Wireless Sensor Network Deployment for Remote Elderly Care Monitoring

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ABSTRACT
This paper reports hands-on experiences in designing, implementing and operating a wireless sensor network (WSN)-based prototype system for elderly care monitoring in home environments. The monitoring is based on the recording of environmental parameters like temperature, humidity and light intensity as well as micro-level incidents which allow to infer daily activities like moving, sitting, sleeping, usage of electricity appliances and plumbing components. The prototype is built upon inexpensive, of-the-shelf hardware (e.g. various sensors, Arduino microcontroller platforms, ZigBee-compatible wireless communication modules) and license-free software, thereby ensuring low system deployment cost. Upon detecting significant deviations from the ordinary activity pattern of individuals and/or sudden falls, the system issues automated alarms which may be forwarded to authorized persons via a variety of communication channels. Furthermore, measured environmental parameters and activity incidents may be monitored through web interfaces.

Categories and Subject Descriptors
C.2.1 [**Computer-Communication Networks**] Wireless communication, I.2.9 [**Artificial Intelligence**] Sensors.

General Terms
Management, Measurement, Design, Experimentation, Human Factors.

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Keywords
Assisted living; elderly, monitoring, wireless sensor network, Arduino.

1. INTRODUCTION
The declining birth rate coupled with increased life time expectancy in the developed world is projected to exacerbate the phenomenon of population aging in the coming years. This effect is expected to challenge the viability of health and welfare systems, requiring substantial public and private financial funding for the maintenance of institutions and infrastructure such as health and elderly care centers, nursing homes etc.

It is, therefore, urgent to investigate solutions that will prolong the staying of elderly people at home, deferring their moving to care centers as long as possible. These solutions should take into account factors that compromise the level of safe living of the elderly. Such factors include sudden ailments and falls, which often provoke injuries such as sprains or bone fractures. Injuries commonly cause temporal motor disabilities or loss of consciousness, making it impossible for elderly who live alone to call for help.

One option that could prospectively contribute towards extending the safe independent living of elderly at home would be the installation of computer and communications infrastructure for remote elderly surveillance, aiming at the continuous monitoring of their condition, early diagnosis of potential health deterioration and detection of hazardous events. Such infrastructure could potentially detect falls so as to immediately notify authorized individuals (e.g. relatives and/or doctors), thereby improving the achievable level of security and ensuring immediate nursing treatment of such incidents. The infrastructures described above fall within the area of assistive environments which have been subject of intensive research in the recent years. Wireless Sensor Network (WSN) installations comprise a key technological substrate in assistive environments.

Herein, we present a remote monitoring research prototype based on a wireless sensor network installation. The main objective of the prototype is to support the safe independent living of elderly living in their home environment; also to mitigate the stress caused to elderly individuals living in non-supervised areas. The main function of the proposed system is to record the daily activity of the elderly (e.g. presence/movement in specific areas of the house, sleep, use of seats, electrical appliances or sanitary facilities) and environmental monitoring (temperature, humidity, light intensity). Prospectively, significant deviations from the "normal" pattern of activity (for instance, prolonged immobility on the bed or detection of prolonged presence at home without food consumption) could be interpreted as evidence of incapacitation or reason to issue alarm. The system also triggers alarms in the event of fall detection. Activity information recorded in a web database and visualized is an intelligible form via a web interface.

The prototype adopts the following design principles, typically not addressed in similar systems:

- It makes no assumptions on the existence of a mobile phone or PC / laptop at home of elderly individuals; rather it only requires an Internet connection.
- It makes no use of 'packaged' hardware solutions (i.e. integrated sensor nodes); rather, it utilizes inexpensive of-the-shelf hardware and license-free / open source software. This property allows the system to easily scale and adapt to new surveillance settings, while ensuring low system deployment cost.
- Activity detection is based on monitoring the interaction of human subjects with a broad variety of home objects, including furniture, electrical appliances, faucets and sanitary ware.
- The prototype makes no use of cameras and microphones for activity recognition, recognizing that such devices are commonly perceived as privacy violators, hence, they undermine user acceptance for such systems. Instead, activity monitoring is undertaken by sensor devices which may easily by fabricated within furniture and home appliances, while the monitored subjects are required to carry minimal equipment to mitigate their reluctance in accepting the system.

The main contribution of this paper lies in the documentation of hands-on experiences in designing, implementing and operating a prototype system for elderly care monitoring in home environments. To meet this objective, we discuss technical trade-offs and design decisions, while reporting implementation details utilized in our deployment framework. To our knowledge, the particular structural, architectural and implementation setting adopted in our proposed framework has not been reported in the literature. We argue that our experiences may serve as a useful guide for the development of research and commercial systems in the field of elderly care monitoring or alike applications.

