Improving Location Accuracy by Combining WLAN Positioning and Sensor Technology

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ABSTRACT
This paper presents a heterogeneous location-aware system that combines two technologies so that their properties can be aggregated to produce more accurate location data. This paper proposes and demonstrates a location system that uses a sensor mounted on a robot to determine its location acoustically and complement the data with location from the existing Ekahau Positioning Engine (EPE). It is shown that the acoustic localization is capable of verifying errors that exist in the location information provided by the EPE. The heterogeneous system resulted in location information that gives 100% accuracy in spatial space information which the EPE was unable to provide all the time. The sensor fusion by combining the acoustic location system with the EPE helped improve the accuracy of location sensing by verifying the location information and increases location data availability.

Categories and Subject Descriptors
I.2.9 [**Artificial Intelligence**]: Robotics - a*pplications, sensors*

General Terms
Measurement, Performance, Experimentation, Verification.

Keywords
Location-awareness, wireless sensor networks.

1. INTRODUCTION
Application pervasiveness can be achieved by providing intelligence in the form of contextual information. If computers can have the same perception as human beings about their vicinity, applications can re-configure their behavior based on the model and state of the environment. With location information, applications can adapt their interface and features in response to the current geological space.

There are already commercial deployments of location-aware applications especially for use outdoors. An example is the Global Positioning System (GPS) used in navigating cars on land and ships in the oceans [5]. Depending on the receiver used, the accuracy of GPS may be about 30 meters. Another technology for outdoor positioning is the telecommunication infrastructure that measures and computes line-of-sight and time-of-flight of radio signals for locating mobile phones. These technologies are not suitable for use in the indoor environment.

Indoor location information has to have high precision and accuracy to at least a couple of meters or less. Most pervasive applications require at least the knowledge of the spatial space the client is in or the relative location of the clients with respect to certain landmarks. Other location-aware applications, such as robot localization, require numerical coordinate location information. The busy indoor environment requires specialized sensors to discover location information accurately and robustly. A single location system is required to provide location information on the tracked client but it will not always give accurate location information and this information cannot be verified. To overcome the single technology location system's drawback, a heterogeneous location system is proposed so that location information from two location-aware systems can be compared to improve accuracy. The use of multiple location systems with different technologies to form hierarchical and overlapping levels of sensing is known as sensor fusion [8]. Multiple location systems can aggregate the properties that are not available in a single technology system.

Section 2 will detail some of the existing positioning technologies. Section 3 will discuss the benefits of having a heterogeneous system. Section 4 will discuss our proposed solution of integrating our existing system with an acoustic location system. Performance of the existing location system will be compared with the proposed solution in Section 5. This paper will then conclude in Section 6.

2. LOCATION-AWARE SYSTEMS
A number of wireless physical medias have been used in devising means for obtaining indoor location information. These include the use of infra-red in Active Badge [13] and PARCTAB [12], radio frequency in RADAR [1], SpotOn [7] and FLARE [3] and ultrasound in Active Bat [6] and Cricket [11]. Infra-red (IR) is a line-of-sight technology and it suffers adversely under the influence of external radiation. Radio frequency (RF) produces location information that is not accurate enough for use in location-aware system because of the variations in the received signal strength due to multi-path propagation especially in the highly cluttered and varying indoor environment as observed in the Ekahau Positioning Engine [4]. RF propagates at a very high velocity that makes precision timing very difficult. Ultrasound and acoustic sound were later adopted as the preferred medias.

2.1 Ekahau Positioning Engine

The Ekahau Positioning Engine (EPE) is completely a software-only solution that utilizes the existing wireless LAN infrastructure [4]. The EPE uses its predictive capabilities to determine location based on the process of site calibration that builds a signal strength model of the environment.

Site calibration involves taking signal samples at different known locations to construct a signal strength model based on signal strengths from various radio channels on the floor. The model is stored in the Positioning Engine. Ekahau clients will retrieve received signal strength values and return the values to the engine for location calculations. The dynamic indoor environment ensures that the radio signal propagation is susceptible to multi-path effect thus making the generated signal strength model inconsistent with the actual signal propagation in the environment. Site calibration creates the empirical model of the signal strength in the environment. Therefore modifying the existing wireless LAN layout after calibration will result in the positioning model to be inconsistent with the new environment. Signal strength at different areas will fluctuate in time due to movement of objects or new installations. This will require re-calibration of the EPE to re-produce a new positioning model.

