
    <dir>242.0</dir>
   </velocity>
  </object>
 </contextElement>
</context>
```

Figure 2. ConteXtML representation of MobiComp context elements for location and velocity.

ContextListener components consume context elements. They typically register an interest in one or more entities and/or particular elements and receive event notifications whenever a corresponding element is put into, or removed from, the tuplespace. On receiving a notification, the listener may get the element from the tuplespace and use it as required. Context aggregators may be constructed by combining Tracker and Listener functions. Here, the Tracker monitors events from the ContextService, rather than a sensor device, and applies a transformation before returning a new element to the tuplespace. Aggregators can perform tasks of any complexity, from simple unit conversions to combining low-level sensor elements to produce an element at a higher level of abstraction. For example, information from temperature, door, window, and light sensors might be used to determine room occupancy.

4. FieldMap, a data collection application

FieldMap is a simple handheld GIS that enables rapid data collection and shared information access in the field (figure 3). It is written in Java and can be run on desktop, laptop or, most significantly, on PocketPC and Linux handhelds. In the field, the minimum hardware requirements are a suitable handheld computer and a portable GPS receiver for sensing the user's current location. Other measuring and communications equipment may be added as needed. Bluetooth wireless connections are now the normal means of communication between these various devices. Indeed, replacing cables with Bluetooth connections has proved to be one of the most significant steps in improving usability in the field.



Map: Canterbury

Layers: Modern base, Roman baths, Roman forum, Roman temple, Roman theatre, FieldNote

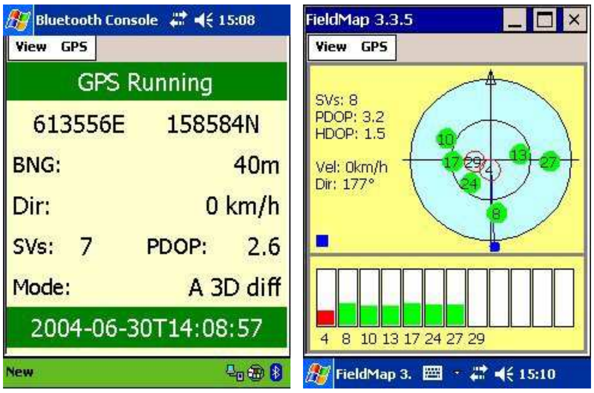
Figure 3: FieldMap layer selection and map display.

Earlier versions, e.g. [25], [26], [27], had been built as experimental self-contained context-aware systems, but the current version has been designed from the outset to exploit the MobiComp infrastructure. It is implemented as a complex context aggregator that derives information from a variety of trackers via the context service. In turn, it sends information about itself and the user's interaction with the map to the context service. FieldMap represents a good example of how a relatively complex application can be assembled using components of the MobiComp infrastructure. This in turn gives it the flexibility to work either as a stand-alone program, or as part of larger scale collaborative research environment.

A map display component overlays selected raster and vector map layers and offers conventional zoom and pan facilities. Whenever the map or area being displayed changes, information about the map – name, spatial reference system, bounding box of visible area, etc. – is sent to the context service. FieldMap receives notification of location changes from the context service, and uses these to update the on-screen cursor showing the current location. Normally, the map scrolls automatically to keep the current location near the centre of the screen.

Location data typically originates from a GPS receiver and is constantly monitored by a GPSTracker component, a specialised implementation of a general-purpose

LocationTracker The GPSTracker is a separate application that can be used independently of FieldMap, and so is able to provide information to the user through its own user interface. The interface displays the current 3D position transformed from WGS84 to the required coordinate system, UTC time, velocity, fix quality, a representation of the current satellite constellation and received signal strengths (figure 4). The GPSTracker places context elements containing this information into the context service, where it is available to FieldMap and other components.



GPS Running

613556E 158584N

BNG: 40m

Dir: 0 km/h

SVs: 7 PDOP: 2.6

Mode: A 3D diff

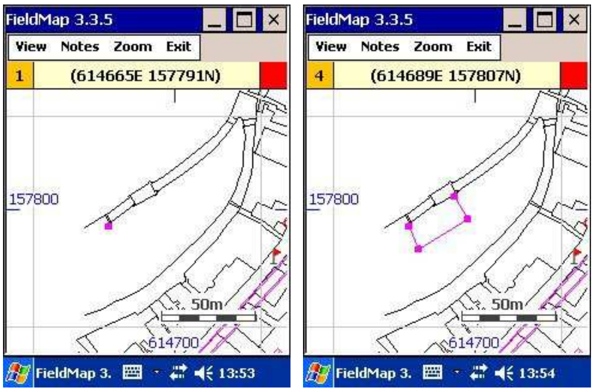
2004-06-30T14:08:57

SVs: 8
PDOP: 3.2
HDOP: 1.5

Vel: 0km/h
Dir: 177°

Figure 4: GPS tracker user interface.

