A simple, technology-neutral lingua franca for location systems, applied to combined indoor-outdoor navigation

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Abstract. One of the challenges in ubiquitous computing research has been that no single location sensing technology is likely ever to meet all requirements. This has led to the development of a number of technical solutions and infrastructures that attempt to hide the complexities of dealing with more than one location sensing technology behind a consistent Applications Programmers Interface. In this paper we propose a lingua franca for location sensing technologies that emphasises simplicity and universality. Our proposal is not tied to any particular location sensing technology and it can be applied to all locations, both outdoors and indoors. In addition, the paper describes a prototype navigation application that has been applied to a retail shopping scenario, in situations where more than one location sensing technology is required.

Introduction

One of the most successful and widespread pervasive computing applications has been handheld, electronic tourist guides, such as the Cyberguide system [2] and the Guide project [7]. These are examples of a more general class of navigation applications, of which in-car navigation systems and personal navigation aids for visually impaired users [20-22] are further examples. The development of so-called "location-based services" also highlights the central importance of location in pervasive computing research and development.

The foundation upon which all of these pervasive computing applications are built is a location sensing technology and infrastructure. In a review of location sensing systems for ubiquitous computing, Hightower & Borriello [16] developed a taxonomy which they intended that ubiquitous computing researchers could use to choose a location-sensing system that is appropriate to their application. They implied that at present, there was no universal location sensing solution. They proposed a number of characteristics by which location systems could be classified, which included cost, scale, accuracy and precision, and most important, the nature of the location information supplied.

In a review of future research challenges facing ubiquitous computing research, Abowd & Mynatt [3] also argued that no single position sensing technology is likely ever to meet all requirements. Their argument was founded on the diversity of characteristics of location sensing technologies and the varied requirements of

ubiquitous computing applications. This position led Abowd [1] and Pascoe [25] amongst others to argue that what was needed by ubiquitous computing researchers was a 'context information service', or a 'context toolkit' [10, 30]. Such a server would, for the location context, allow application programmers to write to a single location-aware Application Programmers Interface, rather than having to write location-system specific code to handle the idiosyncrasies of the particular location system being used. At least two such generic systems for handling context exist: the context toolkit, developed by Dey and others [10, 30], and the context information service developed by [25].

Although it did not form one of the classification axes which Hightower & Borriello [16] used, an important pragmatic consideration is whether the application is intended to work indoors, or outdoors, or both. For larger scale, outdoor applications, the canonical location sensing technology is the Global Positioning System (GPS). While there can be problems with receiving GPS signals, particularly in some urban areas and under dense forest canopies, Global Positioning Systems have worldwide coverage. In contrast, systems that are based on triangulation using cellular telephone networks work only in areas where cellular telephone network coverage is good (predominantly urban areas in developed countries). However, the latter does have the advantage that cellular telephone signals can be received outdoors and indoors. The majority of other location sensing systems require that some form of sensor grid be installed and maintained indoors [16].

In the remainder of this paper we will outline our proposal for unifying the use of location sensing systems. Rather than invent yet another incompatible location sensing technology, or another programmers' toolkit, we propose the adoption of a simple *lingua franca* to allow a ubiquitous computing system to make use of any available location sensing technology at any time. This proposal extends and adapts existing location sensing systems and technologies, and allows them to be used in novel ways, as we will illustrate and exemplify in this paper. In brief, our location sensing framework has the following characteristics:

- It is simple and does not make excessive demands of the host system.
- It uses the same, universally applicable, physical location model both indoors and outdoors.
- It is technology neutral since it is not tied to any particular location sensing system.

Our framework is founded on two premises. Firstly, that the physical location model that is used almost universally out-of-doors, namely latitude, longitude and altitude is equally applicable indoors (we will address some possible objections to this premise later). Secondly, that the NMEA protocol, that is almost universally used by GPS systems to communicate such location information, can also be used to store, represent and communicate physical location information to non-GPS location sensors and location clients, and can also perform this function indoors.