The EPE exposes location information in the form of (x, y, floor) and logical area. The accuracy of the system is about one meter if there is a minimum of seven access points in sight but in a long term the accuracy decreases due to fluctuations in signal strength. The error in EPE can range from 1.5 meters when no one is in the room to 3.0 meters when the room is half filled with people. This is one of the problems noted in RADAR [1].

Applications that obtain location information from the EPE do not know whether the location information is accurate as there is no form of location verification. EPE only knows the signal strength model of the environment but unaware of walls and obstacles. Therefore if a device is near a wall, the EPE may see the device on the other side of the wall. The location given by EPE has greater inaccuracy when a device is near a wall then when it is in the middle of the room. This could be due to radio signal distortion and multi-path effects caused by the wall.

The EPE has been applied as the source of location information for a mobile robot device. With the EPE, the robot is aware of its location and all the locations of other tracked wireless devices. Since the EPE is not precise, the problem propagates to the robot and makes the robot behave indiscriminately. In order to verify the location information, another means of localization is required. All of the existing location-aware systems are homogeneous systems as each focuses on a single technology. The single system design means that the problems they face are inherent to the system and the technology used.

3. HETEROGENEOUS LOCATION SYSTEM

Two very different and independent location systems that use different technologies should be able to complement and compensate each other for more accuracy and better location-awareness. Hightower and Borriello said that "The more independent the techniques, the more effectively they can be combined" [8]. The two sources of location information can validate each other to extrapolate accurate location information.

A research in combining various location systems to form a heterogeneous location system by [2] lacks precise numerical location information. [2] used Session Initiation Protocol (SIP) that had three means of providing location information. They are location profile provided by Bluetooth devices, IR/RF badges that send unique identifiers to access points of known location and an extended DHCP with information about jack locations. The downside of this system is the lack of coordinate information.

Research in robot localization also showed that a single localization method is insufficient for high accuracy localization [10]. As a result [10] proposed using sensor fusion consisting of ultrasonic tracking and image target analysis. Image analysis for localization is not popular but it was also used in the TRIP project by [9] for their sentient computing project. This sensor fusion is an example how combining two independent systems can improve the location accuracy.

This project will combine the EPE with acoustic localization that is supported by a wireless sensor network. The proposed location system to complement the Ekahau Positioning Engine (EPE) uses a wireless sensor network that is designed to apply acoustic sound to approximate distances for localization. Unlike the EPE that tracks all wireless devices from a centralized server, this design in contrast is a decentralized design like the Cricket Location System [11] whereby any devices can track only themselves by performing the location calculations themselves. The acoustic localization will provide location information to complement with the EPE to form the Multi Location Test Verifier so that location coordinates from the EPE can be verified and validated to be accurate enough for use by the robot or any mobile device. The sensor fusion by combining two location-aware systems to produce accurate location information is a heterogeneous design that ensures redundancy of location information to be available all the time and anywhere as long as one system is working.

4. ACOUSTIC LOCALIZATION

The robot will have a Mica2 as a base mote (Figure 3) that broadcasts a radio signal to other fixed Mica2 motes whose locations are known. Concurrently, the robot's base mote also produces a 4 kHz tone. Since radio signals propagate faster than sound, the fixed listening motes will receive the radio signals first. The listening mote will receive the radio signal that instructs the mote to start counting until it detects the 4 kHz tone. Upon hearing the tone, the mote will send back a radio message to the robot the time difference of arrival of the radio and tone signals. The time difference of arrival can then be used to infer distance between the robot and the fixed mote. This is illustrated in Figure 1.

