Home Wireless Sensing System for Monitoring Nighttime Agitation and Incontinence in Patients with Alzheimer's Disease

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ABSTRACT

Patients with Alzheimer's Disease (AD) often experience urinary incontinence and agitation during sleep. There is some evidence that these phenomena are related, but the relationships (and the subsequent opportunity for caregiver intervention) has never been formally studied. In this work, the relationships among the times of occurrence of nighttime agitation, sleep continuity and duration, and urinary incontinence are identified for persons with AD by using innovative, non-invasive technology. Deployments in 12 homes demonstrate both the utility of the technical monitoring system and the discovered correlations between agitation and incontinence for these 12 AD patients. Implications of possible interventions are discussed. Lessons learned for technical, non-technical and health care implications are presented.

1. INTRODUCTION

More than 5 million Americans today are suffering from Alzheimer's disease (AD). Patients with AD frequently experience urinary incontinence (UI), disturbed sleep, and episodes of nighttime agitation. Family caregivers report that coping with nighttime agitation and associated sleep disturbances can be overwhelming and that these disturbances are often a "tipping point" for seeking institutional care for their loved ones [9]. Moreover, the care requirements for urinary incontinence also burdens the caregivers [4, 5]. Now, there is anecdotal evidence that there is a relationship among urinary incontinence, sleep disturbance, and agitation in persons with AD. Urinary incontinence is thought to trigger awakening from sleep, with subsequent agitation. However, there is a lack of systematic evidence that these phenomena are related. In this study, we describe the relationships among the times of occurrence of nighttime agitation, sleep continuity and duration, and urinary incontinence in persons with AD by using innovative, non-invasive sensing technology.

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There are several challenges that need to be addressed in systems designed for monitoring real patients. Sometimes these problems relate to the particular medical condition and sometimes they are more general. In our preliminary work, we found that the realities of actual deployments for real patients with real medical problems give rise to many new requirements, including: the need to use off-the-shelf devices, support for non-expert users (elderly patients or caregivers), easy installation and maintenance, ease of developing the specific software required for a particular instantiation, remote monitoring, extensible monitoring over time, handling the large scale of data, and dealing with the complexity of a variety of persons and environments. Therefore, in this paper, we present a system for detecting incontinence and monitoring nighttime agitation and sleep that is easily deployed in real life settings. The sensors are passive or easily wearable. The collected data are saved in the base station located near the monitoring devices. The base station data is sent to the cloud whenever a network connection is available for proper storage and security. The system also includes monitoring algorithms running both in the cloud and the base-station to detect events causing common interruptions or failures. The system has been deployed in 12 different homes to monitor incontinence events, sleep, and agitation of patient's with AD. The main contributions of this paper are:

- A system for detecting incontinence and monitoring sleep agitation that can be deployed in real world. The system supports easy installation and maintenance, deployment by non-expert users, remote monitoring for detecting common failure events, and handling the large scale of data.
- Collection of deployment data from real patients with AD who experience both urinary incontinence, sleep disturbances, and episodes of nighttime agitation. The

demographic data of these patients varies in gender, race, and age.

- Demonstration of the relationship between urinary incontinence, sleep disturbance, and nighttime agitation based on evidence collected from study participants with AD.

Current treatment for nocturnal agitation in older adults with AD is generally with anti-psychotic and hypnotic medications. Unfortunately, these pharmacological therapies have little success and may have adverse effects on other outcomes, i.e. increased fall rates and decreased quality of life. Based on the preliminary results of this paper, we can say that simple, non-pharmacological nursing interventions such as regularly awakening patients to use the toilet has the potential to reduce nighttime agitation, sleep disturbances, and urinary incontinence in persons with AD. Therefore, these interventions may improve the quality of life for patients and their caregivers which may: delay institutionalization, reduce caregiver burden, and result in substantial savings in the cost of caring for persons with AD.

2. SYSTEM DESIGN

The incontinence and sleep monitoring system is created based on Empath2 [3] framework. The basic architecture of this system consists of three main layers: the sensing layer, the basestation, and a cloud-based web server (with associated database) (see Figure 1). It is noteworthy that there is a two layer monitoring module running both in basestation and cloud to prevent failure or detect failure as early as possible. In addition, most of the design decisions and parameters of the system are based on the preious experimental study of individual sensors, and the justification had been done in references.

