Ambient Sensor System for In-home Health Monitoring

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***Abstract*—In this paper, we deal with a sensor-based monitoring system, which evaluates the health status of the elderly based on daily living activities and provides the forecast of an emergency situation to a local nursing center without explicit user interaction. Here, the main focus is on reasonably priced and noncontact sensors which assure direct recognition of quotidian activities. For meeting these criteria, water flow sensors that are attached to faucets in the kitchen, washroom, and to the toilet are a promising solution. An advantage of this solution is that the system can be readily installed in any type of housing. In addition, this system does not require personal data to be saved or transmitted outside. We will present initial results from some experiments.**

Keywords–Ambient monitering system; Health care; Water flow sensor; Active RFID tag; Vibration sensor; Recognition of quotidian activity.

I. Introduction

We are confronted with an increasing population of solitary elderly many of whom live in their own housing and for whom dangerous situations that may require medical attention are insidious. However, the number of caregivers available for frequent home visits is limited. Thus, new care services, such as the use of monitoring systems, are needed to cut costs in health care while still providing security and adequate medical treatment for people who live alone and are restricted physically.

There are a number of compact wearable sensors used for the detection of emergencies, such as sensors for the observations of vital signs [1]. This kind of emergency sensor has one disadvantage: it has to be worn permanently and operated actively, making it highly limited in regards to functionality and comfort. Recently, research for this aspect of health care has focused on capturing the activities of daily living by using ambient monitoring systems. Such monitoring systems can be divided into two categories: to identify short-term emergencies and long-term variations in health status. In this paper, we focus on long-term variations in the health status, in other words, a sensor-based monitoring system which evaluates the health status of an elderly person based on his/her daily living activities and provides the forecast of an emergency situation to a local nursing center without explicit user interaction.

One method for the early detection of emergency situation is monitoring systems using position sensors. The best-known representatives of position sensors are infrared-ray position sensors, which are installed in the living room, a bedroom, corridors and so on [2]-[4]. Positional information for the person is acquired from the detection place of body heat as he/she moves through the house. A model of the normal day-to-day behavior patterns is created based on the individual's at-home actions, such as their movement patterns, living room use frequency, and living room use time, which are derived from the positional data [5][6]. Problems with the individual's physical condition can be detected when there is a major deviation between the model behavior and actual behavior patterns. The development of the day-to-day behavior models with machine learning methods requires a solid database with a substantially large number of cases in order to achieve reasonable results. Therefore, the installation of such technologies takes a great deal of time.

These position sensors provide only indirect information on daily living activities. From the viewpoint of reliability, it is desirable to directly specify normal daily activities and then to detect variations which may be signs of a dangerous situation. TV cameras can observe daily activities and detect dangerous situations, but from the viewpoint of privacy, their introduction into private homes is limited. A smart meter, which is used for the billing of electricity, can also be used for activity recognition [7]. Daily variations in power consumption are recorded in the smart meter and household appliance use can be ascertained from the variations, allowing the inference of daily living activities. However, it is very difficult to analyze the variations in the current.

In this paper, we propose a monitoring system for the early detection of an emergency situation by using water flow sensors which are attached to faucets in the kitchen and washroom sinks, and in the toilet in the bathroom. These sensors assure direct recognition of quotidian activities, such as urination, kitchen work, and activities related to keeping neatness. For example, the activity of washing one's hands can be derived from the signal of a water flow sensor at the washroom sink. An advantage of this method is that rule-based methods [8][9] can be used for analysis and interpretation of the sensor data. In addition, these sensors are available at reasonable price. The system can be installed easily in any type of housing, and no interaction by the user is required. No personal data, such as photographs or video recording have to be saved in the system or transmitted outside.

This paper is organized as follows. In Section II we describe the brief outline of the proposed method and monitoring system with water flow sensors. Section III describes the technical aspect of the water flow sensors. Section IV contains the implementation of the monitoring system and experimental results. Concluding remarks and future works are given in Section V.

