Indoor Activity Monitoring for Mutual Reassurance

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Abstract. Population ageing is rising issues concerning the sustainability of older seniors assistance. A possible solution can be avoiding early retirement in nurse houses by providing the family and the senior(s) with an unobtrusive monitoring system, mainly based on motion sensors, capable of extending their independent living. The presented system processes the collected data to infer when the person exits and enters, his/her position inside the house, and the occupancy of the house areas. Such information is made available to the family through a set of purposefully designed graphical interfaces and prompt notifications. Preliminary results are satisfying, showing it is possible to restore *Mutual Reassurance*.

Keywords: Ageing · Smart home · Activity monitoring

1 Introduction

In recent years population studies are evidencing a growth of the elderly population. Based on a report of the United Nations [1] the number of the seniors aged over 60 is expected to be 2 billions by 2050, three times their number in 2000. Since the process of population ageing is expected to be *unprecedent*, *pervasive*, and *enduring*, one of the main concerns regards the rapid rise of elderly care costs. Health-care facilities and seniors hospitalization have a significant impact on the life of the older person, while they can be also not affordable for the family. Active and Assisted Living (AAL) has been proposed as a paradigm to overcome such problems, suggesting active and independent ageing in place [2].

To prevent the hospitalization process, it is necessary to preserve the conditions (in terms of needs) of both the seniors and their relatives, according to Maslow's hierarchy [3]. In particular, restoring the awareness of the senior's status and activity can reassure the elderly person as well as the family, providing what we defined in previous works *Mutual Reassurance* [4]. This proficient awareness can be achieved thanks to an unobtrusive monitoring system, delivering the information necessary and notifying undesired happenings.

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The challenges related to the aforementioned issues are addressed by the Assistive Technology Group (ATG) of Politecnico di Milano, working in close collaboration with a social counterpart: CRAIS[1] (*Resource Center for Autonomy and Social Inclusion*). Within this project CRAIS contributed with its professionals in the identification of the needs and the expected activities to be performed by a person: the set of conditions agreed between the senior and his/her family represents a *life agreement* and may concern eating activities, expected daily and nightly movements, indoor presence or absence, etc. In order to provide notifications to the family as soon as undesired happenings are recognized (e.g., unexpected nightly activity, or medicines take time, etc.) we propose a system based on a wireless sensor network monitoring the senior and visualization tools showing information about the inhabitant activities with the possibility to review his/her history. The proposed methodology for live monitoring is based mainly on Home Automation (HA) sensors detecting human activity in areas of interest inside the house. The overall system architecture refers to the project BRIDGe: *Behavior dRift compensation for autonomous and InDependent livinG* is a project on which ATG has been working in recent years [4]. The project aims at creating strong connections between a person living independently at home and his/her social environment by implementing monitoring, and focused interventions according to the user's need.

The rest of this publication is structured as follows: next section reports and analyses previous works based on similar sensors. Section 3 refers to the architecture of the monitoring system, detailing the exploited sensors, the data collection and the processing platform; moreover, Sect. 4 concerns the methodology applied for the activity monitoring and the proposed family perspectives. Finally, Sect. 5 reports the preliminary evaluation outcome obtained with the application of the presented methodology to synthetic data, and Sect. 6 contains the conclusions and the future perspectives.

2 State of the Art

Concerning the development of unobtrusive systems for the enhancement of elderly everyday life, several research projects are devoted to the identification of the action performed by the inhabitant, often referred to as ADL (i.e. Activity of Daily Living). In the proposed settings though the aim is to infer the activity of the person in its broadest sense, presenting the information in an aggregate manner to a remote user.

In such perspective, several projects rely on movement and domotic sensors to collect information in the home environment. As presented in the review by Peetoom et al. [5], the results in terms of identified activities, and precision vary among systems, as well as the acceptance and the stress level reported by inhabitants and caregivers.

Developing probably one of the first projects in this field, Yamaguchi et al. [6] use simple devices (PIR and door sensors) to monitor the human behavior in

[1] http://crais.eu.

indoor environments. The aim was to unobtrusively monitor a person along nine months, proving it is possible to observe the daily cycle of a person's life without him or her being aware of it.