In the remaining sections of this paper we will introduce the background concepts and technologies necessary to understand our lingua franca. We will then explain how our lingua franca works before describing a prototype application that applies the lingua franca in a retail shopping scenario – real shopping, not virtual shopping.

The components of a location sensing technology

At this point it is worth making the distinction between the following components that comprise any location sensing system.

- The *technology* that is used to sense the location. This may be a Global Positioning System, Active Badges [14], Active Bats [4], triangulation from cellular telephones or any one of many other systems (See Hightower & Boreillo [16]for a review).
- The *location model* (sensu Beigl, Gray & Salber [6]) which is used to represent different locations. Different location models are implicitly or explicitly chosen according to the needs of the application. (See the workshop proceedings edited by Beigl, Gray & Salber [6] for a review.)

Location modelling

Outdoors, physical locations normally are given according to shared reference grids such as latitude, longitude, altitude, or a national map grid system. Computationally, locations given in such terms are easy to manipulate and reason about since they are usually represented numerically. Physical locations given in such terms can be translated through gazetteers, maps and other databases into geographical locations, symbolic locations [16] or semantic locations [26] which are more familiar and carry more semantic information about the nature of the location than simple physical locations.

Indoors, we have a similar richness in expressing location, though informal descriptions often predominate. Locations are usually defined relative to the building and room in which they are in, and the furniture fixtures, and fittings within the room, if necessary. In domestic homes, rooms are usually given names according to their function (the kitchen, the bathroom and so on). In offices, hotels and other public spaces, rooms are often numbered, relative to a shared reference system which is unique to each building, but which often repeats itself between buildings. Within each room, when precision is required, locations might be specified relative to other objects in the room, or according to a shared reference grid with a convenient origin. For example, positions could be given in metres relative to an origin in one corner of the room, or even the building, for applications where the interstitial spaces between rooms was important.

The Global Positioning System network

The Global Positioning System (GPS) network consists of twenty four satellites which are in orbit around the earth. Handheld GPS receivers compute their position based on timing how long it takes radio signals transmitted by the satellites to reach the receiver. Therefore, in order for the GPS receiver to be able to compute a precise location it is necessary for at least three satellites to be within line-of-sight at any one time. Unfortunately, the radio signals emitted by the satellites are too weak to penetrate buildings, unlike cellular radio and mobile telephone signals. However, practical experience gained by the authors has shown that some handheld GPS signals

are able to obtain adequate location 'fixes' when placed immediately behind single- or double-glazed windows in trains, planes, buses and buildings.

The GPGCA sentence within the NMEA0183 standard is one of the NMEA protocol sentences that contains location data. It is encoded as follows: $GPGGA,123622,5221.4978,N,00041.6687,W,1,04,2.0,90.9,M,47.8,M,,*6D	
$	Each NMEA protocol sentence must start with a "$" and is terminated by a carriage return / line feed sequence.
GPGGA	Each sentence is identified by a five letter code, consisting of a two letter device identity (GP stands for Global Positioning System), followed by a three letter sentence identity.
123622	The time (defined in UTC) at which the fix was taken.
5221.4978,N	The latitude: 52 degrees, 01.497 minutes North.
00041.6687,W	The longitude: 000 degrees, 42.668 minutes West.
1	The quality of the location fix (0 = invalid, 1 = valid)
04	The number of GPS satellites that were used to obtain the calculated position.
2.0	The 'horizontal dilution of precision'. This is an estimate of the magnitude of the error that may exist in the calculated position.
90.9,M	The altitude, in metres, above mean sea level
47.8,M	The height, in metres of mean sea level, above the WGS84 datum (one of the models used to describe the shape of the Earth).
,,	Two consecutive commas with no space between them indicates a missing data field. In fact there are two missing fields in this sentence because there could also be a data field between the final comma and the * of *6D. These two missing fields would contain data on a differential GPS system if such a system was being used.
*6D	A checksum which is used to ensure the integrity of the transmitted data.

