In-home Health Monitoring System for Solitary Elderly

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Abstract
In this paper we propose a sensor-based monitoring system that evaluates the health status of solitary elderly based on daily living activities, and provides forecasts of emergency situations to a local nursing center without explicit user interaction. We focus on drei daily living activities: urination, kitchen work, and activities related to maintaining physical cleanliness because these activities are closely involved in maintaining a healthy lifestyle and are usually accompanied by the usage of tap water. There is a certain regularity in the usage of tap water in these quotidian activities, and health status is correlated with the regularity. Therefore, the system monitors health status by using water flow sensors which are attached to faucets in the kitchen and washroom and to the toilet. An advantage of this method is that the system can be readily installed in any type of housing at low cost. In addition, this system does not require personal data to be saved or transmitted. We will present the initial results from an experiment.

Keywords: In-home health monitoring system; Solitary elderly; Water flow sensor; Active RFID tag; Vibration sensor; Quotidian activity

1. Introduction

We are confronted with an increasing population of solitary elderly, many of whom live in their own homes and for whom dangerous situations that may require medical attention are ubiquitous. However, the number of caregivers available for frequent home visits is limited. Thus, new care services, such as those that use 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. This kind of emergency sensor has one disadvantage: it has to be worn constantly and operated actively, making it highly limited in regards to functionality and comfort. Recently, research into 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 health status, in other words, a sensor-based

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monitoring system that evaluates the health status of an elderly person based on his/her daily living activities and provides forecasts of emergency situations to a local nursing center without explicit user interaction.

One method for the early detection of emergency situations is monitoring systems that use position sensors. The best-known representatives of position sensors are infrared-ray sensors, which are installed in the living room, bedroom, corridors, and so on\textsuperscript{3,4}. Positional information for the person is acquired from the detection 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 habits, such as their movements, living room use frequency and living room use time, which are derived from positional data\textsuperscript{5,6}. Problems with the individual’s physical condition can be detected when there is a major variation between the model behavior and actual behavior patterns. The development with this kind of day-to-day behavior models using machine learning methods is that they require a solid database with a substantial number of cases in order to achieve reasonable results. In addition, a unique model must be made for each and every person. Therefore, the installation of such technologies takes a great deal of time.

Moreover, these position sensors provide only indirect information on health status. In other words, positional information does not always correspond to vital activities related to health status. 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 privacy concerns make their introduction into private homes limited. A smart meter, which is used for the billing of electricity, can also be used for activity recognition\textsuperscript{7}. Daily variations in power consumption are recorded in the smart meter, and use of household appliances such as a vacuum cleaner and a toaster oven, can be ascertained from the variations, allowing the inference of daily living activities. However, it is very difficult to analyze the variations in power consumption.

In our system we focus on three quotidian activities: urination, kitchen work, and activities related to maintaining physical cleanliness, because these activities are closely involved in maintaining a healthy lifestyle. These quotidian activities are usually accompanied by the regular usage of tap water, and an individual’s health status can be correlated with this regularity. Therefore, we propose a monitoring system for health status that uses water flow sensors that are attached to faucets. An advantage of this method is that rule-based methods\textsuperscript{8,9} can be used for analysis and interpretation of the sensor data. The rules can be derived from experiential knowledge of water usage during urination, kitchen work, and activities related to maintaining physical cleanliness. In addition, these sensors are available at a reasonable cost. 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 are saved in the system or transmitted.

This paper is organized as follows. In Section 2 we give a brief outline of the proposed method and monitoring system. Section 3 describes the technical aspect of the monitoring system. Section 4 describes the implementation of the monitoring system and experimental results. Concluding remarks and future goals are given in Section 5.

2. Overview of the Proposed Monitoring System

In our system we focus on three quotidian activities, that is, urination, kitchen work, and activities related to maintaining physical cleanliness. As mentioned below, there is a certain regularity in the usage of water during these activities and health status is correlated with the regularity. We know that humans urinate an average of six to eight times a day\textsuperscript{10}, thus, if an individual makes much less or much more frequent use of the toilet, then some illness or problem can be suspected. If one wakes two or more times before dawn to urinate it can also be a sign of a poor state of health. Therefore, the number of times and the time of day that an individual urinates are important signs of health status. It is possible to infer the health status by checking the flow of water at the toilet’s flush tank in the bathroom. If a person is healthy, they usually wash their face and rinse their mouth when they get up in the morning and before going to bed at night. They also perform activities such as hand washing during the day to keep themselves clean. Such activities are also important signs of health status, including mental health. The volume of water used at the washroom sink is not large, but the frequency of use of tap water is generally high. Activities such as hand and face washing can be inferred based on the water flow at the washroom sink. Cooking is also a fundamental human activity. It is not only connected with the joy of eating but also deeply affects various aspects of human life such as health. Needless to say, healthy eating habits improve quality of life and help the elderly maintain good health. Therefore, daily kitchen work, including cooking, is also an important sign of health status. At mealtimes people use a large volume of water in the kitchen for cooking and washing dishes. Time periods when the use frequency of kitchen tap
water is high appear in the distribution graph of water use, and are very likely to be observed in the morning, at around lunchtime, and/or in the evening. Such activities can be inferred based on water flow at the kitchen sink. Therefore, monitoring the duration of tap water use at kitchen and washroom faucets and at toilet at particular times of day, makes these three activities (urination, kitchen work, and washing) directly recognizable, and signs of ill health in the elderly can be deduced.

