APPLICATION OF SENSOR NETWORKS IN A SMART APARTMENT

Omid Salehi-Abari*, Furkan Alaca*, James R. Green, and Rafik Goubran
Department of Systems and Computer Engineering, Carleton University

O. Salehi-Abari and F. Alaca contributed equally to this work

INTRODUCTION

Home-based health monitoring systems provide an opportunity to enhance the quality of life for older adults by allowing them to live independently and improving doctor-patient efficiency. These systems are more cost effective than constant medical supervision in an institutional setting and will help in reducing the load on the healthcare system [1]. Studies show that people aged 75 and older are significantly more likely to require health care services than other adults [2].

In this paper we propose a number of non-invasive applications of low-cost and low-powered wireless sensor networks aimed to monitor various aspects of a user's health, daily activities, and environment. Our goal is to increase the perceived level of privacy by the subject as compared to more invasive monitoring technologies such as video cameras. Our approach is to place the sensors in an unobtrusive fashion and to avoid using imaging sensors.

Measurements from simple temperature, humidity, and light sensors can be combined to ultimately aid in health monitoring and detecting medical emergencies. A number of other initiatives have used diverse sensors to track human health and emergencies (e.g. [3], [4], [5]). In the present study, we investigate the use of low cost, low power wireless sensors for tracking indicators of human health. As discussed below, we have actually implemented these systems and conducted a number of proof-of-concept experiments.

We propose algorithms which can be used to help detect shower usage, monitor exposure to natural sunlight, and collect data on day-to-day activities such as refrigerator and bathroom use. The information collected can then be forwarded to health care professionals or emergency contacts. This work was completed during an 8-month senior design project. Although this is a pilot study, we aim to deploy the final sensor network and data fusion system in an instrumented Smart Apartment as part of the TAFETA initiative [1].

METHODS

Wireless sensor hardware

In this study, we have employed the Crossbow Iris mote. The mote uses an IEEE 802.15.4 compliant RF transceiver and uses the unlicensed 2.4GHz band. The mote has a maximum indoor range of 50m, which is appropriate for a one-bedroom apartment. One of the motes was configured as a base station by connecting it to a desktop computer via a USB connection and loading the appropriate software. The other motes can then wirelessly transmit data to the base station using the specified sampling rate. The base station automatically saves the data from the sensors into an SQL database. This allows us to analyze the data in real-time. MATLAB was used to retrieve the data from the SQL database and to perform the required operations on the data.

Overview of application areas

We explored a number of possible applications where the sensors can be used either independently or in conjunction with other instrumentation. Figure 1 shows the floor plan of the one bedroom apartment used by TAFETA and our proposed sensor locations.

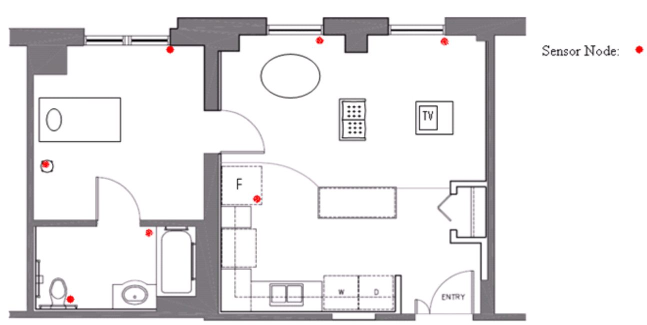

Figure 1: Proposed sensor locations in the one bedroom apartment

Toilet usage

Toilet usage can be monitored by placing a temperature sensor inside the tank, as shown in Figure 2. Since flushing the toilet expels the tepid water from the tank and replaces it with colder water from the pipes, there will be a measureable drop in temperature. Therefore, by collecting periodic temperature measurements and applying a differentiator to the raw data, we can detect toilet flushing events.

