# Towards an Ambient Support System for Continence Management in Nursing Homes: An Exploratory Study

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Abstract: Time consuming and costly, continence care management has become one of the main care demands in nursing homes with potential inadequacy negatively impacting residents' quality of life. While engineering efforts in this area are increasing, these mainly focus on wearable innovations. To support continence care in nursing homes in an unobtrusive manner, we developed an ambient sensor system to continuously monitor incontinence events, e.g., saturated incontinence materials or leakages. In an exploratory study in two nursing homes, we evaluated an early prototype of the sensor system and built annotated data sets. Implemented annotation devices included a smart sensor mat, a toilet timing predicting device, and manual data entry of continence care by care personnel. From our analysis of the preliminary study results based on the first two residents, we learned how challenging the ambient monitoring and annotation of incontinence events is. On the basis of the outcomes, we provide suggestions for further research of ambient sensor systems supporting continence care.



## 1 INTRODUCTION

In long-term care settings, such as nursing homes, over 50% of the older adults experience incontinence, i.e., the involuntary leakage of urine or stool (Offermans et al., 2009). Consequently, continence care has become one of the main care demands (Wagg et al., 2017). Over 20% of care time is spent on direct continence care management, e.g., toileting assistance, and changing incontinence materials (Ouslander and Kane, 1984). In addition, the average cost for management is about US$15 per day per resident (Hu et al., 2003). Continence care is thus time consuming and costly for nursing homes, moreover, it also negatively impacts the residents' quality of life, e.g., by disturbing their sleep (Ouslander et al., 1998). In a generally ageing society, the prevalence of incontinence will only increase, resulting in additional pressure on the already overburdened staff and institutional costs (Wilson et al., 2001; Mather and Bakas, 2002). Previous engineering research focused on wearables, such as the development of smart incontinence wear (Fish and Traynor, 2013; Lin et al., 2017). To the best of our knowledge, no studies involve unobtrusive, ambient sensor technology to support continence care in nursing homes.

We are interested in the potential of an ambient sensor system to support continence care in nursing homes. To evaluate the system, this paper describes an exploratory field study with an early prototype deployed in two nursing homes.

We first elaborate on continence care practices, and how technology approaches can support them. We then proceed with the implementation of the prototype, together with the applications and devices for annotation. Following implementation, a first evaluation of the system is presented through preliminary results and user feedback. We close by putting forward considerations for further system development

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Table 1: Overview of Ambient Intelligence (AmI) technologies evaluated in nursing homes to support care management.

| Authors | Care domain | Technology | Device |
|---|---|---|---|
| Huion et al. | Continence | Wearable | Smart diaper (WetSens) |
| Traynor et al. | Continence | Wearable | Smart diaper (SIM) |
| Wai et al. | Continence | Wearable | Smart diaper (iCMS) |
| Aloulou et al. | Activities of daily living | Ambient assistive living | Unobtrusive sensors & devices |
| Hori & Nishida | Activities of daily living | Ambient assistive living | Ultrasonic sensors |
| Rantz et al. | Activities of daily living | Ambient assistive livings | Unobtrusive sensors & devices |
| Suzuki et al. | Activities of daily living | Ambient assistive living | Infrared sensors |

and associated research studies in nursing homes.

## 1.1 Background

During the day, over 20% of care tasks are directly related to continence care, increasing to 70% during the night. For more interdependent older adults, the estimated time reaches nearly one hour per nursing home resident per day (Ouslander and Kane, 1984; Borrie and Davidson, 1992). Continence care practices involve periodic manual check-ups of incontinence material, toilet visits and continence assessments. Current practices lead to unnecessary controls or delayed interventions, triggering undesired instances such as disturbed sleep (O'Dell et al., 2008). These are uncomfortable situations for care personnel and residents alike.

Efforts have been made to support continence care management through Ambient Intelligence (AmI) systems. AmI brings intelligence to physical environments and measures them through sensors (Cook et al., 2009). It has the potential to improve the healthcare domain and mainly consists of two types of technology (Acampora et al., 2013):

- Body Area Network (BAN): body sensors are attached on clothing or on the body, commonly known as wearables, or even implanted under the skin, e.g., to measure body temperature, blood pressure, or cardiac activity;
- Wireless Mesh Sensor Networks (WMSN): ambient sensors are embedded into the environment, e.g., to measure room temperature, opening doors, or movement.

