Enabling Location-Aware Pervasive Computing Applications for the Elderly[1]

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Abstract

The RERC Center on Aging at the University of Florida is dedicated to creating smart environments and assistants to enable elderly persons to live a longer and a more independent life at home. By achieving this goal, technology will increase the chances of successful aging despite an ailing Health Care system (e.g. Medicaid). One of the essential services required to maximize the intelligence of a smart environment is an indoor precision tracking system. Such system allows the smart home to make proactive decisions to better serve its occupants by enabling context-awareness instead of being solely reactive to their commands. This paper presents our hands-on experience and lessons learnt from our first phase work to build up a smart home infrastructure for the elderly. We review location tracking technology and describe the rational behind our choice of the emerging ultrasonic sensor technology. We give an overview of the *House of Matilda* (an in-laboratory mock up house) and describe our design of a precision in-door tracking system. We also describe an OSGi-based robust framework that abstracts the ultrasonic technology into a standard service to enable the creation of tracking based applications by third party, and to facilitate the collaboration among various devices and other OSGi services. Finally, we describe three pervasive computing applications that use the location-tracking system, which we have implemented in Matilda's house.

Keywords

Pervasive Computing, Context-awareness, Indoor Location Tracking, Ultrasonic Technology, Smart Home, OSGi, Elder Care, Successful Aging.

1. Introduction

The world population of people over the age of 65 is growing rapidly at a rate of 800,000 per month [13]. Eventually, many of these people reach a point where they can no longer live independently. Moving an elderly person into a nursing home often involves huge economic and emotional burdens. Many times, they are not able to pay the large deposits to move into assisted

[1] This research is supported by an RERC Center grant funded by the Department of Education and the National Institute on Disability and Rehabilitation Research (NIDRR).

living facilities themselves, so they turn to the government for funding. Medicare spends approximately 1.5 billion dollars more per year for hospitalization and housing for individuals who live in a nursing home than for those that live independently on their own [4]. It is well documented that those who live in nursing homes tend to require more hospitalizations and doctor visits. Once moved into a facility, it is common for them to become depressed because of their lack of independence and to give up on life. It is in everyone's best interest for people to live independently for as long as possible. Technology could play an important role by providing a smart environment that aids the elderly in being independent. One possibility for this environment is a "smart home."

A "smart home" as defined by this paper, is a home that is able to proactively change its environment to provide services that promote an independent lifestyle for elderly users [14]. The central service necessary to facilitate these dynamically proactive changes is the tracking service. Simply put, the smart home cannot adjust itself if it does not know where the occupant is located. The decision on what kind of tracking system to design is based on five key factors: *cost*, *accuracy*, *size*, *weight* and *power consumption*. After assessing our system requirements, it has been determined that our minimum baseline for cost should remain under US$2,000; the system needs to be accurate within 20 cm (half the distance between shoulders, to help identify orientation); it must be light weight (less than an ounce) and small enough to place on an elderly person's clothing.

The rest of the paper is organized as follows. Section 2 reviews existing location and positioning system technologies. Section 3 describes our design, implementation and testing of ultrasonic positioning system in Matilda's House. It also describes our OSGi-based framework to create an abstract service interface of the positioning system. An experimental evaluation of the accuracy of the system is described in Section 4. Three applications that have been implemented using the OSGi interface of the positioning system are briefly described in section 5. These are: 1) a front door application, 2) an attention capture assistant for elders with AD, and 3) an hotel room navigation system for blind or visually impaired elders. Finally, conclusion and future work are described in section 6.

2. Background on Indoor Location Sensor Technology

Tracking and positioning systems are two different systems often confused by many. With positioning systems, users receive location information from the environment and calculate their own position. This provides privacy in possibly hostile environments for the users and a lot of research is being conducted in this area. A tracking system is a location system that allows a central computer or controller to continuously keep track of user locations. Since privacy within non-hostile home environments is not a primary issue, this is more appropriate for us. We give a brief overview of the technologies and existing systems that may be used to create a tracking system. A more comprehensive survey of location sensor technologies is found at [15].