If the base mote knows its distances relative to three listening motes whose locations are known, the location coordinate of the base mote can be calculated by hyperbolic tri-lateration (Figure 2). Each listening mote has a locus of possible positions for the base mote described by $(x-x_0)^2 + (y-y_0)^2 = r^2$ where (x_0, y_0) is the known location of the listening mote and r is the distance between the listening mote and the base mote. The intersection of three loci will give the location of the base mote. Therefore this localization design cannot calculate location if less than three distances to listening motes are available. Thus it is very crucial that the listening motes must be installed in an unobtrusive location to increase the chance of the tone being heard by the listening motes.

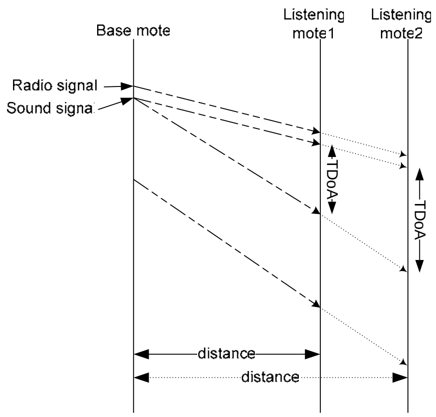

Figure 1. Inferring distance from Time Difference of Arrival

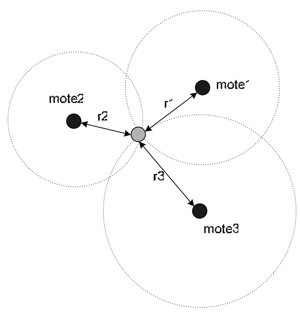

Figure 2. Hyperbolic tri-lateration

Acoustic localization is more applicable to use on a robot than on human beings or stationary items. It constantly emits an audible tone which can be an irritation to the wearer of the Mica2 mote. In the robot's case, it only needs to beep when the robot is on the move which is usual as a safety precaution.

The acoustic localization can work as a separate entity to complement the EPE to determine the most accurate and sensible location information. Furthermore the 4 kHz tone does not penetrate walls. This solves the problem if the EPE should provide the wrong spatial space information.

4.1 Hardware

The wireless sensor network is made up of nodes which are small Mica2 motes (Figure 3). A base mote on a robot will listen for time of flight information from static motes positioned at known locations. The Mica2 motes have a microphone and sounder on each of them. The sounder is use to generate a 4 kHz tone and the microphone has a tone detector that turns the analog microphone into a digital high or low level output when a 4 kHz tone is detected. These two components will be used in conjunction with radio communication to determine distances.

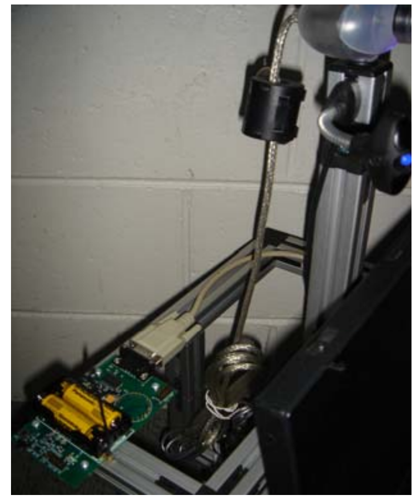

Figure 3. Mica2 mote on ER1[1] robot

4.2 Design Issues

Acoustic was chosen over radio signal strength as the media to infer distances because of several reasons. Radio signal travels at about 300,000 kilometres per second while sound travels at about 340.29 meters per second which is almost a million times slower than radio signals. Accurate time of flight measurement of radio signal on a small scale is very difficult. Furthermore, a one microsecond error will result in 300 meters error but for sound, a one millisecond error will result in only 34.03 centimetres error. It is also very difficult to detect whether the radio signal is suffering from multi-path effects since the received signal might not be original and may have been a delayed one. In the case of sound, the first instant of received sound is always the original since echoes are significantly slower and have lower amplitudes.

There must be no body or obstacles that can absorb or distort sound waves that can adversely influence the tone signal propagation. The listening motes must be installed in high enough places so that there is nothing that can hinder it from listening for incoming tone signals. The spacing of listening motes must about 2 meters apart so that at least three motes can hear the incoming tone. The base mote must always have the sounder facing upwards so that sound energy is propagated upwards to the listening motes.