If required, the user's track can be recorded and displayed as a distinct map layer. However, FieldMap's primary data capture function is to collect georeferenced notes, known as FieldNotes. FieldNotes may be created at any time and are typically associated with points, multipoint sets, polylines or polygons. The geometric component is captured either manually, by the user selecting points on the displayed map, or automatically, by capturing the GPS location at selected points. For example, a field may be mapped as a polygon by walking around its boundary and recording the location of significant points (figure 5).



1 (614665E 157791N)

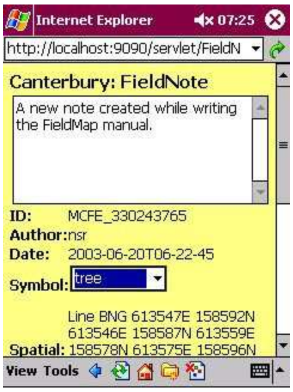
4 (614689E 157807N)

Figure 5: Capturing geometry in FieldMap**.**

FieldNotes are annotated automatically with contextual information including the location, timestamp and creator's identity. Other contextual information may be added depending on the availability of appropriate sensors and Tracker components.

For data entry, the FieldNote is presented to the user as an HTML form displayed using a web browser (figure 6). All automatically captured contextual information is already entered into the form. By default, a minimal form provides a single text area in which the user can enter notes. Whilst this is adequate for many purposes, most field surveys are better served by designing one or more note templates to match specific recording needs. Templates are simply fragments of HTML code that are included in the dynamically created form.

From a GIS perspective, FieldNotes and their associated geometry are grouped into map layers. However, in the MobiComp infrastructure, they are wrapped in context elements and placed into the context service where they become available to any other component that can make use of them



http://localhost:9090/servlet/FieldN

Canterbury: FieldNote

A new note created while writing the FieldMap manual.

ID: MCFE_330243765
Author: nsr
Date: 2003-06-20T06-22-45
Symbol: tree
Spatial: Line BNG 613547E 158592N 613546E 158587N 613559E 158578N 613575E 158596N

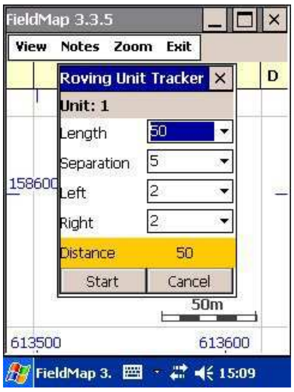
Figure 6: A web form is used to enter FieldNote data.

A FieldNoteTracker component receives notification of new notes and location updates from the service and uses these, together with any user preferences about categories of note content, to select a current set of active notes. The user may then be alerted to the presence of a nearby note, either by an audio alarm, or by automatically invoking the web browser to display the note content. FieldMap also fetches the set of active notes from the service and displays their geometry and an associated icon as an object on the map. Clicking on the object also invokes the web browser to display and, if necessary, edit the note.

4.1 Enhancements resulting from field trials

Many approaches to field survey can be accommodated by capturing appropriate geometry and using templates tailored to the data collection strategy. In normal use, the PDA and GPS receiver are carried by one member of a team who has the responsibility for determining when a recording unit starts and ends, and for entering data about materials found.

In some cases, however, it has proved necessary to develop special modules to suit specific survey methodologies. Colleagues from the Groningen Institute of Archaeology have played a major role in developing survey methodologies using FieldMap and have made significant contributions to its development and testing. Amongst these, the RovingUnitTracker provides a mechanism for capturing all data needed to describe land units surveyed by a team of walkers. The geometry of the area covered by the team is calculated from the number of walkers and their spacing which are entered into a simple dialog (figure 7). As the team moves forward, the dialog shows the distance covered. Variations on this approach enable both the systematic intensive survey of large areas using a regular grid of units, and the *ad hoc* recording of arbitrary areas of interest as they are located during more extensive exploratory surveys.



Unit: 1

Length 50

Separation 5

Left 2

Right 2

Distance 50

Start Cancel

Figure 7: RovingUnitTracker dialog used to define the parameters for a survey unit.