Table 1. The NMEA0183 protocol definition states that all data is transmitted using printable ASCII characters. Data is transmitted in the form of sentences, with data fields being delimited by commas and terminated by the end of the line. One of the more complex sentences, the GPGGA sentences is shown, with a commentary explaining the meaning of the different data fields. For complete information on each sentence, the NMEA protocol standard manual should be consulted [23].

An important feature of many handheld GPS systems (such as those manufactured by Magellan, Trimble and Garmin) is that they can communicate via a standard protocol. The American National Marine Electronics Association standard 0183 (usually shortened to NMEA 0183 [23]) is a voluntary standard that has been adopted by many manufacturers of devices that are used in marine navigation. The NMEA 0183 standard [23] is a combined electrical interface and data protocol for communication between marine instruments. For the purposes of this paper, the important part of the NMEA standard is the protocol, which encodes navigation and control information in a serial message format (Table 1). By using this protocol, it is possible to

communicate with a GPS system via a computer's serial port. Many software toolkits have been written to decode these NMEA message strings and make the location information available in the format required to suit the intended application.

There are at least two other approaches to providing more universal location sensing technologies based on existing GPS technology. The first is to use radio repeaters at the edges of buildings which rebroadcast GPS signals inside, as suggested by some authors [9, 16]. The intention here is that standard GPS receivers (perhaps augmented with amplifiers on the receiving aerial) would be used to receive the GPS signals indoors. This has the considerable advantage that the same receiver can be used indoors and outdoors at the expense of installing extra location-sensing infrastructure.

The second approach is to hide all the technical details of the location sensing device(s) in a software toolkit and write an API which will provide a suitable mechanism for obtaining the last known location by programmatic means. This approach has certain attractions, not least of which is that sensor fusion can be used to combine the results obtained from several location sensing technologies simultaneously, either to improve the estimate of location obtained, or to extend the range of locations that can be sensed into environments beyond that which any one technical solution can provide. Hence the toolkit approach gives the potential for an application to work seamlessly outdoors and indoors by switching from GPS-based location sensing outdoors to another location sensing technology indoors [1, 10, 30].

A lingua franca based on NMEA 0183

Our approach is related to the software toolkit approach, but instead of defining and writing a new software architecture, toolkit and servers, we propose the explicit establishment of a framework based on the NMEA 0183 standard as a lingua franca. The NMEA 0183 standard is a protocol that already exists as an international standard, is well understood, comparatively low cost and is in wide use. The new framework allows NMEA to be applied conveniently to diverse new situations: the NMEA protocol has the potential to be used much more widely than in its usual domain of interfacing GPS devices and marine electronics systems. The core of the protocol defines a standard means of communicating position in three dimensions according to a common co-ordinate system and datum (latitude, longitude and altitude). The protocol also provides a standard means for communicating a wide variety of other kinds of information, for example, encoding the type of device that was used to measure the location; when that measurement was made, and estimates of the errors that might be associated with the location measurement, and so on. We therefore propose that the NMEA 0183 protocol be used as a universal lingua franca for representing and communicating location information not just outdoors but also indoors.

Within this framework, outdoors, we would still use a GPS system as the location sensing device. Indoors, we would use some other location sensing technology, but the mechanism for representing and communicating location to any application that wished to use it would be the same in both environments, namely the NMEA

protocol. (In a later section we will illustrate some simple, cost-effective ways in which sentences in the protocol might be transmitted indoors.)

The explicit universal adoption of the existing, widely used NMEA standard as a lingua franca for location would offer significant advantages over the patchwork use of a variety of incompatible protocols. But diverse new standards continue to proliferate. For example , there is a completely new standard for representing location based on XML [27], as well as many existing XML-based standards for recording spatial data such as the Geography Markup Language, GML [8]. But the NMEA 0183 protocol standard is well known, well defined and is widely used by consumer electronic devices. Furthermore, it is extensible (although to a much more limited extent than XML), so there is a mechanism for defining new NMEA sentences containing additional location information, or data obtained from other electronic sensing technologies. Therefore the NMEA 0183 protocol appears to convey all that is needed of a simple, spatial data standard.

