Smart Wireless Continence Management System for Persons with Dementia

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Abstract
Incontinence is highly prevalent in the elderly population, especially in nursing home residents with dementia. It is a distressing and costly health problem that affects not only the patients but also the caregivers. Effective continence management is required to provide quality care, and to eliminate high labor costs and annoyances to the caregivers resulting from episodes of incontinence. This paper presents the design, development, and preliminary deployment of a smart wireless continence management system for dementia-impaired elderly or patients in institutional care settings such as nursing homes and hospitals. Specifically, the mote wireless platform was used to support the deployment of potentially large quantities of wetness sensors with wider coverage and with dramatically less complexity and cost. It consists of an intelligent signal relay mechanism so that the residents are free to move about in the nursing home or hospital, and allows personalized continence management service. Preliminary results from a trial in a local nursing home are promising and can significantly improve the quality of care for patients.

Key words: incontinence; continence management; wireless sensor network; patients with dementia

Introduction

Incontinence is highly prevalent in elderly patients with dementia due to a decline of intellect and memory, confusion, disorientation, and several contribution factors such as psycho-emotional, care environment, and medical factors.1,2 It frequently accompanies cognitive failure and typically appears in the mid- and late-phase of a dementia illness. This problem is distressing to medical professionals, caregivers, and patients. Good continence management therefore is important as it potentially avoids the situation whereby such patients often lie soaked in soiled diapers for prolonged periods, with poor hygiene and skin breakdown as unsatisfactory consequences.

There are a number of ways dealing with problems of urinary incontinence, ranging from simple techniques to drug therapies and surgery. How to maintain a level of continence for patients with dementia has been thoroughly studied.3 A more appropriate nonmedical solution to this would be the use of a monitoring system whereby alerts could be triggered once a diaper is wet, prompting the need for a diaper change. So the improved assessment and management of this difficult and distressing problem is of great importance. Hence, our work will involve the development of a smart wireless continence management system for patients with dementia in nursing homes and hospitals. The system is meant to address the delay in responding to the need for diaper change following episodes of urinary incontinence in nursing homes and hospitals, and allow fewer demands made on the medical professionals’ and caregivers’ time. The current practice involves the medical professionals and caregivers having to manually conduct periodic checks, leading to unnecessary visitations and/or delayed response.

The smart wireless continence management system is based on the pervasive mote wireless platform4 whereby alerts such as call bell or Short Message Service (SMS) could be automatically triggered once a diaper is wet using wetness sensors, prompting the need for a diaper change. The system can support the deployment of potentially large quantities of wetness sensors with wider coverage and with dramatically less complexity and cost, and once turned on, they can be self-organizing and calibrating automatically. It consists of an intelligent signal relay mechanism so that the residents are free to move about in the nursing home or hospital, and allows personalized continence management service for providing quality care to the patients or elderly. The current system is an exemplar of the steps that will help
in the long term, promoting independent living through the appropriate use of everyday technologies. It is our ultimate goal to commercialize this system once it is proven successful, cost-effective, and beneficial to the elderly.

This paper presents the design, development, and deployment of the smart wireless continence management system. After a brief study on the related works, we address the issues involved in designing and implementing the system. Some preliminary results achieved from trial in a nursing home are presented. Finally, we conclude with current developments and present some future work.

Related Work

Previously, many standalone products existed in the area of continence management. These can be categorized into those that deal with children and those that deal with adults and elderly. Most of the products in the market fall into the first category, and are aimed at toilet training for growing children to help them gain control of their bladder.\(^5\)\(^-\)\(^7\) The products are usually designed for single localized monitoring and are not designed for large number of users or for large-scale and distributed continence management.

In the research community, there are also works related to urine detection devices or sensors. Wu and Siegel\(^6\) from Carnegie Mellon University proposes a low-cost odor-based sensor to monitor incontinence, while Ejaz et al.\(^3\) designed a system for measurement of urine as well as its components using reagent paper. Tamura et al.\(^10\) from Tokyo Medical and Dental University proposed a system based on the principles of temperature and impedance changes to detect urine. Similarly, Eckford et al.\(^11\) used a temperature-sensitive device placed inside a pad attached to a recorder unit to study the problems related to urinary incontinence. Recent work by Siden et al.\(^12\) described the use of an energy-harvesting method with new smart RFID technology called action-activated tag (AAT) to develop a disposable wireless diaper unit. However, not much work has been done for patients with dementia with incontinence problems, either to alleviate patients’ or caregivers’ problems, or to mitigate the problem through controlled voiding in term of a holistic continence management system.

