Wandering Behaviors Detection for Dementia Patients: a Survey

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***Abstract*—Dementia is an age-associated impairment that could affect about 135 million people worldwide by the year 2050. People with dementia suffer from memory and orientation problems, which cause them to wander and get lost. Advances in technologies and connectivity can be leveraged to reduce the risk of unsafe wandering. In this paper, we present a survey of state-of-the-art technologies and methodologies, which are used for tracking and detection of wandering behaviors. The survey provides a compilation of the most related works in the literature and commercial fields, discusses their aspects and limitations, with the aim to benefit future efforts in this domain. We found that several approaches exist to tackle the problem of wandering, where most of the reviewed works tend to focus on the technical side, rather than adopting a user-centric design. We also observe that the commercial systems are lagging behind the research efforts, which can have a great impact if wisely applied in real world applications. Finally, we review the related sides of security, privacy and ethical concerns around the development of tracking systems, and present general recommendations for developing systems that respect these sides.**

***Keywords*—Dementia; Assisted-living; Wandering behaviors; Monitoring systems**

I. Introduction

A. Dementia

Dementia is a general term used to describe a decline in mental ability, which is severe enough to interfere with daily life [1]. Alzheimer's is the most common type of dementia. Symptoms include a wide range mainly associated with a a progressive decline in memory and other cognitive abilities, reducing a person's ability to perform everyday activities, including orientation and way-finding tasks. People with dementia even experience difficulties in finding their way in familiar environments [2]. Dementia syndrome could affect about 135 Million people worldwide by the year 2050 [3]. Healthcare technologies and assistive systems are designed to support everyday life of people with dementia, improving their autonomy, safety and quality of life.

This work was co-funded by the State Secretariat for Education, Research and Innovation of the Swiss federal government and the European Union, in the frame of the EU AAL project Many-Me (AAL-2016-063).

B. Wandering behaviors

The memory loss for dementia patients can cause them to loose their way or wander around a certain location. Wandering is considered as one of the problematic and dangerous behaviors of people with dementia [4]. Such behavior is associated with adverse events among patients, such as falls, injuries, hip fractures, and getting lost [5], [6], [7]. Being lost or the fear of getting lost may lead into other psychological deficits such as anxiety, suspicions, illusions and aggression [3], in addition to social isolation and a reduced quality of life. Moreover, this situation may present a souce of stress and anxiety for relatives and caregivers, and wandering is considered as a major cause contributing to heavy care burdens in nursing practices [8]. Technologies to protect the patients from wandering problems and preventive measures can improve their quality of life and their carergivers as well, by improving the safety conditions of patients [9], [10].

C. Related Work

Lai *et al.* [11] span the literature and study wandering in what concerns the nature of the phenomenon, in order to classify the behaviour, determine the extent of the problem, and the profile of those who are more likely to wander. They found that wanderers are more cognitively impaired, and more likely to have sleep problems, a more active premorbid lifestyle, and used more psychotropic medications. However, they state that the knowledge generated through research remains insufficient to fully explain wandering causes, and suggest that future research incorporate appropriate subject identification strategies, and focused interventions on wanderers. In another survey, Bharucha *et al.* [12] present an overview of systems and technologies used in assisting people with dementia. The presented systems do not focus on wandering problems, but rather on general monitoring of patients and their surrounding environment. These include systems to compensate for cognitive and memory decline (reminders, planning, etc.), environmental sensors (motion, temperature, pressure, light, video cameras, etc.), physiological and functional sensors (metabolic signals, heart rate, blood glucose, gait problems, fall detection, etc.). In a similar more recent study [13], the authors present a wide spectrum of dementia-assistive works. Similar to [12], the study reviews general assistive systems, like care and

rehabilitation, activities of daily living, monitoring, cognitive, and emotional assistance.

D. Scope of the survey

This survey aims to provide a review of state-of-the-art technologies and methodologies for monitoring people with dementia, as to protect them from unsafe wandering behaviors. it compiles different related works in the literature, and reviews the commercial advancements in the field. We also study the problem from an ethical perspective. The survey, run in the frame of the AAL project Many-Me [14], is supposed to serve as a reference for future research efforts in this field, and for developers of new wandering tracking systems. The rest of this paper is organized as follows. First, Section II presents the works in the literature, which focus on the wandering behaviors detection, and describes the different approaches to the problem. Section III reviews the commercial systems for assistive monitoring, and discusses their limitations. Sections IV and V present the security and ethical concerns respectively. Finally, Section VI concludes the paper.

II. Wandering detection in the Literature

Wandering behaviors are considered complex and diverse by nature. Nonetheless, the detection of these behaviors can be approached from different perspectives.

A. Frequency-based Approach

The first approach is the frequency or degree of locomotion based. This approach links wandering behaviors with excessive and continuous ambulation [15]. This is a simple and direct application of the concept of wandering behaviors, however it might suffer from limited accuracy in practice.

