Wandering Analysis with Mobile Phones
On the Relation Between Randomness and Wandering

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Abstract: Population pyramids have rapidly changed their shape worldwide. Specially in industrialised countries, where a steady ageing process is taking place. Due to the ageing of the population, age-related illnesses such as mild cognitive impairment (MCI) and dementia are becoming commonplace and healthcare systems struggle to improve the quality of life of patients and carers. Wandering and disorientation are common symptoms amongst patients with MCI, and they could lead to fatal outcomes. In this article we propose a wandering detection technique based on the analysis of randomness in patients' trajectories, which are gathered by means of standard low-cost mobile phones with GPS.

1 INTRODUCTION

The average age of the world population has increased progressively over the last 50 years as a result of the reduction of fertility and an increase in life expectancy. The ageing of the population poses a formidable challenge for public healthcare systems since they have to face the rise of an aged and very demanding population and their associated health conditions, namely chronic illnesses, injuries and disabilities.

This demographic change results in a huge impact on society and proper countermeasures have to be put in place so as to cope with it in the years to come. The aforementioned ageing of the population leads to an increase in the cases of cognitive disorders like Mild Cognitive Impairment (MCI), Parkinson's disease (PD) and Alzheimer's disease (AD), to name the most common.

MCI is specially interesting because it can be understood as a precursor of early stages of AD and PD and other types of early dementia that imply impaired memory function whilst the cognitive function is generally preserved (Petersen et al., 2001). MCI is a brain function syndrome involving the onset and evolution of cognitive impairments beyond those expected based on the age and education of the individual, but which are not significant enough to interfere with their daily activities (Petersen et al., 1999). Annual prevalence estimates for MCI in the United States range from 3% to 4% in the eighth decade in the general population. Amongst community-dwelling African Americans, the estimated prevalence is 19.2% for those aged $65-74$ years, 27.6% for those aged $75-84$ years, and 38% for those aged 85 years and older. The prevalence of mild cognitive impairment increases with age. The prevalence is 10% in those aged $70-79$ years and 25% in those aged $80-89$ years.

People suffering from MCI and early stages of different types of dementia might experience a decrease in their cognitive capabilities that might affect their mobility patterns but they still have considerably high degrees of autonomy (i.e. they can live alone, walk, exercise). The most apparent impairment is related to their memory function: patients might become spatially and temporally disoriented, and might have problems in finding their way home, or they could forget to accomplish tasks. As a result of the memory function impairment, patients suffering from MCI might follow strange trajectory patterns and wander.

Amongst all symptoms related to MCI, namely memory loss, disorientation, wandering, anxiety, etc. Wandering is one of the most frightening for relatives and carers. People that wander might easily get lost and, as a result, they could put their lives in jeop-

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ardy. In this article, we focus on detecting wandering/disorientation patterns in trajectories gathered by GPS-enabled mobile phones.

The rest of the article is organised as follows: Next, in Section 2 we provide some basic background and an overview of related work. In Section 3 we introduce our method to detect wandering and disorientation and show that there exists a relation between the amount of randomness in trajectories and the appearance of abnormal patterns. Next, in Section 4 we describe our initial experiments with real patients and provide an illustrative example with real data. Finally, the article concludes in Section 5 with some final remarks and lines for further research.

2 RELATED WORK

Research related to the provision of health services by means of electronic devices is very wide. With the aim to provide the reader with a basic background, in Section 2.1 we elaborate on electronic health (e-health) and mobile health (m-health), next in Section 2.2 we recall the SIMPATIC Project to illustrate a novel and recent initiative to provide intelligent monitoring of people with MCI.

2.1 e-Health and m-Health

The healthcare sector has adopted the so-called information and communication technologies (ICT) and, as a result, the concept of electronic health (e-health) (Eysenbach, 2001) appeared. e-Health is contributing to the reduction of costs and the increase of efficiency. ICT might be used for a variety of health-related tasks, namely communication between patients, doctors and carers, distant provision of care, remote support to diagnostic, EHR, medication adherence control, etc. e-Health substantially reduces the displacements of professionals and patients, globally brings down the cost of medical resources, and makes treatments and health watchfulness more comfortable to patients.

After the consolidation of e-health, the generalized utilisation of mobile devices with GPS, or other self-localisation capabilities, (*e.g.*, smartphones) gave birth to the idea of mobile health (m-health). There is no doubt about the huge potential of m-Health since it adds to the advantages of e-health all the benefits related to the ubiquity of mobile devices (*i.e.*, global monitoring capabilities, wide availability and immediacy).