One consequence of our proposal is that Global Positioning Systems technology ceases to be an outdoors-only location sensing technology. Instead, the NMEA protocol can be used to extend the reach of GPS-based location systems indoors. The novelty of our proposal lies in recognizing that the NMEA protocol can be decoupled from the GPS systems that it is most commonly used to communicate with, and be used independently of such systems to represent, record and transmit location information between non-GPS devices, sensors and location clients.

A second area of novelty to our proposal lies in using the standard latitude, longitude, altitude location model as an absolute (albeit slightly unusual) co-ordinate system and reference model inside buildings as well as out of doors.

Latitude, longitude and altitude indoors

Having proposed the NMEA 0183 protocol as a lingua franca for communicating location information, how practical is it to use indoors? There are at least three potential disadvantages to consider.

One widely held belief is that locations defined by latitude, longitude and altitude are too imprecise to use indoors. This is not the case. This mis-conception probably arises from user experiences with handheld GPS systems, particularly in the days before selective availability was turned off, when deliberate errors in latitude and longitude of up to 100 metres were built into the system.

Today, due to errors introduced through varying atmospheric conditions and other sources of error, in practice, the normal accuracy that can be expected of a handheld GPS system is fifteen metres [12] although errors in altitude are frequently much worse. With additional equipment, usually a differential GPS system, this error tolerance can be reduced to 3-5 metres. With networks of permanently installed GPS receivers, horizontal accuracy of a few centimetres is achievable [24]. This is accurate enough for most indoor purposes. Finally, in ideal circumstances, the United Kingdom Ordnance Survey report that the highest precision currently available is about 1mm in the *x*- and *y*- axes relative to WGS84 (the idealized model Global Positioning Systems use for the shape of the earth) and about 2.5 mm in the *z*-axis.

Note, however, that the degree of precision expressible within the NMEA 0183 protocol is independent of particular location sensing technologies. The existing NMEA standard provides for the storage and transmission of co-ordinates with an

accuracy of four decimal places of arc minutes (for example, in the GPRMC and GPGGA sentences). This corresponds to a resolution of distances between points, in principle, of about 20 centimetres, which is more than adequate for the scenarios we are considering. (When at relatively high latitudes, in the case of angles running east-west, a displacement of a ten-thousandth of an arc minute can correspond to even shorter distances – in the UK, about 12 centimetres, for example.) Of course, a moving GPS device reading a signal from a satellite, even with selective availability turned off, achieves nothing like that accuracy. However, position tags in buildings could be surveyed and placed to an accuracy of a few centimetres using techniques such as differential GPS and position averaging. (These position tags are in effect the triangulation points that were used in the past by map makers before the widespread adoption of aerial photography and satellite technology.) Therefore, a device, reading accurately surveyed tags encoded using nothing more than standard NMEA 0183, could achieve resolutions of tens of centimetres. Such an accuracy is adequate for many ubiquitous computing applications, and has a similar order of accuracy to other low cost indoor positioning systems [28].

The second objection is the unsuitability of latitude, longitude and altitude from a human interface point of view as units for indoor navigation (for example, "to find the coffee machine, move 1 arc second south"). This objection misunderstands the level at which we propose to apply our framework. Once a building has been surveyed, and whenever standard NMEA location tags are sensed by mobile devices, units are converted in the user interface to the units best adapted to the user and task (such as imperial or SI units). Application developers and users would work in conventional units and measurement systems. Indeed, software could be used to calculate indoor positions from one accurately surveyed WGS84 position in each building, such as the main entrance. The entrances to a building can be regarded as the physical interfaces to a building, a point that we will return to later in this paper.