In the field, it is not always possible or desirable to visit every location about which information is required. For some cases, if the displayed mapping is of sufficient quality, new data may be mapped by identifying points visually and entering them manually. In general, however, more accurate results are possible using instruments that provide either relative positioning or range, azimuth and inclination measurements of remote locations. For example, FieldMap could be used for direct mapping over a relatively small area, such as an excavation site, using a total station. This approach will be developed further in future field trials.

For a more portable approach, we have developed trackers to support remote measurement using Vector 1500 rangefinder binoculars [33]. A RangeTracker component listens for input from the instrument and creates ContextElements containing range, azimuth and inclination data. When one of these elements is put into the service, a RemoteObservationTracker retrieves it and, using the current GPS location, calculates the remote location and returns another element to the service. FieldMap is then notified of this new element, and may use it in creating the geometry of a new 'remote' FieldNote. These remote notes are automatically annotated with additional contextual information including the current location and the measurements from the instrument.

Other enhancements following field experience include support for recording image, video and audio notes. The image and video recordings are made using a PocketPC camera accessory that plugs into an SD card slot. The audio recordings use the built-in facilities of a PocketPC to create a .wav file. In both cases, specialised trackers detect the new recording and generate an associated FieldNote with an embedded link to the audio or image file. This note may be annotated with additional information as required.

4.2 FieldMap in a Smart Environment

As described so far, FieldMap may be used in the field as a stand-alone tool. All recorded data is held in memory until the user returns to their base where it may be transferred to a laptop or desktop machine. Optionally, data may be read from and written to memory cards. This greatly increases reliability by avoiding data losses should the PDA battery fail whilst in the field. The battery life of mobile equipment has improved steadily over the past decade, but it is still necessary to carry a spare battery or to recharge from a vehicle or backup battery if a full day in the field is required.

Manual data transfer is straightforward and the results can be checked immediately on the larger screen of a laptop or desktop running FieldMap. However, the process is a potential source of errors and data loss particularly when managing data from multiple handheld devices.

Further reliability and opportunities for collaborative working arise when the PDA is able to use a network connection and so participate in a distributed context-aware environment. The underlying context service component regularly checks for available network connections. Whenever a network is available, all context elements marked as 'public' are passed to any of a preferred list of MobiComp servers accessible on the network. In this way, the user's location, information about their current activity, and any FieldNotes that they have recorded become available through the distributed context service.

Bluetooth or WiFi may be used to provide short-range local network connections. Alternatively, full Internet connectivity may be provided by a mobile phone. Local wireless connectivity may be exploited by running a MobiComp server on a laptop or desktop machine at a field office. Apart from the many benefits of wireless networking in a field office – access to shared printers, file exchange, etc. – a MobiComp server installation can be used to automate synchronisation, updating and sharing of information between all devices running FieldMap. Whenever a team returns from the field, the context service of the handheld machine detects the network connection and passes all of its updates to the server. At regular intervals, each mobile device requests available updates from the server so that, soon after the last machine has been brought in from the field, all updates have been distributed to every handheld. Thereafter, it is only necessary to recharge the batteries in the mobile devices so they are ready to use the next day.

A wired or mobile phone Internet connection may be shared by all networked machines in the field office. Data recorded by the mobile FieldMap handhelds may also be fed back to, and information fetched from, servers at the team's home base. The home server might host dynamic web pages that provide an up-to-date account of the progress of the fieldwork campaign, offering a central point of reference for those in the field, and their colleagues at home and around the world.

A second usage scenario is more appropriate for a small team or individual fieldworker, and for short duration campaigns where it is not convenient to establish a networked field office. In this, each mobile team is equipped with a mobile phone to provide an Internet connection. Each FieldMap system sends updates to a home server and, if more than one system is in the field, it may request updates from these other systems from the server.

When live, or at least near real-time, updates are available, a Remote Object Tracker may also be used. When this is running, it monitors location updates from selected other systems and enables FieldMap to display the most recent location, and recent track, of each monitored device.

The mobile phone based approach is, of course, dependent on adequate network coverage, but in many areas this is rarely a problem as new data may be stored locally and sent when a connection becomes available. A potentially greater problem is cost. On most networks, a single field team sending a moderate number of FieldNote updates will find this is a relatively inexpensive option. On the other hand, the cost of equipping several teams with phones and the added cost of sharing large numbers of updates between all devices may be less attractive.

A third usage scenario, as yet not extensively investigated, relies on peer-to-peer (P2P) connections in an *ad hoc* network. Here, pairs of mobile devices would exchange updates whenever they are within wireless range. Over time, information is disseminated throughout the network by indirect multi-hop routes between otherwise unconnected devices. No centralised server need be involved in such a configuration. However, if a mobile device has an Internet connection, it will eventually receive all updates from other devices on the network and can pass them on to a server. It is anticipated that the P2P approach may be better suited to applications such as excavation recording rather than field survey where devices will be spread over large areas and rarely be able to communicate with each other.