Low frequency RF. Low frequency sensors in terms of location systems tend to work in the 418MHz, 433MHz, or 900MHz spectrums. Advantages to this technique are that RF transmitters, receivers, and transceivers can be inexpensive and the availability of research with this implementation. Low frequency tracking systems use time difference of arrival (TDOA) or strength of signal measurements to triangulate position. Examples of these types of systems are the MicroTrax program at Harris Corporation [6] that uses TDOA with an accuracy of 1 meter, and SpotOn at the University of Washington [8] that relies on strength of signal to provide locations within 3 meters. Unfortunately, they do not provide the accuracy necessary for our proactive smart home.

Infrared. An Infrared tracking system works by a mobile device emitting Infrared waves at predefined time intervals. These waves are received and time of arrival (TOA) algorithms are then used to calculate position. An example of this type of system is AT&T's active badge [2]. Disadvantages are undue interference caused by sunlight and accuracy.

Global Positioning System (GPS). After the recently (2001) passed laws requiring that emergency personnel be able to locate a cellular phone user's location in the event of an emergency call, there has been a boom of research to embed GPS systems in these phones. Unfortunately for us, line of sight (LOS) is lost with the satellites indoors. Although progress has been made with assisted GPS (A-GPS) and by massively increasing the number of correlators available for acquiring the encoded GPS signals [5], the overall best accuracy of 10 meters is not precise enough for our requirements.

Ultrasonic. Ultrasonic sensors work in the 40KHz to130KHz range and use time of arrival (TOA) to acquire distance information. This distance information is then applied to trilateration formulas. Trilateration is the process of calculating positions based on distance measurements. Ultrasonic receivers calculate the distance to a transmitter by using a predefined frequency. By using multiple receivers, it is possible to calculate the varied distances from each receiver and thereby obtain an accurate location. A minimum of two receivers is needed for two-dimensional calculations, but four receivers are recommended. The basis of using four transmitters is due to the limitations of ultrasonic signals. Ultrasonic signals are subject to loss of signal due to obstruction, false signals by reflections, and interference from high frequency sounds. However, most of these limitations can be reduced through careful planning, which results in a highly accurate system. The most famous example is AT&T's BAT System [3]. Here, sensors are placed on the ceiling providing an accuracy of within 3 cm. Another example is Hexamite's Low Cost Positioning System [7]. This is the base system we have chosen to use to create positioning services in our experimental smart house known as Matilda's House.

3. Matilda's House: An Infrastructure for Location Tracking

The Elder - Matilda. A test dummy, *Matilda*, shown to the left, is created out of PVC pipes, an RC car, in addition to some other cosmetics (head, face, wig, glasses, etc.) Two beacons are placed on top of Matilda's shoulders and a smart phone is attached to her left hand. Matilda is currently being used to allow anytime experimentation with the positioning system. Without her, it will be impossible to test the system using only one researcher in the lab. In the near future, Matilda will evolve to become a first class research instrument. We plan to fit Matilda with a wirelessly connected embedded computer running either Linux or Windows CE; replace the RC car with a professional robotic platform controlled by the embedded computer; and replace Matilda skeleton with pneumatic joints to allow her to sit, stand, and lay on bed. The objective will be to create a simulation instrument that can run for weeks according to a generated trace of a typical elder daily activities and behaviors. By enabling this kind of simulation, we will be able to test our pervasive computing applications and devices that we will be developing in the future.

Matilda's House. The house occupies about 500 sq ft. in a 971 sq. ft. laboratory hosted in the Computer Science Dept. It consists of a bedroom, a bathroom, a living room, and a kitchen. The house is accessible from the web through live web cams as indicated in [18]. Four Hexamite, Ultrasonic pilots are placed in the ceiling above each corner of the house perimeter. The floor plan of the house is outlined in Figure 1 below.