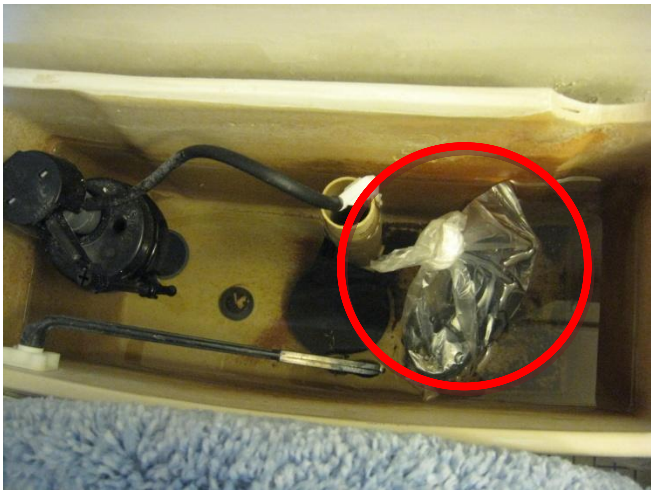

Figure 2: Photo of temperature sensor in toilet tank

Shower usage

Shower usage can be detected by monitoring the humidity in the bathroom. A significant increase in humidity typically indicates that the shower is in use. Shower detection can be helpful for two purposes. Firstly, keeping a record of shower usage can help ensure that the subject is maintaining their personal hygiene activities. Secondly, abnormally long showers can be detected if the humidity remains high for a prolonged period. Before this can be accomplished, sufficient training data must be collected to establish the average time which the person typically takes in the shower. An excessively long shower could indicate that the person requires assistance.

Refrigerator usage

Refrigerator usage can be monitored by using a light sensor inside of the refrigerator. When the refrigerator door is opened, there will be a significant increase in light intensity. Since the light intensity reading will be zero when the fridge door is closed, even the ambient light from the room will be enough to detect an open door. Using a light sensor could have advantages over other methods, such as magnetic switches, since it may be easier to install and it does not change the external appearance of the refrigerator. The light sensor also proved to be more accurate than the temperature sensors as discussed below. Monitoring the refrigerator door can give an indication of whether or not the subject is following their regular eating pattern. In addition, it can help to identify cases where the door is accidentally left open. Note that the refrigerator usage could perhaps be more simply monitored by using a contact sensor in the door. The current solution is preferred for two reasons: 1) we are using the same commercially available wireless sensor mote for all applications and have avoided the need for specialized hardware for each monitoring application; 2) our solution is suitable for retrofitting on any refrigerator and does not require any modification of, nor integration with, the appliance.

Exposure to natural light

It has been shown in studies that older adults are more likely than others to have vitamin D deficiencies due to lack of exposure to natural light [6]. Therefore, it is of benefit to track a subject's exposure over time.

Light measurements can be taken throughout the day to determine the subject's exposure to natural light. To differentiate between artificial and natural light sources, temperature sensors can be placed adjacent to lamps, which can determine whether the lamp is on or off based on the heat relative to room temperature. By combining light and temperature data, we can detect whether the room is lit by artificial or natural light. Also, if the subject leaves their lights on during the day, they can be advised to open their curtains.

Room temperature measurements

The sensor network could help determine whether a window is open or closed. For example, temperature measured near the window could be compared with the aggregate temperature from the sensor network. In an experiment involving three sensors, the state of the window (open/closed) was clearly discernable from the temperature data. While this approach will only work when a significant temperature differential exists between indoors and outdoors, this is precisely when window status information is most useful.

The sensor network can also help determine whether this is an appropriate time to open the window. Temperature and humidity data could be collected from both inside and outside. This information could then be compared in order to inform the subject of whether or not it is an appropriate time to open the window for fresh air. This could be of particular benefit to patients suffering from reduced mental acuity or dementia. A number of proof-of-concept experiments were successfully conducted to demonstrate the feasibility of this approach.

RESULTS

Data was collected and analyzed for each of the aforementioned applications. The sampling rate for each mote was chosen based on the application and the type of sensor (1min for toilet, 1min for shower, 15s for refrigerator, 5min for natural light). For all experiments, the ambient room temperature was 25ºC. Different types of data can change at different rates depending on their time correlation. For example, light intensity can change almost instantaneously, whereas changes in temperature and humidity are more gradual. Consequently, using temperature sensors allows us to use a lower sampling rate without missing any events. Lower sampling rates result in fewer transmissions, which allows for lower power consumption and longer battery life.

Toilet usage

Figure 3 shows the water temperature in a toilet tank. As it can be seen, the water temperature falls suddenly when the toilet is flushed. This permits the detection of flush events by using a differentiator and a threshold algorithm. Many hours of data were collected in order to test the algorithm. As a result we were successfully able to detect toilet flushes which were at least 20 minutes apart. This value is reasonable assuming that only one person is living in the apartment. Toilet flushes which were closer than 20 minutes were undetectable due to the slow recovery of the tank water to room temperature.