B. Navigation-based Approach

The second approach is based on the navigational deficit, and tries to evaluate functional decline by examining how people respond to navigation or wayfinding tasks [16]. One work [17] leverages a mobile device equipped with GPS (Global Positioning System) to learn the standard routes of the subject person in outdoor environments, in order to predict likely destinations. In case a navigational error is detected, it alerts the person through a knocking sound, and then re-routes him to the right path. While the traditional approach is to warn caregivers when people with dementia are wandering, another way tries to directly guide the patient himself, and helps him find his way again when he is lost. An early work in this regard is a robotic assistant walker [18] that helps patients navigate in indoor environments. This system can be used only by patients who require an ambulatory walker device. Similarly in [3], a monitoring and guidance system is used to assist people with dementia in indoor environments, using Ultra-Wideband and iBeacon technologies.

C. Pattern-based Approach

Wandering behaviors can exhibit common characteristics, and can be associated with specific patterns, which can be observed and detected. This approach is based on algorithms that aim to spot the wandering patterns. These can be generally classified into direct travel, pacing, lapping, and random movements [19]. Pacing and lapping movements are considered to be unsafe wandering, as the person is more likely to exhibit such behaviors when he is lost. While the approach considers direct travel to be normal, random movements remain challenging to be judged or classified. In [20], an efficient real-time method is used to detect loop-like patterns based on GPS traces. The method is based on filtering the traces to remove noisy data, which can be typical in some scenarios, and then processing the data points based on angles of direction, and travel distance.

D. Geofencing-based Approach

This is based on limiting the safe zones for people with dementia, by applying so-called “geo-fences”. An unsafe wandering is then considered when the patient surpasses these designated areas [21]. A monitoring mechanism observes the subject person, and warns his caregivers when he leaves the safe zones. An example application can be found in [22], where an implemented module tracks patients' locations using GPS, and reports these locations to a central LoRa (Long Range) station for processing. The module uses reduced frequency as a way to reduce the energy consumption of the system. In the most extreme case, people with dementia are physically restrained behind locked doors. However this is considered an extreme practice that is generally unacceptable [23], from an ethical perspective, especially that general wandering can sometimes be considered as purposeful and therapeutic practice, which can improve the quality of life and offer health benefits for the patients. In contrast, it should be substituted with monitoring techniques to allow individuals to wander safely, like motion detectors as pointed out in [24]. When the safe areas are restricted to patients' homes only, whether residential or nursing homes, then technologies like door alarm systems may be useful [25].

E. Summary

In Table I, we summarize the main aspects of the presented approaches, which are used in wandering behaviors detection.

F. Discussion

The presented works, which are found in the literature, use different approaches to tackle the problem of wandering. Each of these approaches can have its own advantages and limitations. However, most of the works tend to pay little attention to the target users, when developing or evaluating a certain system. Therefore, it is very important to focus on user-centered design for developing systems that are better suited for users' needs.

Table I. Summary of wandering detection approaches in the literature

Wandering Detection Approach	Description	Pros	Cons
Frequency-based	Detects excessive and continuous ambulation of patients	+ Simple to implement as a direct application to wandering definition	- Limited accuracy due to probable false positives
Navigation-based	Detects a navigational deficit and guides the patient indoors or outdoors	+ Increases autonomy of patients by guiding them to correct routes directly	- Needs to learn the standard routes of the patient beforehand
Pattern-based	Detects specific patterns like pacing, lapping, and random movements	+ Unsafe wandering patterns can be detected efficiently	- Wandering exhibiting direct travel or random movements is hard to be judged
Geofencing-based	Detects when the patients go beyond some defined "safe zones"	+ Convenient to leverage GPS-supported devices, or simple monitoring (motion sensors, door alarms)	- Limits the liberty of the patients - Physical restraining of patients is considered unethical

III. Commerial Systems

We present in this section, a review of the most notable systems and technologies that are used to track wandering behaviors of people with dementia, and which are commercially available.

A. GPS-based Technology

In order to monitor a certain user, his location information is determined and communicated to his formal and/or informal caregivers. Since most of the unsafe wandering occurs in outdoor environments, rather than indoor ones, GPS can be used to get an estimation of the user's location. GPS is a widely used technology that offers an acceptable accuracy ($<$10m) in good conditions, like clear weather condition, low density of surrounding buildings and structures, etc. In most of the cases, the provided accuracy is sufficient for the application of wandering detection. The technological advancement in the recent years, has made it possible to implement the GPS receiver on a small sized chip, which can be available in mobile devices (smartphones, smart watches, custom-made tracking devices).

Examples of these devices are Bluewater Security [26] which consists of GPS-equiped wrist-worn watch. The base receiver triggers an alarm when the distance to the watch exceeds a specified threshold (around 80m), indicating the user might be wandering. Mindme [27] is composed of an alarm and location device, both the size of an electronic car key. An alarm is either activated by surpassing a preset zone, or manually by the user in case of an emergency. Otherwise the location device reports location updates periodically. GPS Smart Sole [28] is a similar device, with the advantage that it can be placed into a shoe, reducing the risk of being lost or forgotten by the patient. Comfort Zone [29] is a web-based solution that relies on variable GPS-based mobile devices, and can be used by a caregiver to track the patient. Similar solutions include SafeLink [30] and Revolutionary Tracker [31].