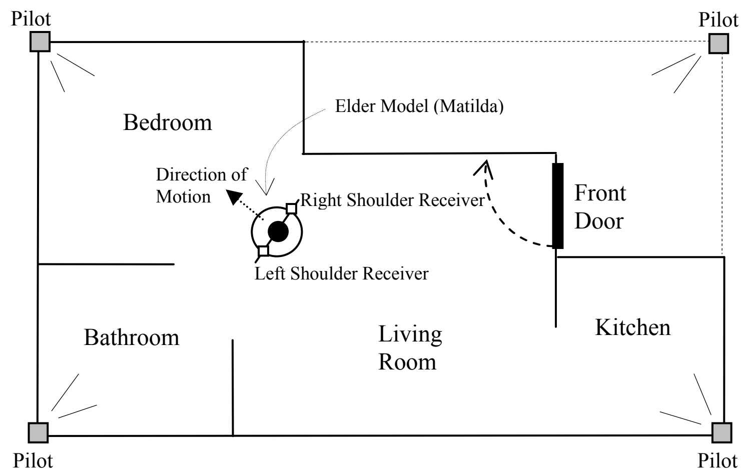

Figure 1. Floor Plan of Matilda Smart House

3.1. The Hexamite Ultrasonic Location Tracking Sensors

Based on the analysis of available positioning/tracking technologies, and based on the requirements listed in the introduction section, we have opted to go with the ultrasonic technology. Our decision was to use the Hexamite's Low Cost Positioning System (HLCPS) [7] as a base tracking system. Hexamite is a very low cost COTS product in its class. Its transmitters (also known as tags or beacons) are very light weight and are power efficient. The transmitters can be programmed by the pilots to enter a deep sleep mode which is another power saving feature. Te system allows the pilot and the transmitters to communicate within up to 16 meters distance.

The Hexamite ultrasonic systems can be set up as both a tracking system and a positioning system. The tracking system is made up of three different devices, HE900M pilots, HE900T beacons, and a HE485 RS485/RS232 converter. The stationary pilots are configured to act as receivers, whereas the mobile beacons as transmitters. For positioning systems, their roles are switched. The Hexamite system uses a high speed RS485 serial connection to relay location information. Typical RS485 cabling provides a wire for power and one for ground. This enables the pilots to be powered through their serial connection.

Each beacon is very lightweight and small, roughly the size of a cellular phone battery. The dimensions are ¼" X 1" X 2½". The beacons have a lithium battery, which lasts 24 hours in active mode and 300 hours in deep sleep mode. By placing two HE900T's on a person's shoulders, the system is able to acquire both her position and orientation.

The reception angle that the HE900M can receive is 130º at 6 meters and 85º at 8 meters. By placing one HE900M in every corner of an area, it is possible to achieve 360º coverage of the mobile beacons. A unique feature is the way each pilot is attached to the ceiling. We use a 3M ultra strong Velcro with an adjustable base that pivots and can be bent to cover a wide range of vertical angles. This design allows for the adjustment of the pilots.

The pilots are set up so that each one can synchronize with the beacons. Initially, all pilots simultaneously broadcast a synchronization signal to the beacons. At the receipt of the first signal, the beacon responds. The TOA from the beacon response is sensed by the pilots to generate the pilot distance to beacon measurement. All pilot to beacon distance measurements are then placed on a distance string that is sent to the location calculation module, which performs the necessary conversions.

This system is highly accurate and currently obtains positions within 22 cm without reflective corrections. This accuracy can be increased to within 3 cm through reflective software correction protocols, details of which are discussed in section 4.1. Each HE900M pilot can retrieve information at a range of up to 16 meters. However, it is recommended for best results that area of coverage should not exceed 6 meters in diameter.

3.1.1. Accurate Location Calculation

With four pilots, two good distance measurements are guaranteed. Two-dimensional calculations can therefore be adequately generated. Our location calculation module parses the distance strings generated by the four pilots and saves the shortest two distances and their corresponding pilots. Then, it converts these figures to actual measurements by adjusting for sensor clock cycles and synchronization methods. The following trilateration formula is then applied to obtain relative distancing information.

$$X_c = \frac{L_2^2 - L_1^2 + L_B^2}{2 \times L_B}$$

$$Y_c = \sqrt{L_2^2 - X_c^2},$$

where L_1 is distance from the second closest pilot to beacon, L_2 is distance from the closest pilot to beacon, and L_B is distance between the pilots.

After each beacon's relative location has been determined, the two are averaged to obtain the person's overall location. This information is applied to a GIS database that contains Matilda's House floor plan. The overall position over the floor plan is then obtained. As an example, figure 2 illustrates how the overall relative position is achieved with pilot 4 being the closest and pilot 3 being the next closest.