2.1 Sensing Layer

The sensing layer has mainly three types of sensor for detecting wetness, nighttime agitation, and speech outbursts (possibly during, before or after agitation). Sensing devices generate either continuous (sleep-sensor) or event-based data (wetness event).

Monitoring Agitation: Agitation of a patient is monitored using two types of device - sleep monitoring accelerometers and TEMPO nodes. The accelerometers capture full body movement and overall sleep quality. Two triaxial accelerometers, sampling at 50 Hz, are placed on the top and bottom sides of the bed. Because the accelerometers are placed just beneath the mattress pad, fine movements is detected without causing direct invasion of the patient. The movement levels for one minute epochs are calculated by computing the mean and standard deviation of the samples. The weighted sum of activity values across a time window of seven minutes is used to estimate wake and sleep periods using Cole's Actigraphy algorithm [2].

However, agitated person often display higher movement in the upper portion of the body, specially movements of the hands. Thus, to collect more detailed data about body movements, TEMPO motes are strapped to the left and right wrists of the patient. TEMPO mote is modified from previous version of wireless inertial body sensors [1], with long-term data monitoring and file management system support up to 2GB. The motion capture capabilities provided by TEMPO include six degrees of freedom sensing sampled at arbitrary frequencies with 12-bit resolution. However, we turned off the gyroscope, which is the bottleneck of the power consumption of the inertial body sensors [6], to extend the life time of the TEMPO mote due to the life time requirement of this application is at least 12 hours for the sleep time at night.

Monitoring Wetness Event: The detection ability of the system is most crucial when a wetness episode occurs. Therefore, a small, lightweight, and wireless sensor named "drybuddy" is used. It uses a magnetic locking system to keep the sensor in place, and electrical conductivity within an incontinence pad to determine if a wetness event has occurred. The reason we adopted drybuddy to detect wetness is its comfortable form factor for patients and convenient use for cargivers, although it still has drawbacks in technical design. For instance, drybuddy uses the X10 wireless protocol, which is not reliable in data transmission, to send a signal when an incontinence episode occurs. Therefore, two X10 receivers are used for better reliable wireless communication of drybuddy.

Monitoring Speech: The system monitors audible speech outbursts by using a microphone. Caregivers often report outbursts or incoherent speech associated with agitation. Therefore, microphone is used to collect information about surrounding sound. Data is processed to differentiate sound from silence and further lowpass and highpass filtering is applied to capture sound that is in the range of human voice. The filtered continuous data is buffered over an epoch window (for instance 1 minute), and then the statistics for the epoch window – such as the mean, variance, min, max, count) are generated. When an epoch is instantiated, it is forwarded to a basestation over the network.

All the modules described above extend the abstract class *AbstractDataCollector*. It is an abstract class provided by the Empath2 framework containing basic functionality such as maintaining a connection to the message broker and handling the serialization and publishing messages to the broker. However, all the virtual functions such as initialization, starting, stopping, and shutting down of the device of each modules are implemented separately without altering the basic frame work structure. For each type of sensor, a new associated data collection class is also created to read the raw sensor data and publish it to the MQQT broker (see details in section 2.2).

2.2 The Base Station

Our system uses the MQ Telemetry Transport (MQTT) protocol [8] as implemented by Mosquitto for the message broker. The main function of the base station is to receive data from the sensing layer, store temporarily and stage for syncing to a web service on the cloud. Therefore, the home controller module of the base station subscribes to all the sensor modules that publishes data to the MQTT broker. The message broker (MQTT) runs on base station and listens for incoming connections. MQTT implements a publish/subscribe message pattern to provide a one-to-many message distribution so that all the modules can be adequately decoupled from one another. In each of the packets (message), the payload is a series of Epochs serialized as a JSON string. MQTT uses TCP/IP to provide basic network connectivity with small transport overhead (the fixed-length header is just 2 bytes), and protocol exchanges minimized to reduce network traffic.