There is even limited work in which a system trial has been carried out institution-wide for elderly with incontinence problems. This may be due to practical issues such as dealing with the mobility of patients, different environmental settings in nursing homes or hospitals, and so on. Our work is different from existing ones as it involves using a distributed wireless sensor network that is scalable and extensible to support the deployment of potentially large quantities of wetness sensors with wider coverage and with dramatically less complexity and cost. It consists of an intelligent signal relay mechanism so that the residents are free to move about in the nursing home or hospitals and personalized continence management features to improve the quality of life of the patients or elderly.

Design Considerations and Methodologies

The aim was to provide key insight into the design of a practical and usable smart system for continence management in nursing homes and hospitals. We will not exhaustively list all the considerations but will selectively elaborate on the important ones such as the sensing considerations, infrastructure considerations, services and intelligence considerations, and lastly usability considerations.

SENSING CONSIDERATION

The currently available enuresis sensors have many limitations such as short wireless communication range, limitation of one user per unit, silo operation in practice, passive and targeted competent user who can act upon receiving alarm signals, etc. In order to solve the problems, as a first step, we integrated one of the commercially available sensor units to the micaZ mote wireless platform\(^13\) so as to extend its functionalities that are lacking from standalone system in our trials. That sensor was chosen due to extensibility, ease of use, and safety reasons as they have been proven safe to be used on humans. This enables us to customize and add additional important features such as multiple users support, larger wireless coverage areas to our system for our purposes of effective continence management. Furthermore, actuators can be added for intelligent intervention and notification. The resulting customized sensor node can also perform in-node processing, event-based signaling, and calibration according to current situations. Meanwhile, we are also in discussion with relevant parties to fabricate a small, low-cost, disposable sensor unit that is better than those that are currently available.

INFRASTRUCTURE CONSIDERATION

In order to monitor the patients when they are moving about within the nursing homes or hospitals, we need a wireless communication network to cover the areas where elderly are commonly in place. We adopt the multi-hop wireless sensor network\(^14\) as our infrastructure. This multi-hop relay network not only extends the coverage of wetness detection but also can provide features such as rerouting for reliability, self-organizing, in-network processing, and so on. We have also included an intelligent signal relay mechanism to provide seamless continuous continence assessment for elderly whether they are on the bed or in a wheelchair anywhere and anytime. In the long term, we hope to further expand the infrastructure.
to support other healthcare applications concurrently such as sleep monitoring, location tracking, etc. by building ambient intelligence in the healthcare institutions.

SERVICES AND INTELLIGENT CONSIDERATION

It is important to provide personalized continence management service to all users as their needs and profiles may differ. We adopted the service-oriented architecture (SOA) approach as we can easily compose the services for each user, and future developers can easily build applications on top of the current system.

In the initial stage, we provided three basic services for users, namely, the intelligence service, alerting and intervention service, and continence planning service. Intelligence service is provided in different levels of the system such as the sensor nodes, relay nodes, etc., so that the system can react in a context-aware and intelligent manner. Alerting and intervention service was provided to automatically notify caregivers during episodes of urinary incontinence such as sending an SMS to the caregiver’s cell phone, audio alert on pager, nurse call bell system, etc. Continence planning service was provided to facilitate continence planning such as timed voiding, planned voiding, etc., and provided detailed and accurate statistics of incontinence episodes. With the aid of automated bladder charting, the patient’s pattern of incontinence throughout the day could be understood. In the future, statistical analysis of past behaviors can be used to anticipate voiding times of the patient, thereby allowing the patient to be brought to the toilet before the incontinence occurrence. This will definitely improve the quality of care. Figure 1 shows a snapshot of the overview of operation flow and services provided by the system.

USABILITY CONSIDERATION

For the system to be accepted by all stakeholders such as the patients, doctors, caregivers, and medical professionals, it must be reliable, nonintrusive, and provide continuous monitoring with minimum false-alarm rate. It must be responsive to the needs of users and provide the relevant services if needed. The software interface is critical to the success of the system, perhaps as important as the system’s clinical effectiveness because it directly interacts with all stakeholders who are always busy. It must be kept simple and user friendly. Furthermore, the operations of the system should be simple so that it will not give an extra burden to the stakeholders. However, we think that the best approach is to perform a trial with all the stakeholders so that detailed analysis of all the requirements can be done.