B. Assisted Technology

While GPS can offer an acceptable accuracy in most cases, the accuracy of the location can be improved with assistance of other technologies, when their coverage is better. In PocketFinder [32] tracking device, GPS is used along with Assisted GPS (A-GPS) and WiFi technology to improve the localization accuracy. The exact address and the speed of the person are communicated to a mobile device or a PC (email and text notifications). Goefencing is also used to define a number of safe zones, and provides alerts in case the GPS leaves the specified area. iTraq with guard mode [33] relies on cellular towers to obtain an estimation of the patient's location. Some other traditional solutions consists of using a special identifier which is kept with the patient, like MedicAlert [34]. On this identifier, critical medical information, a Hotline Number, and a symbol recognized by emergency responders, are all engraved. Emergency Hotline specialists would notify caregivers or family of the situation and location of the patient in case he or she is lost.

C. Summary

Table II summarizes the commercial systems that are used for wandering behaviors detection.

D. Discussion

It is remarkable that although wandering behaviors is a critical problem among dementia patients, the commercial state-of-the-art remains limited. The approach of just tracking the location of the user and communicating the result to the caregivers is a very simple approach. It is also noteworthy that we could not come across any commercial tracking system that makes use of smart algorithms, machine learning, or artificial intelligence, in order to automatically detect wandering behaviors. It is clear that there is still a huge gap between the scientific and commercial state-of-the-art in this field. We believe that there is a great potential in scientific findings that can be invested in enhanced tracking systems, and which would radically change the experience of people with dementia, their family members and caregivers.

IV. Security

In most of the cases, the patient's information (location, traces, being lost or not, etc.) need to be communicated with remote caregivers. This information can be considered sensitive, and could be critical to guarantee the right intervention. Hence the communicated data should be protected against possible attacks and/or eavesdropping. This could be

Table II. Summary of commercial systems used for wandering detection

System	Description	Technology
Bluewater Security [26]	Wrist-worn watch with alarm triggered when maximum distance exceeded	GPS
Mindme [27]	Location device & alarm activated by surpassing a safe zone	GPS
Smart Sole [28]	Tracking device placed into a shoe	GPS
Comfort Zone [29]	Web-based tracking platform based on a GPS-based device	GPS
SafeLink [30]	Mobile tracking device	GPS
Revolutionary Tracker [31]	Mobile tracking device	GPS
PocketFinder [32]	Tracking device with increased accuracy using A-GPS and WiFi	Assisted technology
iTraq [33]	Tracking device using cellular towers	Assisted technology
MedicAlert [34]	Identifier kept with the patient, engraving critical information	Assisted technology

already accomplished by using existing and well-established communication protocols that already take these issues into account. However, it is important to be aware of security issues when designing a new communication protocol or methodology as part of a wandering detection system. In [35], a patient monitoring solution in hospital environments is presented. The work discusses the mitigation of potential denial of service (DoS) attacks on the system, and presents schemes for achieving that.

V. Ethical issues

Assistive technology for dementia patients raises an ethical concern, especially about the processing of patient related information, retrieved from sensors. Dahl *et al.* examined this issue in their studies [36], [37] considering a GPS Tracking System for dementia care. The study stresses the attention that has to be paid to ethics and human values, to better accommodate the values of the corresponding stakeholders. The study observes some biases that should be corrected when considering location-based tracking technologies. Namely, it recommends on building on the abilities of persons with dementia, and considering the use of interactive location-based services that could benefit them directly. Moreover, the provision of highly detailed information about a patient's mobile activities to caregivers, shall be prioritized over his or her right to privacy. The authors also warn that factors such as the physical size of the tracking unit and a highly visible alarm button, might become stigmatizing and devaluing for patients. Additionally, providing feedback to users about the status of the tracking unit and relative accuracy of provided positioning data are factors that increase trust in the system. As a result, it recommends that value elicitation become an important part of the gathering of requirements, and that new design solutions be evaluated in realistic settings in order to gather empirical data on their value impact. Similarly, Wan *et al.* [38] suggest that issues of autonomy, privacy and safety should be constantly negotiated and arranged in accordance with specific and local definitions of patient condition, and that solutions must allow tailoring to meet these conditions. Accordingly, the design and shape of the tracking unit are important features, due to the individual preferences and habits of the patients. Robinson *et al.* [23] state that it is important to establish the views of people with dementia on the acceptability of tracking technologies, prior to evaluating their effectiveness through complex randomised controlled trials.

VI. Conclusion

In this paper, we presented an overview of state-of-the-art technologies and methodologies, for tracking and detection of wandering behaviors for dementia patients. Our main aim was to provide a reference that reviews the works in the field, and presents their aspects and limitations, to benefit future efforts in this domain. We found that most of the works in the literature tend to focus on the technical side, rather than adopting a user-centric design. As for the commercial systems, it was clear that they are lagging behind the research works, which can make a huge potential if applied practically in real world situations. We also studied the related sides, especially in what concerns the security, privacy and ethical concerns around the development of tracking systems.

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