In Empath2, when a sensor is installed, a URL for the mes-

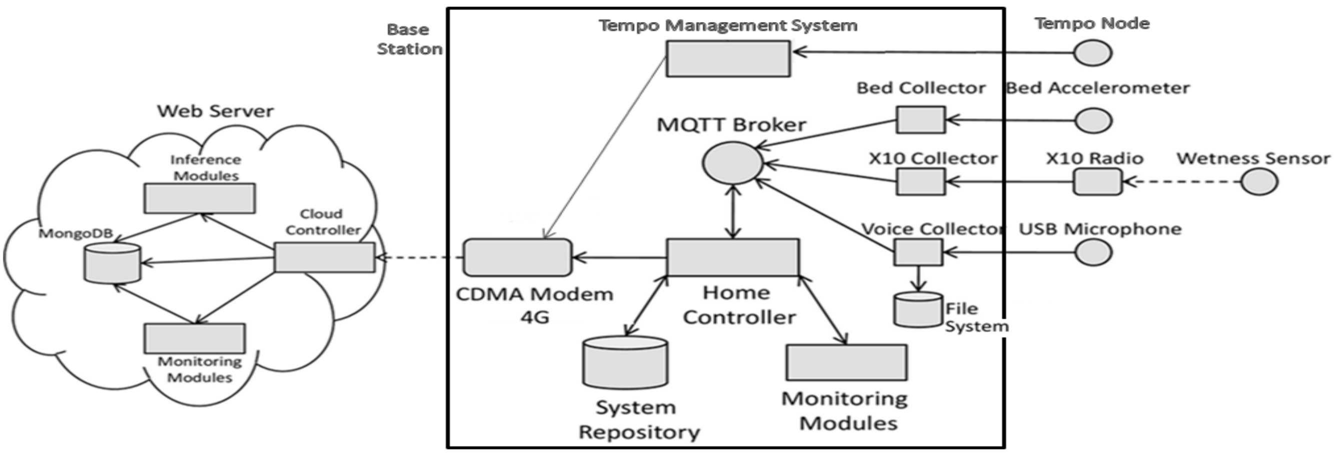

Figure 1: Architecture of the system for detecting incontinence events and monitoring nighttime agitation.

sage broker must be specified as well as a device name. For example, a broker can be located at tcp://10.0.0.1:1883 on a machine and the bed sensor on tcp:10.0.0.8 with device name **bed1**. When the bed sensor collects data for one second, the mean and standard deviation are computed for each of axis of each accelerometer, resulting in a 12 dimensional feature vector. A new *Epoch* is created using the current timestamp, duration, and feature vector. This epoch is serialized to a JSON string and published to the topic: sensors/bed1. When a message arrives, the message is stored in the Controller's local database for later syncing with the Cloud. This local database is implemented using SQLite 3 which is a self-contained, server-less, transactional SQL database engine. Once data is synced to the cloud it is deleted from the base station. Support modules for remote monitoring also exist at the base station.

2.3 Cloud

The third layer is the cloud layer. The system's cloud-based server is implemented by a JAVA web application, thus when the code is compiled it is a deployable WAR file that can be installed into any Java web server container (Tomcat, Jetty, JBoss, etc). We used the Spring3 framework for handling the Model View Controller (MVC) pattern for handling requests from the clients and handling serialization of JSON messages. The Spring Security extension is used to implement authentication and access control using the bcrypt cipher for hashing the passwords on the database. Each user is given a set of roles such as Patient, Clinician, Technician, Administrator, Coordinator, Researcher which is enough to handle course-grain requests to resources. For a more robust access-control mechanism, these roles can be predicated, so that a user can be a Clinician for X, and X is a Patient of study Y and Researcher is a member of Study Y. Before any resources are served, a user must sign in, and a session ID is created and stored as a cookie in the HTTP client, and the communication provided through an HTTPS tunnel.

The primary interface to the web is the Request Dispatcher whose role is to translate the request pointing to a URL to the appropriate Controller to handle processing the task. The Controllers are *StreamController*, handling all access to data in a stream, the *UserController* for handling any information about a *User*, and *ProcessorController* for *Processor* objects.

Table 1: Stream Metadata Examples

Key	Description
Creator	UUID of the user who created the stream
DeploymentID	UUID of the deployment the data came from
TargetID	UUID of a user the stream might relate to
PreferredRenderer	Bar plot, time series, table, etc
Device	Specification of the device make and model

The server is deployed on Amazon EC2 cloud platform. However, the implementation is not platform dependent. One EC2 instance run a Jetty9 instance for our application, and another ran only the MongoDB database. The instance with the database mounted a RAID10 array with 8 GB of Elastic Block Storage formatted with the XFS filesystem.

