



Experimentation of a Nighttime Wandering Assistance System Based on AAL Solutions to Foster Aging at Home

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Abstract. To promote the aging in place of elderly people with cognitive impairment, it is desirable to make their homes more intelligent. With Ambient Assisted Living (AAL) systems, it is possible to define intelligent environments that can take into account the needs of these people. This article presents the results of the experimentation of a Nighttime Assistance System (NAS) for elderly people with Alzheimer's disease. The NAS uses AAL technologies to non-intrusively monitor the Activities of Daily Living (ADL) of an elderly person living alone, to contextualize and adapt the help that will be offered to them. For this experiment, we collected data for five weeks on a person's activities. This work describes how this experimentation was carried out with an emphasis on user needs. It also shows the different patterns of activity observed, with particular emphasis on nocturnal ambulation. Finally, it describes the contextual model set up to support the person in the event of an episode of nocturnal wandering.

Keywords: Ambient assisted living · Nighttime wandering · Context awareness · Ubiquitous computing · Alzheimer's disease

1 Introduction

Context refers to any information that can be used to characterize the situation of an entity, knowing that an entity can be a person, a place, or a physical object [3]. To facilitate aging at home and allow seniors to regain some autonomy in achieving some Activities of Daily Living (ADL), it is important to consider the context in which these people live. Taking into account the context of the assistance to the elderly makes it possible to better adapt the solutions of pervasive computing and ambient assistance. Above all, it offers the ability to these solutions to anticipate people's needs and to act accordingly. It is therefore important, to get contextual information on sub-tasks, places, sensors, actuators, and objects involved in an activity.

Several assistance solutions based on Ambient Assisted Living (AAL) and context awareness have been yet developed [5–8, 10, 29]. They are aimed to foster autonomy at home for seniors by providing environmental cues either to recall an activity to do or the way to perform it.

At night, people with Alzheimer are often experienced nighttime wandering that could provoke anxiety, temporal disorientation, and risks to fall. The contextual assistive system is therefore useful to create a calm environment that encourages people to go back to sleep. This article extends the NAS (Nighttime Assistance System) from [9, 11], a non-intrusive AAL system that allows validating the elderly’s profile by detecting needs and building appropriate environmental cues to overcome the episodes of nighttime wandering. The paper also presents the results of a five-week experiment that took place in the home of a senior with Alzheimer’s disease. An embedded sensor network has collected data on actions, behaviors, and activities performed. To understand all its requirements, a context manager ensures that local and contextual exchanges are propagated throughout the NAS. Open-source middleware, rules-based system, and pervasive computing technologies are used to provide personalized, calm, and automated prompting for the elderly.

The rest of the paper is organized as follows: Sect. 2 discusses the related work; Sect. 3 describes the Nighttime Wandering System; Sect. 4 describes the sensor network and presents the results of the experimentation. Section 5 opens a discussion on the results obtained. Section 6 concludes the article.

2 Related Work

2.1 Smart Homes

More and more, we are witnessing a growing increase in the number of people aged 65 and over [1]. This has the direct implication that the percentage of older people who prefer to stay in their homes and communities is increasing rapidly. In general, this phenomenon is called “Aging in Place” [2]. It is possible to make this possible by using connected objects. Thanks to the Internet of Things (IoT), it becomes possible to transform all homes into smart homes. In this context, smart home technologies could significantly help people to have a better quality of life, to live independently, and to stay in touch with their family and caregivers.

Thanks to their software and IoT components, smart homes make it possible to collect data and thus monitor the state of health, behavior, and quality of life of elderly users, avoiding risky situations and putting users in contact with their family, caregivers, and medical staff [26, 28, 29].

In this type of intelligent environment, it is possible to find several heterogeneous IoT devices which, combined, offer the possibility of recognizing Activities of Daily Living (ADL) [4]. In [6, 9, 11, 16], the authors proposed a platform based on the recognition of activities of daily living to enable seniors to age in place. Rashidi and Cook developed CASAS at Washington State University [29]. CASAS is an adaptive smart home that uses machine learning techniques to discover user behavior patterns and automatically mimic those patterns. User can

modify automation policies, provide feedback on proposed automation activities and introduce new requests.

2.2 Ambient Assisted Living System

Deployed AAL systems deal with much contextual information, based on sensor/actuators information, user actions, user profiles, and ambient information such as humidity, temperature, and so on. The different technologies that accompany aging in place present several challenges:

- Facilitate communication between the elderly and caregivers.
- Monitor the health parameters of the elderly person.
- Monitor the environment and activities of the elderly person’s daily life using sensors to ensure greater comfort and safety.
- Facilitate the mobility of people out of their homes.

