TSW 02-08
November 2002

Location Sensing Technologies and Applications

George Roussos
School of Computer Science and Information Systems
Birkbeck College, University of London
g.roussos@bbk.ac.uk

Executive Summary

In a matter of a few years, the Internet has been established as a popular, everyday communications tool. Its proliferation has created numerous opportunities for commerce and entertainment services which have seen exponential growth rates. At the same time the Internet has opened up opportunities for the efficient and effective management of knowledge and for enhanced learning. The emerging mobile Internet holds even more promise: with it Internet connectivity becomes ubiquitous and access to resources and people is timely and flexible. Indeed, mobile Internet makes possible the so-called mobile learning which offers the opportunity for blended training that employs both face-to-face and remote methods, available whenever and wherever needed.

Furthermore, to be successful mobile Internet services will have to be highly personalised and context aware. Location is a core component of user context and at the same time provides opportunities for user location registration and tracking. Although the use of location information has proven useful in several case studies and prototypes of mobile Internet systems, its wider applicability has been hindered by the existence of a variety of different technologies with significantly different characteristics, different infrastructure and device requirements as well as different cost and limitations. In fact, the particular properties of each system make it a suitable choice for a specific case.

This report aims to provide an introduction to location sensing technologies; a description of characteristics of location sensing systems so as to provide a basis on which to compare their capabilities and applicability in a specific context; two case studies of how location information is being used in higher education settings; and finally a sort guide on currently available systems and technologies.

Key words – location sensing, wireless networks, location based services, mobile learning, ubiquitous computing systems.

1. Location Sensing and the Mobile Internet

In a matter of a few years, the Internet has been established as a popular, everyday communications tool. Its proliferation has created numerous opportunities for commerce and entertainment services which have seen exponential growth rates, but at the same time has also opened up opportunities for the efficient and effective management of knowledge and for enhanced learning. Higher education institutions have been at the forefront of these developments and are now being offered the opportunity to enhance on-campus learning while at the same time to extend their reach to distance and part-time students.

The emerging mobile Internet holds even more promise. Internet connectivity becomes ubiquitous and access to resources and people is timely and flexible. Mobile Internet enables the so-called mobile learning offers the opportunity for blended training that employs both face-to-face and remote methods, available whenever and wherever needed. Thus, on the one hand the mobile Internet enhances the opportunities of higher education institutions to accommodate the needs of ever increasing and more diversified student populations and, on the other to extend the reach of learning activities outside the traditional campus setting.

Mobile learning can support a wide range of activities from on-the-job knowledge aids (for example, delivery of task specific knowledge context) to highly personalised collaboration tools. Indeed, knowledge availability and opportunities for learning are no longer tied to the desk or the classroom but are on demand and available anywhere, anytime. Although mobility opens up exciting new opportunities, it is also a limiting factor in that it restricts the usability and usefulness of the services provided over the mobile Internet: to best serve their purpose, mobile devices have to be small with a correspondingly small display. A further consequence of the small form factor is lower computational capability. For this reason it becomes essential that services offered on mobile devices require little or no navigational effort which further implies that the service itself should be adaptive to the needs of the particular person using the service as well as responsive to the situation that person is in. In fact, in order to be successful, mobile Internet services will have to be highly personalised and context aware. Location information is a core component of user context while at the same time provides opportunities for user location registration and tracking.

Location information can be used in two ways. In their simplest form location aware services and applications can answer questions like "Where am I?" or "Where is room 121?" and project this information on a map thus providing physical space navigational aids. Different answers to "Where am I?" may be required under different circumstances, for example in one case the suitable answer may be "On Malet Street" or in the Senate House, University of London or in room 128 of the Senate House or at $51^{o}31' 17''$ N by $0^{o}7'46''$ W at 4.5m elevation. More importantly, location can be used as a filter for the ever-increasing amount of information available to us on a daily basis. For example, when visiting a new city, searching for information on museums usually implies interest for museums within the current locality and thus the query may be augmented to return more relevant results. Both types of applications employ location information to provide a suitable context for the user activity and may have quite different requirements depending on their context.

Although the use of location information has already proven useful in mobile Internet systems its wider applicability has been hindered by the existence of a variety of different technologies with significantly different characteristics, different infrastructure and device requirements as well as different cost and limitations. The particular properties of each system make it a suitable choice for a particular case. This report aims to provide an introduction to location sensing technologies, a description of characteristics of location sensing systems so as to provide a basis on which to compare their capabilities and applicability in a specific context, two case studies of how location information is being used in higher education settings and finally a sort guide on currently available systems and technologies.