Figure 1 provides the functional block diagram of the proposed monitoring system. The monitoring system consists of three main components: water flow sensors with active radio frequency identification (RFID) tags, an infrared (IR) motion sensor with an active RFID tag, and a small computer with an RFID reader. The water flow sensors are attached to a water pipe near faucets on the kitchen and washroom sinks, and to the water pipe to the flush tank of the toilet in the bathroom. These sensors transmit a radio frequency (RF) signal including ID code, at one-second intervals while water is flowing through the faucet. The IR motion sensor is installed in a place where the resident comes and goes frequently such as in the living room, a bedroom, or corridors. It sends an RF signal with its ID code when the resident passes the sensor.

The computer is placed in the house of the resident and is wirelessly linked with the sensors through the RFID reader. The computer records the receipt time of the ID code sent from each sensor, processes the received ID codes, judges the health status, and sends a report to the nursing center via the Internet.

The reasoning program installed in the computer derives the time and duration of tap water use from the ID codes received from each faucet. In addition, it acquires information about whether the resident remains indoors based on the time stamp of the ID codes received from the motion sensor. This information is used to reduce the uncertainty of deducing health status based on data from the water flow sensors. A model for normal water usage is created based on experiential regularity, as mentioned above. When there are major variations between the model and actual usage patterns, it is assumed that there is something wrong with the resident’s physical condition, and the reasoning program reports a forecast of an emergency situation to a local nursing center. Then, a caregiver will visit the resident to verify his/her condition.

3. Equipment for the Monitoring System

This section describes the technical aspect 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 the 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.
As shown in Figure 1 the monitoring system consists of three main elements: water flow sensors, an IR motion sensor, and a small computer with an RFID reader. A water flow sensor consists of a vibration sensor, a sound-activated switch and an active RFID tag. Figure 2 illustrates the prototype of the water flow sensor. Mechanical vibration in the range of 1 to 10kHz 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 less than 10 euros in the market. Figure 3 shows an example of the vibration microphone clipped to the water pipe to the flush tank of a toilet. The active RFID tag has a unique ID code (8 characters), which provides information about its location in the house. When the microphone detects mechanical vibrations from the faucet, the sound-activated switch turns on the active RFID tag. Consequently, the tag sends a radio frequency signal (2.4GHz) 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 indoors to a range of up to about 15 m, which is sufficient 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.

Figure 4 shows the prototype of the IR motion sensor. The motion sensor consists of a pyroelectric infrared sensor with a Fresnel lens and an electronic circuit to form the module, and an active RFID tag. The motion sensor is installed at a location in the house where the resident comes and goes frequently. The motion sensor detects motion by checking for a sudden change in the surrounding infrared levels, which is caused by the resident’s body heat as he/she passes the sensor. The sensitivity of the sensor is limited to detecting a person up to 4.5 meters away. When the infrared sensor module detects such changes of the infrared levels, the module turns on the active RFID tag for 2 seconds. Consequently, the tag sends an RF signal with its ID code twice (once per second). The monitoring program tallies the number of times an ID code is transmitted to obtain the frequency of the resident’s movements.

Figure 5 illustrates a small computer (Raspberry Pi B+) with an RFID reader. The RFID reader receives the RF signal from the tags, obtains the ID code and reports it to the computer through a USB port. A reasoning program, which is written in C and runs on the Pidora (a kind of the Linux for the Raspberry Pi) is installe on this computer. The number of times ID codes are received from the faucets indicates the amount of time that there is running tap water, and this is proportional to the amount of water used because ID codes are transmitted steadily at one-second intervals while the water is running. The received ID codes are accumulated at one hour-intervals to obtain a distribution of the duration of tap water use for each faucet. On the other hand, the number of times the ID codes is received from the motion sensor indicates the frequency of the resident’s movements in the house. The received ID codes are also accumulated at one-hour intervals to obtain the frequency distribution of the movements. The reasoning program judges the health condition of the resident based on the distribution of the duration of tap water use for each faucet and the frequency distribution of the resident’s movements.
4. Implementation and Experimental Results

The monitoring system was installed in a real housing environment and an experiment was conducted to see whether there is a strong connection between quotidian activities and the time and frequency of water use. The house had a living area of 108 square meters (roughly 15 m by 8 m) and the resident was a 66-year-old man in good health. The IR motion sensor was placed on a cabinet in the living room. 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 sensors was 8 m. First, the sensitivity and reliability of the water flow sensors were checked. The sensors could detect gently running water such as would be poured into a glass.