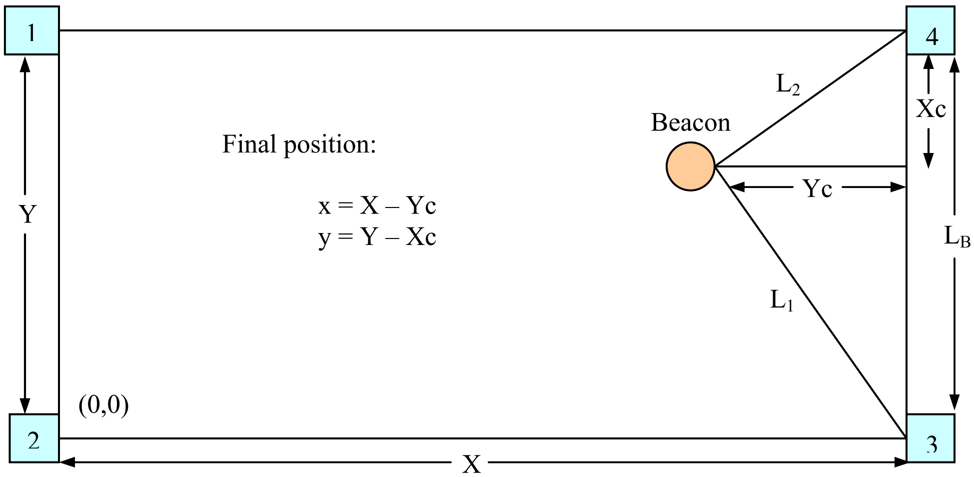

Figure 2. Basic Trilateration Case

3.2. Location Service as an OSGi Service Bundle

Open Service Gateway initiative, or OSGi [12] [16] is an open architecture designed for the delivery of services on the Internet to residential networks. Hosted by a residential gateway, it facilitates the interaction of services from various sources in an organized and coordinated fashion as well. This perfectly satisfies our need for a robust framework that can support dynamic context-aware service composition using core services such as our location service. In order to provide an execution environment for services from diverse devices at a residential area, platform independence is a requirement, which is achieved by being based on Java.

In the OSGi framework [17], a *bundle* is a deliverable application packaged as a JAR (Java Archive) file. It contains zero or more services specified as a Java interface. Services are registered with *Service Registry* so that they can be discovered and used by other Bundles. The OSGi framework provides this execution environment for individual services and their interaction among them.

We have packaged our location system into an OSGi bundle to provide the location service to other services and applications. We have added some eventing capability to enable the location service to be subscribed to, based on rectangular enclosures. In packaging our system, we had to restructure it into the following software components as shown in figure 3.

Communication Module: This module communicates with the Hexamite sensors via the serial port. The communication includes initializing the pilots and reading the beacons' location information from the pilots.

Location Calculation Module: The location information from the Communication Module is processed by this module. It refines the information to a more usable format having the (X, Y) coordinates and the orientation. This refined information is stored in a *Person* object.