The issue of location sensing technologies is particularly timely. On the one hand, traditional telephony and Internet convergence is driven by the need for novel data services and mobility and on the other location-based service provision is readily available by cellular mobile telecommunications carriers. In the UK all major operators offer location aware services, for example Seek and Find by Vodafone which locates cash points, restaurants and tourist attractions in the vicinity of the mobile station. Furthermore, due to the recent deregulation of the necessary spectrum during the past year there has been increasing activity in developing wireless local area networks both in academia and in commercial organisations. Finally, in 2002 the E911 directive came into effect in the US which forces mobile telephony operators to provide location information to emergency services. The accuracy requirements call for 100 metres accuracy in 67 per cent of the cases for network solutions and 300 metres in 95 per cent of the cases for device solutions (the differences between the different types of information will be discussed in the following section). The European Union is currently considering similar legislation under the E112 directive.

The number of available location sensing systems makes it impossible to provide a detailed description of every one of them within the scope of this report; instead wherever suitable specific case studies are examined. The physical properties on which these systems are based would also require a separate report and the interested reader should refer to [6] for this. Finally, in the appendix a comparative chart of location sensing systems and their characteristics is included as well as some pointers for further information on particular systems.

2. Location Sensing System Properties

In this section we will discuss the characteristics of location sensing systems so as to establish a basis on which to compare their capabilities. Particular emphasis will be on the different types of location systems, the type of location information provided, their accuracy, precision, scale and scope. Location sensing technologies are most useful when coupled with spatial representations to support registration and querying. Last but not least, deployment of location-sensing technologies is associated with costs incurred in developing the required infrastructure and each technique will be examined from the point of view of the access device as well as of the required network infrastructure.

2.1 Device versus network location calculation

There are several approaches to location sensing: The most popular approach currently is when the user device performs location estimation calculations using suitable information available wirelessly; an example of such a system is the Global Positioning System (GPS). Alternatively, the network may use information emitted from the device to calculate its position, for example in GSM cellular mobile networks the operator can use timing differences in the arrival of the uplink signal from the handset to several (at least four) base stations to calculate its position. This technique usually requires no modification to the handset and is entirely performed at the network level. Finally, elements of the two methods may be combined for better efficiency and effectiveness where the device and the network co-operate to compute the position. An example of this approach is Assisted GPS (AGPS) used in cellular mobile networks, where measurements of the GPS satellite signals are transmitted from the handset to the network that can provide superior computational power and additional cell ID information to perform the calculation faster and with more accurately.

An immediate implication of the difference between the two systems is that when the calculation is performed at the handset the location information is only known locally and thus the privacy of the individual user protected. In contrast to this, when the network approach is employed then it is the network that maintains information of the location of a particular user and as a consequence the operator of such a system is liable under the data protection directive. Indeed, the mobile device can be used to track the movement of its owner and thus associate them with particular locations at particular times.

A further implication is that when a device calculates its own location it usually consumes much more power to achieve this. In practise this can have a significant effect; for example a GPS enabled mobile telephone has significantly increased power consumption since it must perform a complex calculation to estimate its position accurately as well as detect the weaker satellite signals, so that its battery lifetime is reduced from days to hours.

2.2 Location sensing technologies

There are several fundamentally different techniques that may be used to estimate the location of a person or an object. In general they can be classified in the following classes: geometric, statistical, scene analysis and proximity based. Frequently location aware systems combine these approaches to achieve higher accuracy or precision. It is outside the scope of this report to develop the mathematical foundations of location sensing and the interested reader should consult [6] for the details.

The older and more established methods employ geometric arguments to estimate location. More often than not these are triangulation arguments that refer either to distance (lateration) or angle measurements (angulation). Lateration can be used to compute location from distance measurements from multiple reference positions; for example in two dimensions location can be estimated using three non-collinear reference points and in three dimensions from four non-coplanar reference points. Different location sensing systems that use lateration for have different means to estimate the required distances. The simpler way to do this is when the distance is directly available via probing. However, it is only in special cases (robotics) when distance information is available directly and a more useful way to calculate it is using time-of-flight measurements, that is using the time that a signal with a known velocity needs to travel from a well known reference point to the particular location. This approach opens up a number of timing and clock synchronisation questions that each system that employs this approach has to address. Radio flight-of-time is the approach used by GPS which in order to achieve good accuracy has to maintain the clocks of its satellites within 10^{-13} of a second within each other.

An alternative to time-of-flight for distance measurements is the use measurements of the attenuation of a signal that is, the decrease of the signal strength relative to its original intensity. For several types of signals a function describing the expected decrease in signal strength given the distance exists and can be used to estimate location relative to the source of the signal. A system that uses attenuation in a wireless LAN environment to estimate location is Active Campus described in more detail in section 3. Finally, angulation employs similar triangulation arguments but uses angle measurements. In two-dimensional space two angle and one distance measurement define uniquely a location and in three dimensions two angle measurements, one distance and one azimuth measurement are required. Angle data can be retrieved from so-called phased antenna arrays which are currently in use in commercial aviation guidance systems in the form of VHF Omni-directional Ranging.