There are three basic types of streams in the system. First, there are persistent streams that are stored in a database. Second, and very common, are memory streams that do not have persistence and are populated upon request. This is useful for streams are only needed to produce some report to a caregiver. This allows the Evaluator objects to store the results temporarily like a scratchpad, so that clients can quickly query for the information without requiring the entire inference chain to be recomputed. Third, there are web streams which are data sources that are not stored locally in the system, but rather through another web server on the Internet.

2.4 Monitoring Module

In our real world deployments, we found that the common reasons of system failures is often a very simple one, for example, loss of power, problem in Internet connectivity, or battery drainage in sensor devices. Therefore, the purpose of the monitoring module is to detect the events that trigger system failure and prevent them; as well as to detect failure as early as possible and notify the system administrator. The monitoring is performed in two layers -

Base Station: The monitoring modules in the base station continuously logs the system memory consumption, Internet connectivity status, and battery level of the laptop along with checking consistency in the generated data. These logs are also automatically uploaded to the cloud. Often pets, children, or sometimes adult unknowingly unplug the base station device and subsequently causes it to shut down. Therefore, the base station monitoring device periodically

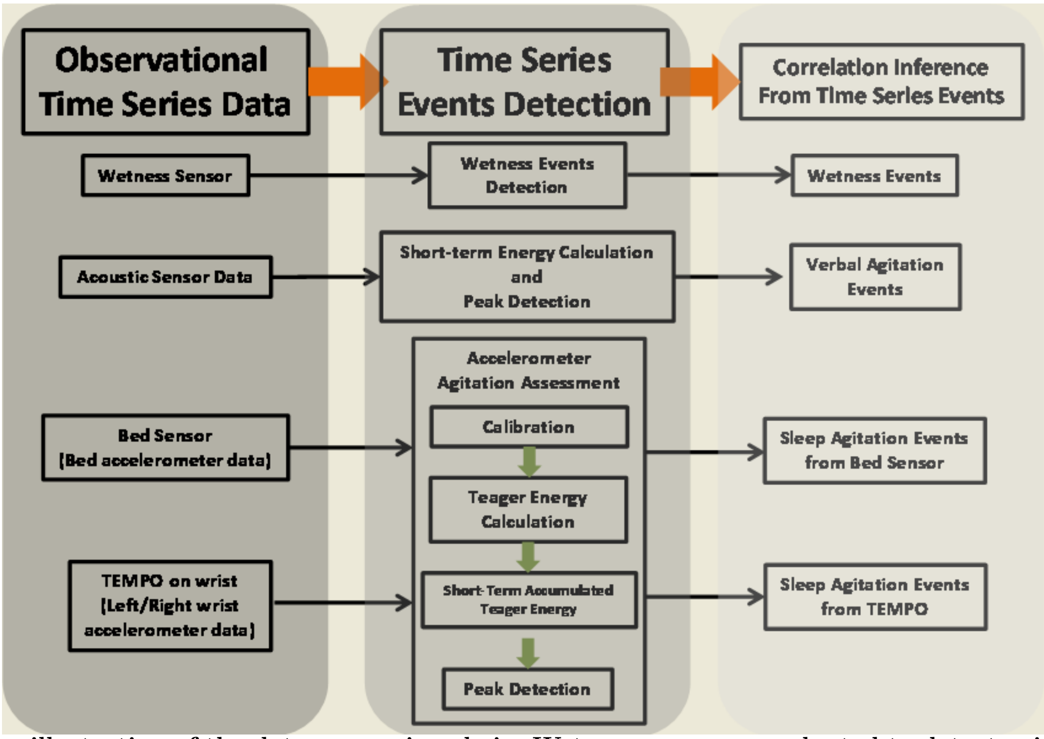

Figure 2: The illustration of the data processing chain. Wetness sensor was adopted to detect urinary incontinence, while acoustic sensor, bed sensor and TEMPO on wrist were used to capture the nighttime agitation. The correlation inference of time series events is evidence of the relationships between nighttime agitation and urinary incontinence.

checks the status of the power. It notifies the administrator (send emails) as soon as it detects that the base station device has been unplugged. As the percentage of power gets lower, the module notifies with higher priority (sends email more frequently and/or sends email to multiple persons in charge).

Cloud: This monitoring part is mainly a script running in the cloud (in separate server). The script checks the following:

- The status of the server running in cloud. As soon as it detects that the server is down, it notifies the administrator.