![Smart Wireless Continence Management System](image)

Fig. 1. Overview and services provided by System.
Figure 2 outlines an overview of the smart wireless continence management system. It consists of the sensor nodes, relay nodes, gateway node, actuator nodes, SMS gateway, CmsController server, CmsViewer client, and so on. The sensor node consists of a single mote interfacing with a wireless diaper receiver unit that receives a one-time detection signal from the sensor transmitter unit that is inserted inside the patient’s diaper. The relay and actuator nodes are co-located and consist of a mote interfaced with a buzzer and a set of light-emitting diodes (LEDs) for notifying the caregivers once urine is detected. The gateway node is the base station mote attached to the computer through an Ethernet programming board and acts as a bridge between the sensor network and user applications.

Figure 3 shows another detailed picture of the customized sensor node, relay/actuator node, and gateway node of the nursing home deployment system.

The software development related to all these nodes that use mote as a generic platform relies on the TinyOS$^{16}$ operating system and nesC$^{17}$ programming language originated from the University of California, Berkeley, for various operations such as sensing, eventing, actuation, and communication. An example of the nesC components wiring diagram for a sensor node is shown in Figure 4.

Besides the nesC software components developed in the motes, all other software modules for CmsController server, SMS gateway, and CmsViewer client are written in Java and communicate in a distributed manner using an SOA approach. A simple reasoning module is now integrated into the CmsController server to learn the patterns of urination of the patients. Service modules for analyzing acquired data from the sensor units, event acquisition, sensor and intervention management, data storage, and trend analysis are also developed. SMS service modules to alert wetness events to caregivers and status of the system to developers such as the battery problem, connectivity problem, and so on were also developed. However, due to the expense of sending the SMS messages per episode of urinary incontinence, the visual and audible alerts from the actuator nodes are preferred by the caregivers.

The CmsController server connected to the gateway node acts as the bridge between the sensor networks and the applications, and provides all the services needed by the end users. The same user interface of the CmsController server at the nursing station can be viewed from a remote location using CmsViewer client through a Web interface. Figure 5 shows a snapshot of the user interface for both local and remote systems.

The operation of the system consists of only four simple steps. First, the wetness sensor is placed into a pad, and then mounted onto the diaper, which the patient will be wearing (Fig. 6).
Second, the infrastructure, which consists of the sensor nodes, relay/actuator nodes, gateway node, and CmsController server, is turned on, and the continence management service is started. Third, when urination wets the diaper, the call bell sounds or an SMS is sent to alert the medical professionals or caregivers remotely. They can also view the status or reports through the Cmscontroller server at the nursing station or CmsViewer at a remote location. Last, the medical professionals or caregivers click the “Replace Diaper” button from the 3D user interface, take out the sensor unit (Fig. 7) and clean up if there is wetness and step one is repeated for another monitoring according to the diaper’s wetness conditions.

**Experimentations and Nursing Home Trials**

We decided to conduct a trial in a nursing home after conducting several experiments in the laboratory in order to prove the usefulness and importance of this system. Initially, the trials were performed with a suitable single elderly patient who had incontinence. We hoped to continue tuning the system for robustness from current trials before a larger trial is conducted with more elderly patients and different nursing homes. The demographic information of the patient who participated in this trial is shown in Table 1.

Along with our system, the regular routine for manual continence care in the nursing home was carried out. This could be used as a baseline to validate the correctness of the system and to study the complications of the system operations from the caregivers’ perspective. The manual routine for checking diaper wetness status is usually scheduled at bathing time and other time slots according to Table 2.

### Table 1. Patient Demographic Information

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>PATIENT’S INFORMATION</th>
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<tbody>
<tr>
<td>Age</td>
<td>Over 80 years</td>
</tr>
<tr>
<td>Diseases suffered</td>
<td>• Age-related involutional changes</td>
</tr>
<tr>
<td></td>
<td>• Peripheral vascular disease</td>
</tr>
<tr>
<td></td>
<td>• Hypertension</td>
</tr>
<tr>
<td></td>
<td>• Mild to moderate dementia</td>
</tr>
<tr>
<td>Incontinence problems</td>
<td>Yes (wearing diapers all the time)</td>
</tr>
<tr>
<td>Physical problems</td>
<td>Unsteady gait, behavioral</td>
</tr>
</tbody>
</table>

### Table 2. Manual Caregiving Schedule

<table>
<thead>
<tr>
<th>NO.</th>
<th>TIME OF THE DAY</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>2:00 am</td>
</tr>
<tr>
<td>2</td>
<td>8:00 am</td>
</tr>
<tr>
<td>3</td>
<td>12:45 pm</td>
</tr>
<tr>
<td>4</td>
<td>5:30 pm</td>
</tr>
<tr>
<td>5</td>
<td>9:30 pm</td>
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</table>
The nursing home layout and various components of the current smart system being deployed are shown in Figure 8.