A third problem with latitude, longitude and altitude, particularly with locations obtained from hand-held Global Positioning Systems is that altitude estimation is notoriously inaccurate. This is another area in which accurately surveyed position tags inside buildings could improve upon estimates of altitude that routinely are obtained from GPS systems. The NMEA standard provides for the storage and transmission of altitude in metres to an accuracy of one decimal place, that is, 10 centimetres. Again, altitudes could be calculated relative to a single, accurately surveyed WGS84 position within each building, thus improving considerably on positions in the z-axis that are normally associated with GPS technology. Note that vertical lines as measured accurately by Global Positioning Systems are not necessarily parallel to local plumblines (technically due to differences between WGS84 and the Geoid – a surface defined by points on the earth of equal gravitational potential), but divergences are negligible for our purposes. For example, in a hypothetical building five kilometres tall, where a point on the roof was reported by accurate GPS measurement to be vertically above a point on the ground, the points might in fact be revealed by a plumbline to be horizontally displaced by a distance of the order of seventeen centimetres [24]. This is unlikely to a problem in most indoor applications in typical buildings. Where extreme precision is essential, clients with access to Geoid models [24] can correct even errors of this kind internally to a high precision.

In any case, for most urban navigation tasks it is precise local relative distances that generally matter rather than, for example, precise height above sea level, or precise distance from locations on a different continent. NMEA 0183, used as a lingua

franca for locations expressed relative to WGS84 (or another model) has the capacity to perform well in these respects.

In summary, the existing NMEA 0183 standard is capable of storing and transmitting positions to within an accuracy of about twenty-five centimetres anywhere within the world, above or below ground. This degree of accuracy, we argue, is more than adequate for many ubiquitous computing applications. With the definition of new sentences, which are provided for within the NMEA standard, locations measured to arbitrary precision can be stored and transmitted.

Indoor location beacons

In the previous section, we argued that the NMEA 0183 protocol could be used indoors for representing and communicating location information. We proposed that buildings could be surveyed and position tags could be located within buildings to a precision of just a few centimetres. But how would a mobile computing device read these tags? There are many ways in which these tags (or base stations in the terminology of other developers of indoor location sensing technologies) could be read.

One of the more obvious technologies is to use beacons that broadcast their latitude, longitude and altitude to the local environment, encoded in NMEA 0183 or some other format. Potential mechanisms that have, or could be used to broadcast NMEA sentences include:

- diffuse infrared signals like the Active Badge location system [14], or early prototypes of the Cyberguide system [2],
- ultrasound, like the Active Bat location system [2, 28],
- radio frequency identify (RFID) tags [31], or
- Bluetooth or radio frequency broadcasts based on the IEEE 802.11b standard [5] that have a greater range than RFID.

Finally, the location of the tag could simply be encoded as a bar code or data glyph [15, 19, 29]. We will describe our experiences with the technologies that we have employed for indoor location beacons in a subsequent paper.

Moving between location-sensing technologies: the outdoors-indoors transition

One of the details that should he handled transparently by any system that purports to be technology independent is handling the transition from one location sensing technology to another. The transitions that will occur most commonly are those which take place when moving from outdoors to indoors, and vice versa. In other words, the physical interface to a building.

We propose that at each entrance to a building, indoor location beacons should be placed which broadcast the precise location of that building entrance so that it can be received by anyone who enters the building. Having such beacons at each entrance serves two functions. First and foremost, it signals to the framework that a change in the location sensing technology has taken place since this location message will be received from a different source. Secondly, it can provide to the application a precisely determined location since it may well have been using imprecisely

determined locations obtained from a Global Positioning System (particularly altitude).
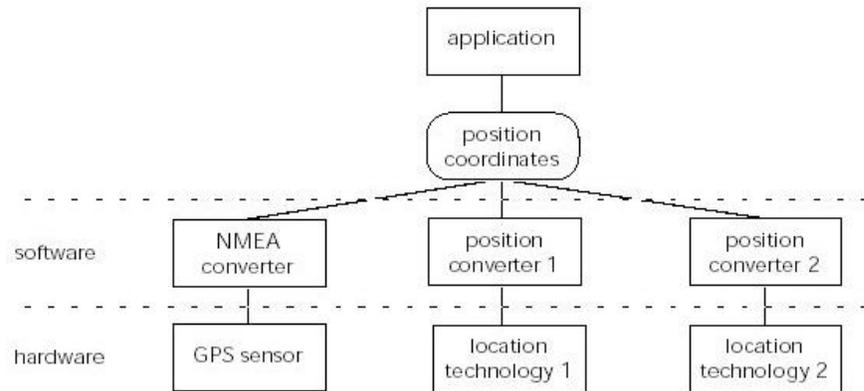

Fig. 1. An example system architecture for our location sensing framework. Boxes denote hardware and software component, the box with rounded corners denotes a protocol for communicating position information.