The remainder of this article is structured as follows: Section 2 reviews related work. Section 3 discusses functional and technical considerations with respect to our implemented prototype. Finally, Section 4 concludes our work.

2. RELATED WORK

During the last few years a variety of systems for elderly care and activity monitoring and health-care applications have been developed [9]. These systems usually focus on monitoring the activities and the wellness of an elderly living alone at home or in a controlled environment. The types of activities monitored, can be categorized in: daily living activities, fall and movement detection, location tracking, medication intake, and medical status [1]. Depending on their focus, the applications may employ different equipment such as wireless sensor networks, cameras, RFID tags and sensors, infrared based Small Motion Detectors (SMDs), passing sensors, MEMS sensors, and operation detectors.

Applications for fall and movement detection focus on following user movements and detecting user falls [11]. Medication intake applications focus on monitoring the intake of prescription and over-the-counter drugs [3]. Other systems aim at medical status monitoring: they collect clinical data such as heart rate, pulse, glucose monitoring, and elaborate a current-state diagnosis of the patient [7]. In [12] AlarmNet is proposed, an assisted living and residential monitoring network for pervasive adaptive healthcare in assisted living communities with residents or patients with diverse needs. AlarmNet integrates environmental, physiological, and activity sensors in a scalable heterogeneous architecture. It monitors a series of variables, storing the data and processing the information to detect any abnormalities.

Applications for daily living activities focus on monitoring the activities of individuals at home. In [8] an application is proposed which employs RFID cards, a database that maintains a very large number of human activities, and a fast inference mechanism that allows the remote identification of a person's actions. Monitoring activities of an individual using camera based sensors or CCD cameras are proposed in [6] in which the images of the person are taken and analyzed. Systems using accelerometers and RFID communication technology for elder monitoring in assisted living are reported in [5]. Such privacy invasive systems certainly require elderly's consent but even if they are used with the consent of the person involved, certain social and legal issues may arise and therefore, are not always acceptable [4].

In [10] a framework integrating temporal and spatial contextual information for determining the wellness of an elderly has been modeled and behavior detection has been designed. The developed prototype is used to forecast the behavior and wellness of the elderly by monitoring the daily usages of appliances in a smart home.

3. EXPERIMENTAL TESTBED

Our prototype system has been deployed in a controlled part of a house and comprises a WSN of nine nodes: four nodes installed in the main rooms of the house (bedroom, bathroom, kitchen, living room), two nodes mounted on furniture (armchair and dining chair), a wearable node, an actuator node and, finally, a coordinator node.

Out of the above mentioned nodes, the ones installed in the rooms and the furniture are used to collect environmental parameter values (e.g. temperature or light intensity) and activities information (e.g. the elderly entered the kitchen, opened the fridge, laid on the bed, flushed the toilet, sat on the chair, etc.). The wearable node is worn on the elderly's arm and is designed to detect falls, also allowing calling for help in emergency situations (through pressing a 'panic' button). The actuator node is used to remotely (either in manual or automated fashion) control any electrical device (e.g., automatic adjustment of the fan depending on the room temperature). The coordinator node is enrolled in the collection / processing of activity information as well as uploading the information to a web database so that it becomes accessible via standard web interfaces. Figure 1 illustrates our system architecture.

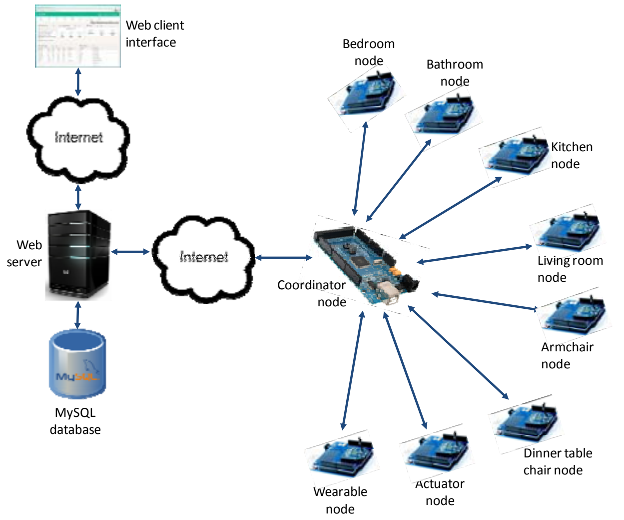

Figure 1. Experimental testbed architecture.

Table 1 elaborates on the types of activity status monitored as well as on the hardware modules utilized to build three representative sensor nodes.

Table 1. Types of activity status monitored and hardware integrated on sensor nodes.

