SUPPORTING DIAGNOSTIC DECISION FOR EARLY DETECTION OF A NEURODEGENERATIVE DISEASE ON A BEHAVIOURAL ALTERED PATTERN BASIS

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ABSTRACT

This paper describes the various aspects and steps of a multidisciplinary project called BEDMOND which aims at the development of an ICT-based system for the early detection of Alzheimer's disease (AD) and other neurodegenerative diseases on the basis of data assessment with health professional criteria. BEDMOND project addresses a system that supports the decision making process for the doctor, automating the information process related, first, to the recognition and modelling of the daily activity performed by the elder while being at home and, then, to the interpretation of deviations and behavioural changes detected. The system is a future-market extension for current tele-assistance technology and service enhanced with smart-home environment. BEDMOND considers that daily activity under two main scopes: first through the elder's daily routine -considered as a sequence of activities of daily living (ADL) - and then concretely through some specific behaviours highly concerned with mild cognitive impairment (MCI) typical symptoms (oversights and forgetfulness –medication intake, appointments, etc.-, disorientation –spatial and temporal-, loss of interest and isolation, etc.). First the requirements of such a behaviour pattern based assistant are discussed, then the system architecture deployed is introduced; next step deepens into the applied reasoning layers for the situation recognition, interpretation and data representation layers. Finally, next steps and some conclusions are also depicted.

KEYWORDS

Early detection, cognitive decline, behaviour pattern.

1. INTRODUCTION

The BEDMOND Project [1,2] aims at developing an ICT-based system for an early detection of AD and other neurodegenerative diseases, focused on elderly people while living at home. With such an early detection health professionals can later on apply an also early treatment which will help the elder to live longer in an independent way at home by delaying as long as possible AD appearance. The project started in June 2009, and it is just finishing its implementation phase, prior to test in real environment and situations until May 2012. Five sheltered homes will be equipped with the smart-home and tele-assistance technology involved (unobtrusive and low-cost) in order to validate the complete system for about a year time.

BEDMOND is based on a continuous monitoring of the elders' behaviour during their daily living so it can be matched against a user activity profile, set up within a training period. The results of this periodical matching can provide relevant information to the health experts to evaluate whether an AD at early stage could appear to start. So, all the data gathered by the BEDMOND system, initially taken from home sensors network, later processed to daily activities recognition patterns and finally interpreted through a rule-based engine (where health professionals knowledge is the key), will be later, periodically presented to the medical expert to determine whether, at the sight of the reports, activity by activity, the behaviour changes shown may mean the beginning of a cognitive decline or just a casual deviation. After detection, health experts will very likely apply a pharmacological treatment to the elder and BEDMOND system will keep on monitoring user behaviour in order to assure that the supported treatment takes effect on the delay of AD appearance.

2. NATURE OF THE PROBLEM

The motivation of the activities and the work presented here are mainly driven by the demographic changes and the related increasing prevalence of neurodegenerative diseases. The progressive ageing process of European population will bring out an increased number of people at risk of needing care. Indeed, studies estimate a duplication of the number of people with dementia (one of the age related diseases) every 20 years, if today's age-specific prevalence rates persist [3]). As the prevalence of dementia increases with age, it is estimated that the risk for dementia doubles every five years after the age of 65 and that nearly 50% of people aged 85 and older suffer from AD [4]. Currently, international estimations come from 30 million people in the world suffering from dementia, most of them in developing countries (66%). Moreover, 4.6 million new cases are expected to occur every year and in 2050 people suffering from dementia will reach a number of 100 million. According to the European Community Concerted Action on the Epidemiology and Prevention of Dementia Group [5], there are 5.5 million people estimated with dementia living in Europe.

There is considerable interest in the ability to diagnose dementia of the Alzheimer type in the earliest possible stage of the disease. The earliest diagnosis is critical for families and clinicians for a planning and management of the disease in terms of drug treatment and behavioural interventions. It is known that people with Mild Cognitive Impairment (MCI) have a higher risk of developing AD compared with older persons without discernable cognitive impairment. An early diagnosis allows an early treatment, aiming on slowing the course of the AD, and therewith supporting an autonomous and independent living of the patients in the privacy of one's home. Diverse studies suggest that first indicators, that raise suspicions of a possible neurodegenerative disease, are subtly manifested in patients' daily behaviour patterns. Thus, an interest emerged for developing a technological system that can record and code behavioural changes occurring in the daily life of elderly persons applying low level sensors in the home.