Given the fact that the NMEA 0183 protocol can be extended with additional sentences, there is scope for augmenting the protocol with additional sentences that signal that a change in the location sensing system has, or is about to take place. This is particularly useful when making the transition in the opposite direction, since it often takes several seconds for most GPS systems to obtain a good location 'fix' from satellites.

A simple, low overhead framework

One of the benefits of our framework is that is conceptually simple and it has a small system overhead for the user and application developer. All that an application developer has to do is to write program code that accepts locations (position coordinates in Figure 1) from multiple sources via some sort of software multiplexing which could be as simple as a web server, communication middleware such as Tspaces [18] or through programming language support. Each of the different location sensing technologies would make their location data available to the application via some standard protocol (the position coordinates in Figure 1).

We originally conceived that the lingua franca would use the NMEA 0183 protocol as the means by which position coordinates would be represented and communicated, but a generalisation of our proposal would be to devise another protocol that was used internally to communicate location information. In Figure 2 we present a candidate format that is based on XML.

```
<GeographicalPosition
        altitude="0"
        latitude="52.04308"
        longitude="-0.75225"
/>
```

Fig. 2. An alternative format to the NMEA 0183 protocol for communicating location information. This format is based on XML and communicates the essence of the location, namely three real numbers representing the latitude, longitude and altitude.

One of the simplest system architectures that implements this framework would be a small mobile computer such as a PDA with a Global Positioning System attached to it by a serial cable. The application communicates with the GPS via the PDA's serial port. In essence this is all the hardware that is required in order to build an outdoor tourist guide or a navigation application [2, 7]. In order to make this application work indoors as well, all an applications programmer has to do is to extend the application to listen to the PDA's infrared port. If the PDA receives location information transmitted using the same NMEA 0183 protocol that the GPS uses then the programmer has only to write one set of routines to decode this protocol. Program code to do this is reasonably straightforward to write, and examples in several programming languages are readily available on the internet. Alternatively, a hardware multiplexor could be used that allowed multiple serial devices, all communicating with the host using the same protocol, to connect to a PDA through a single serial port.

Notice that this example is standalone, since it does not require network access, nor does it require a context server which gives the location in the format that the application requires on request [10, 25, 30]. Although solutions that do have such a server may be generalised to other contextual data, inevitably they have a larger hardware and software requirement because of the increased infrastructure overhead.

Application scenarios

In this section we describe some potential scenarios in which our lingua franca could be used and we describe our prototype application that demonstrates our proposal in operation. The common theme running through all these scenarios is that of the user moving between areas served by different location sensing technologies. Of course, navigation within an area served by a single system should not present any technical problems, apart from what to do when the user moves out of range of the location sensing system and thus loses the capability to update their location.

At present, the easiest way of ensuring that the user must pass from one location sensing technology to another is for them to move from outdoors, where location sensing systems based on Global Positioning Systems predominate, to indoors, where some alternative location sensing technology has been installed. As long as this indoor infrastructure is capable of providing location information through the NMEA protocol, or in the latitude, longitude altitude coordinate system, that is all that is required by our lingua franca.

The first scenario surrounds visitors to university campuses, large commercial facilities, hospitals and so on. Visitors usually arrive at a central visitors reception. Security and safety considerations aside, visitors are often given verbal directions or a map, and asked to make their own way to their destination within the facility. Instead, they could be given the precise location of their destination, perhaps scanned into their PDA as a bar code. A navigation application running on their PDAs would then lead them to their destination, via some sort of moving map display or audio directions.