Research can be found on the development of smart incontinence wear, i.e., a BAN with a wearable detecting the saturation level of material via an integrated humidity sensor and alerting care personnel for required check-ups. Exploratory studies in nursing home settings evaluated several smart diaper prototypes, identifying and testing technical specifications (Table 1) (Huion et al., 2019; Traynor et al., 2014; Wai et al., 2010b). Conducted research to develop an intelligent Continence Management System (iCMS) for nursing homes via smart incontinence materials and wetness alert notifications on a smartphone for care personnel, faced several technical challenges (Wai et al., 2008; Wai et al., 2010a; Wai et al., 2010b; Wai et al., 2011). The researchers concluded that desirable features of an intelligent continence care management system could range from unobtrusive continuous monitoring to odour-based detection, pointing towards a recommendation to shift continence care technology from BANs to WMSNs.

In contrast to the technological solutions to support continence care, WMSN is already thoroughly researched and evaluated in the care domain of activities of daily living (ADLs) by the name of Ambient Assistive Living (AAL) (Table 1) (Aloulou et al., 2013; Hori and Nishida, 2005; Rantz et al., 2010a; Suzuki et al., 2006). To monitor ADLs, research utilised ambient sensors and devices, ranging from low cost sensors (e.g., pressure sensors, motion sensors, bed sensors, and vibration sensors) and devices of interaction (e.g., camera, speakers, and tablets) (Aloulou et al., 2013; Rantz et al., 2010a) to ultrasonic sensors (Hori and Nishida, 2005) or infrared sensors (Suzuki et al., 2006).

Monitoring via ambient sensors presents an opportunity to develop unobtrusive technology for user groups like nursing home residents. Although, plenty of AAL research is conducted in nursing home settings, to date and to the best of our knowledge, no literature can be found in this area on ambient continence care monitoring.

## 1.2 Scope of this Work

This paper focuses on the implementation and evaluation of the prototype of an ambient sensor system to unmask incontinence events through an exploratory study. Present nursing home technology and technically validated devices were used to annotate continence care events and, afterwards, label them. Our aim is then to avoid these unpleasant incontinence events in the future. The first results of this study will enrich further development of the ambient support system and provide suggestions for future research studies in nursing home settings.

# 2 IMPLEMENTATION

The explorative field study was carried out in two nursing homes to build annotated data sets, necessary for system evaluation and further technical development. Data was acquired via four different sources (Figure 1):

- The sensor system prototype (blue): a developed non-obtrusive sensor system that was evaluated;
- Manual data entry by care personnel (red): nurse calls via the nurse call system (green) and continence care (Report Inco) via the resident care file (cyan);
- The Toilet Timing Predicting Device DFree[1] (purple): validated non-invasive ultrasound technology;
- The smart sensor mat Texible Wisbi[2] (brown): validated wet sheet technology.

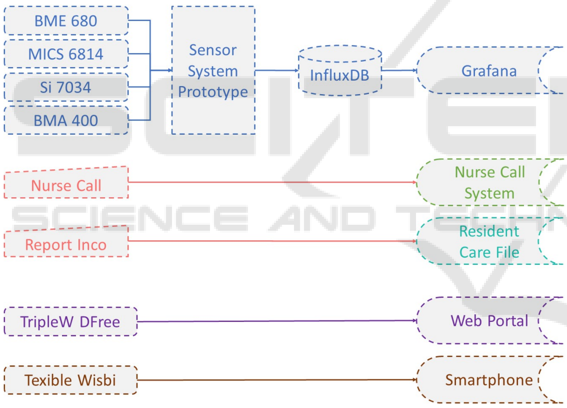


Figure 1: Implementation overview of the sensor system prototype, the manual data entry, and technically validated devices.

## 2.1 Sensor System Prototype

The aim was to develop a sensor system to identify incontinence events. To preserve residents' comfort, we wanted the system to be unobtrusive and, therefore, to include ambient sensors.

We developed a sensor system prototype to be attached to a care bed, monitoring and detecting incontinence events (T'Jonck et al., 2019). The prototype was designed with commercial off-the-shelf components. The chosen sensors were breakout boards, i.e., click boards, from MikroE[3] that use the mikroBUS™ specification: Weather click, Temp&Hum 2 click, Accel 5 click, and Air quality 5 click. The decision to integrate the Air quality 5 click sensor was based on research concluding that this sensor is able to detect concentrations of ammonia (NH3) in the range of concentrations that are present in urine (Strauven et al., 2019).