3. PREVIOUS WORK

AD is an irreversible, progressive brain disease characterized by the development of amyloid plaques and neurofibrillary tangles, the loss of connections between nerve cells in the brain, and the death of these nerve cells. Scientists don't yet fully understand what causes AD. Research conducted and funded by the US National Institute on Aging (NIA) and others is advancing the field of AD genetics [6]. The *early-onset AD* is caused by a number of different gene mutations on chromosomes 21, 14, and 1, and each of these mutations causes abnormal proteins to be formed. Scientists know that each of these mutations causes an increased amount of the beta-amyloid protein to be formed. Beta-amyloid (Abeta) is a major component of AD plaques, one of the crucial pathological findings in AD [7]. Moreover, Abeta may play a role in prediction the conversion of MCI to AD. Most cases of Alzheimer's are of the *late-onset form*, developing after age 60. In this case, the risk factor is related to the apolipoprotein E (APOE) gene found on chromosome 19. Several studies confirmed that the APOE ε4 allele increases the risk of developing AD. Another possible risk-factor gene, SORL1, was discovered in 2007. Researchers found that when SORL1 is present at low levels or in a variant form, beta-amyloid levels increase and may harm neurons.

On the other hand, advances in biomedical sciences are boosted by the introduction of new non-invasive imaging technologies. Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET) or Computerized Tomography (CT), are now widely used to diagnose the development and progression of several pathologies, including cardiovascular diseases and cancer. Now, the combination of all those imaging techniques is becoming more and more relevant. Recently, amyloid tracers for PET-MR imaging have been developed. Therefore, in the near future PET-MR imaging combination may become an important tool for in vivo amyloid screening, contributing to early diagnosis as well as evaluation of treatment response in AD.

Concluding, the study of the early detection of neurodegenerative diseases is being widely carried out looking for the root and causes of the brain degeneration, through several biomedical brain-centred fields, namely through genetics and proteomics and then through neuroimaging. However, much less has been done through the detection and analysis of different symptoms that rapidly appear to show externally, namely through behavioural changes in the person.

4. PURPOSE

On a basis of a behavioural change recognition and interpretation, BEDMOND development pursuits the early detection of a neurodegenerative disease, by means of both, an intelligent processing of the data gathered from the person activity while being at home and an adequate and professionalized manner to periodically present this processed information to the doctor. Several steps are to be tackled, from the requirements specification to the field trials for system testing.

4.1 Requirements of a Behaviour Pattern based Assistant

In order to gather the needs and requirements of both, caregivers and health professionals, a mix of quantitative (questionnaires) and qualitative (focus groups) methods was applied in two European countries (Spain and Austria). A total number of 13 caregivers and 10 health professionals participated in the focus groups. Additionally, in both countries 21 questionnaires were applied to caregivers and 20 to health professionals. Results from focus groups could show that there are several observable changes that indicate the beginning of the disease such as: personality changes (e.g. sadness, apathy), cognitive deterioration (e.g. forgetting appointments or taking medication) and behavioural changes (e.g. personal hygiene, abandonment of activities). Based on these results a questionnaire was designed in order to collect detailed information about the frequency and severity of the behaviours indicating the start of the AD. The questionnaire structure included the following sections: 1) Socio demographic data; 2) Symptoms in people with neurodegenerative diseases; 3) Possible benefits of BEDMOND system; 4) BEDMOND system acceptance and functions.

Because of a question of limited space for this paper, we will introduce the results obtained directly from health professionals, who definitively specified the same behavioural changes as those indicated by caregivers. They only added a new category: biomedical changes. Feedback from health professionals resulted in a long list of behaviours that are indicating AD. The most frequent rated behaviours can be seen below in table I.

Table 1. Selected behaviours that occur during daily life of Alzheimer patients (health professionals)

PROBLEM BEHAVIOUR	FREQUENCY (%)	BEDMOND SYSTEM CAN HELP (%)
Forgets what day it is	57.9	31.6
Reduction of attention	52.6	15.8
Loses, misplaces or hides things	47.4	36.9
Forgets medical appointments, important dates or taking medication	47.4	57.9
Reiterative behaviour (ask the same question continuously, to do the same action repeatedly,...)	47.3	26.3
Increased strategies to conceal the errors (self-justification)	47.3	10.6
Difficulty with coordination and organization (Problems to do the cooking, shopping,...)	47.3	36.9
Difficulties in coming up with the correct word (they use words like: “give me that” instead of “give me the plate”)	42.2	10.6
Lack of interest in things and abandonment of profitable activities	42.1	15.8
Changes in personal hygiene (showering bad or refused, not wanting to shave...)	42.1	26.3

A main requirement was coming from the elder at home. BEDMOND system was planned to be as unobtrusive as possible to not disturb the elder person living at home during daily life activities and not hide relevant behavioural deviations. In contrast, results from focus groups with caregivers and health professionals during the requirements phase highlighted that such systems must have some added value/benefit for the user at home to raise their acceptance.