Scene analysis uses a suitable representation of the area under observation as well as images from the particular point of view to identify features of a scene and thus draw conclusions about the location of the viewpoint within this area. Usually, geometric representations of space are employed and image-processing techniques are used for simplification and feature extraction from images obtained through vision systems to improve performance and accuracy. However, scene representation can be other than geometric/visual: For example a model can be constructed using signal strength profiles combined from different reference points and associating particular locations of the area in consideration with particular features of the profile. Visual scene analysis is frequently used in robotics and signal strength profiling has been used in the RADAR system.

The probabilistic approach to location sensing considers the problem as one of machine learning: using signal strength data from various known locations infer a model that can be used to make predictions about the location associated with a set of new signal strength data. Building such a model involves the construction of a probability function from a histogram of training data which estimates the probability that a particular measurement corresponds to a particular position on an area profile. This technique can be improved by employing the tracking heuristic that is that if the previous location of an object is known than its new location is expected to be near the previous one after a short period of time. The Ekahau software based location-sensing system uses the probabilistic approach on different physical layer technologies including wireless LAN [8], Bluetooth [2] and GSM/GPRS.

Finally, a location can be determined as being proximal to a known reference point within a specific, limited range. Proximity can be determined either via physical contact or wirelessly. In the latter case, proximity of the object to the reference point is understood as containment within an area defined by the capabilities of the wireless access mode for example when a GSM mobile telephone registers with a particular base station (cell ID) or when an automatic identification system –most frequently radio frequency based (RFID) but also infrared or Bluetooth—records the unique identification number of the particular object. RFID systems vary widely in capabilities including range, data transfer rate and so forth. The reverse approach can also be used where the reader is transmitting proximity information at regular intervals and the device can use this information to retrieve location aware services. An example of this approach is the Cooltown beacon that use the IrDA protocol to transmit the URLs where information associated with particular locations is stored.

2.3 Physical position and semantic location

From the point of view of the type of information available location sensing systems can be characterised as either physical or semantic. Physical information provides the position of a location on a physical coordinate system, for example the School of Computer Science and Information Systems at Birkbeck College is at 51°31′ 17″ N by 0°7′46″ W at 4.5m elevation. On the other hand, semantic information employs textual descriptions of location and may be either geographic semantic, for example WC1E 7HX, or place semantic, for example on the first floor of the University of London Senate House North Block.

Whether physical position or semantic location is used the information provided may be either absolute or relative. Absolute position implies a location system that employs a shared reference grid for all located objects, for example latitude, longitude and altitude. On the other hand, a location system that uses relative positions can have a distinct frame of reference, for example near Tottenham Court Road or three metres from the traffic lights.

Of course, in many cases it is possible to transform one type of location information to the other. For example, given access to map information a latitude-longitude pair can be used to retrieve semantic information, for example 51°31′ 17″ N by 0°7′46″ W can easily be transformed to "Senate House, University of London" or WC1E 7HX. For good examples of these and other possible transformations see www.streemap.co.uk. In some cases it is also possible to move between relative and absolute position. It is straightforward to transform an absolute position to a relative one if a second reference point is available and also in many cases it is possible to use multiple relative readings to retrieve an absolute position when the absolute positions of the reference points are known.

The distinctions along the absolute/relative and physical/semantic split should not be seen as inherent system capabilities but rather as a useful abstraction for the identification of the types of information available at any one system. They also have significant repercussions for deducing derivative and higher-level spatial attributes, for example orientation (in which direction am I travelling?), velocity (how fast do I travel?) and connectedness (can I move from this to that location?).

The most common system for location sensing in use today is the Global Positioning System (GPS). GPS was developed by the U.S. Department of Defence as a satellite system, predominantly designed for navigation but currently gaining prominence as a timing tool especially in the context of cellular communication systems. GPS is based on a constellation of twenty-four satellites, six in each of three orbital planes spaced at 120º apart and three extra to provide fault tolerance as well as their ground stations. GPS receivers use the satellites as reference points to calculate geographical positions, which are accurate to within a few metres. GPS has been put into different uses including to locate ships on the ocean and to measure the height of Mount Everest. Today GPS receivers have been miniaturized to just a few integrated circuits, becoming very economical, and have found their way into cars, boats, planes, construction equipment, telephones, movie-making gear, farm machinery and even laptop computers (cf. figure 1). A GPS receiver uses time measurements relating to the arrival of satellite signals to compute the latitude, longitude and elevation of the location (figure 1a). A more powerful device (for example figure 1b) can store map data and show the computed location on a map thus transforming an absolute physical position to an absolute semantic one. It can also compute directions to selected destination thus transforming the location information to relative semantic (for example turn left at the next junction).