A Raspberry Pi[4] was used as room gateway to send sensor data via an Long Term Evolution (LTE) network to a secure InfluxDB[5] database. Data was stored in real-time and could be exported from Grafana[6], an open source visualisation application that supports the direct integration of the InfluxDB database. The Grafana dashboard monitored the sensor modules remotely and in real-time.

The sensor system prototype recorded sensor data every second. The temperature, humidity and ammonia sensors were fixated in the middle of the bed bar, located on the side of the care bed (Figure 2). The accelerometer was positioned between the bottom of the care bed and the mattress. Sensor data was collected during the entire study.

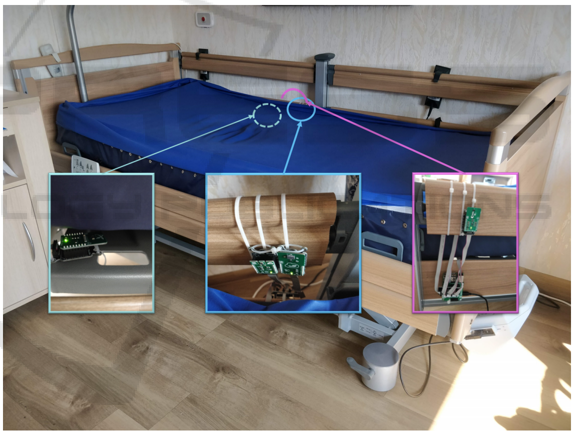

Figure 2: Picture of the sensor module at the care bed, including the Accel 5 click (left), the Weather click and Air quality click (middle) and Temp&Hum 2 click (right).

## 2.2 Manual Data Entry

The manual data entry of the care personnel provided additional insights in the care needs of participants and was entered through two nursing home technologies, the nurse call system (NCS) and the resident care file (RCF). Care personnel was requested to provide this data during the entire study. Each annotation was

[1] dfree.biz/en/
[2] www.texible.at/
[3] www.mikroe.com/
[4] www.raspberrypi.org/
[5] www.influxdata.com/
[6] grafana.com/

Table 2: Timeline of the exploratory field study in the first nursing home for two residents.

| Timeline | Action |
|---|---|
| 19/07/19 | Installation sensor module, NCS application, RCF incontinence report |
| 21/07/19 | Start measurement for three weeks with resident 1 |
| 29/07/19 | Start DFree & Wisbi |
| 12/08/19 | End sensor measurement resident 1 |
| 14/08/19 | Start measurement for three weeks with resident 2 |
| 21/08/19 | Start DFree & Wisbi |
| 04/09/19 | End measurement resident 2 |

timestamped to link the entry to the sensor data afterwards.
Residents can call for assistance via the NCS, a communication and management application. If residents need assistance, they call by pushing an alarm button, that generates a call at the care personnel's phone. For this study, care personnel received smartphones with the application 'Call Manager'[7], designed for this purpose, and running on the Televic NCS (Figure 1). When a nurse call was triggered, care personnel could, via the application, first select the reason of the call from a list and then an appropriate action to assist the resident from a contextual list.

The RCF is a software application that stores information about the health and care plan of residents. Care personnel can obtain all necessary information about the residents they care for via the RCF. For this study, additional continence care content was added to Corilus' RCF application, 'Geracc'[8], to let care personnel report more extensively about conducted continence care tasks (Figure 1). The additional tasks ranged from the check up of incontinence material to toilet visits. To facilitate the extra input, a Microsoft (MS) Surface was installed in participants' room, allowing care personnel to enter the information right after taking care.

## 2.3 Validated Technology

The *TripleW Toilet Timing Predicting Device DFree* detects bladder size by using harmless, non-invasive ultrasound technology. The sensor is placed at the abdomen in the area of the pubic bone. The main unit, i.e., another part of the device connected to the sensor, sends data wirelessly to a secured web portal of TripleW. Participants were asked to wear DFree for three to four days.

The *smart sensor mat Texible Wisbi* is a portable application and consists of an intelligent mattress pad that detects the humidity level of the fabric. In addition, Wisbi consists of an occupation detector to detect presence on the sensor mat. The sensor mat is attached to an external transmitter that sends the data through a WLAN network to an application on a smartphone. The smart sensor mat was placed between the mattress and sheet of a participant's care bed so they lied on the fabric when lying in bed. The smart sensor mat was used by participants during the same period as DFree.