Mobile health (m-health) can be defined as the discipline founded on the use of mobile communication devices in medicine, or more specifically, the delivery of healthcare services via mobile communication devices, or: "Emerging mobile communications and network technologies for healthcare systems" (Istepanian et al., 2006). The use of mobile devices helps to perform tasks more efficiently. Especially the remote monitoring of patients and the communication between professionals, relatives and patients will highly benefit from m-health. m-Health extends the capabilities of indoor monitoring environments and it is a powerful tool that allows the advance of several lines of research, namely the continuous assessment of the state of patients, the early detection of emergency situations, the detection of changes in health conditions, the detection of abnormal situations, the early detection of fragile situations, etc. Some interesting examples of m-health applications can be found in (Solanas et al., 2013)(Postolache et al., 2012)(Foundation, 2013).

2.2 The SIMPATIC Project

It is apparent that continuous surveillance can help people with mild cognitive impairments (MCI) and dementia but, current methods have several limitations: (i) surveillance could be seen as a serious privacy invasion (Martínez-Ballesté et al., 2013), (ii) monitoring is not autonomous and, (iii) abnormal behavioural patterns are neither analysed nor detected.

With the aim to avert some of these limitations, the SIMPATIC project (Martínez-Ballesté and Solanas, 2014), has developed a new intelligent and autonomous system that monitors the location of patients, who suffer from MCI. Figure 1 shows some screenshots of the SIMPATIC Project web-based control environment.

The system behaves autonomously (without the need for user intervention) and also intelligently (*i.e.* it learns from the users and adapts to their behaviours), also it is able to detect abnormal users' behaviours. In addition, the system reacts to risky situations, namely the user is in a dangerous area (*e.g.* the edge of a cliff), he/she is not moving for a long time, he/she is wandering, etc. The SIMPATIC Project, which is currently ongoing, is collecting location data from several patients diagnosed with MCI. Specially, it is focussed on people diagnosed with GDS-3 and GDS-4[1].

3 WANDERING ANALYSIS

The act of wandering is defined as walk or move in

[1] Global Deterioration Scale (GDS)

Figure 1: Screenshots of the web-based control interface of the SIMPATIC Project. From top to bottom: Users registration page, Trajectory monitoring and filtering page and, alarms log page.

leisurely or aimless way or, travel aimlessly through or over an area. This behaviour appears in people with MCI and, if it is properly detected, it could alleviate further risks of suffering serious injuries as a result of the disorientation. Our main aim is to propose an automatic method that can detect wandering by means of analysing the mobility patterns of monitored patients.

Our assumption, that we aim to discuss next, is that trajectories that contain wandering patterns have more randomness than trajectories free of wandering or disorientation. Next, we discuss the rationale behind this assumption and we propose a method to analyse the degree of randomness of a trajectory by means of graph cycles analysis.

3.1 Rationale

Impairments in memory function, typical in people with MCI, could translate into abnormal mobility patterns, for example, patients will follow strange paths to reach their homes, or they will go to the supermarket more frequently (because they forget to buy what they need).

These abnormal mobility patterns can be seen as short-length cycles present in the trajectories of patients (*e.g.* disoriented patients going home might walk around their block until they find the right entrance). On the contrary, trajectories that are clearly guided (*i.e.* without disorientation) will have long cycles (*e.g.* patients leave their home, go to the cinema, and go back home).

Thus, our goal is to design a system that allows us to detect the percentage of short and long cycles in the trajectories of patients. Then, if our system detects short cycles it could raise a wandering alarm.

3.2 Wandering and Randomness

With the aim to shed some light over our assumption, we have simulated several trajectories with a variable amount of randomness, and then we have analysed the number and length of the cycles found in those trajectories.

Figure 2 shows three trajectories that we will use as examples to illustrate our point. In the first trajectory (Figure 2-left) we have defined three locations and we have simulated a regular, deterministic way to reach them and go back to the origin. Since we are considering a regular squared grid, at every given location, the next move is selected amongst 8 possibilities so that the distance to the destination is minimised. In the second trajectory (Figure 2-centre), at each step of the trajectory, we have a 0.5 probability of choosing a random move and 0.5 probability of moving like in the first trajectory. Finally, the third trajectory is completely random (*i.e.* at every step of the trajectory, the next move is chosen uniformly at random from the possible eight options).

Once the three trajectories are simulated, they are represented as a graph $G = \{V, E\}$. Where V, the vertexes, are the center of each cell of the grid and E, the edges, are the transitions from one cell to the next.

After creating each graph, we apply an algorithm to determine the number and length of Eulerian cycles. This way, we detect cycles of length[2] 2, 3, ... and we count how many cycles of each length are found. This information if plotted in Figure 3.