II. Overview of the Proposed Monitoring System

Many quotidian activities that are involved in maintaining a healthy life are accompanied by the usage of tap water, and there is a strong connection between such activities and the time and duration of tap water use. For example, a large volume of tap water is used for cooking and washing-up before and after a meal. Therefore, based on the duration of tap water use at each faucet at particular times, day-to-day activities are directly recognizable. There are some conventions about the usage of tap water in daily living. The proposed monitoring system uses such conventions to understand the daily living activities and to deduce signs of ill health in the elderly.

The water flow sensors of the monitoring system are fixed on faucets in the kitchen and washroom sinks, and on the toilet in the bathroom in the user's house, and the monitoring system records the duration of tap water use at one-hour intervals. The knowledge and conventions used in the monitoring system are as follows. According to medical knowledge, humans urinate an average of five or six times a day. If there is much less or much more frequent use of the toilet, then some diseases are suspected [10]. It is possible to infer this by checking the frequency of water usage in the bathroom. If the user is a healthy person, he/she washes his/her face and rinses his/her mouth when he/she gets up in the morning and before going to bed at night. He/she also performs activities, such as hand washing during the day. Such activities can be inferred based on the data from the water flow sensor at the sink. In addition, at meal times, people use a large volume of water in the kitchen for cooking and washing dishes. Some peaks of water usage appear in the distribution of the use duration in the kitchen. Based on these conventions and this knowledge, the health status of the user can be inferred.

The model for the normal water usage is created based on such conventions. When there are major deviations between the model and actual usage patterns, problems with the user's physical condition are detected. The reasoning can be based on a decision tree which is organized using the conventions and knowledge of water usage. At midnight, the reasoning program checks the time and duration of water use at every faucet. If there is a major deviation between the model and the activities of the day it reports the forecast of an emergency situation to a local nursing center. Then, a caregiver will visit the user to verify his/her condition.

III. Equipment for the Monitoring System

This section describes the technical implementation of the proposed monitoring system. We considered the following factors for the system design. The two most important factors are the selection of suitable sensors and software technical realization. The sensors must be reasonably priced and must assure direct recognition of quotidian activities. The sensors must also be easy to install in any type of housing without high-cost remodeling. A wireless connection is also an important factor. In addition, the monitoring system must not be operated or configured by the user. No personal data should be saved in the system or transmitted outside.

Fig.1 illustrates the functional block diagram of the monitoring system. The monitoring system consists of two main elements: water flow sensors attached to a water pipe near a faucet and a notebook computer that is placed in the house of the user. The sensors are linked with the computer wirelessly. The computer collects data from the sensors, processes it, and sends the report to the nursing center via the Internet at the fixed time.

The water flow sensor consists of a vibration sensor and an active Radio Frequency IDentification (RFID) tag. Fig.2 illustrates the prototype of the water flow sensor. Mechanical vibration in the range of 1000 to 1500Hz occurs at the water pipe near the faucet while tap water is running. The vibration sensor is designed to be attached to the water pipe near a faucet to pick up the mechanical vibrations. A ready-made vibration microphone used for tuning musical instruments can be applied to the vibration sensor, which is available for about 10 euros in the market. Fig.3 shows an example of the vibration microphone clipped to a water pipe near a faucet.

The active RFID tag has a unique ID code, which provides information about its location in the house. When the microphone detects mechanical vibrations from the faucet, the active RFID tag is switched on. Consequently, the tag sends a radio frequency signal (315MHz) with its ID code. The signal is transmitted at one-second intervals while the water continues to flow through the faucet. The tags can send signals to a range of up to about 10m, which is sufficient for collecting the ID codes in a normal house. The proposed monitoring system measures the time of running water from each faucet to obtain the use frequency and duration of tap water use in everyday life.

Fig.4 illustrates an RFID reader with a notebook computer. The RFID reader receives the RF signal from the tags, obtains the ID code and reports it to the computer through an RS-232c serial port. The number of ID codes received indicates the amount of time that there is running tap water and is proportional to the amount of water use because ID codes are transmitted steadily at one-second intervals. The computer accumulates the received ID codes at one hour-intervals and then the distribution of the duration of tap water use can be obtained for each faucet. The computer is responsible for recording the ID codes and evaluating the health status based on the distributions of the duration of tap water use. It also makes the report of the day at the fixed time, which includes warning messages if there is a forecast of an emergency situation.