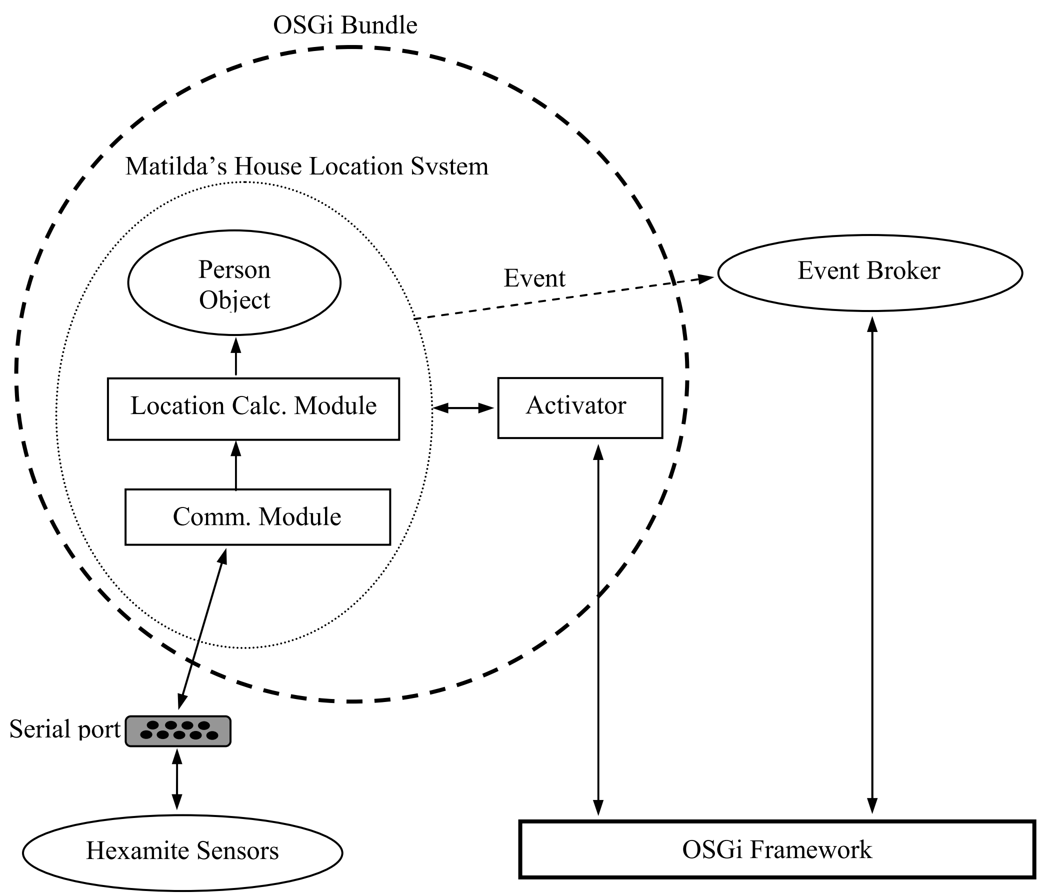

Figure 3. ICTA location service OSGi bundle

Figure 3 shows the location service packaged as an OSGi bundle. The *Activator* component and the *Event Broker* component are our additions to the OSGi framework for the packaging. By interacting with the OSGi framework, the Activator component provides a mechanism for the location service bundle to be started or stopped from the framework's management interface. The Location Calculation Module is changed to generate an event containing location information, which is thrown to the Event Broker [9]. Any client interested in the location event will have to register with the Event Broker.On receiving this event, the broker sends the corresponsing event object to all the registered clients. This way the location information can be shared by multiple applications simultaneously within the OSGi framework.

4. Experiments

The accuracy of the system was the main focal point of our experimental investigations. To assess accuracy, one must measure the error. We have classified error into four different categories: absolute, environmental, reflective, and resonant errors. Our experiments involved taking 1356 measurements in 22 selected positions in Matilda's House. Positions were chosen to maximize obstruction problems by having Matilda's head block the nearest beacon.

Accuracy is based on comparing the relative location sensed by our location service with the real measured positions. In order to obtain the measured positions, lines are suspended under each of Matilda's beacons to mark the beacon positions on the ground, the area perimeter is defined by suspending markers below each pilot and then pulling a string tight between them, and the metric tape measure has to be perpendicular to the area perimeter. After repetitive measurements at the same location, it was determined that the current measurement process has a $\pm$ 2cm accuracy rate.

Absolute errors are different for each pilot and are caused by crystal clock frequency variations. Absolute errors are possible to correct because the amount of the error has a linear relationship per distance. To calculate the amount of error per pilot, three data sets are run at one-meter intervals from the pilot. The meter intervals are further enhanced by creating an arc that contained three points. One point is positioned directly in front of the pilot and the other two are spaced at approximately 45-degree intervals from the pilot.

Ultrasonic pulses are subjected to outside environmental influences. These influences are noises in the form of ultrasonic collisions. Collisions are wave patterns that have the same frequency as the systems. Wave patterns in the same frequency as the ultrasonic system will cause the message passed from the pilots and beacons to dissipate or reflect. Several test experiments are created to test the system under normal household activity. These are radios, yelling, keys jingling, and finger snapping. Jingling keys produces the highest frequency sound and as a result is the only test that made the system unstable. This problem is solved by the very nature of a smart house. A smart house would eliminate the need for elders to carry keys on them by automatically opening whatever door the person approaches.

Reflections by ultrasonic waves are caused by the ultrasonic ping bouncing off an object and are the major cause of errors. Unlike absolute errors, reflective errors fail to create any sort of linear relationship. Through our experiments, two types of reflective errors can be defined, non-disclosure and outside receiving angle (ORA). Non-disclosure reflective errors bounce off multiple walls and are directly linked to bad reads and actual positioning error. Figure 4 below illustrates how reflective errors cause inaccuracy.