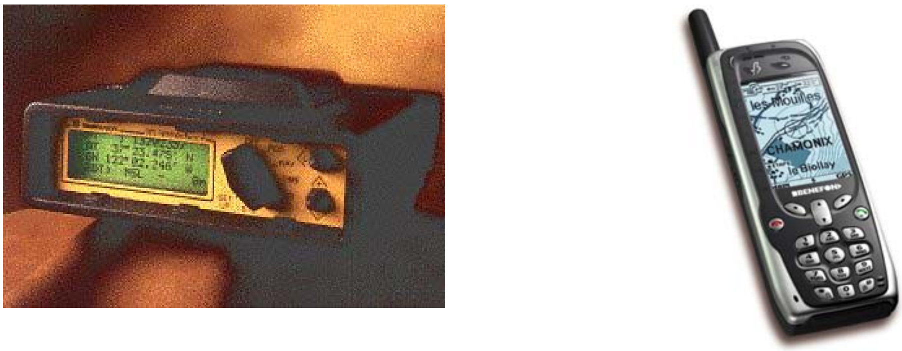

Figure 1. Portable GPS receivers: (a) The Trimble Pathfinder, and (b) The Benefon GPS telephone.

2.4 Accuracy and Precision

The examples of the previous section raise naturally the question of accuracy, for example when latitude-longitude pairs are used in the format shown at the previous section (degrees, first and second minutes) it is possible to differentiate only between positions that are at least 0.02 miles or approximately 31 metres apart. The property of the smaller distance that a system can differentiate is called the accuracy of the system. If more resolution is required, for example to pinpoint an object the size of a car or a person, then a more accurate system should be used. For example, although GPS can provide accuracy of approximately 1 to 3 metres this is not possible under all circumstances and for all devices. Inexpensive GPS receivers can only locate positions to within 10 metres 95 percent of the time. The percentage of the times that the prescribed accuracy is achieved is called precision of the system.

Accuracy and precision are often the two axes of a trade-off: less accuracy may be traded for more precision. Thus, using only one of the two attributes of spatial location is not a suitable measure for comparison of location sensing systems. Rather, location systems should be assessed on the basis of the error distribution incurred when locating objects, taking into account any dependencies, for example the required density of infrastructure (for example satellites, base stations, radio frequency readers and so on).

Although accuracy and precision are suitable measures of the effectiveness of location sensing technologies they cannot be considered in isolation to the overall system that employs location information. Frequently it is possible to combine the position data with other information available on the system to improve the prediction of location. For example, in a IEEE 802.11b wireless local area network the position of a mobile station can be estimated from signal strength readings at the base station resulting in location estimation with accuracy of approximately 4.5 meters. Using knowledge of the operating environment (including but not restricted to area size, location of walls, furniture and materials) the system can be calibrated and the accuracy of the location information increased to approximately 1 meter for the same number of base stations. This should not come as a surprise since the majority of available location systems employ some form of technology that depends on the transmission properties of either radio or ultrasound signals. Furthermore, in most cases a straightforward (albeit costly) means to increase accuracy is to add more units of infrastructure. For example, in cellular mobile systems like GSM location sensing accuracy based on cell ID can be easily increased by reducing the size of the cell. As a matter of fact, this is the usual case since cell size varies from 300 metres in urban environments to 20 kilometres in rural areas.

2.5 Other properties

In addition to the characteristics discussed in previous sections, one of the most important properties of a location sensing system is coverage that is the area in which the system can locate objects. Different location systems have very different scope varying from a few centimetres to global. GPS can be used simultaneously by an unlimited number of receivers anywhere in the world while radio frequency identification (RFID) systems can locate objects only within a few meters of the location of the reader and cannot accommodate more than a specific number of concurrent tags.

Of course, developing further the infrastructure may extend the scope of a location sensing system. For example, the coverage area of a RFID system can be extended from a single room to the whole building by deploying more RFID readers. However, the cost of the extended deployment might be considerable. Thus, when considering location sensing from the point of view of scale an appropriate measure is the number of locatable objects (for example GPS receivers or RFID tags) in the coverage area per unit of infrastructure (for example per base station or per reader).

A final consideration for location sensing systems is their limitations. Since the majority of them depend on the propagation properties of radio through space their effectiveness and efficiency is correlated to the environment. For example, in this section we noted that the scope of GPS is global. However, GPS receivers are unable to operate effectively in two situations: first, when they are in an urban canyon that is a artificial canyon structure created by very high buildings and second indoors where the signals are very weak.

3. Case Studies

In this section we review selected case studies of the use of location information for the provision of mobile learning services. The first case study is the Active Campus project at the University of California at San Diego and shows an approach for location aware service provision in the context of a traditional HE setting that is, in the classroom (via the ActiveCalss application) and on campus (via the ActiveCampus Explorer application). The second case study is Labscape a joint research project between University of Washington and Intel, which employs location information to track and record research activities in the context of an integrated electronic laboratory notebook. Finally, we discuss the Guide project at the University of Lancaster, which aims to show the value of location sensing for providing contextualised information in outdoor activities and can be used to provide support during field trips.