4.2 BEDMOND System Architecture

The findings of the requirements phase of the BEDMOND project have been fed into scenario writing. The main stakeholders are elderly people living at home, caregivers (being the ones providing daily care and feeling responsible for the elderly) and remote health professionals. The scenarios describing the future use and impact of the system from a stakeholders view have been used to identify actors, use cases and features which were modelled with Enterprise Architect in Unified Modeling Language (UML; [8]) and lead to the first iterations of the system architecture and the database model. The BEDMOND system is meant to be a platform and a hub exchanging information between these stakeholders and a tool to fulfil the BEMOND goals of supporting diagnoses and treatment.

Because of the involvement of different local and remote stakeholders the architecture is split into a home and a server side. To achieve a maximum of data security and a minimum amount of data transfer the raw data is stored on the home side and only pre-processed data is transferred to the server side. Main components of the server side are - besides the server interface and the server side database - the caregiver and health professional interfaces. Low level sensor data will only be stored in the home side database which is important for privacy reasons as well. At the elder’s home smart sensors are installed and the core components URC/UCH [9] and HOMER [10] are used and integrated. Only pre-processed data is transferred over safe and secure connections to a server where higher level processing, back-ups, user registration and management, etc., take place. The needed components to achieve alarm generation are all put on the client side, so that they can also work offline for safety and security reasons. Finally Google Calendar is used to store appointments and create reminders in a ubiquitous way.

The integration of the URC/UCH as applied in BEDMOND allows the integration of devices and services by using just one communication protocol towards the user interfaces. URC/UCH technology also brings scalability and adaptability to the BEDMOND system, allowing its future expansion by the development of APIs with “plug and play” capabilities and an efficient and seamless integration of new home automation devices (new sensors, actuators) and new services. And what is more important, also on the area of user interfaces, UCH permits a high degree of freedom on the choice of the technology and protocols used in the User Interfaces. For instance it is possible to have web based interfaces, TV based interfaces, speech driven UIs, screen readers for visually impaired and even BCI systems.

The HOMe Event Recognition System (HOMER) integrates the local sensors and performs pre-processing. It is based on an Apache Felix OSGi, which enables modularity and execution on various operating systems with the Java Runtime Environment (JRE). This fact is another aspect of hardware abstraction and independence. The usage of an OSGi framework provides remote maintenance and individual adaptability of the system: the components, in the form of bundles, can be remotely installed, started, stopped, updated and uninstalled without requiring a reboot of the system. The interactions and dependencies between bundles are handled by the framework itself. Standards for medical device communication and home automation networks are integrated to enable communication to appropriate devices. These technologies are to count on important aspects for an AAL service platform (security, modularity, extendibility and interoperability).

4.3 BEDMOND Intelligence: from Home Sensor Data to Disease Diagnostic Representation

4.3.1 Data Acquisition (Sensors)

The sensors used within the smart home network for activity detection are commercial-off-the-shelf and low-cost, namely conventional Konnex (KNX) home automation sensors [11] and other wireless sensors with a proprietary protocol. The commercial partner IBERNEX has also developed a phone call detector for incoming and outgoing calls and a piezometric sensor for pressure detection which also allows tracking the heart and respiratory rates while resting in bed. This couple of new sensors is integrated within the tele-assistance system provided by IBERNEX. All of these sensors, as well as the tele-assistance system, are applied and connected to HOMER. Communication is established via RF-link to a gateway, which is USB-connected to a PC. All the sensors are battery powered and therefore do not need any cables, which eases the positioning and mounting in the home. Table II lists some of the non-expensive and non-invasive sensors integrated in the current BEDMOND acquisition system prototype.

