Exploring the Potential of Ultrasonic Position Measurement as a Research Tool*

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Abstract

This paper describes a simple indoor positioning system that uses ultrasonic and RF technologies, and further outlines research which has been enabled by the system. Existing indoor systems are expensive and have substantial user or physical impacts. This system is inexpensive and has minimal impact. It has been used at the University of Sussex to help understand how children collaboratively explore mixed reality spaces, and it has also assisted with research into digital and physical co-visiting in the Mackintosh Interpretation Centre of the Lighthouse in Glasgow.

1 Introduction

The measurement of position is one of the fundamental requirements of location aware computing. The introduction of GPS has been a significant factor in the development of *outdoor* location aware computer applications. This paper describes work that has been carried out using a simple *indoor* positioning system using ultrasonic and RF technologies designed to promote indoor research [1].

There are three technologies commonly used for indoor location systems - ultrasonics, infrared and RF. Infrared systems tend to rely on the user taking explicit actions to identify their presence [2]; and RF systems require sophisticated (and often cumbersome) antenna [3] - ultrasonics offer a low cost solution which can operate without any explicit user interaction. Shortcomings of ultrasonic systems arise from loss of direct signal and interference. These can be minimised and sophisticated systems produced by commercial suppliers such as Intersense [4] and AT&T [5] have successfully implemented ultrasonic positioning with impressive results. The Cricket Location-Support System developed by researchers at M.I.T [6] provides low cost position estimation designed to achieve portion-of-a-room granularity using a network of beacons. We describe the use of a simple system developed by the University of Bristol Wearable Computing Group as part of the Equator IRC, supported by the EPSRC, focusing on the integration of physical and digital interaction [7]. This simple design gives results providing accuracies of 10-25cm and has proved suitable for several research applications.

Two Equator projects have successfully used the positioning system. The Hunting of the Snark led by the University of Sussex [8] in which research was carried out into understanding how children collaborate, discover and reflect upon new kinds of experiences in mixed reality spaces, and the City project led by the University of Glasgow [9] where the design was extended to provide an ambitious installation in the Mackintosh Interpretation Centre of the Lighthouse in Glasgow. The system has also been successfully used for other research by Hewlett-Packard not described in this paper [10].

2 Positioning System Design

To determine position in a 3D space using trilateration we require three distance measurements. In this system we use a RF signal - or ‘ping’ - as a synchronising pulse followed by four precisely timed ultrasonic signals - or ‘chirps’. This arrangment allows the times-of-flight between four separately located transmitting transucers and a receiver to be determined. These times-of-flight are converted to distances by factoring them with the speed of sound. We use four to increase the range of the system and to compensate for occasions when one signal is lost - it also simplifies the geometric calculations.

The ping, containing an eight byte coded packet broadcast by a 418MHz FM short range transmitter, ensures that the receiver is synchronised to the transmitter. The packet consists of two identifier bytes, and six bytes of room specific information. The maximum range of the ping is 100

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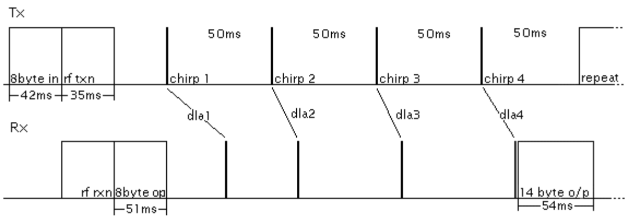

Figure 1. Timing diagram (not to scale).

metres, though this can be reduced to enable separate systems to operate in adjacent rooms.

The chirps consist of 48 cycles of 40kHz generated by a PIC microcontroller and are transmitted sequentially at 50ms intervals as shown in Figure 1. We use 48 cycles as 1ms of signal is relatively easy to identify using simple test equipment. Open face piezo transducers manufactured by Polaroid [11] have been selected to give optimum results. These devices provide the widest possible transmission angle combined with high output(tx)/high sensitivity(rx). The four ultrasonic transmitters are mounted, facing vertically downwards, on the ceiling of the room to be covered. They are placed at the corners of a square and connected to the transmitter module which contains the microcontroller, ultrasonic drivers and RF transmitter. In our 4.2m x 6.5m test room we have obtained better than 15cm accuracy within the square using 2, 3, and 4 metre square configurations with a ceiling height of 3.2 metres.

The receiver uses a matching RF receiver, decoder and PIC microcontroller, and an operational amplifier to process the ultrasonic chirp. These components are mounted in a small module which is either attached to a palmtop computer with a graphic display, or, in the case of a wearable computer, placed on the shoulder(s) of the user. A rechargeable PP3 9v battery can provide sufficient power for a full day's operation. The PIC is programmed to measure the number of 100us delay units occuring between transmission and reception of each chirp. Each delay unit corresponds to 3.4cm, giving an optimum resolution of 2.4cm at one and a half metres below the centre of the transmitter square. The delay units are combined with the eight bytes from the pinger and sent to an RS232 output.