3.1 UCSD Active Campus

Active Campus [5] is a full scale research project at University of California, San Diego designed to investigate the effectiveness of location-based mobile computing applications in enhancing the "culture of learning" of the campus community. Active Campus was conceived as a response to the rapid growth of student numbers on the UCSD campus that has not been matched by similar growth of staff and resources.

The two main applications of the system, available using UCSD provided personal digital assistants, are ActiveClass, designed to encourage classroom participation and ActiveCampus Explorer (ACE) designed to encourage chance interactions and discoveries around campus. The design of both applications aims to foster user interactions with the physical world, not to draw users into their PDA thus leading naturally to a location aware design.

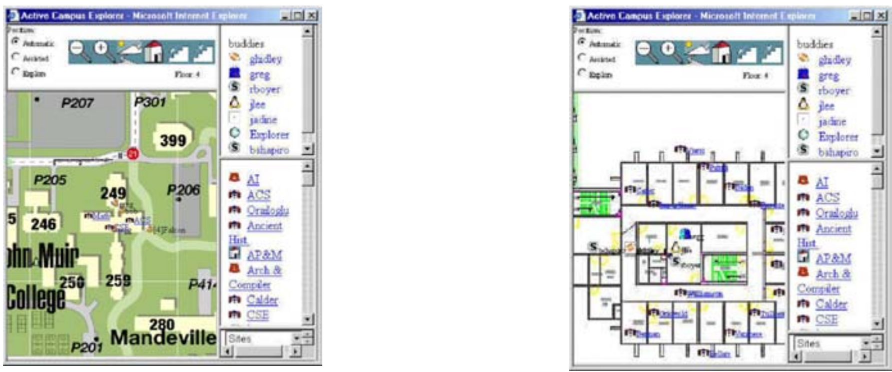

Figure 2. ActiveCampus Explorer: (a) Outdoors view, and (b) Indoors view.

ActiveCampus Explorer uses location, time, personal interests and hyperlinking to web documents to notify users of nearby interesting activities of information. For example, staff and students can use ACE to locate research labs, classrooms, instructions to the library branch that holds a particular piece of information they need and so on. ACE can also be used to locate colleagues, a fact that has raised considerable controversy and concern due to its implications for the privacy of individuals. Another aim of ACE is to make the UCSD campus "transparent" so that anybody can look into departments, labs, and libraries. Finally, ACE provides the ability to communicate with nearby colleagues using a purpose built instant messaging system as well as to use the so-called "Digital Graffiti" a means to annotate physical locations with hyperlinks to web pages, thus providing the basis for a new form of personal expression.

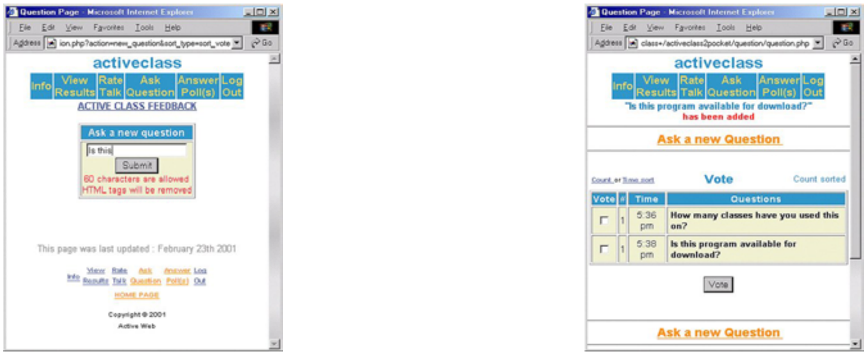

Figure 3. ActiveClass user interface and discussion aggregator.

ActiveClass addresses the problems created by ever increasing class size and diversity that reduces the quality as well as the quantity of verbal participation by the students as well as verbal interaction between lecturer and students. Students have fewer opportunities to ask questions thus reducing the feeling of intimacy with the subject matter with the immediate result that students find little value in attending lectures. Also, due to the reduced participation and opportunities to exchange of ideas and experiences students become passive and less critically thinking. ActiveClass attempts to use PDAs as a complementary channel to lectures (class members are identified by their location in a particular classroom) by broadcasting anonymously aggregated questions and comments about the class. To avoid disruption person to person communications are not supported.

3.2 UW Labscape

The Labscape project [1] aimes at simplifying cell biology laboratory work by introducing a hybrid physical/electronic workflow system that, first collects and organises data where and when they are created and then, makes this information available where it is needed. In fact, Labscape may be viewed as an extension of the traditional laboratory notebook, which produces a more complete record of experimental work with less effort and at the same time provides the basis for collaboration as well as increased individual efficiency.

