A Study of the Localization Methods to Help Elderly Patients in their Home Environments

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Abstract
Patients with various movement hampering illnesses who have been admitted to hospitals are at low risk of being injured as they are under strict observation by hospital staff and electronic systems. However, once these patients move into their homes, it becomes difficult to monitor them and warn them of potential hazards. For example, Chronic Obstructive Pulmonary Disease (COPD) is a group of progressive lung diseases that obstruct airflow. It affects millions of adults in the USA alone, with a world estimate of 64 million by the World Health Organization. COPD patients have breathing apparatus attached to their mouth, which is then connected to oxygen tanks via pipes. These individuals run into various problems such as walking too far away from the tank, tripping over the plastic pipes, etc. Most of these patients have limited resources to invest in expensive tracking devices, or to get personalized help at home. To solve some of these problems, one must first be able to reliably locate them and keep track of them at all times. The objective of this work is to propose a comprehensive, multi-sensor platform that can be reliably installed at homes. We explore a variety of low-cost tools and techniques available. This includes satellite tracking of cell phones attached to the patient, ultrasound and laser range finders mounted on walls, iBeacons, etc. We also discuss some of the fancier tools on the horizon, which may soon be available for household applications.

Keywords
COPD, lung disease, Wi-Vi, ultrasonic, laser range finder, ZigBee,

Problem statement and goals
Elderly patients who have a wide range of movement hampering diseases typically need to remain in hospitals with constant monitoring by the hospital staff to ensure their safety. This is less than desirable due to the high costs of staying at a hospital for a prolonged period. When these patients move to their home or even a nursing home environment, the monitoring is not that strict and may put the patient in danger if they walk too far away from their designated location or room. We are interested in finding

different location-tracking technologies that allow us to keep track of elderly patients that stay at home which are low-cost and easy to implement so that the monitoring may help prevent potential incidents at home. In this way, the elderly patients will have the comfort of living in their own homes, while still being monitored from a distance.

Introduction

A good example of the application of our work is an ongoing problem with Chronic Obstructive Pulmonary Disease (COPD) patients [1-4] who are sent home after treatment. There are various ways to detect and differentiate this disease against other lung diseases [3] and our group has done work in this area in the past through the development of a low-cost spirometer [4]. The primary treatment is the use of supplemental oxygen through portable or non-portable oxygen tanks. In most cases, a pipe is used to transfer oxygen directly into the patient’s mouth and, in situations where there are elderly patients who stay at home for long periods; a wide range of different problems can arise. Elderly patients, and in particular COPD patients and their oxygen needs vary based on their medical conditions, age, and mobility. Those who are currently residing in a hospital or have been moved to old age/nursing centers are taken care of by the staff. Thanks to the constant stream of personal attention that these patients receive in these locations, not many problems are present. However, for patients who are healthy enough to stay at home by themselves, the situation is different. The big problem here is how to locate these patients in order to keep track of them at all times in case something goes wrong. These patients may move far from their gas cylinders, making the oxygen supply risky. Our proposed solution is to keep track of where a patient is in the home, and if the patient starts to move too far away from their oxygen tank (or designated spot), an automated system can detect this and inform the patient and/or the caregiver. In order to do this, we need to set up devices in every room of a patient’s house and these devices will need to communicate their information to each other wirelessly so the patient’s location is known at all times.

There are a wide variety of devices and technologies that can accomplish this task. However, it is important to identify which device can calculate the distance of the patient most accurately and efficiently along with keeping other constraints in mind such as cost and ease of access. The goal of this study is to research multiple different technologies to see which one could accomplish this task most effectively and cheaply.

Overview of Technologies

A. Arduino Based Devices:

To set up some of our experiments we had to choose an easily programmable and low-cost microcontroller. We chose Arduino UNO [10] for most of the experiments, though we did try BASIC Stamp [14] some measurements. We used external sensors such as a Laser Range Finder and an Ultrasound Sensors, which were coded using the Arduino IDE to measure distance.