Due to the large coverage areas needed, two relay nodes were used in this trial. One relay node was fixed just in front of the room in which the subject stayed most of the time and another one in the common dining area. For the gateway node, it was fixed outside the nursing station. Figure 9 shows one of the relay cum actuator nodes that was fixed just in front of subject’s room and the gateway node that was fixed outside the nursing station, respectively.

When the wetness event was detected in the sensor node that was attached to either the bed side or the wheelchair, depending on the location of elderly, the LEDs and buzzer at the actuator nodes near the elderly current location could be activated. This enabled the caregivers to provide essential care to the patients immediately after the incontinence episodes.

In the nursing station, the caregivers or the nurses were also notified through the user interface as well as visual and audio alerts for the episode of wetness diaper event as shown in Figure 10. The episode of the wetness event could also be archived in the database of CmsController server. The nurses could then operate the system with a simple and user-friendly user interface for detection of the next wetness event.

Results and Discussion

Preliminary results after a 1-week trial were very encouraging as the system functioned correctly and the wetness event could be detected. There was no false alarm during the trial, although the detection rate was only around 50%. Figure 11 shows the actual result of the wetness detection through manual observations by the caregivers during their routine check from the first week of the trial. According to records, there were a total of 21 routine checks by the caregivers during the week in which there were 14 real wetness events.
events. The system was able to automatically detect 7 episodes of wetness out of the 14 wetness events.

The zero false-alarm rate during the trial was expected and is comparable to the result of the mockup in the laboratory before the deployment phase. In order to maintain positive behavioral response of the caregivers to the system and to gain their trust in the initial stage of the trial, we have deliberately reduced the sensitivity of the wetness sensor to eliminate any false alarm. It is important because any false alarm will reduce the practicality of such a system, especially when the caregivers are already so busy with their routine work.

There are a few factors that affected the detection rate during the trial. One key factor was the location of the wetness sensor that is being put in the diaper unit. When the wetness sensor was not being put in the optimal position of the diaper, the detection rate would be lower as there is limited contact between the wetness sensor and the urine. We also observed that different types of diapers worn by the elderly will also affect the detection rate. Diapers with different properties such as different speed of wetness spreading through the diaper, the area in which the wetness is confined, etc., will affect the wetness detection from the sensor. Likewise, the sensitivity of the sensor to wetness that can be adjusted also affects the detection rate. We are still trying to fine tune the process and to find the optimal position in the diaper to put the wetness sensor to improve the detection rate. It is expected that with further trials, the process will be improved and an optimal position will be found, and we will be able to achieve high success rates of detection.

In addition, through close observations from the trial, we found that the way caregivers handle the system also affects the detection rate. In many occasions, we realized that the sensor node was not placed in the appropriate location when the patient was being moved around. In the current trial, only one sensor node was placed at the bedside or wheelchair according to the patient’s location. If the sensor node was not within the coverage area when the sensor unit was transmitting the wetness detection signal, the detection event would not be able to reach to the CmsController server. Learning from this experience, we will provide one sensor node each on the bed and wheelchair in the next trial for seamless connectivity without incurring any actions by the caregivers. Furthermore, we realize that we have not conducted sufficient training to educate the caregivers to fully realize the significance of the trial. Records show that the scheduled manual wetness checking routine was not strictly followed as the caregivers feel that the process will incur extra workloads. Hence, it is important for us to educate them about the significance of their involvement in the trial and the importance of following the correct operation procedures.

We are currently planning a second deployment phase of around 10 patients. Before starting the trial, we will perform surveys on the caregivers to gather feedback on how to improve the current system and the process of continence management. We will also conduct more training sessions about the important aspects of the system. It is envisaged that with further trials and improvement in the technical and operation process, the detection rate will increase significantly. Likewise, the functionality and usability of the system will be further enhanced to produce a new generation of continence management services that will improve the quality of life of the stakeholders. Hopefully, this work will lead to the discovery of new knowledge about the incontinence needs of patients.

Conclusions

In this paper, we present the design, development, deployment, and initial trials of a smart continence management system based on a multi-hop wireless healthcare sensor network for patients with dementia in institutions such as nursing homes or hospitals. Preliminary results from a trial are very encouraging. We are still in the process of fine-tuning the system in order to obtain a better detection rate. Our next goal is to perform trials with more patients or elderly to improve the functionality and usability of the smart wireless continence management system for better quality of care.

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Disclosure Statement

No competing financial interests exist.

REFERENCES