One of the criticisms that is often levelled at location data obtained from global positioning systems is that the altitude is usually much less precise than the latitude or longitude. Indoors, this imprecision ceases to be a problem since the position of indoor location beacons can be surveyed. Therefore scenarios that involve moving between floors of a building are entirely possible since different floors within a building can be discriminated easily. Finding your car when you have left it in a multi-storey car park becomes entirely possible. Here you would simply enter the location of the parking bay into your PDA and the system would guide you back to your car when you have completed your business. Which might have been going to the theatre or cinema.

When you book your tickets, you could be supplied with the full geographical position of your seat in the theatre, as well as the more usual alphanumeric seat numbering systems that public auditoriums use. While this is more conventional and comprehensible to humans, the precise geographical location of the seat can be used in a variety of ways by ubiquitous computing systems. Recall that the latitude, longitude and altitude coordinate system is sufficiently precise that it is possible to distinguish between seats in a theatre. The problem of navigating within the theatre and auditorium to your seat is perhaps most easily solved through a combination of building- and room-scale location sensing technologies, perhaps coupled to location beacons that could conceivably identify each seat uniquely.

First and foremost, such a system can be used to guide the theatregoer from their home to their seat in the theatre. Secondly, a ubiquitous computing application could look for what is known about the type of location where the theatregoer is and the nature of any enclosing objects (the theatre). This could, for example, be used to block incoming mobile telephone calls.

Having the facility to make inferences founded on a consistent, standard location model is rather easier than trying to make inferences based on detecting other low-level features of the environment. In his recent critique of context-aware computing, Erickson [11] argues that a context-aware mobile phone would find it extremely difficult to infer the abstract notion of being in a theatre. But if that telephone was aware of its location, and had access to a good location model, the telephone could work out that it might be appropriate to use a vibration rather than an audio alert of an incoming call. Such a system could also work in hospitals where the making of mobile telephone calls is often banned.

The final scenario that we will discuss is one that we have implemented. It is a simple tour guide and shopping assistant for Milton Keynes shopping centre (which it is claimed has the world's longest shopping arcade and over three miles of shop fronts). While there is a main arcade that is all effectively indoors, there are other outlying arcades where shoppers must go outside in order to get to them. This presents the classic problem that we have addressed in this paper of how to switch between location systems, in a navigation application.
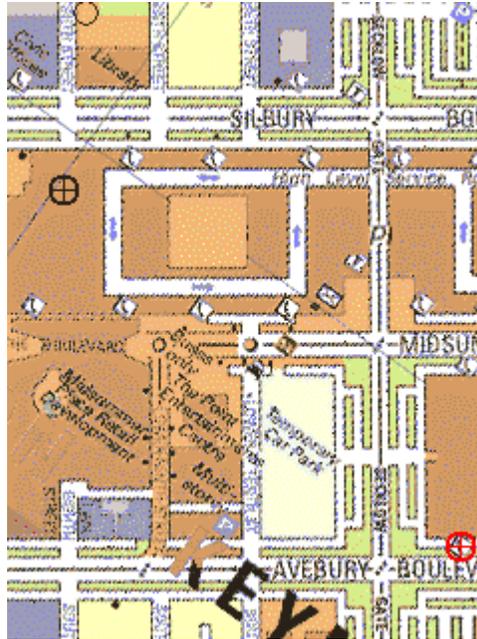
Fig. 3. A map of part of the Milton Keynes shopping centre displayed on the PocketPC map application. The user's current position is outside the Sainsburys shopping centre at the ⊕ symbol, bottom right. The yoghurt stall that they wish to visit is in the main shopping centre at the location similarly marked, top left. For further information on the scenario and map application, please see the text.