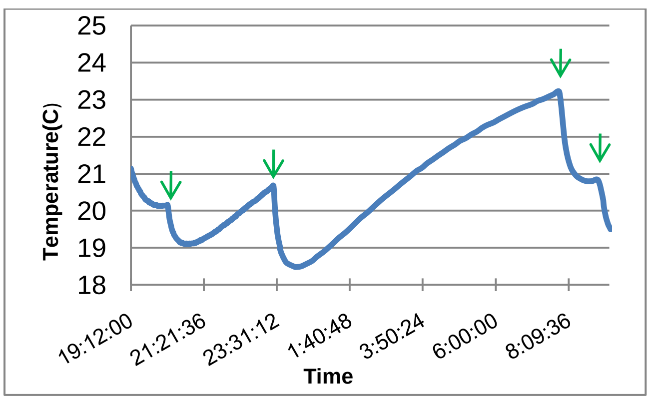

Figure 3 : Water temperature in toilet tank (flushes are indicated by arrows)

Shower usage

In order to detect the shower usage, we placed the humidity sensor 1m away from the shower. We found that the humidity rose sharply after approximately one minute. However the drop in humidity had a large delay after the completion of the shower. These delays depend on factors such as bathroom size and sensor location. The state of the exhaust fan (i.e. on/off) also impacts the rate of decrease in relative humidity following a shower (but does not delay the increase in humidity at the start of at the shower). The shower detection algorithm worked regardless of the state of the fan. Although we were not able to detect the exact shower duration, we were still able to detect the shower usage event. In addition, it may be possible to detect excessively long showers provided that delays are constant for a given installation. An excessively long shower could be an indication that the subject requires assistance.

Refrigerator usage

Figure 4 shows the light intensity measured by a sensor placed inside a refrigerator door. The peaks in the plot indicate the events where the refrigerator door was opened. The sampling rate for this application needs to be relatively high in order to capture all of the events. This is due to the abrupt nature of the changes in light intensity. Initially, we tried to detect these events by measuring the change in temperature in the refrigerator door when it was opened. However, this was found to be impractical due to the insignificant change in temperature when compared to the temperature oscillations caused by the refrigerator compressor turning on and off.

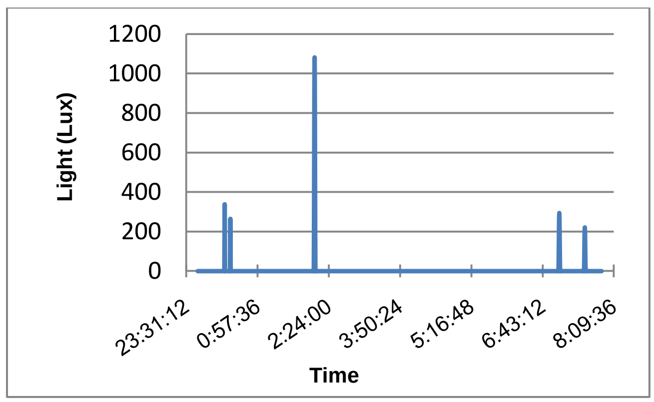

Figure 4: Refrigerator light (light is zero when refrigerator door is closed)

Exposure to natural light

Figure 5 shows the light intensity and the lamp temperature during night hours. When the lamp is turned on, there is a sharp increase in both the light and temperature readings. For low sampling rates, which allows for better battery life, we found that it is more favourable to monitor the lamp using temperature measurements. Since changes in temperature are more gradual with respect to time, it is more reliable to detect the events based on temperature rather than light. As can be seen from Figure 5, relying solely on the light sensor may lead to undetected events if a low sampling rate is used. By combining the light and temperature data, we will be able to monitor whether the light is on or off throughout the day. When the light is on, we will see a rise in both temperature and light measurements. On the other hand, if the subject opens or closes the curtains, a sudden change will result in the light intensity graph without any observable change in the temperature. This is illustrated in Figure 6, which shows the light intensity of the room and the lamp temperature during daytime and evening hours.

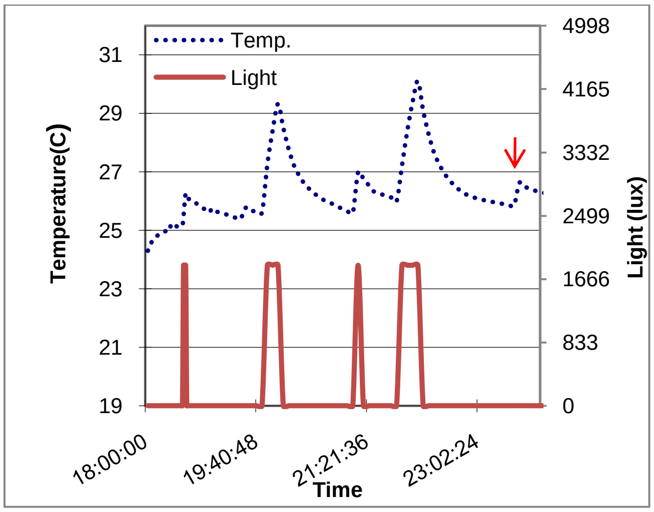

Figure 5: Room light and temperature at night (Arrow shows undetected event using light sensor; sampling rate of 5 minutes used here.)