- It checks the streams of running deployments. If no data is uploaded from any stream for a particular amount of time from a particular base station, then it is assumed that either the network is down or a failure occurred in the base station. If failure occurs but the network connection is available, the system administrator is often capable of solving the problem remotely.

- If a data discrepancy is found (no wetness event detected by system, but wetness reported by patient/caregiver), then notify an administrator. If the problem is not solvable remotely (battery runs out in the wetness sensor), than quick steps are taken by visiting and if required replacing system parts.

This multi-level monitoring ensures that we can detect problems as soon as possible and also often determine the exact problem.

3. DATA PROCESSING

A wetness sensor was used to detect the UI events, while other sensors include TEMPO on the wrist, an acoustic sensor and bed sensors were used to capture the nighttime agitation. Figure 2 illustrates the data processing chain which consists of two steps: time series events detection and correlation inference from time series events. The detected events contain wetness events from the wetness sensor, verbal agitation events from the acoustic sensor, sleep agitation events from bed sensors and from the TEMPOs on the wrists. In addition, the detected agitation events from TEMPOs and bed sensors contain information not only about the peak time when the events happened, but also about the duration of the agitation.

3.1 Wetness Events Detection

Ideally, the wetness sensor sends an indicator signal when an incontinence episode occurs. However, there are still some challenging issues in real-world deployments. For instance, UI events with long duration will trigger the wetness sensor more times than we expected. In order to get rid of the overlapped wetness events, we added time window constrains into the wetness sensor data to avoid the overlapped events. It means the detected wetness events were the clean data within the time window constraints.

3.2 Verbal Agitation Assessment

Acoustic sensor data was used to detect the verbal agitation of the subjects. Initially, low-pass and high-pass filter is applied to remove silent periods or sounds that are not in the range of human voice. For each 1 min audio clips that

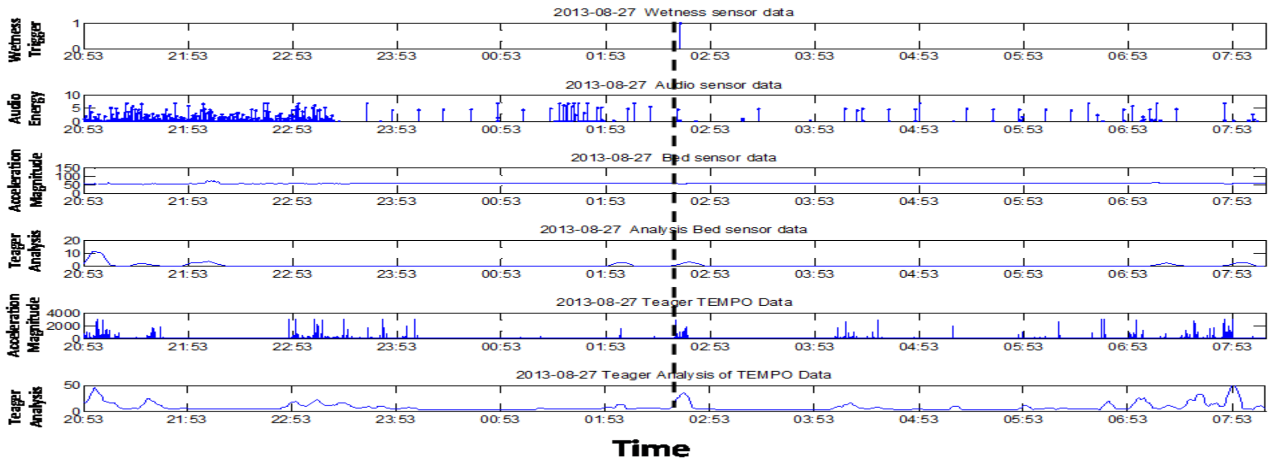

Figure 3: Illustration of the correlation inference process for data collected at the night of 2013/08/27 for participant 002. The duration of the collected data is 11 hours, started from 2013/08/27 20:53 to 2013/08/28 08:13. Wetness events detected from wetness sensor, short-term energy of audio sensor, sum of acceleration magnitude from bed sensor, Teager analysis from bed sensor, sum of Teager energy from TEMPO and Teager analysis from TEMPO, are plotted in rows, respectively. The salient time point of wetness event was 02:36PM 2013/08/28. After searching a 10-minutes window, the sleep agitation event detected from TEMPO was found at 02:35PM with 7-minutes duration, and another sleep agitation event detected from bed sensor was found at 02:42PM with 9-minutes duration.

contains human voice, 19 most significant MFCC features (including energy and pitch of the signal) are calculated. We calculated the short-term energy of the acoustic signal and recorded the piece of the signal only if the energy signal was higher than an energy threshold. Therefore, the verbal agitation assessment is based on the scale of the short-term energy of the acoustic signal and recorded as the verbal agitation events whose energy of signal is higher than the specified energy threshold.

