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# A structured approach for the designing of safe AAL applications

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ABSTRACT

(*Context:*) Cognitive diseases such as Alzheimers affect millions of people around the world. One common characteristic of such diseases is that the patient may assume irrational behaviors, which may result in damage to property or, much worse, in injury to family members or to the patient him/herself.

(*Objective:*) These kinds of behaviors must be monitored via intelligent systems in order to guarantee the safety of the patients.

(*Problem:*) They are characterized by their unpredictable and irrational nature which makes the development of monitoring software complex, this being the main challenge that must be faced.

(*Proposal:*) In order to address this issue, our paper presents a structured approach to address the modeling and development of intelligent Ambient Assisted Living Systems for the monitoring of the behaviors of cognitively impaired people. The main impact of our contribution concerns both the automatic identification of irrational behaviors and a methodology for the design of safe AAL applications specifically targeted at users with cognitive or mental diseases. To prove the feasibility of our approach, we show a use case scenario in which we apply our solution to model a monitoring system able to recognize anomalous situations.

(*Results:*) The preliminary results have shown that the application of the proposed process allows developers to improve the safety of the patient in a domestic environment.



## 1. Introduction

Cognitive diseases such as Alzheimer's, Parkinson's and Autism affect millions of people around the world, reducing the quality of life of the patients and their relatives. Cognitive impairment diseases show symptoms which fall into several categories such as remembering, learning new things, or making decisions that affect everyday life. An estimated 5.1 million Americans aged 65 years or older may currently have Alzheimer's disease, the most well-known form of cognitive impairment; this number may rise to 13.2 million by 2050 (LE, 2003).

In extreme cases, the patient can show irrational behavior losing the ability to understand the danger of a situation. These behaviors could lead him/her to perform actions or behaviors which could compromise his/her safety, these situations define what we model as anomalous behaviors or situations.

In other words, an anomalous situation is the result of the execution of incorrect actions or the misuse of objects and/or devices.

In order to better understand this definition, let us consider a situation where a patient picks up an object. Suppose that the object has the properties of being inflammable (like a plastic dish) or electric (like a radio). In this situation, due to the impairment cause by his/her, he/she could place the object in contact with a heater or a sink.

These kinds of behaviors must be monitored in order to avoid situations in which the safety of the patient is put at risk.

Modern technologies allow the conception of new Ambient Assisted Living (AAL) applications to monitor the behavior of the patient and possibly prevent damage and injury. Several research challenges, however, must be faced.

Among these challenge, the difficulty of identifying irrational behaviors automatically and the lack of well-established methodologies and tools for the rapid prototyping of applications hinder the wide diffusion and commercialization of such technological solutions.

Indeed, due to the temporary irrationality of the patient, the behavioral disorder manifested is very often not stereotyped (not

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identifiable with a predefined pattern), irrational and difficult to predict.

At the same time, it is important to face the issue of how the system should react when an anomalous behavior is identified.

In this work we provide a solution to address these issues by defining a new approach which relies on the definition of correctness properties for the environment and the global behavior of the patient.

The proposed approach aims at providing a methodology for the development of intelligent monitoring systems. In detail, our reference scenarios are those in which the main tasks are directed at monitoring subjects affected by cognitive diseases such as Alzheimers.

Our contribution defines an *ad-hoc* design process for the AAL domain in order to guarantee *safety* requirements in *intelligent* ambients.

Defining our system as *ad-hoc* means that our solution has been conceived to be applicable to different kinds of scenario for the monitoring of the behaviors of patients with cognitive diseases or metal disorders(e.g. Alzheimer's, Autism, Schizophrenia) within the domain of AAL.

The concepts of *safety* are relating to the capability of the approach to guarantee the safety of the monitored patients in terms of avoiding dangers or anomalous situations.

The system is described as *intelligent* due to the use of agent-based reasoning process which allows the identification of the dangers for the patients.

Summarizing, we have defined a development process with specific tasks for the design of High-Confidence AAL applications specifically targeted at cognitively impaired users. Among the others capabilities, the process defines tasks for i) the identification of behavioral disorders and abnormal activities; ii) the safety of people inside the environment; and, iii) the recovery of a safe situation whenever an anomalous behavior is detected. For each of these tasks, a set of tools (i.e. design patterns, modeling mechanisms and software services) is provided.