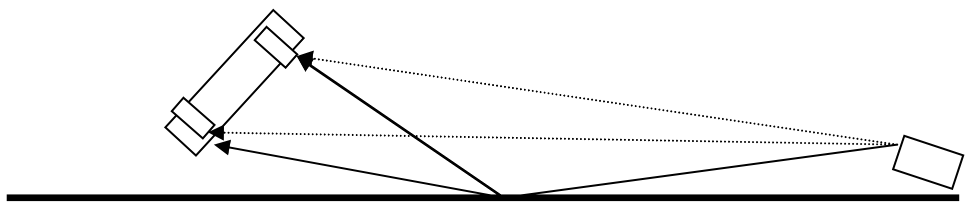

Figure 4. Reflective Error

Here, the dashed lines represent the true distance, but the actual distance recorded is a result of the reflection.

ORA errors occur because the beacon reads a signal or ping from a pilot that is outside its receiving angle. The HE900T pilots have a receiving angle of 130 degrees at a distance of up to six meters. Having this angle leaves an angle of 25 degrees per side that can cause misreads.

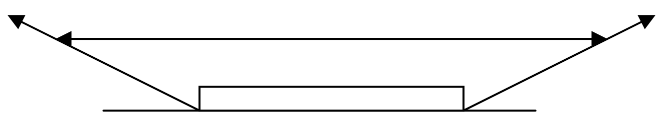

Figure 5. Outside Receiving Angle Error

If any reads come in outside the receiving angle, they might return incorrect results or fail to get picked up. By placing the beacons on top of the shoulders and with the pilots facing downward, the ORA errors are not a factor. Reflective correction algorithm is to be implemented in the next phase of our project.

Finally, we define resonant cross errors as synchronization errors that occur midway between two pilots. There exists a line that crosses the area where the distance is almost equal between two pilots. In this area, it is possible that the second shortest pilot will get registered as the closest. This occurs if the second closest pilot has a better angle of exposure than the closest in the cross area. More experiments need to be conducted though to determine the exact width of the cross.

4.1 Experiment Results

Of the 22 position experiments conducted, 1356 system results have been recorded. The data was broken down into X/Y positions for each beacon, the max and min, and average to determine the number of bad reads and quantitative actual error. A bad read is defined as any number that has a difference that is greater than 400 mm from the average. Bad reads occurred 45 times or 3.3% with all but two occurring with the left beacon. Actual error was calculated by creating a central person location for both the average results and the real measurements then comparing their difference. The actual error was found to be within 22 cm in the worst case and within 1 cm for the best. Figure 6 below separates the actual error of the 22 sub cases into four categories.

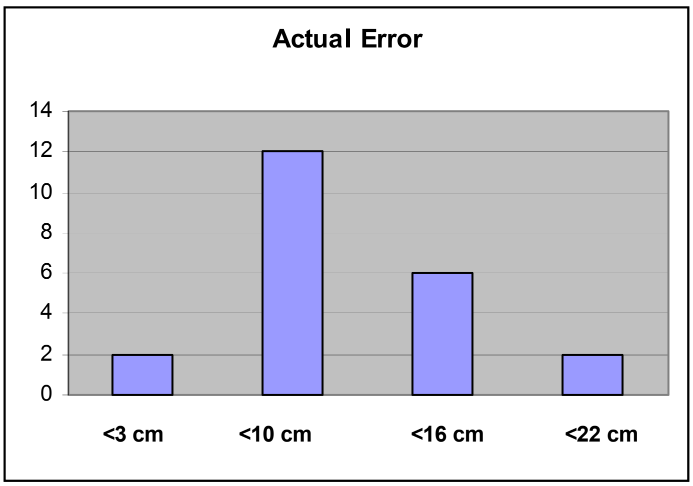

Figure 6. Actual Error

5. Enabled Applications

The following applications have been enabled by our location service and its OSGi bundle interface design. The use of the location service required only the addition of a few lines of code into each of these applications. Each application is described briefly below, and a detailed video showing the application in action is provided and made accessible to the reader.

5.1 Remote Monitoring Application

We have implemented a simple remote monitoring application using our OSGi-based location service bundle. The application simply registers with the location service requiring location update on timer event of certain value (e.g., every 5 seconds). The application services requests submitted by remote monitoring users by shipping an applet that communicates back as frequently as the timer event to bring back location updates.