Using acoustics to determine distances is not a robust solution as the tone detector is vulnerable to detect all kinds of 4 kHz noises. Loud noises could also mask out the 4 kHz tone. Therefore to ensure that the mote is actually listening for the correct tone from the base mote, a low pass filter is programmed into the mote for limited robustness.

5. RESULTS DISCUSSIONS AND COMPARISON OF PERFORMANCES

An application called Multi Location Test Verifier (MLTV) has been developed to concurrently obtain location information from the Ekahau Positioning Engine (EPE) and the acoustic localization system. MLTV is a visualization client that maps the location information onto the floor plan of the room where the

[1] http://www.evolution.com

experiment was carried out to give a visual perspective of the locations as seen by the two different location systems.

5.1 Results Discussions

The first Multi Location Test Verifier results on the acoustic localization and EPE Positioning showed that the acoustic localization is a promising location system as shown in Figure 4.

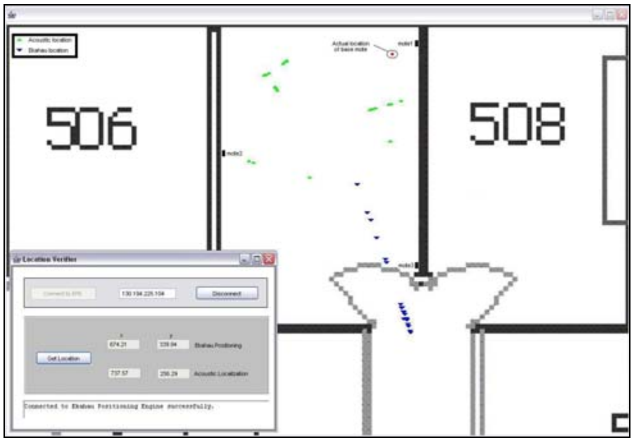

Figure 4. Tracking view when tracked device is near mote1

The first test had the mobile device (base mote) situated nearer to mote1. This location was chosen because there is greater error from EPE when the device is nearer to walls. Most of the acoustically determined locations are between mote1 and mote2; and between mote1 and mote3. This indicates that the tracked device is somewhere nearer to mote1 which is true. Of all the samples taken, 80% indicate that the location is nearer to mote1 and 100% were located within the room. On the other hand, locations provided by the EPE had greater errors. EPE located the device to be nearer to mote3 which is on the other end of the room. Of all the samples taken, a 45% of the samples indicate that the tracked device is in the room. This shows that the acoustically determined locations are more accurate than the EPE. This is useful in validating useful and accurate location information from EPE when a device wants to know its location.

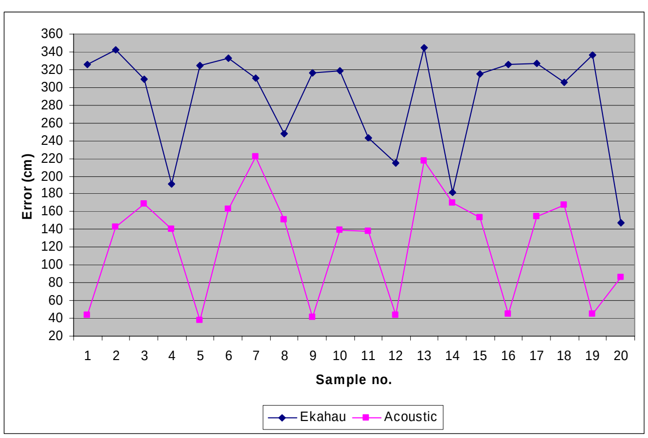

Figure 5. Location errors for acoustic localization and Ekahau Positioning Engine

The amount of errors for each sample is shown in Figure 5. Each sample was taken at about ten seconds one after the other. The acoustic localization method has an error that ranged from 38.10cm to 221.85cm with an average error of 123.40cm for this first test. The EPE produced an error that range from 146.97cm to 343.31cm with an average error of 287.98cm.

Figure 5 also shows that the characteristics of the EPE and acoustic localization have an almost similar pattern in their performance. This could be due to the varying environment factors such as temperature, speed and direction of air flow and so on. Since the locations from the EPE and acoustic localization were taken concurrently, the two location systems are influenced by the same environmental variables. In this first test the acoustic localization system has better accuracy than the EPE as the EPE suffers from greater error when the tracked device is near a wall.