5. MobiComp applications beyond field survey

Although FieldMap has been developed specifically to suit the needs of scientific data collection in the field, it uses several MobiComp components that have much wider applications. Apart from its intended use, FieldMap itself is in almost continuous use as the mobile component of a person and vehicle tracking system (see the 'Where am I?' section on the author's home page [34]). Amongst other more conventional navigation and route-finding applications, information from this source is being used in an experimental system intended to learn and recognise patterns in individual behaviour [35].

With or without a map interface, FieldNotes are a form of georeferenced information that may be accessed using any suitably equipped device. The FieldNoteTracker component, with its ability to trigger the display of notes when their active areas are entered, provides an effective mechanism for disseminating spatial located information to the mobile user. The approach builds on earlier work that was inspired by the idea of virtual 'Post-it' notes located in 3D space [22], [23], and has been demonstrated as a potential basis for delivering tourist and other local information services [36]. Because FieldNotes are presented to the user in the form of a web page, they are not restricted to simple textual and form-based information, but may include any multimedia content within the limitations of the mobile device.

GPS location fixes, particularly when using differential corrections from systems such as the US Wide Area Augmentation System (WAAS) [37], the European Geostationary Navigation Overlay Service (EGNOS) [38] or the Japanese Multi-Function Satellite Augmentation System (MSAS), typically provide positioning within a few metres. Potentially, this level of precision may be maintained in urban and other situations where satellite visibility is restricted, by systems such as SISNet [39] where the correction data is delivered via the Internet. If greater precision is required, the GPSTracker can be used with dual-frequency survey instruments.

Whilst GPS is an appropriate location technology for most field surveys and for other outdoor applications such as tourist and site information systems, indoor applications require a different source of location data. Indeed, they may also employ different spatial models, based on containment, adjacency or accessibility. We have had some success using Bluetooth and WiFi devices as beacons at known locations. A BeaconTracker component recognises nearby wireless devices. If the device is previously unknown, it is added to a database of sightings. The database may be initialised with locations of known fixed devices, or the tracker can supply an approximate location if it is available from another LocationTracker source. Over time, the location of initially unknown beacons may be refined by multiple sightings. A similar approach is used in the Intel Research Place Lab system [40], and we are investigating the possibility of interoperation between these systems.

For many applications, including tourist and museum guides, it is important to know which direction the user is facing. Often there may be several items of interest in the immediate vicinity and it is helpful to directional information to the visitor. With GPS and some beacon-based systems it is possible to derive orientation, but normally this is only possible when the user is moving. Orientation may be derived, with varying degrees of reliability, from the user's last known direction of travel, or from sensors such as accelerometers or electronic compasses. Several forms of OrientationTracker have been developed to address this need.

Beyond strictly spatial applications, the MobiComp context-aware infrastructure has the, as yet unexplored, potential to support many other aspects of the preservation of cultural heritage. For example, it might be used together with extensive sensor networks to integrate environmental monitoring systems in preserved buildings or in museum storage and display areas. By using RFID tags, and trackers associated with suitable detectors, it should be possible to build systems that can track objects as they are moved around a working environment. This might be used in museum inventory control and for tracking the passage of objects through various conservation procedures.

6. Conclusions

This paper began by setting the background to smart environments in current ubiquitous computing research. Context and location-awareness were introduced as key elements, and the importance of sharing contextual information between mobile applications and those 'embedded' in the environment was stressed.

The MobiComp infrastructure, an experimental system for supporting distributed context-aware systems, was introduced and described. To illustrate how the infrastructure may be used in developing context-aware applications, the technical composition of the FieldMap application was discussed. FieldMap is a handheld GIS program designed to enable rapid data collection and information sharing in the field.

Several usage scenarios for FieldMap were presented as illustrations of the flexibility of MobiComp. The simplest of these was stand-alone use in which the context-aware behaviour merely assists in automatically capturing information such as location, time and user identity whenever data is recorded. At a higher level of complexity, mobile instances of FieldMap share contextual information either by direct interaction, or through fixed servers. The automatic sharing and synchronisation potential of such configurations represents a step towards smart field environments.

Finally, an outline was presented of the potential for MobiComp, and tools such as FieldMap, to support a spectrum of applications in the cultural heritage domain from initial data capture, through preservation and management, to public dissemination.

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