Figure 7 shows the applet displaying the floor plan of Matilda's house as well as her position (living room). A video describing this application can be viewed on the web as described in [19].

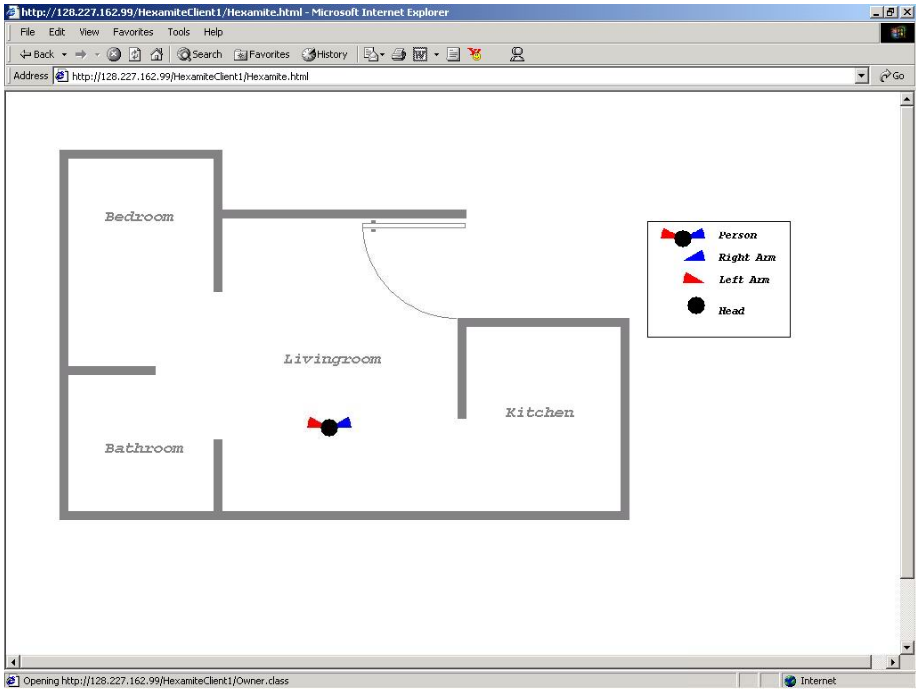

Figure 7. An Applet Showing Matilda's House and Matilda's Location and Orientation on a Web Browser

5.2 Attention Capture Application

We have developed an *attention capture* application [24] that attempts alternative mechanisms in an increasing order of intervention and interactivity. This ranges from simply calling the elder's name (MIDI Audio output) on her smart phone, requesting the elder to respond in certain way (e.g. press the "OK" button on the smart phone). If attention is not secured, richer audio is attempted by playing special songs and special sounds and then the name-calling is repeated and confirmation is again request. If this fails, the phone vibrator on the smart phone is actuated, and output the name calling using pre-recorded sounds of family members. The protocol progresses to using visual cues by playing a video clip on the video monitor facing the elder (we assume the use of multiple video monitors). The location service in Matilda's House is used to determine the orientation of the patient, and to subsequently select the ideal monitor to play the video clip. We currently have two flat panel displays mounted on different walls in the mock up house.

The state machine of this application is shown in Figure 8 below. A complete video of this application can be viewed on the web as cited in [20].