In Dalal et al. [7] a system for elderly people living alone is presented, its aim is to provide warnings in case of emergency conditions and to recognize health issues through the identification of anomalies in IADLs (Instrumental Activities of Daily Living) patterns. PIR sensors and an instrumented bed are used to collect data, on which a rule-based approach is applied to associate sensors groups with specific actions.

In Zhang et al. [8] the same sensor technology is used to build a dense network at floor level to track heat sources as they move around in the house. The aim is to track the persons position and motion direction in house rooms.

Other research projects have a different approach, involving more elaborate systems and pervasive instrumentation. Damarla et al. [9] propose a complex system where different sensors (e.g., chemical, electrostatic, PIR, cameras, etc.) collect information joined to monitor the inhabitant's life. Even if the aim is the same of the previous systems, cameras and extended sensorization have a negative impact on system acceptance.

Kaye et al. [10] propose a system for indoor monitoring with simple and unobtrusive home devices. The main source of information is the extended network of PIR sensors, for fine person localization, enriched with the details obtained by door sensors. The data in this work are also transferred to a remote SQL database, approaching to the architecture of cloud services.

Higher level analyses are performed by Yang and Hsu [11], who propose a set of *activity features* measuring the intensity, the frequency, the regularity, and the anomalies of the activity patterns. The results show how it is possible to estimate the daily activities rhythms and to detect unusual behavior in unexpected situations.

3 System Architecture

The core of the BRIDGe project is a wireless sensor-actuator network that enables home automation as well as user activity monitoring through a rich and flexible communication system toward the relatives and the carers. The basic infrastructure is composed of two subsystems, one residing inside the dwelling and one standing in the cloud.

3.1 Domotic Sensors

Active and Assisted Living (AAL) and Home Automation (HA) technologies are attracting much attention and their growth and diffusion bring the comfort pervasive home control. Nonetheless such expansion also provides a wide choice of market devices to be exploited to monitor and assist fragile people at home.

Focusing on the type of sensors, the choice of unobtrusive devices has fundamental importance. Cameras and microphones are known to be not well accepted by people, especially in their dwelling: to respect privacy and to limit the perceived invasiveness of the system, we choose HA devices that are not even acquiring personal information. Thus the hereby presented system relies only on HA devices sensing and acting on the home environment and not the inhabitant. The only exception is represented by motion sensors, being well tolerated.

Smart Homes devices market is highly competitive and many different solutions in terms of technologies, standards and companies are available nowadays. The choice of the technology to employ is crucial, since it brings a wide set of opportunities but also inevitable restrictions [12]. The BRIDGe system technological choice is Z-Wave [4], drawn considering many factors as suggested in the analysis by Saidinejad et al. [13]. Above all, thanks to the wireless communication, the battery power supply, the small dimensions design, and the modularity Z-Wave devices can be easily integrated in the existing electric plant of a house.

3.2 Data Collection and Processing

In order to provide the high level information about activity monitoring, a device inside the dwelling is needed to collect and the process the data. To approach such issue we exploited a Raspberry Pi 2[2], equipped with a Z-Wave daughter board and the Z-wave.ME[3] software stack. Such solution has several advantages: the hardware is low cost, easily purchasable and installable. This home server is capable of interacting with the HA sensors network, retrieving, processing and buffering the data, before forwarding them to the remote subsystem.

There are two possible moments to process the data: right after they are collected by the home server, or remotely and asynchronously when received by the remote server. This implies that depending on its aim it may be advisable to perform the computation on the most suited subsystem. More explicitly, the processing requiring low delay (ideally real time), the operations triggering immediate responses on the actuators, the extraction of information requiring prompt notification, etc. need to be performed on the home server.

Considering the scope of this work, the computation is performed on the home server. The data collected live from the Z-Wave HA network are fed continuously to a stream processing engine. The chosen software for this task is Esper[4], an event series analysis and event correlation engine. It is programmable to perform queries and processing over dynamic sets of real-time changing data, exploiting the Event Processing Language (EPL). Its peculiarity is the possibility to express pattern semantics and complex temporal consequentiality. Moreover, EPL capabilities can be extended thanks to the integration of extra custom components written in Java. About the remote subsystem, it is important to stress that it provides the web applications to visualize and store efficiently the history of all the data, both collected and obtained by processing.