## 2.4 Participants

We recruited ten residents across two Belgian nursing homes, Sint-Bernardus in Bertem and Biezenheem in Kortrijk, in collaboration with the nursing home's care personnel. Participants' rooms were provided with the sensor system prototype for three weeks. Ethical approval to conduct the research was obtained from the Social and Societal Ethics Committee of KU Leuven with protocol number G- 2019 01 1510.

Inclusion criteria for participants were: 65 years or older, living in one of the two participating nursing homes, having continence care needs (Katz score above 1 for Continence (Katz et al., 1963)), and being able to participate independently, understanding the purpose and involvement and providing consent (Mini-Mental State Examination (MMSE) score above 18 (Folstein et al., 1975)). An exclusion criterion was when the resident had a separate medical condition that influences continence.

# 3 EVALUATION

Measurements were completed in the first nursing home as the exploratory study was ongoing in the second nursing home. Three out of five selected participants from the first nursing home were excluded: one removed themselves before the start, one decided to discontinue during the study, and one was transferred to another ward. Therefore, this section discusses the preliminary results from two residents, measured over a period of three weeks from July to September 2019.

[7] www.televic-healthcare.com/en/solutions/mobile-alarming

[8] www.corilus.be/en/elderly/careconnect-elderly

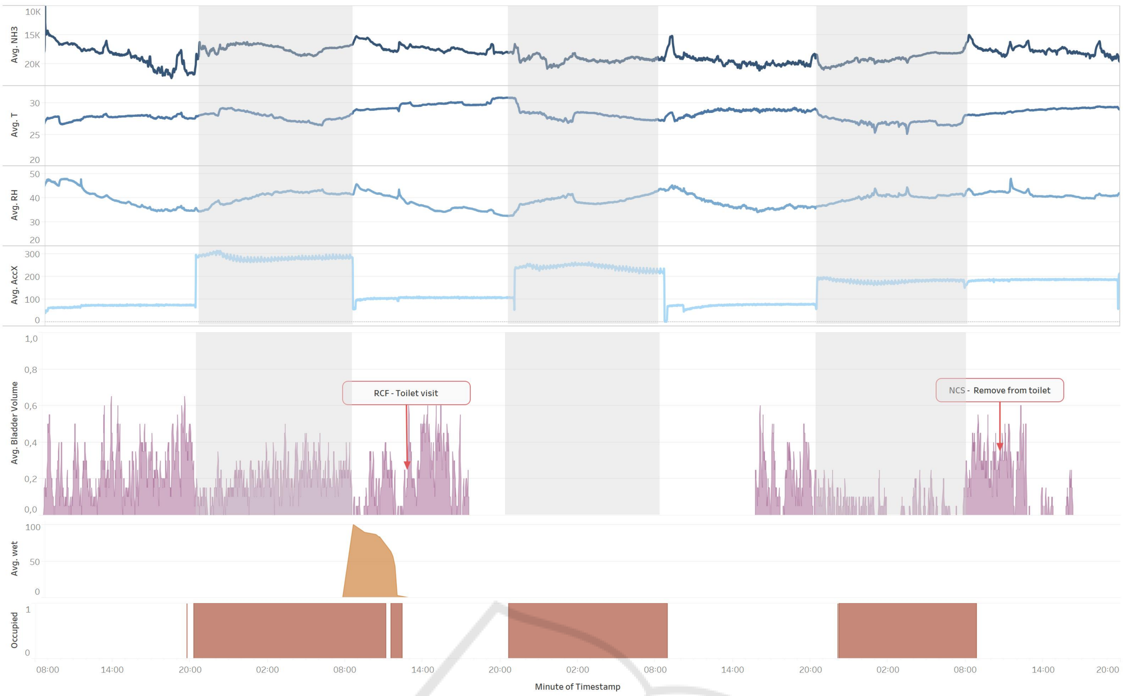


Figure 3: Time series plots of data from Resident 1: the sensor system prototype with the ammonia (NH3), temperature (T) and humidity (RH) sensor, and the x-axis of the accelerometer (AccX) (top), the DFree (middle), and the Wisbi wetness and occupation detector (bottom) over a period of 3.5 days.

Table 2 presents a timeline of all systems and applications used during the study.