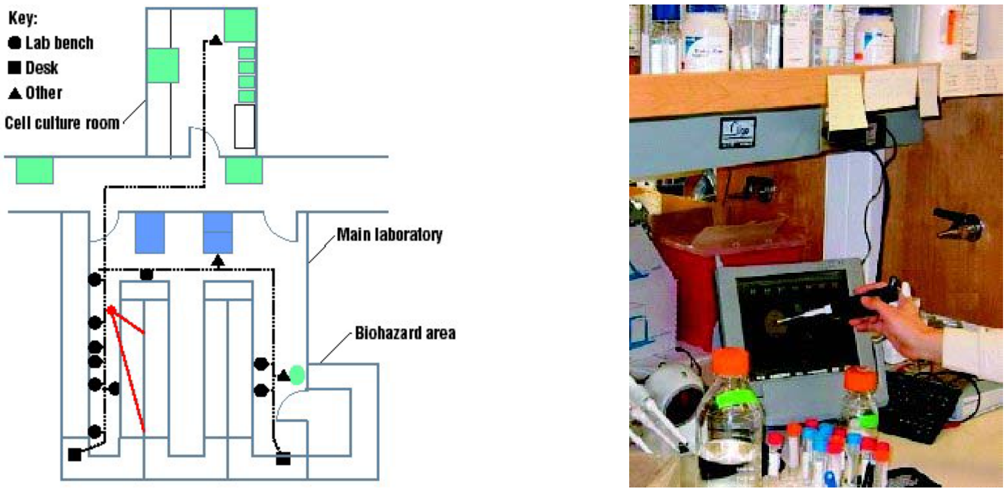

Figure 4. UW Labscape: (a) tracking a researcher during experimentation, and (b) Labscape workbench with RFID proximity sensors.

The project first addressed the requirements of laboratory work by recording in video and then analysing the working practises of researchers as well as identifyied the factors that may influence the outcome of an experiment. For example, the project team discovered that although laboratory work appears complex and the tools and instruments used are diverse, the researchers themselves perform a small number of abstract operations albeit in rather different contexts. Also, recording every detail of the experiment was crucial since it might have an effect on its outcome. Ambient room temperature, length of time before processing samples and calibration errors in particular instruments are all-important aspects of an experiment and must be recorded.

Alternative sensor technologies were considered and evaluated for their suitability in Labscape. Several technical restrictions were identified and for this reason the project opted to base the system on multi-modal interactions between the researcher and Labscape rather than aim at a completely transparent and non-disrupting experience.

Location sensing plays a central role in Labscape and is supported by a hybrid location sensing system based on proximity. Proximity to a particular object or location is sensed either via RFID badges (cf. Appendix) or via direct contact with a touch screen. Location information is used for application migration and for resource control. Each researcher in the system is given an RFID badge that uniquely identifies them. This unique identifier provides authentication for access to Labscape applications as well as triggers the migration of the user interface from one display to another closer to the position of the researcher. The project is currently in evaluation but initial evidence is encouraging.

3.3 Lancaster's Guide

The Guide project [3] at the department of computer science at University of Lancaster was initiated in 1996 and went into four weeks of trials during the summer of 1999. The project can be viewed as part of a second wave of ubiquitous computing research projects which followed the initial work at Xerox PARC and AT&T Labs in Cambridge. In contrast to the initial ubiquitous computing research projects the Guide had rather modest scope and focused on a particular case study that of context aware tourist information provision.

The Guide project differed to previous work in two significant ways, first by opting to employ off-the-self hardware components rather than developing purpose-built technological infrastructure. And second, by deploying the system in realistic rather than laboratory conditions and performing an extensive field trial with users actual visitors to the city of Lancaster. This second aspect of the project offered the first opportunity to evaluate the reaction of the wider public to the deployment of ubiquitous computing systems. The field trials were carried out with the approval and assistance of the local tourist office.

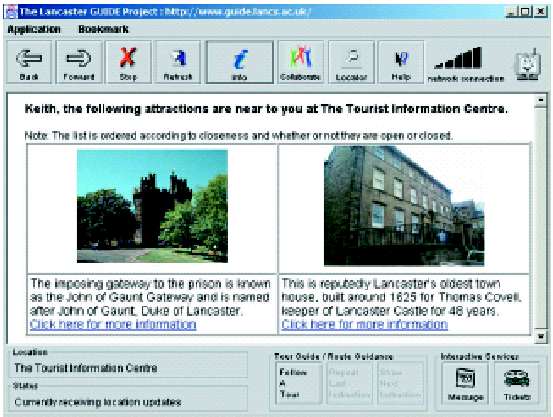

Figure 5. Lancaster's Guide: (a) user device, and (b) localised info delivery.