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[2] www.raspberrypi.org.

[3] http://z-wave.me.

[4] www.espertech.com.

3.3 Data Visualization

The data collected (both directly from the HA network and after the processing), have to be provided in a proper form to the family or the relatives of the inhabitant. At this aim the remote server provides a specific web application for the visualization of the data. In particular, two main channels are available to transfer the information between the remote and the home servers. The first channel is used by the house server to periodically (once per minute) upload messages to the remote server, this channel is mono-directional and is implemented using a REST (REpresentational State Transfer) API on the remote server. The second channel is a bidirectional one based on the publish and subscribe paradigm implemented through an open source library called crossbar.io, this second mechanism enables real time communication also in the opposite direction (from the remote server to the house server) in order to offer remote access to house services from outside, using the remote server as gateway. Indeed it is worthy to mention that all the information from the remote server is accessible only after authentication of the user.

4 Indoor Activity Monitoring

The core of the proposed work is the possibility to provide aggregate and immediate information to the family, through visualizations or prompt notifications.

Probably one of the simplest way of providing coarse information regarding the indoor activity of a home sensorized with HA devices, is being aware of where the person is inside the house, in terms of *area*. When using the concept of *area* we refer to (an entire or to) a specific portion of a room: the presence of the person in such space implies a high probability he/she is performing an interesting task, induced by the objects/furniture. The areas distribution has to be defined depending on the specific needs of the person and his/her family, with the assistance of social professionals [12]. Similarly, also the definition of the requirements for the visualization and notification of information should be carried out by the family and the seniors with the aid and assistance of professionals, in order to find the most fitting solution.

4.1 Localization and Presence

The target of the implemented HA data processing is to define the person position inside the house. Using a set of PIR motion sensors, their activations follow the position of the person along the dwelling. However these sensors remain in *active* status for a certain lapse of time, resulting also in several active sensors at the same time. It is necessary to associate each sensor with its field of view, and with its house area, in order to infer where the person is when triggering a specific sensor. Moreover, sensors become inactive if the person stops (e.g., sits at a table, on the sofa, lays on the bed); intuitively, the person position is related the activation of motion sensors, giving more importance to the most recent information and recalling the last valid position when sensors turn off.

Given a set of areas $\mathcal{A}$, the focus is to infer which $A_i \in \mathcal{A}$ contains the person position $\mathbf{x}_p$. HA sensors response can be exploited to infer the person's position depending on the interaction with them.

In detail, associating to each sensor s_i its *space* σ_i, i.e. the fraction of the house in which the person can activate its response, we can estimate the instantaneous position of the person starting from the active areas. To take into account the sensors activation persistence, we introduced an exponential weighting of the activations:

$$w_i(t) = \exp\left(\frac{t_{last} - t_{a,i}}{\tau}\right); \tag{1}$$

where the further the sensors activation ($t_{a,i}$) is, with respect to the last activation – taking into account all the sensors – (t_{last}) the lower its space contributes to the final position estimation, depending on a decay parameter τ. The reference of the decay is t_{last} rather than the current time instant because the person is more likely to be in the last visited space. Otherwise, if the person moves to another space σ_i, it is expected to trigger the sensor s_i accordingly, updating t_{last}.

The person coordinates $\mathbf{x}_p$ are estimated based on the set of weighted sensors spaces, by applying the barycenter function $B(\cdot)$:

$$\hat{\mathbf{x}}_p = B\left(\bigcup_i \{w_i\sigma_i \colon s_i \text{ is active}\}\right) \tag{2}$$

To simplify the computation and reduce the processing load, the barycenter function is reduced to a discrete form. In particular a grid $\mathcal{G}$ of evenly spaced points $\mathbf{x}_g \in \mathcal{G}$ is distributed across the home. Let's also introduce the activation function f as:

$$f(s_i, t) = \begin{cases} 1 & s_i \text{ is active} \\ 0 & \text{otherwise} \end{cases} . \tag{3}$$