To address those challenges, several mechanics are used [10, 23, 24, 29]. Among those solutions, AAL middleware is mainly preferred to facilitate the homogenization of different technologies, while semantic approaches based on ontologies help represent different knowledge.

3 Nighttime Wandering System

The Nighttime Assistance System (NAS) [9, 11] aims to detect the onset of episodes of wandering to assist during the night. It meets the needs associated with awakening and encourages people to go back to bed. It is designed using a ubiquitous and ambient approach to create an adaptive environment that is sensitive to the presence of a person. It requires a design approach centered on users, thus putting the technology in the background, giving way to assist in transforming their homes into smart homes. Several opportunities are offered by this approach to support older people to perform certain activities of daily living. Based on their life habits, it is possible to adapt the environment in which they live to their illness or age. To regulate the circadian rhythm proceeds, NAS works in two phases. The first phase, called the monitoring phase, involves the installation of a set of sensors in the home to gather the activities and habits of the person. The second phase, which is the assistance phase, offers personalized support based on the information collected. The NAS provides objective data on the behavior of the resident’s home, which will be supported by physiological and subjective data collected from elderly people with Alzheimer’s disease and their caregivers.

4 Experimental Assessment

This section presents a five weeks deployment of the augmented context-sensitive NAS. for several weeks in an experiment with a lady of 86 years old, living alone

and suffering from Alzheimer’s disease. Particular emphasis is placed on the creation of the contextual environment, the construction of functional modules, and their deployment at home. To better meet the needs of the person, four constraints had been set:

1. The solution must be pervasive and contextual for better monitoring of needs.
2. NAS could provide oral messages, but just when necessary.
3. At all times, the system monitors its status and can give information on the possible breaking.
4. Avoid any inconvenience to the person by making all deployed technologies non-intrusive and calm.

The home is a flat house composed of one open room divided between the living room and kitchen, and one bedroom. This experimentation has required 101 sensors distributed in 30 electronic devices and 4 actuators distributed in 3 bloom lamps and 1 sound system.

4.1 Methodology

This section describes how the Context Awareness Architecture, has been implemented. It focuses on creating and transforming the living space of the person into a smart space. This is a multi-contextual collaborative environment of the real world, with the individual and his needs at the center.

Sensor Installation. The first step is to make an inventory of the physical environment to identify the furniture, the rooms, and the habits in the daily use of certain objects, priority or non-priority movements in and between rooms, the use of household appliances and electronic devices. This process makes it possible to have complete cartography of the places and a precise idea of the organization and the disposition of the various sensors and actuators. This mapping is called the *SmartDomus*, that is, the smart part of the house that is subject to a continuous, contextual process of assistance.

Localization and Pervasive Identification. A smart home may understand, learn and respond to the needs of users. To do this, it must know what is happening. Sensors are used to collect environmental data in an ambient manner. Eleven Motion detectors are used to locate the elder when any movement is in a room. If there is no movement, several pressure sensors scattered on most chairs help to determine the presence of the person in the room. Figure 1 shows how part of the person’s smart apartment was realized. This part is called *SmartDomus*.

4.2 Material and Methods

Every detail of the experiment has been readjusted to the requirements of the person. In this experiment, the basic scenario set up to satisfy the needs of the

person was gradually updated to better take into account the specificities of the person. Two main phases have been used, with different levels of complexity and varied expectations. The following subsections show in detail the steps taken to determine the interactions between the sensors, the environment, and the system. The following table lists the different types of devices (sensors, actuators, controllers, computers) used for the experimentation. All the sensors are Z-Wave sensors to avoid wired sensors that necessitate breaking holes in the wall Table 1.

Once the room identification in the *SmartDomus* is complete, sensors must be physically and logically labeled. Physically, labels are affixed on each device according to the place where it will be installed. Logically, each sensor must be linked to the controller so that it can be associated with the same Z-Wave logical network whose controller is the main node. Generally, this association is done in the controller and can differ from one controller to another. For the sake of simplicity, the sensors have the same logical name as the physical ones.