A second test was carried out at the other end of the room by situating the tracked device near mote3 (Figure 4). At this location, the acoustic localization successfully determined the location to be around mote3 at 90% of the time. Although the error distance for the EPE is not very big, it provided wrong spatial space information. The locations EPE provided indicated that the tracked device is outside of the room in which it is actually in. This is misleading especially for mobile application such as robot localization. This is an example where another location system is useful in verifying the accuracy of the EPE. Thus the acoustic localization system can verify the EPE's location information since it has better accuracy.

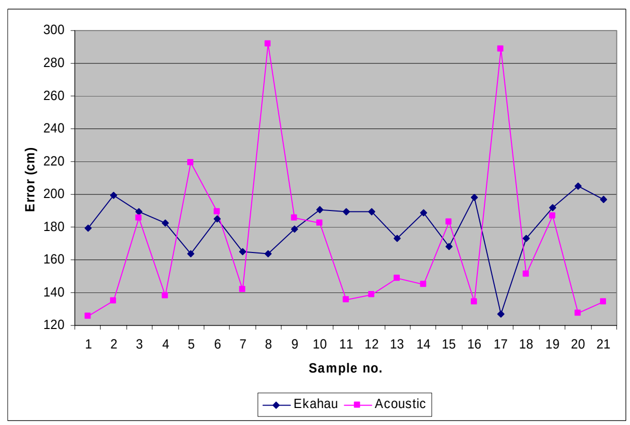

Figure 6. Location errors for acoustic localization and Ekahau Positioning Engine

Figure 6 shows the distance error from the actual location of the tracked device. The acoustic localization method has an error that range from 125.59cm to 291.58cm with an average error of 189.97cm for this first test. The EPE produced an error that range from 163.50cm to 205.03cm with an average error of 180.94cm. Errors in the acoustically determined locations have bigger variation because it is near the door where wind draft can be flowing in and out of the room. The error margin in the previous location is smaller because it was previously located in the room's corner where atmospheric condition is more stable than near the door.

The accuracy of the acoustic location system is about 2 meters error. The localization rate is about 90% with at least three nodes that can audibly hear the tone beep.

5.2 EPE vs Acoustic Localisation

The designs of the two systems are different. The EPE has a centralized design where the Positioning Engine computes and provides location information of all tracked clients. The acoustic localization system is decentralized as the client is tracking itself thus providing the location information to itself only.

The decentralized design of the acoustic localization also ensures privacy of the tracked client. Location information is provided directly to the tracked client only. Thus not everyone can see the tracked client's location unless the client decides to publicize its location details. On the other hand, the EPE is a centralized server which knows location of all tracked clients. Anyone who can access the EPE can list all tracked devices and locations. The information may be exploited and privacy may be breached.

Time taken to retrieve location coordinate is significantly faster in acoustic localization than the EPE. The EPE has a delay of about 2-5 seconds when tracking devices. The acoustic location system is capable of obtaining location in just about 1 second which is significantly faster than EPE. This is because the EPE suffers from network delays but the Mica2 base mote only needs to communicate with nearby listening motes. Tracked clients need to relay information of received signal strength to the EPE through the wireless infrastructure. The rate at which tracked client devices take signal strength samples is also another factor that determines how fast the EPE can provide the location.

The advantage for the EPE is that it uses existing 802.11 infrastructures and no additional proprietary hardware. It is a Java-based software only technology that is easy to deploy and cheaper than most other location-aware systems. The acoustic localization system requires a wireless sensor network to communicate and listen for the 4 kHz tone. The cost of setting up the using the Mica2 motes is proportional to the scale of coverage. Listening motes need to be installed in many places. This is expensive in cost and management.

The drawback to the acoustic localization system is that it cannot return a location if less than three receivers return the time difference of arrival information of the radio and tone signals. The EPE can still provide location information even if there are less than three access points but the error increases with less access points.

Overall the acoustic location system was harder to use as the motes need to be properly placed and oriented and the room has to be free of noise. On the other hand, the EPE was easier to use.