3 The Snooper

The 'Snooper' device is based on two main components - an H-P Jornada 548 PDA and an enhanced ultrasound position sensing receiver. The Snooper is intended to provide a tool for children to discover virtual items hidden in the real world. The four transmitting transducer ultrasonic positioning system was installed in a 3.0 by 3.5 metre room.

Figure 2. Children with the 'Snooper'

The receiver was augmented with a two axis electronic compass providing orientation data that is combined with the ultrasonic position data at around 2Hz. The Jornada PDA has a Windows CE operating system running on a Hitachi 133MHz SH3 processor. This is suitable for analysing the position data, providing a graphic display and playing audio files.

Three display options were experimented with. These were intended to help us assess the importance of providing an overall view of all surrounding virtual objects; automatic orientation; and a display of only the objects in the user's field of view. Our experiments use image display and audio playback to give the user immediate feedback when a virtual object has been discovered. The three options were a conventional *map* display showing a plan view of the room; a *radar* display showing the relative position of the virtual objects around the user appropriately orientated; and a *lens* view which only showed the objects in the field of view of the user, again appropriately orientated.

Each time the position of the user is updated by the positioning system, a table of images and their associated locations is searched for a match. When a match is found an associated image is displayed to indicate success in locating one of the virtual items, and an audio prompt is triggered. The children easily understood the purpose of this device and moved around the room in search of the items. They had no problem understanding that the invisible, as represented as pictures on the screen, could also be realised as physical tokens. They also readily understood the floor map used and their position in relation to it on the Snooper tool.

The positioning system worked reliably with problems only being experienced when both children 'crowded' around the receiver obscuring the ultrasonic paths, and also when the Snooper was tilted causing the compass to misread.

Figure 3. The Mackintosh Centre

4 The Mackintosh Centre

In the Equator City project based in Glasgow, we have been combining mobile computers, hypermedia and VR systems into one larger system which aims to weave digital media into the physical spaces that people use, and to do this in meaningful ways which show and support their activity. We are exploring ways that people can interact and maintain awareness of each other, even though they may be spatially separated, by using a variety of interaction devices and media. The life and work of Charles Rennie Mackintosh provides a well documented theme for our research and hence the Mackintosh Interpretation Centre in the Lighthouse [12] was chosen as a suitable starting point for this project.

The need to determine the physical position of the user in the Mackintosh Centre was critical to determining the interests and path of the user. This 13 by 20 metre room (see Figures 3 and 4) presents considerable challenges - it is subdivided by a 2.3 metre high partition, contains four 2.1 metre high open cubicles, and any installed positioning system must, for aesthetic reasons, be well hidden - precluding the ceiling mounting of transducers.

The maximum area previously covered by the ultrasonic positioning system had been 4.2 by 6.5 metres. After exploratory laboratory testing it was found that it would be worthwhile to investigate a positioning system based on ultrasound signals reflecting off the ceiling of the Mackintosh Centre. The original four transducer ultrasonic system was extended to provide eight transmitting transducers. Four of these were placed, facing upwards, along the top of the partition, and the other four were centrally placed on top of each of the cubicles, also facing upwards. This arrangement met the aesthetic considerations, though it relied on using the reflected signals that bedevil other ultrasound positioning systems. It was recognised that there would be areas where the positioning would not work satisfactorily

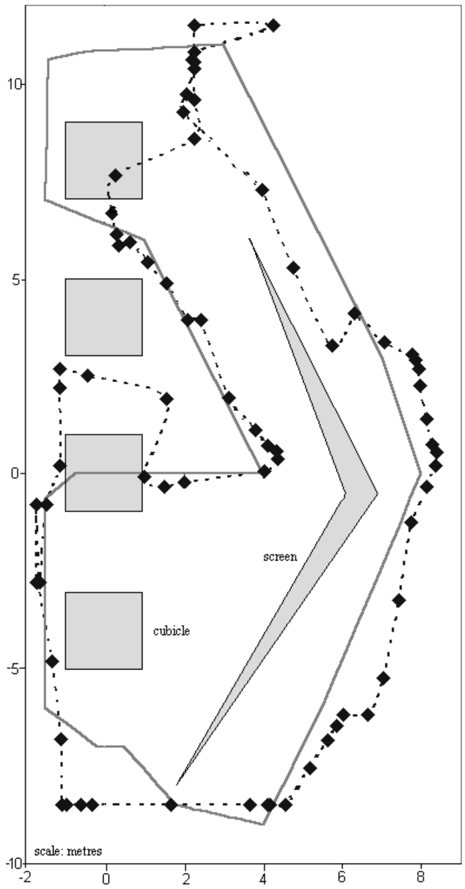

Figure 4. Mackintosh Centre Test Path.

e.g. inside the cubicles and in areas shadowed from the reflected ultrasound. This installation provided an ideal environment to test the limitations of a simple ultrasound system. An initial installation and testing demonstrated that the theory worked in practice, however there were problems with range, deadspots, accuracy and jitter.