Fig. 1. The smart part of the house: *SmartDomus*

Table 1. List of equipment used for experimentation

Type/Room	Device - Action
Bedroom	Pressure - Lying - down/on Motion - Movement in the bedroom Contact - Door opening/closing Contact - Wardrobe opening/closing
Toilet	Pressure - Bathroom Motion - Movement in the toilet Contact - Door opening/closing Contact - Pharmacy box opening/closing Water detector - Flush toilet
Kitchen	Electric Measuring - microwave power Motion - Movement in the kitchen Contact - Door opening/closing Contact - Drawers opening/closing Contact - Fridge opening/closing Contact - Freezer opening/closing Contact - microwave on/off
Living room	Electric Switch - TV power Motion - Movement in the living room Contact - Door opening/closing Contact - Drawers opening/closing Pressure - Couch Lying/Sitting down/on Pressure - Armchair Sitting down/on
Outdoor	Motion - Movement in the veranda Motion - Movement in the staircase
Ambient information	Temperature Humidity Brightness
Actuators	Philips Hue Bloom Lamp - Cues Bluetooth speaker
Wearable sensor	Actigraphy - accelerometer
Controllers	Vera lite 3 Philips Hue Bridge Arduino
Ranger	Extender Z-Wave module ranger
Computer	Computer Core I5

The Aeotec multisensor 4 in 1 sensor was used for motion, temperature, humidity, and light detection. Each drawer and door of the *SmartDomus* has been equipped with contact sensor type Everspring sm810 door/window contact. In sanitary facilities, water sensors have been installed to detect water flows. Aeotec water sensor has been used for this. For the detection of the presence of the bed or chairs water sensors have been hacked, to add several flexiforces mounted in parallel, as shown in Fig. 2. This transformation allows us to maintain a certain homogeneity in the Z-Wave protocol. All other diffuse information is collected by the sensors' brightness, temperature, and humidity sensors aeotec multisensor 4 in 1. Concomitant use of sensors will provide the system with the ability to search for the information needed to facilitate contextual assistance in *SmartDomus*.

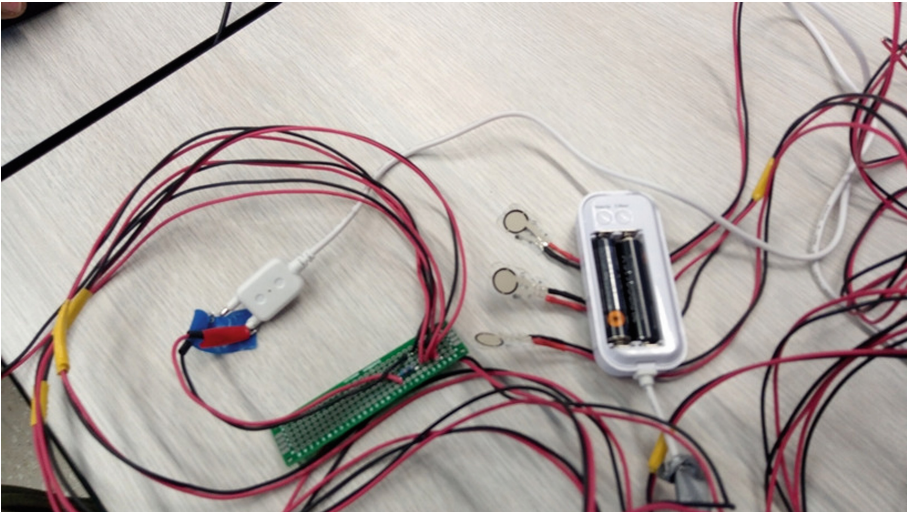


Fig. 2. Hacking the water sensor.

Profile Modeling of the Person. Before beginning the experiment, health questionnaires, dementia identification tests, and questionnaires on the needs and preferences of the person have been submitted to the elderly and also to her caregivers. Then, in a user-centric design, a custom scenario is created to offer support in the *SmartDomus*. This personalized information made it possible to learn that the person was no longer doing the dishes or preparing meals in the kitchen. It is then not necessary to install devices to detect the actions associated with these activities. We equip the elderly with wearable sensors, that is a bracelet containing an actigraph, which gives information about Profile modeling that begins before the beginning of the experiment, and then continues throughout the experiment. The experiment is divided into two phases. During

the first phase, which lasts for 2 weeks, sensors are installed and send information about the habits during the night. The assistance scenario is then built based on the lifestyle habits collected. During the second phase of experimentation, which lasts for three weeks, modeling and profile rehabilitation meetings were held to refine the patterns identified in the activities of the person’s daily life. For five weeks of experimentation, four follow-up meetings were conducted to verify and refine the person’s profile.