Table 2. List of sensors and home location

Room	**Furniture**	**Sensor**
Bathroom		presence / motion sensor
	Cabinets and drawers	reed switch
	Shower panel	reed switch temperature sensor
	Toilet (floor)	pressure sensor
	Plug (shaver, hairdryer)	power plug sensor
Kitchen		Presence / motion sensor smoke sensor
	Refrigerator, freezer	reed switch
	Microwave and oven	power plug sensor reed switch
	Cooker, Toaster, Coffee machine	power plug sensor
	Washing Machine	power plug sensor
	Drawers (cutlery)	reed switch
	Cupboard (plates, glasses, cups,..)	reed switch
	Chairs	pressure sensor
Bedroom		presence / motion sensor
	Bed	pressure sensor
	Wardrobes and drawers	reed switch
Living room		presence / motion sensor
	TV, VCR, DVD, CD	power plug sensors
	Sofa, chairs	pressure sensor
	phone	phone sensor
Hall		presence / motion sensor
	Drawers, Entrance door	reed switch

4.3.2 Situation Recognition

The reasoning layer deepens into several levels, regarding the different sensors involved and the information provided by them. A first raw description divides the set of rules of the BEDMOND system into a couple of main blocks: low level and high level layers, two consecutive reasoning steps. Low level layer is related to information retrieved directly from sensor events or a basic data fusion. It is what BEDMOND calls the basic step in “Situation Recognition” phase. Some specific sensor events are able to provide relevant information by themselves; this is the case, for example, for the events triggered by the technical alarms (smoke and water leak). A single alarm event is informative enough to make the system react automatically to prevent a risky situation. A next level of processing could include a counting of the number of alarm events registered; for example, if the system receives a certain number of alarms in a certain period of time, the system could reason in the way to detect a hazardous behaviour of the person living at home (“basically processed data”). Another sub-level in this basic main block concerns the combination of data provided from several sensors. With a pressure sensor detecting the person in the sofa and a power consumption plug sensor activated by the TV set, the BEDMOND system can determine that the person is currently watching TV at that moment (“combining raw unprocessed data”). If those events are further processed, for example taking into account the moment of day when they are triggered and their repetition during several days of the week, a type of sub-activity of daily living being performed by the person can be inferred (“combining basically unprocessed data”).

4.3.3 Situation Interpretation

But this is not enough to build a model or pattern of the daily activity of the person. In BEDMOND scope, a daily routine pattern - as much accurate and detailed as possible - is highly relevant and has to be built, because any single deviation might be important for the physician to early diagnose a neurodegenerative disease. And here it comes up the high level layer of reasoning, what BEDMOND calls the "Situation Interpretation" phase, mainly divided in two main blocks: on the one hand, the behaviour modelling and tracking and, on the other hand, the behaviour interpretation and actuation modules.

Rules regarding the first main block can be considered as "software developers" rules whilst the second one is obviously devoted to the health professional's knowledge and experience. Both of them also include several sub-levels. Starting from the previous basic reasoning level, BEDMOND learns and sets up an activity of daily living (ADL) like, for instance, taking breakfast. This concrete ADL is made up of a sequence of several sub-activities previously registered: open the cabinet and take a cup → open the refrigerator and take the bottle of milk → ... This reasoning level for ticketing the sub-activities and subsequent ADL is really relevant for the early detection of a neurodegenerative process because some changes on the sequence or the duration of certain sub-activities in such ADL may provide interesting information for the doctor. In a similar way it occurs to the next step of BEDMOND reasoning: there is a requirement for building the daily routine of the person, as a new sequence of ADL (sleep → get up → breakfast → personal care → home tiding → lunch → ...), taking into account that any deviation, change or even disappearance of an ADL in the daily routine sequence is a prodrome or early symptom of MCI too.

Up to this stage, the situation interpretation planned in BEDMOND could be common to many other applications taking profit from human behaviour monitoring techniques ("software developers" reasoning). However, a second level (set of rules) concerns strictly the application field in which this project is aligned: the MCI detection as the clue for the onset of a pathologic cognitive decline. Apart from some changes in the daily routine, it appears that some specific behaviours of the person are considered as potential MCI symptoms, like some of those listed in table I. This detection is not directly correlated with deviations upon a behaviour pattern, though some of them can be assimilated, up to a certain extent, to changes in the way that some ADL are performed. There is no behavioural pattern for reminding appointments, for example, but this kind of forgetfulness must be registered for an early detection of MCI. This level is much linked to sensor data fusion and to an imaginative but reliable way of detection. The third level of reasoning for this first main block deals with the deviation calculation when comparing the behavioural pattern versus the daily tracking.