Our system runs on a PocketPC. At present it communicates over a wireless network with a standard web server running on a laptop computer. The web server simply supplies location data to the map application shown in Figures 3 and 4 according to the location format shown in Figure 2. This location data is obtained from position converters linked to a variety of location sensing technologies that are connected to the laptop computer. The reason why we are using a laptop computer to host the location sensing technologies is for implementation simplicity. It is much easier to attach the multiplicity of peripheral devices that are required to a laptop computer than it is to a PocketPC, if one wishes to exploit more than one location sensing technology in an application. It is worth noting in passing that our prototype uses the same software infrastructure that we developed to support highly dynamic and ad-hoc computing environments [13].

The prototype allows us to obtain location information from a Global Positioning System or from a 'Wizard of Oz' simulation of an indoor location technology. We have demonstrated this scenario in the laboratory using the Wizard of Oz technique but we have not yet tested it in the field.

Suppose that a user completes their shopping at the Sainsburys supermarket in the outlying Food Court (See Figure 3). They then realise that they have forgotten to buy any lemon flavour organic yoghurt, but recall (or a search on the shopping centre's web site would tell them) that there is a stall that sells yoghurt in the main shopping

centre. Such a web search would also give them the location of the shop which they could copy into their map application. (At present our prototype application only plots the current location and destination, but future versions will provide improved navigation support, perhaps via an audio rather than a visual interface.) Since they are outside, their moving map application shows a map of part of the shopping centre (Figure 3).
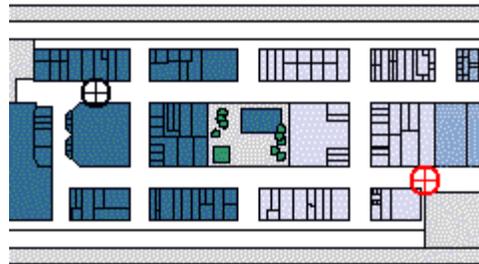

Fig. 4. An internal plan of part of the Milton Keynes shopping centre displayed on the PocketPC map application. The user's has just entered the main shopping centre (at the ⊕ symbol, bottom right). Again, the yoghurt stall that they wish to visit is at top left. (The reason why the screen dump has a large white space at top and bottom is because of the shape and orientation of the shopping centre relative to the screen of the PocketPC.)

On entering the main shopping centre the display switches to an indoor view (Figure 4) where the individual shops can be seen. Clearly both maps could be displayed to a greater level of detail but we are limited by the small size of the PocketPC display.

Recall that the map application is receiving a continuous stream of location data giving the user's current position, and it is not otherwise aware of when the user passes indoors. The application must use the location data to compute the most appropriate map to display as well as update the map with the user's current location.

Future versions of the prototype will improve on the map display and will integrate properly with indoor location sensing technology. Initially this will be based upon bar code technology that we have already prototyped in other ubiquitous computing applications. In addition, we plan to improve upon the navigational help that is given to users, including exploring the possibility of integrating our lingua franca with our work on audio interfaces to Global Positioning Systems – AudioGPS [17].

Conclusion

The lingua franca that we have presented for unifying communication of position information from multiple location sensing systems at the same time is intended to have the following properties:

- To be conceptually simple and lightweight in implementation, making few demands of the application programmer, location sensing technology or host system.
- It uses latitude, longitude and altitude as a universally applicable, consistent, physical location model which can be used both indoors and outdoors.
- Although the NMEA 0183 protocol on which the lingua franca is founded is most closely associated with Global Positioning System technology, our lingua franca is not tied to that technology and it can be used to communicate location information from other systems, as our prototype application and experiments that we will report on elsewhere, have demonstrated.

We have also shown that the two fundamental assumptions on which our lingua franca is founded are reasonable. Firstly, that the physical location model of latitude, longitude and altitude can be applied indoors. Secondly, that the NMEA 0183 protocol, can also be used to represent and communicate physical location information from other, non-GPS location sensors to client applications.

In conclusion, our lingua franca is by no means the only possible approach to providing an architecture that unifies location sensing systems. However, we believe that its distinguishing properties of simplicity, ability to work across many location sensing technologies and universal applicability make it a suitable candidate for adoption by other ubiquitous computing practitioners.

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