The initial tests were mainly based on following a predetermined trail around the Mack Room over a period of two minutes. This trail was designed to include areas which were known to have inadequate ultrasonic coverage. The tester stopped for five seconds at each of eight reference spots around the room. The trail is shown as the continuous line in Figure 4. The diamond markers show the actual positions as measured by the ultrasonic system; they are connected sequentially by the dotted lines.

While an accuracy of within 0.5 metres was achieved 50% of the time, figure 4 clearly shows that position sensing was severely degraded when the user entered a cubicle. Consequently experiments were carried out to compare infra-red, RF and ultrasonic beacons within the cubicles.

The infra-red beacon required explicit action to ensure that it had been found and the range of the RF beacon was difficult to set accurately and depended on receiver orientation. These were rejected as being unsuited to our needs. The ultrasonic beacon benefited from the feature of simple range adjustment. By extending the existing eight transducers with an additional transducer fitted underneath the ceiling of each cubicle we were able to achieve satisfactory results.

As well as limited public demonstrations of this system, ten trials were conducted with two participants visiting the Mackintosh Centre using a digital interface and a third actually in the room tracked by the ultrasonic positioning system. The participant in the room was given a display which showed a map with their position, and the notional positions of the other two participants visiting from their digitial worlds. One digital visitor also had a map display, and the other entered a 3D model with avatars representing all three visitors. The participants were connected by an open audio communication system. Each trial lasted approximately one hour with the participants completing a series of investigative tasks. Initial observations showed that the participants carefully managed their bodily positions with respect to each other, as in conventional collaborative digital environments, and showed little problem with mapping between between physical objects and those in the graphic displays. Further detailed analysis of the results of the trials is underway.

The ultrasonic installation in the Mackintosh Centre successfully demonstrated possibilities for extending the coverage of the positioning system design in a difficult environment. While areas of poor coverage remained due to the peculiarities of the room, the system adequately supported testing which involved the use maps displaying the positions of the participants.

5 Conclusion

We have developed a low cost indoor ultrasonic positioning system and demonstrated its usefulness for research purposes. In particular we have worked with children who have shown their capacity for understanding and adopting location awareness in finding virtual objects in real spaces. The City project has shown the value of location awareness for enhancing synchronous visiting and communication in real and digital environments.

This work has demonstrated potential for location based services in indoor environments. We are currently researching the possibilities of integrating multiple positioning technologies to provide location based services which span both indoor and outdoor use.

References

[1] C. Randell and H. Muller. Low cost indoor positioning system. In *UbiComp 2001: International Conference on Ubiquitous Computing*, pages 42–48, September 2001.

[2] R. Want and A. Hopper. The active badge location system. In *ACM Transactions on Information Systems*, pages 91–102, January 1992.

[3] F. Raab, E. Blood, T. Steiner, and T. Jones. Magnetic position and orientation tracking system. In *IEEE Transactions on Aerospace and Electronic Systems*, volume AES-15 no.5, pages 709–718, September 1979.

[4] Intersense home page. http://www.isense.com/.

[5] A. Ward, A. Jones, and A. Hopper. A new location technique for the active office. In *IEEE Personal Communications Magazine*, volume 4 no.5, pages 42–47, October 1997.

[6] N. Priyantha, A. Chakraborty, and H. Balakrishnan. The cricket location-support system. In *6th ACM/IEEE International Conference on Mobile Computing and Networking.*, August 2000.

[7] The equator interdisciplinary research challenge. http://www.equator.ac.uk/.

[8] Yvonne Rogers, Mike Scaife, Eric Harris, Ted Phelps, Sara Price, Hilary Smith, Henk Muller, Cliff Randell, Andrew Moss, Ian Taylor, Danae Stanton, Claire O Malley, Greta Corke, and Silvia Gabrielli. Things arent what they seem to be: innovation through technology inspiration. In *Designing Interactive Systems 2002*, pages 1–11. ACM Press, June 2002.

[9] Ian MacColl, Dave Millard, Cliff Randell, and Anthony Steed. Shared visiting in equator city. In *Collaborative Virtual Environments 2002*. ACM Press, September 2002.

[10] R. Hull, J. Reid, and A Kidd. Experience design in ubiquitous computing. Technical Report HPL-2002-115, HP Labs, 2002.

[11] Polaroid home page. http://www.polaroid-oem.com/.

[12] The lighthouse, scotland's centre for architecture, design and the city. http://www.lighthouse.co.uk/.