4.3 Processing

To better take into account the heterogeneity of the data, a middleware that handles several communication protocols is installed. This middleware reads the data from the controllers, then formats them and transforms them for later use. For simplicity, we chose the **OpenRemote** middleware installed in a docker. This middleware written in Java makes it possible to make an inference using the rules-based first-order logic. For the persistence of data, a Postgres SAL DBMS is used. It is installed on a specific docker. The use of several dockers facilitates microservice management and scaling up. The docker-compose module facilitates the orchestration and management of the different dockers used.

The user-centric scenario design defines an inference mechanism that ensures that each assistance rule produced meets the requirements of the person’s profile. The middleware provides an inference layer for writing these rules. For the sake of simplicity, simple rules are written and then aggregate to cover complex situations. This facilitates the use of an incremental and scalable method throughout the process. All written rules are tested on-site to ensure that they meet the needs of the person.

Raw data of each type of sensor and actuator are sent to the corresponding controller, here on vera lite 3, Arduino, and Philips Hue Bridge whenever an event occurs. The vera lite presents collected data of sensor events in standardized formats such as XML or JSON. The format of raw data is (deviceId, value). This represents a part of context acquisition. For example:

$$(244; on) - (125; on) - (20; on) - (25; 9.586) \quad (1)$$

The labelization and contextualization transform them in the following sequence:

$$\begin{aligned} & (ToiletRoomMotion_1; on) \\ & (ToiletCarpetPression; on) \\ & (ToiletWaterFlush; on) \\ & (TVPowerMeter; 9.586) \end{aligned} \quad (2)$$

The processing context analyzes each of the information received, groups it by pattern, and then sends it to the reasoning context for the application of the assistance rules. At each iteration, the context of the person’s profile is

consulted, and the relevant information associated with the current scenario is therefore included in the treatment context. The label (2) becomes

$$if(ToiletWaterFlush == on \&\& ToiletCarpetPression == off) then action \quad (3)$$

Each pattern is translated by rules written in Drools language, where cron jobs monitor the arrival of events. Figure 3 shows an example of a notification to the person. This rule urges her to ask him to return to bed if she is up for 25 min between 0 am to 6 am. Reminders are gradually displayed every 10 min if she is not in her bedroom. An audio recording is played in case of complications. This recording is the voice of a caregiver asking her not to go outside and reassuring her before inviting her to go back to bed. Its operations are set up in the context manager and the context processing. All this information is stored in a database, iteratively and continuously in this vocal message.

```
rule "Nighttime wandering assistance in case of kitchen wandering "
    timer (cron: 0 25/10 0-6 * * ?)
when
    Event( source == "vSystemActive", value == "on" )
    Event( source == "HallMulti2Motion", value == "on" )
    Event( source == "RoomMulti2Motion", value == "off" )
    Event( source == "RoomMulti1Motion", value == "off" )
then
    execute.command("KitchenHue10n");
    playFile();
    sendMonitoringInformation(GLOBAL_INFORMATION, source);
    watchGlobalTimer();
end
```

Fig. 3. Partial view of nighttime wandering assistance rule.

To ensure the reliability of the system, a mechanism for managing faults and errors is put in place. The system can inform about its status and indicates what problems it encounters. In this case, a ping and pong program allows the set to test the state of the controller and the middleware. In case of failures, an email is sent to inform the caregiver about the situation. An additional layer has been added to inform the remaining battery level (here 28% was chosen). Another remote ping system is used to check the state of the local computer where the application is installed. The middleware sends pong messages every 10s in the form of heartbeats to notify of its proper functioning. This information is stored in a file, every 15s a cron job reads this file. In case of problems, an alert email is sent to inform about the state of the system to put a quick solution in place.