6. CONCLUSION AND FUTURE WORK

This paper demonstrates improving location-awareness by using WLAN positioning and sensor technology. The experimental results are encouraging as location error is small. This suggests that location-aware services can be enhanced with technologies complementing each other. The existing Ekahau Positioning Engine (EPE) and the acoustic location system complement and compensate each other in verifying and choosing the more accurate location information. The Multi Location Test Verifier (MLTV) showed that the acoustic location system can discover incorrect location information provided by the EPE. This shows the benefit of having a heterogeneous location-aware system. One might suggest that one very accurate location system is sufficient but the homogeneous design inhibits the system to a certain capability such as limited coverage and objects tracked. Therefore, the aggregation of the properties of different location systems can give a location system that has a larger tracking area and tracks more things with better accuracy.

Future work on the location-aware sensor networks should focus on improving the accuracy of the time measurements. A larger scale sensor network should be setup to prove the ability of the location system to track mobile clients. The acoustic location system can also be extended to track clients quietly and robustly by using ultrasound that will make the system robust.

7. REFERENCES

[1] Bahl, P. and Padmanabhan, V. N. (2000), 'RADAR: An In-Building RF-based User Location and Tracking System', *IEEE INFOCOM*, Mar 2000, Tel-Aviv, Israel, 775-784.

[2] Berger, S., Schulzrinne, J., Sidiroglou, S., and Wu, X. (2003), 'Ubiquitous Computing Using SIP', *13th Int. Workshop on Network and Operating Systems Support for Digital Audio and Video*, June 2003, ACM Press, 82-89.

[3] Christ, R. and Lavigne, R. (2000), 'Radio Frequency-based Personnel Location Systems', *IEEE 34th Annual Int. Carnahan Conf. on Security Technology*, Oct 2000, Ottawa, Canada, 141-150.

[4] Ekahau (2002), "Ekahau Positioning Engine 2.0: 802.11-based Wireless LAN positioning system", An Ekahau Technology Document (http://www.ekahau.com), Nov 2002.

[5] Getting, I.A. (1993), "Perspective/Navigation – The Global Positioning System", IEEE Spectrum, vol. 30, no. 12, Dec 1993, 36-38.

[6] Harter, A., Hopper, A., Steggles, P., Ward, A., Webster, P. (1999), 'The Anatomy of a Context-Aware Application', *5th Annual ACM/IEEE Int. Conference on Mobile Computing and Networking, MOBICOM'99*, Seattle USA, Aug 1999, 59-68.

[7] Hightower, J., Borriello, G., Want, R. (2000), "SpotON: An Indoor 3D Location Sensing Technology Based on RF Signal Strength", UW CSE Technical Report #2000-02-02.

[8] Hightower, J. and Borriello, G. (2001), "Location Systems for Ubiquitous Computing", *IEEE Computer*, vol. 34, no. 8, Aug 2001, 57-66.

[9] Ipina, D.L., Mendoca, P.R.S. and Hopper, A. (2002), "TRIP: A Low-Cost Vision-Based Location System for Ubiquitous Computing", *Personal and Ubiquitous Computing*, vol. 6, no. 3, May 2002, 206-219.

[10] Jarvis, R.A. (1992), 'Autonomous Robot Localization by Sensor Fusion', *IEEE Int. Workshop on Emerging Technologies and Factory Automation*, Aug 1992, 446-450.

[11] Priyantha, N.B., Chakraborty, A. and Balakrishnan, H. (2000), 'The Cricket Location-Support System', *6th Int. Conf. on Mobile Computing and Networking*, Boston, USA, Aug 2000, 32-43.

[12] Schilit, B.N., Adams, N., Gold, R., Tso, M.M. and Want, R. (1993), 'The PARCTAB Mobile Computing System', *4th Workshop on Workstation Operating Systems*, Oct 1993, Napa, USA, 34-39.

[13] Want, R., Hopper, A., Falcao, V. and Gibbons, J. (1992), 'The Active Badge Location System', *ACM Transactions on Information Systems*, vol. 10, no. 1, Jan 1992, 91-102.