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A Multi-Agent System for Acquired Brain Injury rehabilitation in Ambient Intelligence environments

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ABSTRACT

Acquired Brain Injury (ABI) is becoming an epidemic problem in our society, especially among older adults, being known as “the Silent Epidemic”. People with ABI demand solutions in research that offer them with a relearning process such that they can recover not only their physical skills but also their cognitive abilities. In this context, the inherent characteristics of Ambient Intelligence (AmI), transparency and intelligence, have turned it into one of the best approaches to square up to the impairment that ABI can cause. As AmI proposes the development of context-aware systems that integrate different devices to recognize the context and act accordingly, these systems can react promptly to the needs of people with ABI while they carry out their rehabilitation process. Moreover, the exploitation of a Multi-Agent architecture emerges as a natural solution to develop AmI systems, since agents are reactive, proactive and exhibit an intelligent and autonomous behavior. Therefore, in this paper, a Multi-Agent architecture (MAS) for healthcare AmI systems is presented. It contributes to treat people with ABI by using specific devices to control the patient's movements and some physiological responses, such as the variation of the heart rate, during her rehabilitation process. In this way, the natural relationship between AmI and MAS is exploited. Finally, how this system is used to both design and execute therapies for people with ABI is presented.

1. Introduction

Toronto ABI network states [1] that people with ABI have suffered “damage to the brain that occurs after birth and which is not related to congenital disorders, developmental disabilities, or processes that progressively damage the brain”, but to different causes such as traumatic brain injury (TBI), brain tumours, degeneration of the blood vessels, etc. Unfortunately, this problem is affecting more and more people every year. Just for instance, according to the Brain Injury Centre [2] TBI is more common than breast cancer, spinal cord injury, HIV/AIDS, and multiple sclerosis (MS) combined. This explains why it is being known as “the Silent Epidemic”.

All of us are exposed to suffer this problem. However, older adults are among the most affected ones as they are more prone to suffer accidents [3]. For this reason, the development of any solution in this area must pay special attention to the needs and constraints imposed by this collective, because they are usually reluctant to the use of technology. For instance, a household survey [4] about ICT use carried out among 1001 people from England and Wales in 2003 showed that the use of computer was a minority activity amongst older people, because they considered it had low relevance to their daily-life. *Ambient Intelligence* (AmI) has become a meaningful advance in this sense, as it represents “the future vision of intelligent computing where environments support the people inhabiting them” [5], that is, it sets the focus on people's real needs.

As Ducatel et al. [6] state, AmI promotes the development of innovative and intelligent user interfaces “embedded in an environment that is capable of recognizing and responding to the presence of different individuals in a seamless, unobtrusive and often invisible way”. This means that AmI systems become *transparent* as people do not perceive their complexity neither their presence, and are *intelligent* to react in a proactive and sensitive way [7] at the same time. These two characteristics have had a great impact because it has allowed technology to be used by people who, otherwise, would have been probably computer illiterate.

AmI systems have enabled [8] bringing health and social care to the

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patient instead of bringing the patient to the health system. They have many different purposes, ranging from training for cognitive rehabilitation [9] till physical rehabilitation [10]. This work is part of *Vi-SMARt* project (Virtual, Social, Multi-sensorial and Adaptive systems for the Rehabilitation of people with ABI), a project aimed at designing an AmI system for rehabilitation of persons with ABI. This paper focuses on those aspects more directly related to rehabilitation of motor impairment problems. One of the main features of our system is that it provides therapists with support to design new therapies, to adapt them to each specific person and to control their execution instead of using a fixed set of exercises. In this paper, we present the Multi-Agent [11] architecture that supports the execution of the therapies. The rest of the paper is structured as follows. After this introduction, Section 2 presents the related work. Then, in Section 3, the architecture of the rehabilitation system is detailed. Section 4 describes how to design, execute and adapt therapies by using Vi-SMARt. Finally, the conclusions and future work are described in Section 5.

2. Related work

ABI, as defined in the previous section, may result from a number of different causes, either internal or external depending on the origin of the injury. Internal causes are the most frequent among older adults, usually due to vascular disorders, such as strokes or haemorrhages. External causes, generally known as traumatic brain injury (TBI), are usually due to traffic accidents, falls, etc. As observed from the causes described, all of us are exposed to this problem to some extent in our lives. As people with ABI have suffered brain damage, this can result in different long-term deficits depending on the area injured and the level of damage, turning into *physical deficits*, *cognitive deficits*, *emotional problems* and *behavioural deficits*. People with ABI must be provided with a proper treatment as soon as possible because there is increasing evidence of its effectiveness during the first stages after injury [12]. Although their treatment is carried out in a healthcare centre, this alternative has several drawbacks, especially in terms of the time available for the treatment process. Moreover, Christiansen et al. [13] have confirmed that the use of computers in the treatment process encourages and stimulates cognitive behavior and helps the patient to recover damaged functions and overcome disabilities. However, two of the main challenges that any system for the treatment of ABI must face is that it must be both *adaptable*, taking into account different parameters, such as age or damage level, and *adaptive* so it reacts promptly to the state of the patient as she progresses during a rehabilitation session.