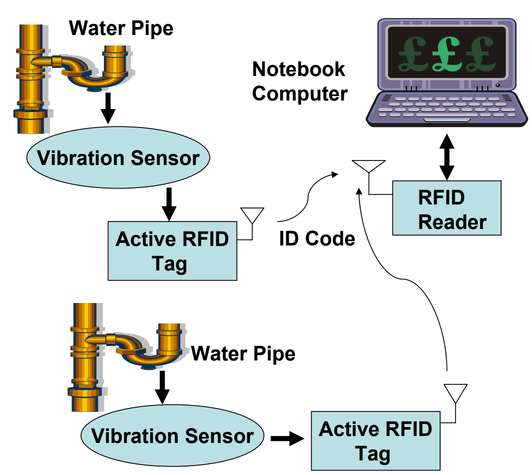

Figure 1. Functional block diagram of the monitoring system, which consists of vibration sensors, active RDIDs and a notebook compute with a RFID reader.

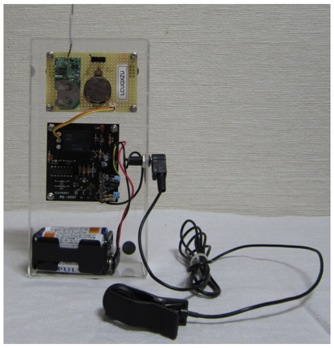

Figure 2. Prototype of the water flow sensor which consists of a vibration microphone, an audio amp., an active RFID tag with an antenna, and a battery.

Figure 3. The water flow sensor is installed at the sink. The vibration microphone is clipped to a water pipe near the faucet.

IV. Implementation and Experimental Results

The monitoring system was installed in a real housing environment and the experiment was conducted to see whether there is a strong connection between quotidian activities and the time and frequency of tap water use. The house had a living area of 108 square meters (roughly 15m by 8m) and the resident was a 65-year-old man in good health. The water flow sensors were set at the kitchen sink, the washroom sink and the toilet's flush tank. The maximum distance between the RFID reader and the water flow sensors was 7m. First, the sensitivity and reliability of the water flow sensors was checked. The sensors could detect gently running water such as would be poured into a glass.

Fig.5 illustrates an example of the distribution of the duration of water use at the toilet. The water flow sensor was set on the water pipe connected to the toilet's flush tank in the bathroom. The horizontal axis of the graph denotes time, which starts at 2 a.m., at one-hour intervals. The flow sensor transmits its ID code at one-second intervals while water is flowing into the flush tank. It continues for about 60 seconds to fill up the tank. The vertical axis shows the duration of water use for the received ID code. From the graph you can see that the resident urinated seven times on this day, at an average interval of 2.5 hours.

Fig.6 shows the graph of the duration of tap water use in the kitchen. The water flow sensor was set on the water pipe connected to the sink's faucet. The time period when the frequency of water use becomes high was observed twice. The first was during the lunch hour and the second one was at mealtime in the evening. The graph shows that the resident prepared meals twice on this day. The total time of water

Figure 4. RFID reader and a notebook computer for data acquisition and processing.

flow is relatively short because the house is equipped with a dishwasher. The peak of the distribution in the middle of the night appears to be caused by drinking tea or something.

Fig.7 shows the graph of the duration of tap water use at the washroom sink. The water flow sensor was set on the water pipe connected to the sink's faucet. This sensor is intended to detect quotidian activities, such as face washing and brushing of teeth. In other words, this is a sensor to detect activities for keeping neatness. The distribution of the duration had a peak in the morning. This means that the resident used tap water for brushing his teeth and washing his face. He also rinsed his mouth around midnight and performed activities, such as washing his hands during the day.

