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Rich contextual information for monitoring the elderly in an early stage of cognitive impairment

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ABSTRACT

With the increase in the elderly population, there is a concomitant growth in the number of cases of cognitive impairment. The early stages of these disorders can cause the elderly difficulties in performing their daily activities. To improve their independence while keeping their caregivers informed, this paper presents a monitoring system that focuses on the use of rich contextual information to detect a wide variety of a cognitively impaired person's routines and deviations from those routines. A detailed architecture of the system is presented together with an in-depth description of the algorithms for the identification of routines and deviations. In an experimental test with students, the algorithms identified some 91% of the routines and some 96% of the deviations.

1. Introduction

Currently, over 20% of people in developed countries are elderly (65 or more years old), and the major growth of this age group means that it is likely to reach some 26% of the population of these countries in 2030 [1]. Elderly persons are more likely to have cognitive disorders that lead to a loss of memory, reasoning power, and other cognitive functions. Estimations indicate that 17% of the elderly are cognitively impaired, with diseases such as Alzheimer's, Parkinson's, or DLB (Dementia with Lewy bodies) [1]. The trend is upwards, with the expectation that it will be 21% in 2030 [2]. These are diseases that make it difficult for the person to perform such routine tasks as going for a walk, to their health centre, or shopping. Difficulties in performing daily activities are associated with diminished quality of life, poor self-esteem, anxiety, and social isolation for both the cognitively impaired elderly and their caregivers [3] since it is not only the elderly person who is affected, but also the lives of their caregivers (usually their own families) who are forced to stay constantly aware of the elderly person's well-being. In developed countries, elderly persons typically want to have some autonomy, so that, whenever possible, they adapt their routines by adding new elements to their homes and/or using new technologies that facilitate the performance of their everyday tasks and, at the same time, allow caregivers not to have to constantly accompany them.

In recent years, healthcare companies have made significant progress in the development of software systems and devices that improve the monitoring and treatment of the cognitively impaired elderly [4]. For example, they have developed systems that control the location of the elderly person under care using RFID in order to ensure that they remain within safe areas [5].

One of the current challenges is to enhance the quality of life of those who still have some autonomy and live at home rather than in care centres, by applying new information technology paradigms. One of the paradigms that has most potential

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in this context is the *Internet of Things (IoT)* [6] since its main objective is to integrate information technology with people's daily lives [7,8]. This integration is usually aimed at obtaining information from the environment so as to automate repetitive tasks.

Smartphones, smartwatches, and other wearables are currently being used to monitor the location and vital signs of people with dementia. Thus, the caregivers can get alerts when a specific parameter is deviating from its normal values, for example, when the heart rhythm exceeds the values set by the caregiver, or when the impaired person is located in an area that the caregiver has not marked as safe. Currently, there are various commercial applications using one or multiple devices to improve eldercare and to increase autonomy. Examples are Project Lifesavers PAL (Protect And Locate) Tracking System [9] and Tweri [10]. These apps require the elderly person and/or the caregiver to set up a massive amount of parameters to adapt the application to their particular needs. For instance, the caregiver must configure the safe or dangerous areas, and the elderly person their routines or the location of their home.

The integration of the IoT paradigm with such devices and applications is markedly susceptible to improvement. There is still a large gap between the network where the information gathered by the devices is processed and exchanged and the reality of physical life and its context [11]. In general, various parameters of the system in question need to be configured manually, and this is far from making technology work for people in that it forces them to be aware of needing to introduce new routines or modify the parameters whenever a change occurs in their habits. Thus, if an elderly person using one of these apps changes their walking routines, the caregiver has to actively change them in the app. In a more appropriate IoT scenario, technology should take into account the context of the people it should be serving, learning from the context and at all times pro-actively taking actions according to the situation and expectations [12,13].

There is ongoing research into processing the contextual information obtained from specific devices with the aim of detecting people's routines and anomalous situations, enabling applications to learn from the contextual information without needing any active configuration. In [14], the authors define an approach that reduces the amount of contextual information that has to be defined by the elderly and their caregivers in order to monitor the sequence of steps followed during the execution of housework. In this case, caregivers have to describe the tasks and the places where they are performed, and this information is subsequently combined with a specification of the available sensors and actuators to build a working model that is capable of analysing ongoing activities. CoReDa [15] is an approach guiding elderly people to complete their activities of daily living (ADLs). The system uses wireless sensors to obtain contextual information from the tool's use in different ADLs, and a TD (λ) Q-Learning technique to learn different users' ADL routines. In [16], the authors propose an algorithm for processing the GPS trajectories of elderly people in order to, first, model an individual's movement trajectories as a graph based on their historical GPS traces, and second, identify in real-time outlying trajectories that have a definite wandering or deviation pattern as potential instances of disorientation.

These works focused on learning techniques applied to specific contextual information in order to facilitate the definition of routines and the monitoring of certain activities. However, performing these activities usually involves additional environmental elements, so that more contextual information is required. For example, the task of making and drinking a cup of coffee will be different if the elderly person is alone from when they are accompanied by a caregiver or friend. Likewise, they may have a walking alone routine, but if they are accompanied by a caregiver, breaking their routine to take a longer walk might well be acceptable. Therefore, to allow for more comprehensive routines and improve monitoring of the cognitively impaired elderly in different environments, it will be necessary to consider and process further contextual information.

Such a use of richer contextual information is proposed in the People as a Service model (PeaaS) [17]. PeaaS is based on the use of smartphones as sociological virtual profiles of IoT users in the sense that they contain the timeline of all the data and actions that their sensors have gathered along with the information that can be inferred from that timeline (i.e., the users preferences, activities, moods, professions, goals, etc.). These devices are highly customized, and accompany their owners in all their daily activities, accumulating an immense amount of information [18,19]. In addition, they can be paired with external elements which can provide more accurate information for certain parameters. Examples are biometric sensors, indoor location sensors, and other connected household devices. PeaaS is a social model that emphasizes the smartphone as a service provider. This model on the one hand facilitates interactions with the smartphones of other users – also taking these interactions into account as part of the context of each user – and, on the other, it allows the owners to control the information provided by their mobile devices so as to maintain data privacy and security.

In this paper the PeaaS model is applied to the development of a mobile application for monitoring cognitively impaired elderly who have some degree of autonomy. The aim of this system is to detect the user's different everyday routines (schedules, movement patterns, etc.). Then, the smartphone monitors the user's daily activities, and takes action if any deviation is detected (for example, guiding the elderly person to finalize an activity, or alerting their relatives). The identification of routines is based on all the contextual information available, such as the time, the location (indoors or outdoors), biometric data, the relatives or caregivers accompanying the elderly person, or the weather. The analysis of this information allows a wide variety of recurring activities to be detected, together with all the contextual information associated with those activities. The routines identified are stored together with their contextual information (including variations of any single routine in which only specific contextual elements change) and the transitions between them that the user follows. Finally, we define an algorithm to identify deviations from the routines, and to detect when, depending on the contextual situation, it is necessary to trigger an alert. All this allows us to identify a greater number of activities, to better control the conditions in which each activity should be performed, and to detect which deviations from routines

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