Each space σ_i is then considered: based on the activation function and the temporal weighting, the barycenter is obtained as a weighted summation. Formally:

$$\hat{\mathbf{x}}_p(t) = \frac{\sum_i \left[f(s_i,t)w_i(t) \cdot \sum_{\mathbf{x}_g \in \sigma_i} \mathbf{x}_g\right]}{\sum_j \left[f(s_j,t)w_j(t)\#\left(x_g \in \sigma_j\right)\right]}; \tag{4}$$

where $\#\left(x_g \in \sigma_j\right)$ is the number of grid points included in the space σ_j.

Furthermore the obtained position $\hat{\mathbf{x}}_p$ is compared to the areas in $\mathcal{A}$ to obtain their expected occupation given the estimated person position.

Even if very important, the information concerning the presence in home might not be sufficient to the awareness required by the family. A needed enhancement concerns the identification of the absence of the person, or more precisely, the detection of the moments when the person enters and exits the house. To such aim, we can identify two models representing entrance and exit. Let us formalize them in the following simplified statements:

Exit. The sensors activations detected before the main door opening and closure are all followed by the corresponding deactivations, within a time lapse compatible with their normal functioning in absence of the inhabitant; Person status changes from present to absent;

Entrance. The inhabitant was absent, while now any of the sensor detects activity; Person status changes from absent to present.

It is clear how for both these statements the temporal sequence is relevant. Indeed the hereby presented model neglects burglar intrusion and other happenings, considering them out of the scope of this work.

Both the position and the occupation data are stored first on the home server and then on the remote subsystem, where the family and the relatives can access them.

4.2 On-Demand Information Delivery

Indeed one of the fundamental phases of the mutual reassurance is the information delivery to the family. The simplest way of providing such information is a set of multimodal visualization tools integrated in a web application. In particular we propose three data representations, characterized by different elements and capabilities strongly complementary.

The first data representation is a *live perspective* of the house (Fig. 1): it shows the instantaneous status of all the sensors and HA devices deployed, as well as the person's position and the areas occupation. Such view is designed to provide a prompt and clear perception of the instantaneous house status and to have an idea of the ongoing activity.

The second visualization, called *time machine* (Fig. 2) allows the exploration of the historic data. The appearance is very similar to the live perspective, but the data displayed are extracted from the database: the user can set a specific date and time, play the activations at custom time scale, seek along the day for a specific condition, etc. This tools enables to manually verify the inhabitant behavior in an asynchronous way.

Third, we propose a *bubbles diagram* (Fig. 3), for the aggregated and synthetic visualization of the house areas occupation along time. This enables to visualize the time spent in each house area: the wider the circle hovering the corresponding area, the longer the overall time spent there. Indeed, variations of the inhabitant behavior that imply changes in the daily routine, modify the distribution of the presence in the house. These are better to be investigated: a sick person would spend much more time in the bedroom, or would not exit from the house, or even spend an anomalous lapse of time at the toilet, etc. In all these situations the family may require to be aware of such happenings and changes.

4.3 Notifications

When monitoring the activity of an elderly person whose independence is threatened by the possibility of domestic accidents, it is important not only to recognize and detect them, but also to get notified right after they have taken place.

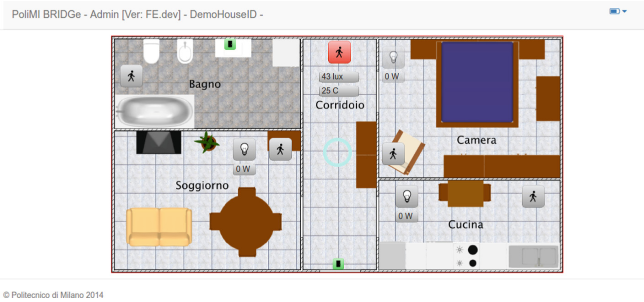

Fig. 1. Live perspective of the house status. In this visualization the person is localized in the corridor (cyan ring), and the corresponding movement sensor (in red) is triggered. (Color figure online)