As note previously, the Guide system was designed to provide context aware tourist information to visitors to the city of Lancaster. The context considered was defined by the visitor's own interests which were explicitly input to the system as well as that created by tracking their movement around the city. The system was designed as an extension to a standard hypertext data model and its adaptive elements were designed to respond to the particular user profile, collected geolocation information and navigational aides. Visitors interacted with the system using tablet PCs connected to information servers over IEEE 802.11 wireless local area networks. Location information was retrieved via cell ID of the wireless LAN base stations. The wireless network covered a significant part of the city centre and the accuracy provided by the system was 200 metres.

The system was evaluated on a sample of sixty tourists the majority of whom had very little experience of using the web. Nevertheless, the users commented favourably to the concept of a location aware system and showed significant interest in its usage. Despite the low accuracy of the cell ID location sensing system that was employed the integration of location in an information system proved an interesting information navigation model. Users navigate the information space both explicitly through the Guide user interface and implicitly by their movements in the physical world.

4. Conclusions

The location sensing technologies discussed in this report are technically robust, well developed and ready to be used in learning activities. However, as shown in the case studies of the previous section, mobility is a novel computing paradigm and its integration in useful systems that support learning effectively is still a few years away. However, the use of mobility and location awareness open up novel opportunities that potentially can transform many aspects of higher and further education organisations. Indeed, mobile learning has several novel aspects[1] and a suitable pedagogy needs to be developed through experimentation with the new systems.

The emergence of next generation mobile systems --usually referred to as ubiquitous or pervasive computing infrastructures-- will be heavily dependent on location information for a variety of tasks. Ubiquitous computing refers to a pervasive "fabric" of intelligent instruments, appliances, information sources and information analysis tools all tied together by high-speed wired and wireless networks, and may include personal software service "agents" that remove the burden of constantly searching for, gathering, and analysing information in a data rich environment.

Mark Weiser introduced the vision of ubiquitous computing in the early 1990s and its implications for on-campus learning were discussed in [12]. Unlike previous technologies ubiquitous computing systems are deployed to such extend that they become an integrated part of everyday life. Although the opportunities opened up by such systems are unique there are also several significant challenges related not only to technology –which although it progresses at an exponential growth rate still lags far behind the ubiquitous computing vision—but primarily social, legal and economic. Ever small-scale research ubiquitous computing systems cause considerable stress with members of the public when invited to participate. Furthermore, even the more conservative estimates of infrastructure costs and return on investment related to the deployment of ubiquitous computing consumer systems [11] show that the wider deployment of such systems will be slow. However, of the elements of ubiquitous computing that are expected to appear sooner, location sensing is a prime candidate.

In this report we attempted to provide an introduction to location sensing technologies; a description of characteristics of location sensing systems so as to provide a basis on which to compare their capabilities and applicability in a specific context; two case studies of how location information is being used in higher education settings; and finally a sort guide on currently available systems and technologies.

[1] Mobile learning is a fragmented experience due to distractions caused by its on-the-go nature, it is highly emotional and personal and limited by the characteristics of the mobile device. See also http://learninglab.stanford.edu/projects/mobilelearning/ for other experiences.

Appendix. Location Sensing Systems Comparative Chart

Name	Technology	Accuracy	Precision	Continuous	Type	Abs	Cost N	Cost D	Scale	Notes
GPS	Radio time of flight	1-5m	95-99%	Yes	Physical	Yes	High	Medium	Global	1
A-GPS	Radio time of flight, base stations	9m	90%	Yes	Physical	Yes	High	Low	Potentially Global	2
Active Badge	Infrared, proximity	room	100%	No	Physical	No	High	Low	Room	3
Active Bat	Ultrasound, time of flight lateration	9cm	90%	Yes	Physical	No			Room	4
Cooltown	Infrared, Proximity	1m	n/a	No	Semantic	No	Low	Low	Single Location	
RFID	Radio Frq, proximity	varies	varies	No	Semantic	No	Low	Low	Single Location	
BBK Beacons	Bluetooth, proximity	2m	100%	No	Semantic	No	Medium	Medium	Network coverage	
MotionStar	Magnetic, scene analysis, lateration	1mm	100%	Yes	Physical	No	High	High	Scene	
PinPoint 3D-iD	Radio frequency lateration	1-3m	n/a	Yes	Physical	No	High	High	Building	5
Cricket	Ultrasound, RF, time of flight	4x4 ft	100%	Yes	Semantic	No	Low	Low	Single location	
GUIDE	IEEE 802.11, cell ID	200m	100%	Yes	Physical	No	Medium	Low	Network coverage	
RADAR	IEEE 802.11, signal strength, scene	4.5m	n/a	Yes	Physical	No	Medium	Low	Network coverage	
Ekahau	IEEE 802.11, Statistical	.9m	80%	Yes	Physical	No	Medium	Medium	Network coverage	6
BlueSoft	Bluetooth, microcell ID	10m	n/a	Yes	Physical	No	Medium	Medium	Network coverage	
Lessig	Bluetooth, cell ID, scene analysis	1m	n/a	Yes	Physical	No	Medium	Medium	Network coverage	
Bluetags	Bluetooth, signal strength	1m	n/a	Yes	Physical	No	Medium	Medium	Network coverage	
Blipnet	Bluetooth, signal strength, scene	1m	n/a	Yes	Physical	No	Medium	Medium	Network coverage	
Spot ON	Ad-hoc network lateration	varies	n/a	No	Physical	No	None	Low	Cluster coverage	