### 3.1 Data Exploration

Data is explored for resident 1 (Figure 3) and resident 2 (Figure 4) individually by time series plots over a period of 3.5 days. Resident 1 was a 92-year-old woman, used a wheelchair due to a physical disability, and highly dependent on carers. She was also functionally incontinent (i.e., unable to get to a bathroom for one or more physical or mental reasons). Resident 2 was 88-year-old woman and an active resident who independently took care of herself. She experienced urge incontinence (i.e., unable to postpone the desire to void).

The results of the *sensor system prototype* are displayed at the top of the figures, for the ammonia (NH3), temperature (T) and humidity (RH) sensor, and the x-axis of the accelerometer (AccX). For resident 2, the accelerometer lost connection during the study and is not included in the plot. The y-axis of the NH3 signal is reversed for better understanding, as the sensor's response is inversely proportional to the NH3 concentration. As the sensor module was installed at the care bed, only periods when a resident was in bed are relevant for data analysis. To illustrate this time range, the nights are marked grey. Resident 1 went to bed around 20:00 and woke up around 08:00. Resident 2 had a different circadian rhythm and went to bed around 23:00 and woke up around 09:00.

The *NH3 signal* varied less in time during the night, compared to the day. This can be explained by the difference in motion. During the day, residents were moving around, opening/closing doors and windows, received care, or had visitors. During the night, the room was quiet, providing less motion and, therefore, a more stable signal. For resident 1, we would expect an increase of the NH3 signal at night when she was in bed, wearing incontinence material, and a decrease in the morning when she was lifted out of bed. For multiple nights, we could identify a gentle increase of the NH3 signal over time. After the night, an elevation was observed which might relate to the change of the night incontinence material in the morning. For resident 2, we did not expect the same variation as she went to the toilet at night as well. Hence, the NH3 signal remained more stable at night.

We noticed that the *temperature* raised during the day and lowered during the night, and how the *humidity* values related inversely to temperature measures. Both levels and variances were in accordance with our expectations for the season and environment.

The *AccX signal* was low during the day and

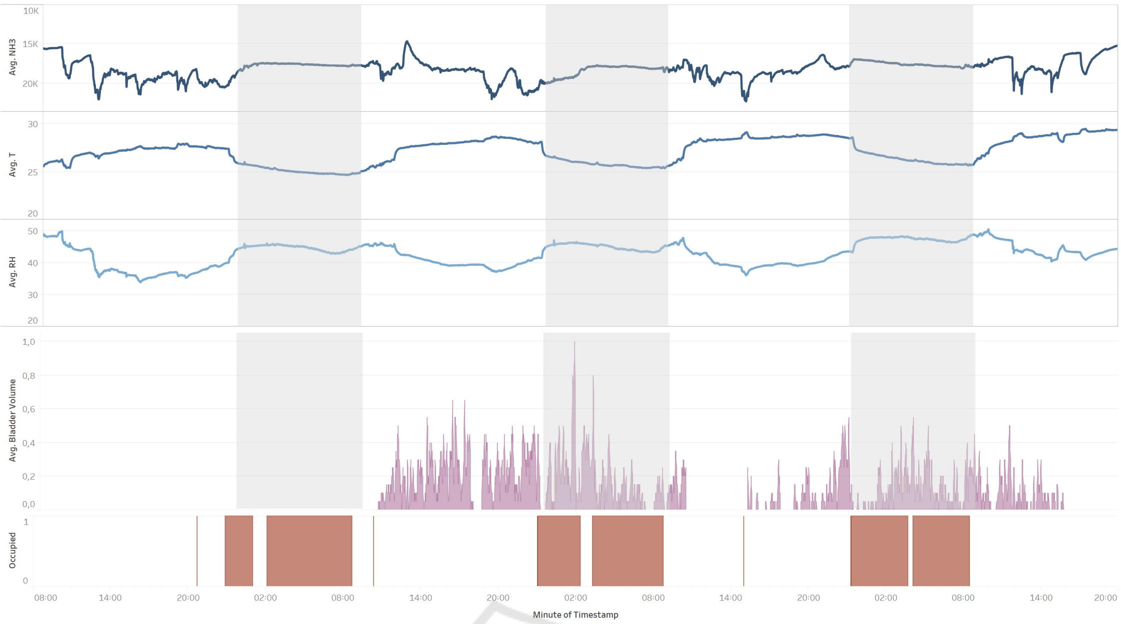


Figure 4: Time series plots of data from Resident 2: the sensor system prototype with the ammonia (NH3), temperature (T) and humidity (RH) sensor (top), the DFree (middle), and the Wisbi occupation detector (bottom) over a period of 3.5 days.

high during the night, following resident 1's day/night regime. Therefore, the accelerometer can be considered an out-of-bed detector.
The AccX signal remained high after the third night, when we would expect it to turn low. The reason for this alteration was uncertain as, for example, it was possible resident 1 stayed in bed that day, or care personnel made up the bed and changed the position of the sensor.