A1. Ultrasound Sensor (PING):

Ultrasounds are sounds that are inaudible to human beings as their frequency is much higher than what we are normally able to hear. Ultrasound sensor-based Systems use these Ultrasounds to complete certain tasks and, in our experiment, we utilized a device that could measure distance based on the time taken for a sound to bounce off a wall and return to its source [11-12]. Since the speed of sound varies with temperature, a reliable thermometer has to be integrated with the system to measure instantaneous temperature and then to find the speed of sound based on temperature. For our experiments which were done in a room, we used the National Weather Service website [13] to find the speed at room temperature at the time of experiment.

A2. Laser Range Finder (LRF):
LRFs work similarly to Ultrasound Based Systems as they emit a laser beam that travels and bounces off from distant objects. We use the model from Parallax [14]. Based on the time it takes for the laser to return to the source, the device calculates the distance of the object that the laser had bounced off. If the laser beam takes a long amount of time to return, the object is far away [15]. The calculation of the distance is made by using the speed of light alongside the time taken for the beam to return in order to find the distance of the object.

B. Android Cell Phone-based experiments

B1. Satellite Tracking:
Satellite Tracking is a very common method used for calculating the position of an individual, as can be seen by the frequent use of GPS systems in everyday usage of people's lives [16]. However, their main application is locating vehicles on the road and hence their accuracy is not at a level where it can be reliably used for patients. We modified a GPS tracker App from MITAPPInventor [] for this purpose.

B2. iBeacon Transmitter:
iBeacon transmitters are devices that use Bluetooth technology in order to broadcast certain information to nearby devices and communicate with them [5-9]. For the purposes of this study, we experimented with an iBeacon device to see if it could calculate and transmit the distance between itself and the cell phone.

C. Possible Methods in Near Future

C1. Zigbee Devices:
Zigbee devices are used to create personal area networks with small, low power digital radios and can be used for home automation or medical device data collection [17-21]. Precise measurement of distances using two ZigBee compliant devices has been explored in the past [19] with an accuracy of less than 10 cm. This is deemed good enough for patient localization. The use of these devices in our experiments is currently very limited and we are working on getting better ZigBee radios and explore them further.

C2. Wi-Vi:
Wi-Vi stands for Wi-Fi Vision and it is a relatively newer system in which Wi-Fi signals are used to track motion even behind walls [22-24]. The technology treats the human body as an antenna array and uses the reflections of its transmitted signals to track a person. Other techniques such as MIMO interference nulling are used to ignore reflections being made by other objects in a room so that the only thing being tracked is the human. The technology allows identification of even simple gestures made behind a wall. Hence this is a promising technology for patient tracking even when they are moving in the house. We have not explored this technology yet but expect to explore this in detail later.

Experimental Results

Satellite Tracking:
For this experiment, we used an Android device that had an application installed on it, which could connect to a Satellite that would track and determine the phone's position, similar to a GPS. As expected, this too proved to be far too unreliable as GPS technology is more focused on giving a general

estimate of a person's position relative to the planet whereas our study needs more accurate distances that can work in homes.

iBeacon Transmitter:
For this experiment, we used an iBeacon device and connected it to a phone in order to see how accurately it could calculate the distance between the phone and itself. The initial testing of the device showed that it was highly inaccurate when considering the smaller margin of error we have in calculating distance. It is effective in giving a very rough estimate of one's location so it could be useful with broader scopes such as with GPS technology, but for the more precise solution that our study desires, this system may not be reliable.

Ultrasound Sensor (USS):
For this particular experiment, we set up an Ultrasound Sensor with an Arduino UNO and attached it to an LCD Display that would update every 10 milliseconds to provide accurate measurements at all times (see Figure 1). The small knob to the right of the LCD allowed for control of the brightness in order to control power consumption. Overall, the Ultrasound Sensor showed very little error in measuring the distances provided, even in an extremely noisy environment that included other Ultrasound Sensors. Its accuracy stayed consistent for all distances explored.