Figure 6 illustrates the frequency distribution of the resident’s access to the living room. The horizontal axis of the graph denotes the time at one-hour intervals, starting at 2 a.m. The vertical axis shows the number of times ID codes were received from the IR motion sensor. The sensor was placed on a cabinet in the corner of the living room connected to the corridor; thus, the motion sensor was activated only when the resident went in and out of the living room along the corridor. The sensor transmitted its ID code twice at one-second intervals, each time the resident passed it. The number is proportional to the frequency of access to the living room. Based on the time stamp of the received ID codes from the motion sensor, it can be seen that the resident got up at around 8 a.m. and went to bed at around 1 a.m. During the day, he stayed in the house and followed his daily routine. The data gathered about the subjects’s quotidian activities was used to reduce uncertainty in deducing health status based on data from the water flow sensors.

Figure 7 illustrates the distribution of the duration of water use at the toilet. The horizontal axis of the graph denotes the time at one-hour intervals starting at 2 a.m. The vertical axis shows the duration of water use in seconds. The water flow sensor was set on the water pipe connected to the toilet’s flush tank in the bathroom. The flow sensor transmitted its ID code at one-second intervals while water was flowing into the flush tank; it took about 60 seconds to fill the tank. The graph shows that the resident urinated 10 times on this day, at an average interval of 1.7 hours.

Figure 8 is a 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. A high-use period was observed once after the evening mealtime. This implies that the resident used tap water for washing dishes and so on. The total time of water flow was relatively short, but the graph also shows that the resident prepared meals in the morning, at around lunch time, and in the evening on this day.

Figure 9 is a 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 maintaining physical cleanliness. The volume of water used at the washroom sink was not large, but there were high-use periods. The distribution of the duration had a peak in the morning. This implies that the resident used tap water for activities such as brushing his teeth and washing his face. Other peaks imply that he also performed other activities, such as rinsing his mouth around midnight and hand washing during the day.
The reasoning program regards the duration of water usage at each interval as one quotidian activity if the duration is above a fixed threshold of time. When the number of quotidian activities coincides with given criteria, it is assumed that there is some problem with the resident’s physical condition. The criteria for judgment were created based on the model of normal water usage, which was derived from medical knowledge and regularity, as mentioned in Section 2. A brief outline of the criteria is as follows.

- If the frequency of urination is greater than twice in the night (from 2 a.m. to 5 a.m.), there is an assumption of "something wrong".
- If the resident remains indoors during the day time and
  - the frequency of urination is lower than 4 times or greater than 11 times; "something wrong".
  - the frequency of water usage at the kitchen is less than once; "something wrong".
  - the frequency of water usage at the washroom sink is less than once; "something wrong".
- If the resident is out of the house for a long time, then the numerical values for these criteria are reduced in proportion to that time.

Each night at 2 a.m., the program judges the resident’s physical condition based on the criteria and sends out a report for the day by e-mail. In this experiment, the e-mail was sent to the author’s office. Figure 10 shows an example e-mail message, which consists of four items: "Urination", "Kitchen Work", "Activities for cleanliness" and "Movements in the house". The first three items consist of a judgment and the list of the times of major water usage that was used for the judgment. The fourth item includes only the list of the times of the resident’s movements in the house. The judgment of each item was denoted as "Something Wrong" if the number of quotidian activities coincided with the given criteria, and otherwise as "Normal".

5. Concluding Remarks

We proposed a sensor-based monitoring system, which evaluates the health status of solitary elderly based on daily living activities. The system monitors three quotidian activities that are closely involved in maintaining a healthy
lifestyle: urination, kitchen work, and activities related to maintaining physical cleanliness. These quotidian activities are usually accompanied by the usage of water, and since there is a certain regularity in the usage of water, it can be is correlated with the health status of the resident. There is a demand for a reasonably priced, noncontact sensor system that can directly recognize these quotidian activities. In addition, the monitoring system should be affordably installed into any type of housing. To meet these demands we proposed the water flow sensors using vibration microphones that can be easily clipped to a water pipe leading to a faucet.

We made a prototype of this monitoring system from electronic parts that were all available in the market. The prototype of the monitoring system was checked in a real house and the experiment produced the expected results from the water flow sensors. The initial results will be followed by more practical trials where the system will be installed in various home environments and subtler criteria for generating automatic alert messages will be derived. This is currently in preparation.

References