The model of the normal water usage was created based on the following medical knowledge and conventions. According to medical knowledge, humans urinate an average of six to eight times a day. If there is much less or much more frequent use of the toilet, then, some diseases are suspected. If you awake two or more times at midnight to urinate it is also the sign of a poor state of health. At meal times, people use a large volume of water in the kitchen for cooking and washing dishes. The time period when the use frequency of tap water is high appears in the distribution graph, and it is very likely to be observed in the morning, at around lunch time, or in the evening. You wash your face and rinses your mouth when you get up in the morning and before going to bed at night. You also perform activities, such as hand washing during the day. A large volume of water is not used at the washroom sink but the use frequency of tap water is apt to become high.

At every midnight (2 a.m.), the reasoning program checked the use frequency of tap water at the faucets. The program counted the duration of water usage at each interval as one quotidian activity if it was above a fixed threshold time. When there were major deviations between the time and number of activities and the model it was considered that some problems occurred in the user's physical condition. The reasoning for detecting the problems was done on a decision tree which was organized based on the model, and the report of the day was sent out by e-mail. In this experiment, the mail was sent to the author's office at midnight. Fig.8 shows an example of the e-mail message, which includes three items: ”Urination”, ”Kitchen Work”, and ”Activities for Neatness”. Each item consists of a judgment and the list of the time of the major water usage, which is used for the judgment. If there is a deviation between the normal model and the actual activity pattern the judgment of each item is denoted as ”Something Wrong”. If not, the message is ”Normal”.

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Figure 5. Distribution of the duration of water flow at the toilet's flush tank.

Figure 6. Distribution of the duration of tap water use at the kitchen sink.

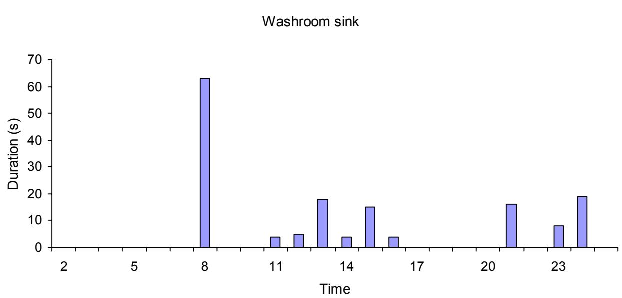
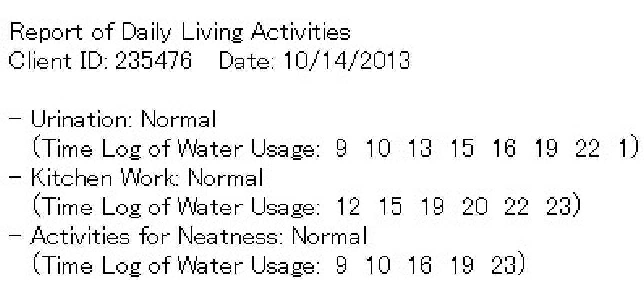


Figure 7. Distribution of the duration of tap water use at the washroom sink.


Report of Daily Living Activities
Client ID: 235476 Date: 10/14/2013

- Urination: Normal
  (Time Log of Water Usage: 9 10 13 15 16 19 22 1)
- Kitchen Work: Normal
  (Time Log of Water Usage: 12 15 19 20 22 23)
- Activities for Neatness: Normal
  (Time Log of Water Usage: 9 10 16 19 23)

Figure 8. Example of the e-mail massage which is sent to a caregiver at regular intervals.

V. CONCLUDING REMARKS

In this paper, we dealt with a sensor-based monitoring system which evaluates the health status of the elderly based on daily living activities. Here, the main focus was on reasonably priced and contactless sensors which assure direct quotidian activity recognition. To meet these demands we proposed the water flow sensors attached to faucets in the kitchen and washroom and to the toilet. The advantage of this solution is that the monitoring system can be built affordably into any kind of housing. We made a prototype of the monitoring system from electric parts which are all available in the market. The prototype of the monitoring system was checked in a real house and the experiments showed that the expected results from the water flow sensors were obtained. The initial results will be followed by more practical trials where the system will be installed in various home environments and criteria for generating automatic alert messages will be derived. This is currently in preparation.

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