3.3 Sleep Agitation Assessment

Sleep agitation assessment was based on the data from TEMPO and bed sensors since TEMPO and bed sensors were used to monitor the sleep activity of the subjects. The sensors in TEMPO motes on the wrists and bed sensors are accelerometers; therefore we adopted the same agitation assessment technique for both. After the data was collected, signals were rescaled offline using the calibration data. The vector magnitude was calculated from the tri-axial accelerometer signals to provide information about the acceleration magnitude regardless of orientation. Hanson [7] introduced a technique to provide assessment of essential Tremor severity by applying the Teagar Energy Function, and Bankole [7] extended the application of the technique to agitation assessment in dementia. However, the calculation process of the Teager Energy Function is based on Short-time Fourier transform (STFT) which has high computation complexity. In order to reduce the complexity of computation for the long-term dataset, we adopted the variable length Teager Energy based feature [10]. The short-term Teager Energy was calculated at every minute throughout the night. A five minute frame of Teager data was analyzed around each data point taken (2.5 minutes on either side). Agitation is indicated by large increases in the average Teager value over brief periods of time, as the agitation instance surrounding incontinence typically only appears for a few minutes at a time. Since the different individuals have different agitation levels, therefore, the individualized thresholds were estimated to assess the agitation. Any smaller magnitude shift could not be distinguished from typical night time body movement. The average Teager level was occasionally higher at both the beginning and the end of the night, but these values did not typically correlate to incontinence instances. Their prolonged timeframe would indicate that the movement is due to the participant falling asleep at night or waking up in the morning, so any prolonged variation in the average Teager energy function that continue from the beginning of the data collection or which continue into the end of data collection were ignored during this analysis.

3.4 Correlation Inference

After the events detection from the time series sensor data, correlation inference was conducted on the time series events. In order to find the correlation among nighttime agitation, verbal agitation and sleep agitation, the wetness events were used as salient times during the night, and then a search method was conducted in a short-time window around each salient time point. If other agitation events were found in this short-time window, the wetness events in the salient time point and the agitation events will be considered to be correlated successfully. In addition, the correlated events are recorded in time order, especially indicating the agitation events happened before or after the wetness events. Ideally, we expected that the verbal agitation can be detected from the acoustic sensors; however, many types of noise during the real-world deployments were merged into the recorded sound of the acoustic sensors, such as dogs barking, caregiversâĂŹ sounds, or sounds from the TV or radio. These noises made the verbal agitation task for the person with AD much more challenging than we imagined. Therefore, in this pilot study, we did not find meaningful correlation between wetness events and verbal agitation events. In the future, noise filtering can be applied to the acoustics in order to better use sounds as additional indicators of agitation.

As one example, Figure 3 shows a correlation inference among wetness events and sleep agitation events at the night of 2013/08/27 for participant 002. Wetness events detected from wetness sensor, short-term energy of audio sensor, sum of acceleration magnitude from bed sensor, Teager analysis from bed sensor, sum of Teager energy from TEMPO and Teager analysis from TEMPO, are plotted in rows, respectively. The salient time point of wetness event was 02:36PM 2013/08/28. After searching a 10-minutes window, the sleep agitation event detected from TEMPO was found at 02:35PM with 7-minutes duration, and another sleep agitation event detected from bed sensor was found at 02:42PM with 9-minutes duration. In addition, although the peak time point of the sleep agitation events slightly lag behind the salient time point of the wetness event, it is still reasonable to consider that the sleep agitation happened precede the wetness event because the beginning time of sleep agitation happened earlier than the peak point.