The figures' middle sections display the output of *TripleW DFree* by the average bladder volume per minute. The signal was continuously spiking, and harder to be examined visually in time than foreseen. In addition, DFree had a short battery lifetime of ca. 24 hours so the device had to be charged periodically, which explains the gaps in the plots.

The output of *Texible Wisbi* is visualised at the figures' bottom. For resident 2, Wisbi did not detect any wetness; subsequently only the occupation plot is included. When the occupation signal was high, this largely corresponded with the marked night times, except for some disparities. For resident 2, we observed low occupation periods during the night. The resident mentioned she went to the toilet at night, so we could assume these low signal periods coincide with these instances. To define the resting night times, the Wisbi was more accurate as the predefined ranges based on the habitual times. We could see one wetness peak for resident 1 at the second morning. The DFree plot showed a low bladder volume at the same time and the NH3 signal increased. This means it was possible that the incontinence material became oversaturated or leaked. On the other hand, the AccX signal was low, and in contrast, the occupation detector of Wisbi high. Since the accelerometer was located behind the upper part of the care bed and the sensor mat under the bottom, it was possible the resident was sitting on the bed. For resident 1, the same unexpected high signal for the occupation detector was not noticed as for AccX after the third night. Therefore, it was more likely that the position of the accelerometer changed, for example, after making up the bed.

In the window of 3.5 days, one annotation was made via Geracc, where care personnel assisted resident 1 at the toilet, and one via Call Manager, where resident 1 called to be taken off the toilet. We would expect the bladder volume to decrease before these annotations, which was observed for the first annotation but not visible for the second.

During the measurement period of three weeks, 18 nurse calls were recorded via *Call Manager*: 16 for resident 1 and two for resident 2. The number of entries seemed low as resident 1 needed assistance for each toilet visit and used the NCS to alert care personnel when ready. For this reason, we would expect at least two calls per day (i.e., 42 calls for three weeks). Although the total number of entries was rather low, Figure 5 gives some insight in the type of nurse calls. It appeared that resident 1 called more than resident 2, and mostly for toilet assistance and

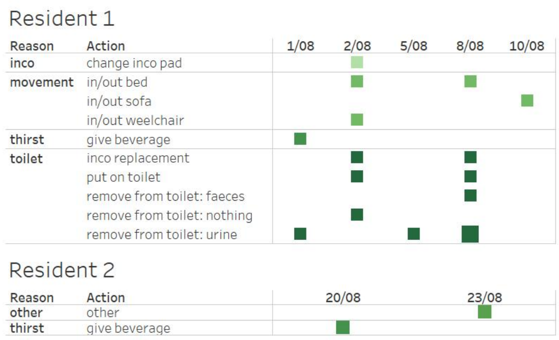


Figure 5: Result of manual data entry by care personnel via Call Manager for resident 1 and resident 2.

movement. This can be associated with her physical impairments, whereby she needed more assistance with ADLs compared to resident 2.

Via *Geracc*, three continence care records were generated for resident 1 and none for resident 2. In relation to the nurse call records, the number of annotations in Geracc was remarkably low, as there should be at least a continence care record for each toilet assistance. On the basis of the three records, we could only identify that all records entered were toilet visits and that incontinence material was changed during each toilet visit, even if the material was not yet saturated.

### 3.2 User feedback

When we finished the study in the first nursing home, we obtained user feedback. Residents who participated were asked how they experienced their participation in a one on one conversation with a researcher. Care personnel of the ward was asked for their feedback in group by two researchers during their daily ward meeting.