Laser Range Finder (LRF):
For this experiment, we set up a LRF with an Arduino UNO with a similar setup to that of the Ultrasound Sensor (see Figure 1). We repeated the same procedure as previously, that is, we placed a wooden block at varying distances and checked to see what the LRF calculated the distance to be. Our results show that the LRF was mostly accurate in calculating distance when the object being used for testing was colored white. However, the LRF became very inaccurate at large distances when a darker colored object was in front of it.

ZigBee:
ZigBee is based on the IEEE specification 802.15.4 and allows low power digital radios to communicate with each other. They have been extensively used in medical device data collection, sensor networks, etc., and have already been tested for precise distance measurements and the results are promising. For example, Schwarzer et.al. [19] report errors in the range of ~15 cm using their multi-transmitter method.

Conclusion

The technologies explored in this work proved moderately effective. The iBeacon Transmitter and Satellite Tracking software were far too inaccurate to use in domestic environments. Satellite tracking remained highly unstable with position coordinate fluctuating up to 20 ft. while standing at a fixed point. That means it is impossible to decide which room the patient is actually located in. iBeacon signal showed similar behavior when it was at a distance far from the receiver (cell phone). This is understandable as iBeacon software is relatively new and devices that are far more expensive would be needed to gain more accurate results. However, the two methods did prove useful in providing the first estimate of the location within a few feet of the patient.

Next came the Ultrasound sensor (USS) and Laser range finder (LRF) systems. The collected data showed that both systems were accurate in calculating short distances (< 1-2 feet). During the testing phases, we noticed an interesting effect. In theory, the LRF is expected to be more accurate and reliable than the USS as light travels much faster than sound. As such, the LRF should be outputting distance values that would be relatively more recent, and thus more accurate than the USS. However, the attached electronics make it slow and hence the distance measurements don't get updated faster than USS. Hence, both USS and LRF provide essentially the same level of accuracy. The LRF also becomes heavily inaccurate when objects of darker colors are in front of it. ZigBee radios turned out to be more difficult to calibrate and provided a reliable mid-range measurement (a few feet).

Hence, our current model of the comprehensive care solution includes all the sensors sending data back to a cell phone via low-cost IoT chips, plus satellite tracking of the cell phone of the patient. This makes it a multi-sensor system that can be used to track elderly patients while they are staying alone at home.

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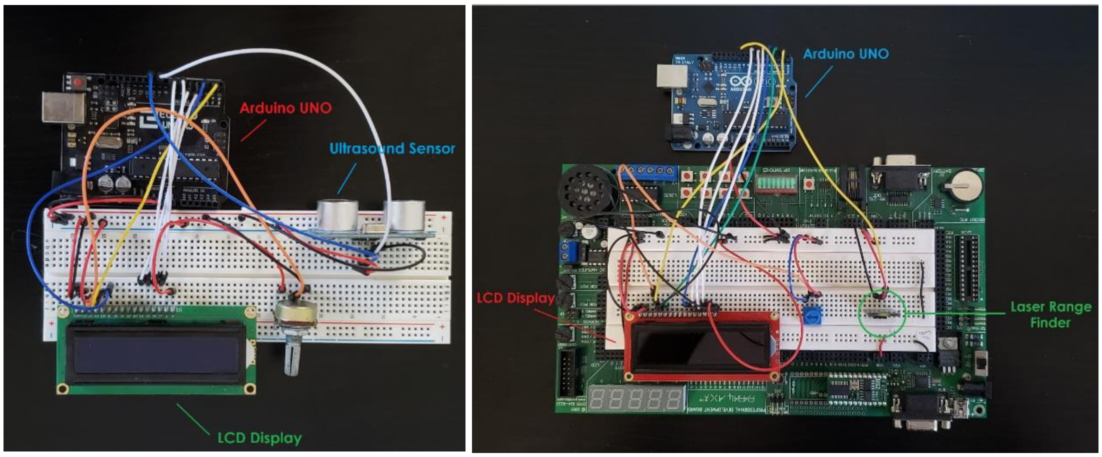

Figure 1: The Ultrasound sensor and Laser Range Finder setups used to make measurements