Node	Activity type	Hardware
Bedroom node	• Movement • Presence on bed • Step upon the mat next to bed • Light intensity • Temperature, humidity • Panic status	• Arduino UNO • XBee RF Module (+XBee shield) • Prototype shield • Motion detector • Force sensing resistor • Light intensity sensor • Temperature and humidity sensors • Panic status button • Electronic components and breadboard • Power adapter
Kitchen node	• Movement • Use of electric appliances (microwave oven, oven, toaster, kettle, fridge), drugs cabinet and sink's faucet • Light intensity	• Arduino UNO • XBee RF Module (+XBee shield) • Motion detector • AC/ DC current sensor • Light intensity sensor • Water flow sensor • Magnetic contact (reed) switch • Electronic components and breadboard • Power adapter • Electrical equipment and plumbing components
Wearable node	• Panic status • Fall	• Arduino Lilypad • XBee module (+ XBee breakout board) • Accelerometer • Panic status button • Battery

The total acquisition cost for the hardware required to implement the nine prototype nodes has been ~$580 (fall 2014).

3.1 Hardware

The network nodes have been implemented by gluing together independent modules, such as various kinds of sensors, microcontroller board, wireless communication module, power supply, etc. Arduino has been chosen as a microcontroller platform as it comprises an open source, flexible, low-cost platform. The wireless communication among the nodes and the processing element is undertaken by low-range, ZigBee-compatible RF modules; this is because ZigBee modules are available at lower cost, while also reducing power consumption (therefore, energy requirements) compared to alternative wireless technologies. Figure 2 shows pictures of two representative nodes.

(a) (b)

Figure 2. (a) The bathroom node; (b) the wearable node.

3.2 Software

We have developed software (based on the Arduino programming language [2]) uploaded on network nodes, tailored to the role and functionality of each node. In particular, the software executed by microcontrollers undertakes the collection of information measured by sensors, data processing and information transmission to the wireless medium. The processed information is received by the coordinator node and then forwarded to the web server.

Furthermore, we have developed PHP software that allows remote monitoring of elderly residents via standard web interfaces. This software undertakes the storage and management of sensory data in a MySQL database, exports statistics and creates dynamic graphs. The remote surveillance data are available through http://eldercare.gr[1]. Authorized individuals are allowed to view current and historical data about: temperature, humidity and light level values; number of activations for electric appliances (oven, microwave oven, toaster, kettle, fridge), faucets, the drugs cabinet, the flush and the actuator; batteries voltage level (for the nodes mounted on pieces of furniture as well as the wearable and the actuator nodes); activity (presence, laying on bed, sitting on chairs) triggered alarms (due to falls/panic incidents and node failures). The user may also remotely control the actuator node, for instance switch on/off an electric fan. Figure 3 illustrates an example online report of human activity in the controlled environment.

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[1] The database maintains activity statistics for the period July 9th to October 26th, 2014.

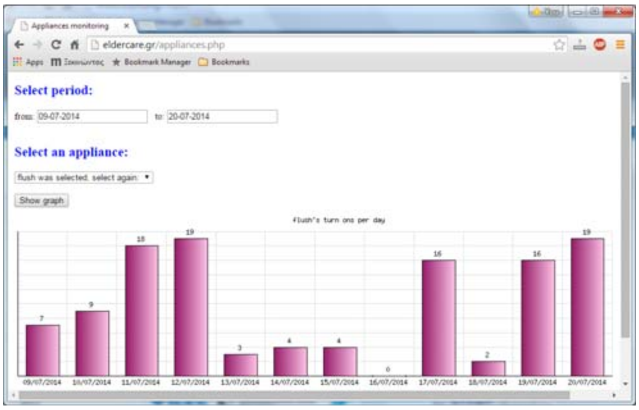

Figure 3. Visualization of activity: toilet flushing occurrences

The experimental setup of our prototype may be viewed from http://youtu.be/ogPEZW5rsN0. An overview of the online presence and activity monitoring is given in http://youtu.be/IbktK5lj5-8 fall alarm The triggering of a fall alarm is demonstrated in http://youtu.be/8F6czU7G-OU.

4. CONCLUSIONS & FUTURE RESEARCH

This article addressed practical implementation aspects for low-cost WSN-based systems enrolled in the remote monitoring of elderly people living at home. We document experiences and how-to design and implementation decisions which may comprise a useful guide for the development of relevant remote surveillance research or commercial systems.

Our future research plans include the implementation of prototype extensions to cover other aspects of well-being surveillance, such as air quality monitoring to detect fire or high concentration of carbon monoxide, automated control of air quality/cleaning devices, etc. Further, actuator nodes could be used to display reminders in the event of abnormality detection (e.g. to switch off the oven or to take medication).

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