4. EVALUATION

Starting from May 2013 until August 2014, our home wireless sensing system was deployed 12 times in participants home settings. Although many other challenges were encountered during these real-world deployments, we successfully gathered study data from 10 participants. Table 2 summarizes the collected data. The system failed in data collection only once. Participant 003 admitted to the research plan in the beginning, but quit later. Participant 005 declined to use the TEMPO on his wristband because the caregiver believed that these devices would be irritating for the participant. This data demonstrates the effectiveness of the deployed system and its monitoring mechanisms.

The result of correlation inference among the wetness events and sleep agitation events is summarized in Table 3. The ratio of correlated wetness events is 49% (43/88). Almost half (21/43) of the sleep agitation events happened before the wetness event while the rest of the agitation incidences (22/43) happened after the wetness event. What is most important about these results is that we can correlate wetness to agitation. For example, if a person is agitated we can alert the caregiver to wake the patient before they have an episode and this avoids cleanup. If a wetness event occurs without prior agitation we can alert the caregiver to replace the undergarment which may avoid the subsequent agitation, thereby improving sleep for the patient.

As one example, consider participant 009. Participant 009 is the person with whom we have the most complete data, presented in Table 4. Participant 009 is an 89 year old female who was verbally agitated and physically non-aggressive at baseline. She had moderate cognitive impairment, with good physical mobility. She was not taking any diuretics, psychotropics, or anti-cholinesterase medications that might have affected either urinary incontinence or agitation. She had more than 5 co-morbidities in addition to her dementia diagnosis. Medical records indicated that she was incontinent of large amounts of urine on a nightly basis. A total of 12 sleep agitation events were detected by the TEMPO wrist devices were correlated with wetness events, while 10 sleep agitation events detected from bed sensor were found to be correlated to wetness events. Four wetness events were found to be correlated to agitation incidences as measured by both

Table 2: Data summary of the deployments

ID	Duration	Wetness Sensor	Acoustic Sensor	Bed Sensor	TEMPO
001	05/08/2013 05/13/2013				✓
002	08/27/2013 09/02/2013	✓	✓	✓	✓
004	08/27/2013 09/02/2013	✓	✓	✓	✓
005	12/18/2013 12/22/2013	✓	✓	✓	
006	01/02/2014 01/08/2014	✓	✓	✓	✓
007	01/02/2014 01/07/2014	✓	✓	✓	✓
008	02/05/2014 02/16/2014	✓	✓	✓	✓
009	02/18/2014 02/23/2014	✓	✓	✓	✓
010	07/03/2014 07/09/2014	✓	✓	✓	✓
011	04/22/2014 04/28/2014	✓	✓	✓	✓
012	05/29/2014 05/25/2014	✓	✓	✓	✓
013	06/30/2014 08/06/2014	✓	✓	✓	✓

Table 3: Correlated wetness events of the deployments

ID	Total Wetness Events	Correlated Wetness Events	Sleep Agitation Events before Wetness events	Sleep Agitation Events after Wetness events
001	-	-	-	-
002	5	4	4	0
003	-	-	-	-
004	3	3	1	2
005	5	1	1	2
006	0	0	0	0
007	6	5	2	3
008	7	4	3	1
009	33	18	7	11
010	19	2	1	1
011	0	0	0	0
012	6	5	1	4
013	4	1	1	0
Subtotal	88	43	21	22

Table 4: Correlated wetness events of participant 009

Date	Time of Sleep Agitation detected from TEMPO	Wetness Events	Time of Sleep Agitation detected from Bed Sensor	Indicator (Before/After)
2/19/2014	2:04	2:06		B
		4:01	4:02	A
		4:45	4:48	A
2/20/2014	23:01	23:06		B
		1:47	1:51	A
	6:33	6:27	6:33	A
	7:33	7:30		A
2/21/2014		22:25	22:28	A
		00:32	00:34	A
	1:41	1:42		B
		2:12	2:15	A
	3:18	3:15		A
2/21/2014	21:10	21:19		B
	22:20	22:20	22:23	B
2/22/2014	20:29	20:20		A
	22:25	22:31		B
	1:57	1:49	2:00	A
	6:00	6:01	5:58	B

TEMPO and bed sensor devices. Seven agitation incidences began before the urinary incontinence event and eleven incidences of agitation occurred after the urinary incontinence event. In fifteen incidences, no agitation was detected either before or after the urinary incontinence event. This implies that using the intervention scheme mentioned above, seven times a clean up could have been avoided, eleven times the clean up could have occurred quickly thereby improving sleep, but fifteen times there would have been no benefit. This illustrates the complex nature of correlation between incontinence and sleep quality.