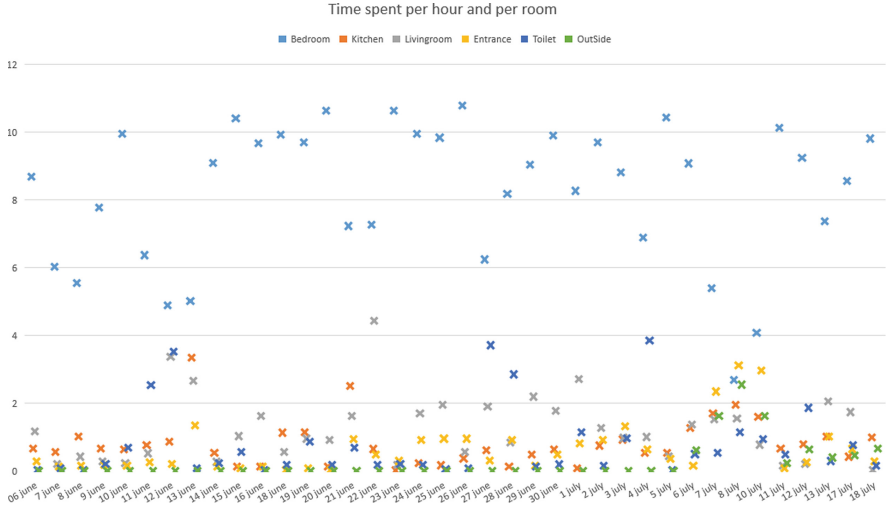


Fig. 4. Time spent per hour and per room between 8 pm and 8 am.

5 Results and Discussion

During all these 5 weeks, the system collected data continuously on 7/7 and 24/24. The data relating to the test days after the installation of the sensors and after the installation of the actuators have been removed from the dataset. A breakdown of electrical energy occurs for 1 day, leading to 2 days out of order. So in total 5 days of data were excluded. The results presented in this section focus on tracking the activities of the person during the night, that is, between 8 pm and 8 am. A total of 1,827,789 entries were collected. After labeling and cleaning (noise removal), synchronization, and network control information, membership, in the *SmartDomus* during the experiment, the data went to 1 523 656 entries. Then the restriction of night hours gives a total of 360 174 rows of data. Each data line represents an event produced by the person and captured by a sensor.

Figure 4 shows the average duration of the senior’s presence per room for each night during the entire experiment. It shows that she spends more time in her bedroom than in other rooms. We classify nights into three groups, group of nights. The first group, the better night, is composed of nights of less than 6 h spent in the room. Among others, there are 7, 8, 12, and 13 June. The second, the average night is composed of nights about 8 h (6, 14 ...) in the bedroom. The third group corresponds to about 10 h per night.

Figure 5 shows the time spent outside the bedroom in minutes per night. The calculation is made from the moment the senior is lying on her bed and comes out to satisfy any need. The notion of lying on the bed is defined as a continuous period, the only activities observed are those on the bed. This calculation makes it possible to observe the nights when she spent more time outside her room. The graph shows that during the night of July 8 she spent 310.35 min, about

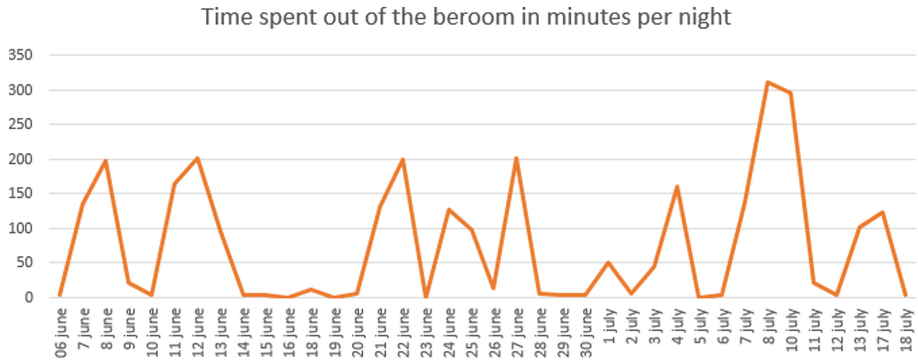


Fig. 5. Time spent out of the bedroom.

5 h, out of her room. Another relevant night is the night of June 12 when she spent 201.54 min, 3 h, out of the bedroom.

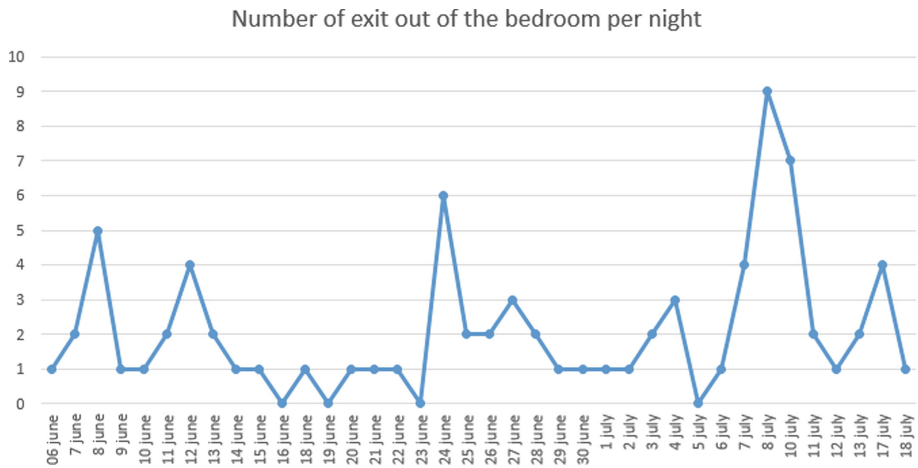


Fig. 6. Number total of exits out of the bedroom.