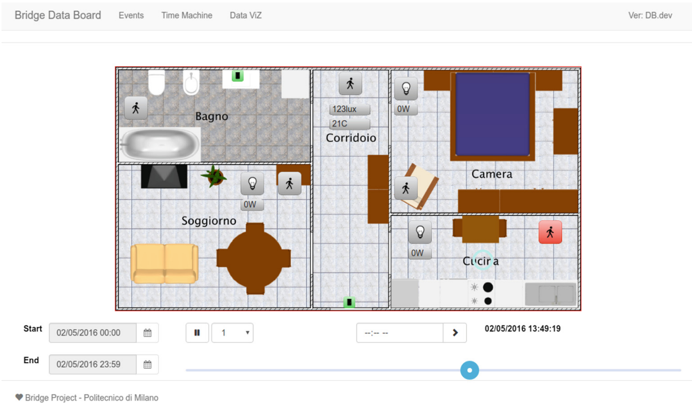

Fig. 2. Time machine visualization: the inhabitant is shown in the kitchen (cyan ring) right after lunch. The horizontal bar enables to browse the visualized instant in time.

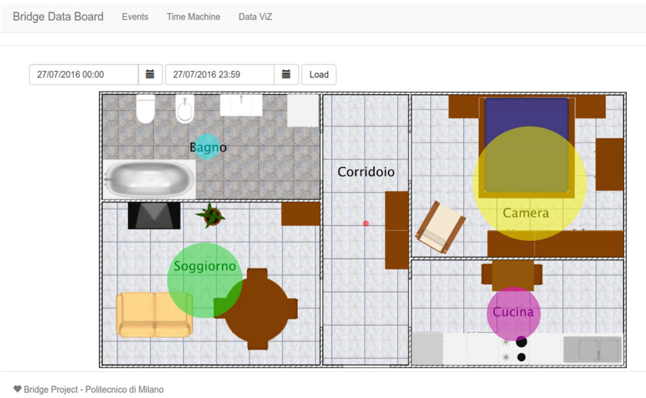

Fig. 3. Bubbles diagram visualization: the rooms occupancy is displayed, the wider the circle the longer the time.

Depending on the content of *life agreement*, the system should provide some pieces of information as soon as possible through notifications. Two simple examples can be: a prompt notification to the family when the person enters or exits the house, or a daily notification about the time spent in the bedroom.

We propose as notification tools two widespread general purpose communication media: e-mail and Twitter[5]. Since these modern communication technologies provide lightweight free client applications for smartphones, where to receive instantaneous notifications, it is convenient to leverage them. Concerning the reliability of such communication channels, it would be indeed worthy to analyze their Quality of Service; however we believe that this analysis stands out of this work's scope. In details the home server generates a notification, through e-mail and/or Twitter, whenever an interesting happening takes place.

5 Experimental Results

Even if testing the system with real-world data would have been interesting, it was impossible to retrieve a dataset with specific situations, as advisable for this work scope. Given these conditions, we exploited synthetic simulated data of a smart home. The simulator we used, called SHARON [14], enables the configuration of the person's behavior in terms of basic needs (e.g. eat, sleep, etc.), of place and time routines of the performed activities, but also the design of the all virtual environment (e.g. map of the place, areas, appliances, sensors, etc.). The results proved the validity of the approach on simulated data.

However, the evaluation of the system on real world data is surely more interesting. To such aim the project is currently in recording data on two pilot installations and trying to recruit more testers. The preliminary results of this testing phase are encouraging.

6 Conclusions

In the hereby presented work we propose an integrated system for the monitoring of indoor activity of independent elderly people, which is intended to be a tool to restore the mutual reassurance between the family and the seniors living alone.

The system comprises the collection, transmission, storage and analysis of HA data, to provide aggregate synthetic information: the coarse scale person localization, the house rooms occupancy, the presence at home and other customizable complex events. The set of visualizations and the notification mechanism enables the family to have an insight of the inhabitant activity.

Preliminary results on synthetic data and real world installation are encouraging: further tests will be carried out. To such extent it would be interesting to evaluate also the visualization system on an audience of testers.

[5] http://twitter.com.

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