Last levels rise up after measuring deviations over the pattern, regarding firstly the interpretation of those deviations and secondly the actuation required after such interpretation. Health professional criteria are now in the rule sets. These rules define the domains of the personality related to the executive function where the changes or deviations should be included (memory, disorientation, social affairs, etc.) but mainly and overall set the limits for the deviations in order to be considered as mild or critical.

4.3.4 Diagnostic Assistant Presentation

The data representation level is also a high-level layer, probably the most important one since it can decide whether the tool is useful (friendly and usable) or not. In this paper the focus is on the data representation approach for the health professional as main end-user of the system. The main challenge was not about how to get the information to show but mainly about how to present the information to the user. This is also a relevant part of the reasoning machine behind the BEDMOND system, and it has been briefly introduced in the previous chapter. The main motto to get a usable and friendly tool for the clinicians was double: adapt and simplify. Adaptation is basically done gathering the information retrieved and intelligently processed into one of the international scales that health professionals use to assess the cognitive decline (CD) status. Among these international scales for screening and scoring CD, the Clinical Dementia Rating (CDR) scale was selected. This scale presents two advantages over the rest: first, it scores CD in a range coming from the sane status (score "0") up to the severe cognitive impairment (score "3"), being MCI - the detection target - in the middle of the range (score "1"); besides, different behaviours to detect are classified into six domains (memory, orientation, judgement and problem solving, community affairs, home and hobbies and personal care), and each of these domains can also be scored, providing relevant information for the health professional. Simplification is tackled through visual tools providing main conclusions at a glance. On a traffic-light interpretation basis, the information is quickly shown on green, yellow and red colours.

4.4 Next Steps

Within the BEDMOND project, the team has performed an extensive analysis of requirements for a behaviour based pattern assistant for the early detection and management of neurodegenerative diseases. An interoperable architecture has been specified and integrated in the BEDMOND platform, which follows the requirements of modularity, interoperability, and extendibility. BEDMOND team is currently finishing the system prototype modules: data acquisition, behaviour pattern modelling, activity tracking, deviation calculation and MCI interpretation. The current focus has stepped from the rule based engine implementation for "situation recognition" and "situation interpretation" in the "medical language" of the health professional up to the information presentation for the three types of users: elder at home, caregiver and health professional. Information representation is done by means of the application of adapting and simplifying criteria for the health professionals to get a quick conclusion about the information periodically reported: on the one hand, BEDMOND uses their international screening scales and questionnaires to classify and score the cognitive decline status and behavioural symptoms related; on the other hand, BEDMOND applies their own knowledge to configure and interpret the deviation values under a simple traffic-light colouring model. A laboratory prototype for technical validation and performance testing has already been set up to test the whole functionality and interfaces accessibility and usability. As a next step expert trials followed by first trial site installations in Spain and Austria are planned.

Beyond the BEDMOND project, some other new and emerging technologies could be integrated as enhanced functionality providers for a more accurate and extended behavioural characterization and also as assistive aids and home automation for ADL execution: indoor and outdoor identification and location technology both, for the person and for the objects, sound and speech technology, new smart-home sensors, actuators, smart objects and medical devices (portable or wearable), affective technology for emotional state and stress situations detection, etc.

5. CONTRIBUTION OF THE PAPER

This paper -and BEDMOND project related- explores a new field for the early detection of neurodegenerative diseases, going through an ICT *ad-hoc* system which has its basement on current and future tele-assistance services over a smart home environment. Some behavioural changes occurred while being at home, objectively detected, recognized and interpreted through health professional's criteria can rapidly inform the doctor about the appearance of some MCI symptoms at an early stage so then clinic test can be applied to certify whether a pathological cognitive decline is about to start or not and drug treatment started.

6. CONCLUSION

The risk of undergoing dementia is associated so much to genetic factors as environmental. Although potentially is a strong genetic risk [12], the genetic factors are not modifiable at the moment. The environmental factors can modify the risk of undergoing dementia by their influence on the moment of the clinical expression of the symptoms, although they do not influence the presence or global absence of pathology, contributing to 'brain reserve' or 'cognitive reserve' [13,14,15]. But this is just a way to tackle a preventive step of the neurodegenerative disease. Meanwhile, health professionals are searching for a tool for the early diagnostic so that they can early apply clinical test and pharmacological treatment to slow down the disease progression. Combining tele-assistance and smart home technologies, we are able to provide the doctor with such objective information about behavioural changes prior to the disease is patent.

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