5. LESSONS LEARNED

The system was deployed in 12 different homes to monitor incontinence, sleep, and agitation of non-institutionalized persons with AD. Several important observations are made based on the experience which includes technical, non-technical, and health care implications. Some of the technical problems have been solved and some are identified as our ongoing future work. The lessons learned are described below.

5.1 Non-technical

- Deployments must be installable by non-technical experts, e.g., contracted system installers or home caregivers. In our case studies, minimal time by our research team was needed to train the family caregivers in setup and maintenance of the body sensors.were able to perform the installations.
- Deployment time must be as short as possible. The architecture must have the capability to quickly discover the emplaced sensor nodes, activate the system, and importantly test that the installation is fully operational in an end-to-end manner, i.e., from sensors to cloud to users. Our system was deployed by non-expert user in about half an hour.
- The voice agitation sensor picked up other sounds besides vocal outbursts, including the snoring of the participant. It was also not possible to automatically and accurately discern the character of all vocalizations, especially whether it was an intelligible utterance or a mumble.
- The DryBuddy device had connectivity problems, in one instance producing a false negative despite a incontinence episode occuring. This was confirmed by both the husband attending to the episode, and the weight of the pad afterwards. Although the DryBuddy was triggered, the signal was attenuated and lost in transmission. We fixed this problem by introducing multiple X10 receivers on either side of the bed to more closely detect when the device is triggered, so the signal could not be blocked the patient's body. Adding more DryBuddy sensors on the pad was another potential option, however it was too uncomfortable for the user.
- People do not necessarily sleep on their bed when they sleep, which affects the accuracy of the data. For example, one participant often fell asleep in front of the television on the sofa many nights, and also took frequent trips on weekends and did not sleep on the mattress.
- Devices fail and the software will crash, therefore a system that allows remote administration is vital, so that problems can be resolved without traveling or entering the patient's home. The monitoring modules of our system helps to identify problem quickly and most of the problems can be solved remotely.

5.2 Technical

- Mobile broadband Internet connections are not always available when needed, and the connection can drop while in use. This occurred much more often than we expected, but most especially in homes in more remote locations. Consequently, the system allow for a local backup (such as a SQLite3 DB on the base station) and a background daemon to reliably synchronize and upload new data when a connection is made.

- The architecture must support frequent monitoring of the correct operation of the system, to ensure that the sensors are working, recording and transmitting properly, and that the data itself are reasonable. The system provides monitoring support at points throughout the architecture (in both the cloud and base station levels).

- The system must be resilient and cognizant to actions of patients and caregivers over the lifetime of the system. Minimizing assumptions required for the system to operate properly is critical. Will the system still work if a sensor or device is turned off or moved from its expected location? What happens when there is a power outage in the area? At a minimum, redundancy of critical components is required and any affected or missing data should be tagged with meta data explaining the situation.

5.3 Health Care Implications

- While our data do not support that all agitation is linked to urinary incontinence, this relationship occurs frequently enough to undertake interventions to reduce incontinence.

- The frequency with which agitation begins prior to the urinary incontinence event may indicate that the sensation of the need to void is causing agitation, rather than wetness. This finding has implications for the timing of toileting of persons with AD.

- Those data that reflect the timing of incontinence events provide the needed information to develop individualized toileting schedules, which could reduce incontinence and agitation.

- Participants' consistency of incontinence and agitation patterns over the data collection period increases the feasibility of implementing a toileting schedule that can be successful and maintained.

6. CONCLUSIONS

Alzheimer's disease (AD) is the 6th leading cause of death in the U.S. The sufferers are not only the patients, but also the caregivers on whom it takes a devastating toll. Nearly 60 percent of Alzheimer's and dementia caregivers rate the emotional stress of care-giving as high or very high; about 40 percent suffer from depression. The burden is in large part due to nighttime agitation, and this paper shows the relationship of urinary incontinence and sleep agitation from a deployment of a novel sensor system in the homes of 12 Alzheimer's patients. The intervention method proposed in this paper should not only improve patients' overall health and prevent side effects resulting from unnecessary anti-psychotic medications, but it will also help ease caregiver burden and associated stress and depression.

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