Both *residents* were unfamiliar with the devices and applications installed in their room for this study. It was an adjustment of their environment which felt uncomfortable. However, after a few days, they adapted to the changes. One resident enjoyed to be involved and notified care personnel when a device was not working properly (i.e., when the lights were not blinking). Wearing the sensor of DFree was perceived tolerable, at least for a few (ca. four) days. The level of tolerance depended mostly on the mobility of the resident. For example, resident 2 walked around during the day and had to think about the clothes she could wear when wearing DFree, so others would not see the device. The use of Wisbi went largely unnoticed by the residents.

*Care personnel* found it difficult to recommend residents as suitable participants. In a nursing home, only a limited number of residents have a MMSE score above 18 and are able to understand the purpose of and involvement in a research study.

The sensor system attached to the care bed might be designed more robust or cased for care personnel to ease making the bed or cleaning underneath. Largely, care personnel had little experience with smart electronic devices, e.g., smartphones. This made annotating challenging for them as they were learning to operate a new device as well as a new application. DFree was perceived as easy to use, once they found the proper sensor location on the abdomen of the resident. They preferred a longer battery lifetime as they had to remove and reload the device daily. At last, they experienced Wisbi as straightforward to use.

## 4 DISCUSSION AND CONCLUSION

As mentioned before (see Table 1), technical innovations to support continence care in nursing homes are predominantly wearable systems. After conducting several trials, including exploratory studies, researchers (Wai et al., 2010b) stressed the importance of an unobtrusive system and odour-based detection. When looking at other care domains, e.g., ADLs, using AmI to design unobtrusive technology is already further explored. On the basis of the need to support continence care by ambient monitoring, a first prototype was developed.

Through the implementation and evaluation of the prototype via an exploratory study, we evaluated the preliminary results from two participants of the first nursing home. They provided us with sensor data from the prototype, together with data from devices for annotation purpose to obtain a reliable ground truth. In this paper, we analysed and compared data from all devices in a window of 3.5 days. Patterns were found that illustrated the alteration of the environment among day and night, and indicated that the accelerometer can be used for out-of-bed (or occupation) detection. The NH3 signal was highly influenced by an environment in motion. During the night, the signal was smoother as the environment was more steady. The visual identification of incontinence events appears to be challenging. To lower the influence of motion, we suggest to locate the NH3 sensor at a position on the care bed where less motion occurs, e.g., under the sheets, and to integrate the sensor system in a robust case.

Finding and providing an appropriate annotation method in exploratory studies to label ground truth is known to be challenging, but also incredibly valuable for further qualitative, in-depth data analysis (Alshammari et al., 2017).

Once initiated, a trial could not be repeated, as nursing home residents are frail elderly and would not have the resilience for a second try. Every day without annotation can be seen as an expensive loss (Hein et al., 2017). Common practice for annotating AmI studies is to videotape the recording session and to label the data based on the video footage afterwards (Plotz et al., 2012). Although this technique provides an accurate labelling, it is ethically inappropriate to videotape in real-life situations due to privacy reasons (Aicha et al., 2017). Our sensor setup was in nursing home residents' rooms for three weeks and would interfere with the privacy of the residents as well as their relatives and nursing home staff, who all enter the room during the study. In addition, it is uncertain that incontinence events occurring under a sheet, would be noticed on video footage. For this reason, we opted for a combination of manual data entry and technically validated devices (DFree and Wisbi) to enable ground truth labelling. The obtained data of Wisbi was straightforward, however, the data from DFree turned out to be harder to interpret than expected.

Manual data entry by care personnel, e.g., via log sheets or questionnaires, was similarly part of our protocol as previously mentioned by AmI research (Table 1) (Aloulou et al., 2013; Rantz et al., 2010b; Suzuki et al., 2006). However, in our study, we encountered multiple difficulties to let care personnel annotate. Care personnel was inexperienced with the use of smartphones, which caused insecurity in using the device and generated issues directly related with the smartphone, instead of the application use. These issues eventually resulted in frustrations and a reduced usage of the devices. As a result, the number of annotations were limited. To obtain an enriched set of manual data entries for exploratory studies in real-life settings, such as nursing homes, we suggest to extend the information about the use of the annotation applications with an explanation of the used device or enabling annotation through devices that have already been used by the annotators prior to the study.

We will continue our research with an in-depth analysis of all acquired data and ground truth labelling to deconstruct this complex data and identify incontinence events, e.g., the saturation level of the incontinence material or leakages. Further research of an ambient monitoring system supporting continence care should consider the altering environment and monitor at places with the lowest impact. In addition, care personnel should be assisted more thoroughly and consistently in the annotation process.

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