In this sense, as AmI technologies are expected to be *sensitive, responsive, adaptive, transparent, ubiquitous*, and *intelligent* [14], they emerge as a natural alternative to develop these systems. It is worth noting that *intelligence* is one of the most critical characteristics, as it makes AmI systems more sensitive, responsive, adaptive, transparent and ubiquitous. The main reason is that intelligence helps in understanding user environments and, consequently, in providing adaptive assistance [15]. This explains why AmI entails contributions from different AI areas [16], specially, Multi-Agent System (MAS) [11]. There is a natural relationship between AmI and MAS [17]. AmI proposes the development of context-aware systems that integrate different devices to recognize the context and act accordingly. Agents provide an effective way to develop such systems since agents are reactive, proactive and exhibit an intelligent and autonomous behavior [18]. Agents react to humans based on information obtained from sensors and their knowledge about human behaviors within agent-based AmI applications [19]. Rashidi and Mihailidis stated in [20] that AmI can be exploited in different application areas, being rehabilitation one of them.

In the *rehabilitation* field, we can find some works that propose intelligent robotic systems to assist the physical rehabilitation process of the patient, e.g., for lower limb rehabilitation [9] that uses a MAS to detect bioelectric and physical signals through a sensor network located in the patient's body in order to determine his movement intention and assist him in doing such a movement. Another different proposal, called OntoRis [21], offers an ontology-based rehabilitation service that the patient can use to acquire comprehensive information about his prescribed rehabilitation treatment, or it can simply serve as an interactive learning platform for people interested in this particular medical field. Abreu et al. [22] focus their attention on cognitive rehabilitation, namely on using 3D games for neuropsychiatric disorders rehabilitation. These authors propose a MAS for automatic control while the patient is playing a 3D game in order to reduce the human intervention needed to manage the execution of software processes. Another interesting system has been proposed by Tian et al. [23] that uses the fusion of low-cost inertial measurement unit (IMU) and Kinect techniques to monitor upper limb motion. Other system [24] promotes the use of neural networks and interaction changes of the people to classify mental fatigue so that it can be properly managed in the context of rehabilitation. Another similar approach is IAServ (Intelligent Aging-in-place Home care Web Services platform) [25], which produces a personalized healthcare plan to meet the desire of patients of still living in their own house. This is done by first submitting the patient's profile to IAServ by the healthcare professional, and then this profile is converted into an ontology specification to enable the generation of a personalized care plan for the patient, provided by an inference engine.

Neural Networks (NNs) have been also exploited in different aspects of healthcare. In [29], NNs are defined as “trainable systems that can *learn* to solve complex problems from a set of exemplars and generalize the *acquired knowledge* to solve unforeseen problems”. There are some works [28,29] that reflect how Artificial Intelligence (AI) mechanisms can be embedded in AmI environments to make them more intelligent, adaptable, energy efficient and suitable to the user's needs. In this sense, the main AI approaches that could be applied in AmI are *NNs* and *Fuzzy systems*. They can be used alone or jointly to address a great variety of problems. There are some works that apply NNs within an AmI system. For instance, some authors [20] use them for recognizing complex activities. Other authors [5] use NNs as part of a vision-based fall detection system which extracts video features (3D motion, shape or inactivity) to detect falls. Another work [30] presents how to train a NN that takes as input those characteristics that describe the user's interaction patterns and provides as output an estimation of the user's mental fatigue. Moreover, there are other works that illustrate the perfect integration of such approaches, i.e. AmI and NNs, with agent-based systems. For instance, in [31] a multi-agent system is presented for the purpose of controlling a building environment in an smart way in order to achieve effective energy and comfort management. In this sense, it includes a NN to predict the indoor temperature preferred by the occupants, using data of the outdoor temperature and the associated time. Namely, in the healthcare area, other works have been published, such as the one in [26] that presents the SALSA framework for developing AmI hospital systems. Its architecture incorporates a reasoning component which uses a NN for controlling the agent's actions. Other work [27] presents an agent-based architecture that combines simple sensors with an intelligent algorithm based on NNs able to recognize different activities occurred in an AmI environment, such as sleeping or eating, as well as abnormal behaviors. Initially, our proposal includes fuzzy reasoning mechanisms, but, as described in Section 4, our inference agent is ready to integrate other engines, such as NN, for the purpose of learning.

Vi-SMARt has some similarities with respect to the one presented by Abreu et al. [22] as we also propose a *MAS* that is able to control the performance of all the tasks that a patient is doing during a rehabilitation therapy. However, unlike the work mentioned before [9] about physical rehabilitation, where an intelligent controller is used to manage the robot behavior, our proposal is focused on the performance