The time outside the bedroom is linked with the number of times she leaves her bedroom once she is lying down. Figure 6 shows the number of times per night she left the bedroom. Overall, it appears that this corresponds to past periods out of the bedroom. The diagram shows that on the night of July 8, she left her bed 9 times. Thus, Figs. 5 and 6 allow us to conclude that on the night of June 12 she left the bedroom 4 times, and was more than 201 min out of it. The night of July 8th shows that she has been out of the bedroom 9 times and has made more than 310 cumulative minutes out of the bedroom.

Based on the information collected, and the analysis carried out, a grouping of nights was proposed. Three categories have been identified. The first is the better night category, these are nights where the number of exits after the couch is less than 3 and the cumulative total duration of the exits is less than 30 min. The second category is corresponding to so-called average nights. An average night is a night whose number of trips is between 3 and 5 and the duration is less than 180 min. The last category is the bad night category, considered to be the one where the exit number is greater than 5 and the total duration is greater than or equal to 180 min. These criteria are suggestive and are suggested only based on observations made. Figure 7 shows the proportions of the different nights.

Representation of nights between 8 pm and 8 am

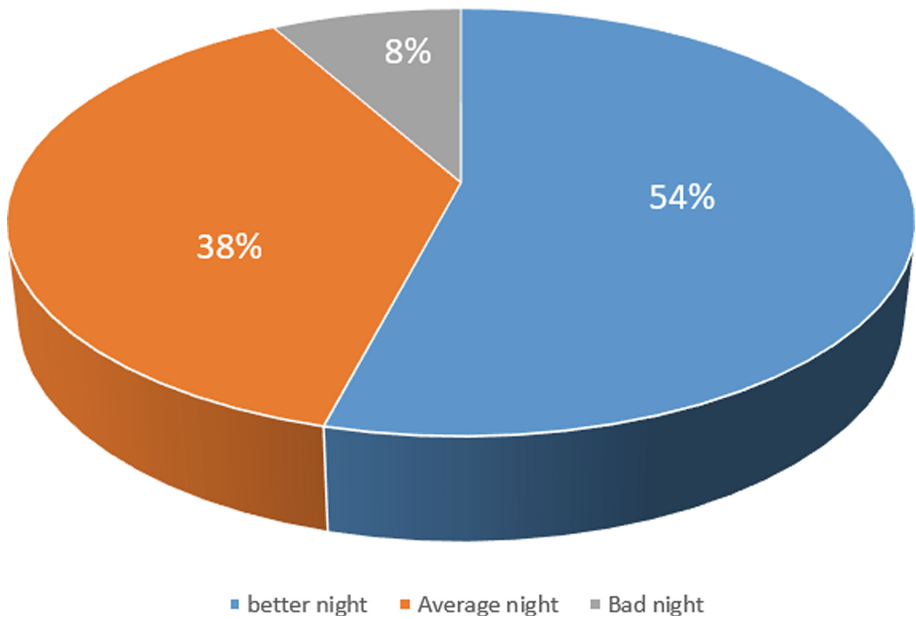


Fig. 7. Proportion of night.

According to these criteria, it follows that the percentage of average nights is quite high. Changing the cumulative total of times per exit can easily switch days from one category to another. For example, the transition from 180 min to 120 min for the average day’s category will considerably increase its percentage. So these values are more influenced by the duration rather than the number of times she went outside her bedroom.

6 Conclusion

This paper described home-based experimentation. During several weeks, the non-intrusive and quiet system deployed collected through sensors and actuators information on the activities of the daily living of the person. The analysis and evaluation of the results show that the performance of the proposed architecture meets the requirements of context-aware systems. On the other hand, analysis of the data on the night activities makes it possible to understand nocturnal wandering behaviors from a data point of view. Experimental data revealed night patterns specific to the user.

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