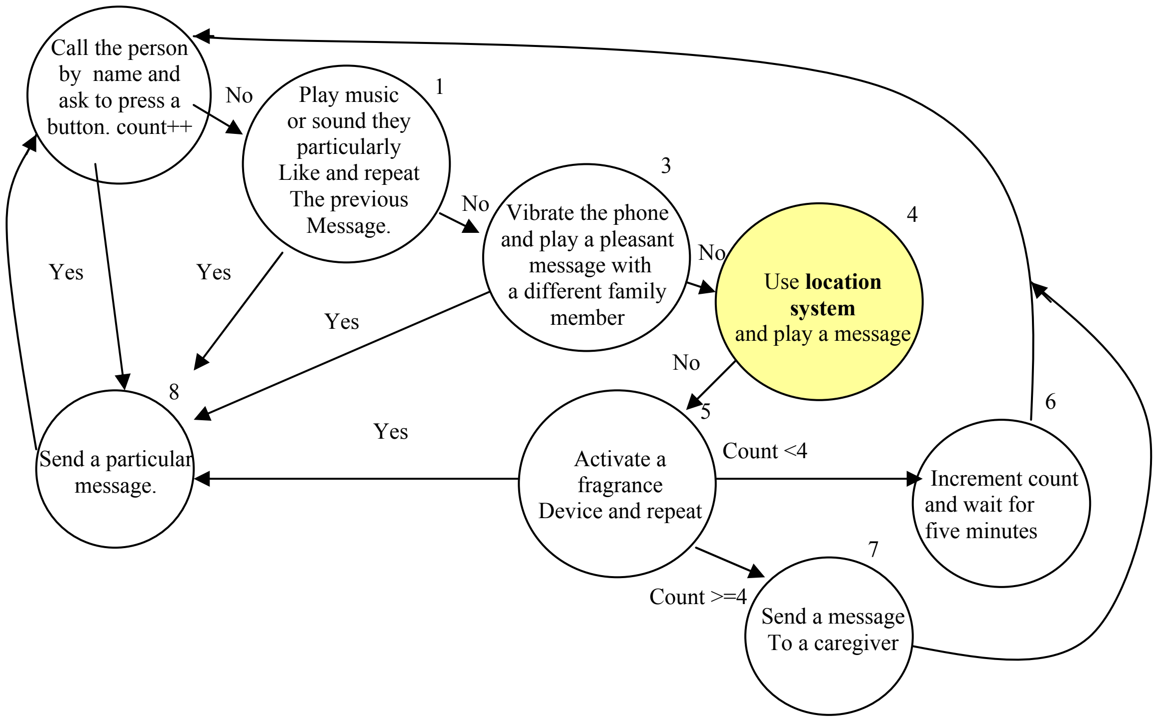

Figure 8. State Transition Diagram of the Attention Capture Application

Similar to *attention capture, Front door* is another application that uses the location service to locate the elder and her orientation before activating a nearest monitor to show live video and audio of visitors at Matilda's House front door.

5.3 Blind Guide to Hotel and Conference Rooms.

This application is based on the Drishti system [22][23] developed at the University of Florida. Drishti is an outdoor (pedestrian) navigation system for the blind. It uses precision positioning system, wireless connection and wearable computer to keep a blind person as close as possible to central lines of walkways on campus and downtown areas. Drishti has been extended to encompass indoor navigation based on the ultrasonic location service in Matilda's House. On user's command, Drishti can be switched to indoor navigation answering a different set of queries than the user would normally ask in outdoor mode. Among the indoor queries are identifying context (room type, orientation, list of nearby furniture or obstacles), navigating from a room to another, listing all furniture in a room, describing where an object is relative to the person (where is bed?). A video describing this application can be viewed on the web as described in [21].

6. Conclusion

Matilda's Smart House presented in this paper is the groundwork for our ultimate project goal, i.e., creating a smart home and mobile smart assistants for the elderly. On top of this infrastructure, we plan to develop context-aware applications to help the elders live a safe and independent live. The indoor precision location service is a first step towards enabling a rich class of applications that target our research goals. We have presented details of our system which is based on the ultrasound technology. Although our achieved error rate of 22 cm sounds intolerable, it is not when you consider the object being tracked, people. A human can easily have a width of 22 cm. This error will be further reduced, when we introduce reflective error correction algorithms. These algorithms will be based on rigorous tests to create a fingerprint of the reflective nature of ultrasonic waves in Matilda's Smart House. The method will be similar to the various fingerprinting algorithms used by other indoor location studies [1] [10] [11].

We are currently refining the location service as mentioned above and are making extensive use of it to put it to a stressful test. We have implemented several applications that make use of the location service. We briefly described these applications and provided links to more details videos that show their demonstrations.

Acknowledgements

We are thankful to Paul Bennett for his diligent work in setting up the mockup house and in watching for all the details and regulations while we are deploying our systems and its cables through the house walls. Thanks also go to Steve Moore for giving Matilda a face lift and for placing her on an RC car. Prior to her upgrade, Matilda was a cardboard on a camera tripod. Sree Kuchibhotla assisted in the OSGi service bundle design. Finally, Hicham Zabadani, Wenzheng Gu, David Nordstedt and Wendong Li provided endless assistance in setting up the demos.

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