We adopt a range of technologies and paradigms for the definition of the approach. Both the monitoring and the detection of patients' behaviors are defined by means of the Situation Awareness paradigm (Ye, Dobson, & McKeever, 2011) and Situation Calculus (McCarthy, 1963); the recovery is based on the Planning domain definition language (PDDL) (McDermott, 1998), a planning algorithm used in Artificial Intelligence (AI). Preliminary results have shown both that the application of the proposed process allows developers to improves the safety of the patient in a domestic environment. The research activity, therefore, aims at developing safe environments for cognitively impaired people.

In Section 1 we provide an overview of the related work; in Section 2 we give a description of the back- ground technologies; in Section 3 we describe the proposed approach; in Section 4 we show a use case to prove the trustworthiness of the approach; and finally, in Section 5 we provide a discussion of the lessons learnt, our conclusions and our directions for future research.

## 2. Related work

The literature provides several solutions for the detection of a patient's behavior. In terms of research projects, some solutions have been developed to provide smart homes and Ambient Assisted living (AAL): Microsoft's EasyLiving project (Brumitt, Meyers, Krumm, Kern, & Shafer, 2000) recognizes the activities performed by the inhabitants by means of cameras and other devices deployed in the domestic environment, the iterative room iRoom (Johanson, Fox, & Winograd, 2002) detects the iteration between the user and a walk-up display deployed in the home; and the CASAS smart home project (Cook, Schmitter-Edgecombe, Crandall, Sanders, & Thomas, 2009) monitors a set of activities such as hand-washing or cooking by means of sensors deployed in the house. All these examples only focus on the detection of normal activities without either considering possible dangerous situation nor providing any kind of recovery strategy.

The main feature of a monitoring system is the recognition process of the patient's behaviors and so the quality of recognizing behaviors improves as the accuracy of the activity recognition process increases. For this reason, the literature proposes several works on activity recognition methods and solutions. In the paper (Tran, Calcaterra, & Mynatt, 2005) the authors model complex activities like cooking into a sequence of atomic actions; segmentation and tracking are applied to a video stream in order to recognize the correct sequence of actions. The video stream is acquired by means of cameras deployed in the kitchen environment.

Instead of encoding human motion for action classification, (Jain, van Gemert, & Snoek, 2015) proposed a method for action localization by a strategy based on the 2D sequence of bounding boxes.

Another approach has been proposed by (Jain, Gemert, Jgou, Bouthemy, & Snoek, 2014), in their work authors face the problem to include information from human-to-objects interactions and combined them into several datasets in order to transfer information from one dataset to another.

In (Kern, Schiele, & Schmidt, 2003) the authors propose using multiple acceleration sensors distributed over the patient's body to recognize activities. All cited works aim at recognizing a single action or sequence of actions. Our research goes beyond these works and tries to reach a higher semantic level, that of behavior recognition. In other words, we aim to monitor the user's activities and understand if such activities can produce dangerous or anomalous situations.

An approach used for the designing of AAL systems has been described in (Parente et al., 2011). In this paper the authors present *Evidence Reasoning* (ER) modeling (Shafer, 1976) to model the activities of daily living (ADL) of a user in a monitored environment. ER is a useful and flexible approach to describe the uncertain and heterogeneous nature of the data.

The main drawback with these three techniques is their inability to reason over time. In our solution, we have overcame this limitation by means of the concept of the *Situation* which is the milestone concept used in both situation awareness and situation calculus.

Evidential Ontology Networks (EONs) work in a similar way to the ER approach discussed above. The main difference in EONs lies in a more formalized representation of the application domain by means of ontologies (Maedche & Staab, 2001). EONs are a good solution to counter any uncertainty over the data. The definition of the model is based on the existing domain knowledge and presents a low computational cost. As for ER, the main weakness is related to the absence of any time dependencies amongst the entities.

Another example of use of ontologies comes by (Riboni & Bettini, 2011), the authors propose a structured symbolic knowledge as the environment in order to allow the recognition of the activities among a set of candidate actions which are identified by statistical methods.

In (Monekosso & Remagnino, 2010) and (Singla, Cook & Schmitter-Edgecombe, 2008) the authors model human behaviors by means of Hidden Markov Models (HMM) (Rabiner & Juang, 1986). However, a HMM shows a weakness when it is applied to patients with cognitive diseases.

Patients with cognitive diseases show bizarre and unpredictable behaviors, and therefore an approach based on HMMs would be very complex due to the large set of transitions of all possible future actions performable by a patient.