Notes

1. GPS does not work indoors and in urban canyons and has low accuracy in bad weather conditions.
2. A-GPS requires GSM or other cellular mobile network infrastructure.
3. Interference by sunlight and fluorescent light.
4. Dense ceiling sensor grid requirement usually implies significant infrastructure modification.
5. Proprietary solution.
6. Software only.

Glossary

2.5G	Usually refers to mobile communication systems in between the second and third generations, frequently GPRS
3G	Third generation mobile communications systems
AOA	Angle of arrival, an angulaton location estimation technique
A-GPS	Assisted Global Positioning System
Bluetooth	A family of personal area networking specifications maintained by the Bluetooth SIG
Cell ID	Identification number or string of a particular base station in a cellular mobile communications system
GPS	Global Positioning System
CDMA	Code division multiple access is an alternative to GSM
IEEE 802.11b	A protocol specification for wireless networking
IrDA	An infra red based data transmition set of standards.
GPRS	General Packet Radio Service provides mobile internet, always on connectivity to current GSM networks
GSM	Global System for Mobile communications is a standard for second generation cellular mobile
ID	Identification, usually identification credentials
IEEE	Institute of Electrical and Electronic Engineers
ITU	International Telecommunications Union
RFID	Radio frequency identification
TDOA	Time difference of arrival, the inverse of TOF where timing differences are computed from different base stations to determine the location of a mobile host
TOF	Time of flight, a lateration location estimation technique used in GPS
UMTS	Universal Mobile Telecommunications System is a 3G protocol defined by ITU
URL	Uniform Resource Locator
Wi-Fi	Wireless Fidelity -- A synonym for IEEE 802.11b protocol based networks
WLAN	Wireless local area network, used frequently as a synonym for IEEE 802.11 protocol based networks

References

[1] L. Arnstein, G. Borriello, S. Consolvo, C. Hung, J. Su, 2002 "*Labscape: A Smart Environment for the Cell Biology Laboratory*", IEEE Pervasive Computing, vol. 1, no. 3, pp. 13-21

[2] Bluetooth, Inc. 2001, *Bluetooth Core Specification v1.1*, Bluetooth SIG.

[3] N. Davies, K. Cheverst, K. Mitchell, A. Efrat, 2001 "*Using and Determining Location in a Context-Sensitive Tour Guide*", Vol. 34, No. 8, pp. 35-41.

[4] K. Finkenzeller, 1999 *RFID Handbook: Radio-frequency Identification Fundamentals and Applications*, John Wiley and Sons Ltd.

[5] W.G. Griswold, R. Boyer, S.W. Brown, T.M. Truong, E. Bhasket, R.Jay, R.B. Shapiro, 2002 "*ActiveCampus: Sustaining Educational Communities through Mobile Technology*", University of California, San Diego, Department of Computer Science and Engineering, Technical Report.

[6] J. Hightower and G. Borrielo, 2001 "*Location Sensing Techniques*", University of Washington, Computer Science and Engineering, Technical Report UW-CSE-01-07-01.

[7] B. Hofmann-Wellenhof, H. Lichtenegger and J. Collins, 2000 "*Global Positioning System: Theory and Practice*", Springer-Verlag, Vienna.

[8] IEEE Standard, 1999 *802.11 Wireless Package,* IEEE Press.

[9] S. Pradhan, C. Brignone, J-H. Cui, A. McReynolds, M.T. Smith, 2001 "*Websigns: Hyperlinking Physical Locations to the Web*", Vol. 34, No. 8, pp. 42-48.

[10] T. Roos, P.Myllymoki and H.Tirri, 2002 "*A Probabilistic Approach to WLAN User Location Estimation*", Int. J. Wireless Inf. Networks, Vol. 9, No. 3.

[11] G. Roussos, L. Koukara, P. Kourouthanasis, J.O. Tuominen, O. Seppala, G. Giaglis and J. Frissaer, 2002 "A case study in pervasive retail", ACM MOBICOM WMC 2002, pp. 95-100.

[12] M. Weiser, 1998 "The Future of Ubiquitous Computing on Campus", Com. ACM, Vol. 41, No. 1, pp. 41-42.