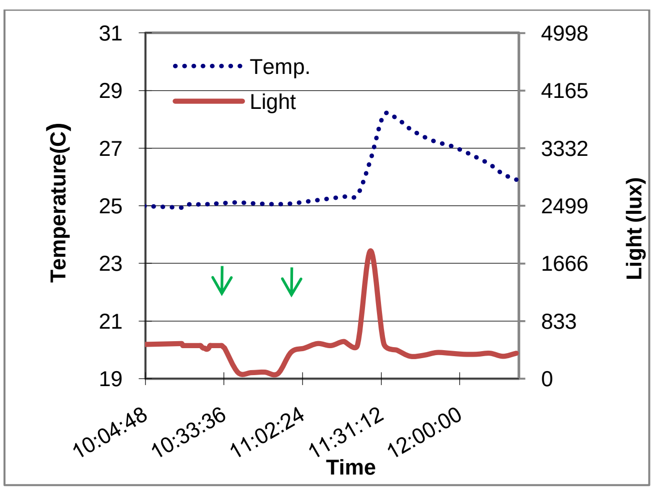

Figure 6: Room light and temperature during day-time hours. (Closing and opening of curtains are indicated by arrows. The unmarked peak is due to an artificial light source.)

CONCLUSIONS

The system presented in this paper is designed to monitor the health and day-to-day activities of the subject. By using the temperature and humidity sensors, we were able to monitor room temperature as well as toilet and shower usage. Adding the light sensors to the system allows us to monitor refrigerator usage, room lighting, and the subject's exposure to natural light. The algorithms used in this study have relatively low complexity. While more complex pattern classification algorithms such as neural networks or decision forests may be investigated in the future, the low complexity of the current approach increases the likelihood that the results will generalize to new patients and new locales [7].

Future work will focus on integrating this system with other smart home technologies. For example, light measurements can be combined with bed occupancy to monitor sleeping patterns (which is of great interest for patients with senility). Lastly, while the Crossbow mote hardware used here is convenient for rapid prototyping, ultimately we plan to develop custom hardware with only the subset of sensors required for this specific application. For example, complex sensors such as GPS are supported by the Crossbow mote platform but are not required in the Smart Apartment, and therefore a simpler microcontroller may be selected for the final system. Through optimization of parameters such as sampling rate, choice of microcontroller, and choice of wireless communication frequency band, we hope to achieve lower cost, smaller size, and lower power requirements.

ACKNOWLEDGEMENTS

This study was supported by a grant from the Natural Sciences and Engineering Research Council of Canada.

REFERENCES

[1] A. Arcelus, M. H. Jones, R. Goubran, F. Knoefel, "Integration of Smart Home technologies in a health monitoring system for the elderly", IEEE First International Workshop on Smart Homes for Tele-Health, Niagara Falls, Canada,2007

[2] M. W. Rosenberg, E. G. Moore, "The health of Canada's elderly population: current status and future implications", Canadian Medical Association Journal, pp. 1025-1032, 1997.

[3] R. Aipperspach, E. Cohen, and J. Canny, "Modeling human behavior from simple sensors in the home," *Lecture Notes in Computer Science*, vol. 3968, p. 337, 2006.

[4] J. Chen, A. Kam, J. Zhang, N. Liu, and L. Shue, "Bathroom activity monitoring based on sound," *Third International Conference, PERVASIVE*, Springer, p. 47–61, 2005.

[5] I. Neild, D.J. Heatley, R.S. Kalawsky, and P.A. Bowman, "Sensor Networks for Continuous Health Monitoring," *BT Technology Journal*, vol. 22, 2004, pp. 130-139.

[6] F. M. Gloth, C. M. Gundberg, B. W. Hollis, J. G. Haddad, J. D. Tobin, "Vitamin D deficiency in homebound elderly persons", JAMA, vol. 274, pp.1683–1686, 1995.

[7] R. O. Duda, , P.E. Hart, D.G. Stork, Pattern Classification, 2nd ed., Wiley, 2001.