[2]The lenght is measured as the number of nodes in the cycle.

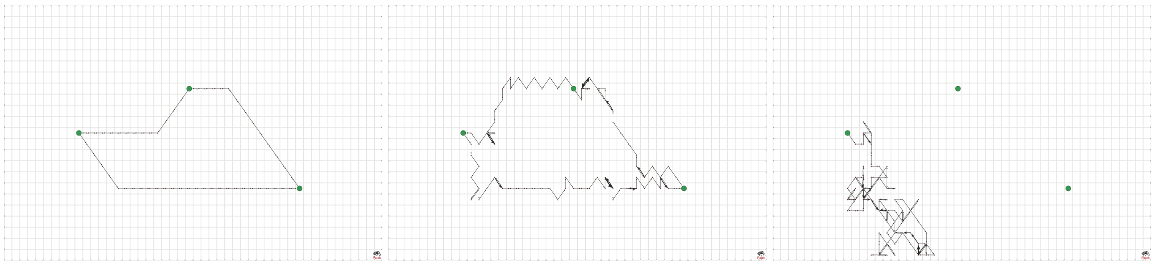

Figure 2: Simulated trajectories. From left to right: deterministic trajectory, semideterministic trajectory with 0.5 random probability and, random trajectory.

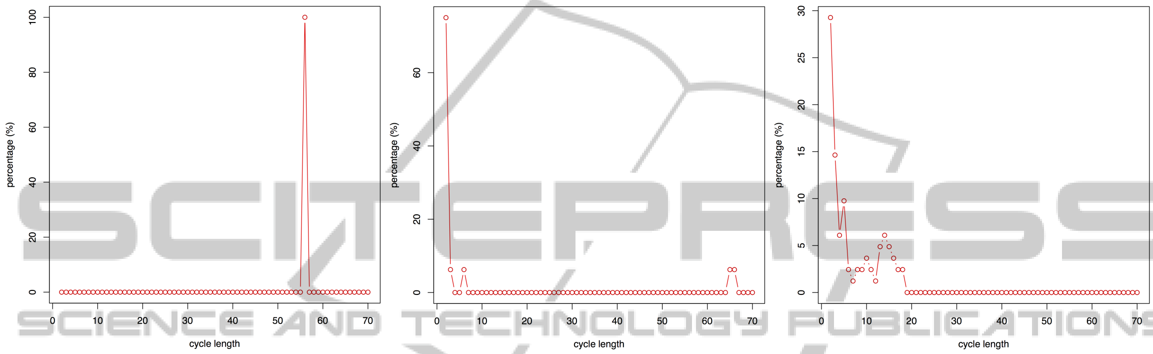

Figure 3: Percentages of cycles depending on their length. From left to right: cycles for the deterministic trajectory, cycles for the semideterministic trajectory and, cycles for the random trajectory.

It can be observed that the first trajectory (with 0 probability of randomness) has a single cycle with a length of 56 steps. Thus, 100% of cycles are long. In the second case (with 0.5 probability of randomness), there is a large number of cycles of short length (90%), whilst only 10% are long. A similar result is obtained with the third trajectory (with 1 probability of randomness) and 100% of the found cycles are short.

From these preliminary experiments, it could be inferred that adding randomness to a guided trajectory leads to an increase in the number of short cycles. Thus, although it has not been proven with statistically sound experiments, we aim to use our assumption to detect wandering by analysing the percentage of short cycles in a graph.

4 INITIAL RESULTS WITH REAL PATIENTS

With the aim to test our proposal with real patients (within the SIMPATIC Project), we have collected the trajectories of people diagnosed with MCI and we have analysed their behaviour. To do so, we have selected a group of 15 people aged from 65 to 83 diagnosed with MCI (GDS-3, GDS-4). Each patient has been provided with a mobile phone equipped with GPS and a data plan to send their data to our central server every three minutes. The procedure illustrated in Figure 4 works as follows:

First, our server receives raw data from the patients' smartphones every three minutes and stores them in a MySQL database. Each packet of data contains the latitude and longitud provided by the GPS, a time-stamp, the values of the accelerometers, the state of the smartphone battery and the temperature. Next, every 15 minutes the data are converted from the operational MySQL database into a strategic PostGIS database with a PHP script. Once we have the information in the PostGIS database, we study it and we find the number of cycles of the patient's route with a Java program and an API library (designed ad-hoc). After obtaining the results, they are sent for visualisation and further analysis to three different outputs, namely a web viewer to use OpenStreetMaps, R to plot the results of cycles and Pajek to plot the resulting graphs, *G*, of the trajectories.

For the sake of clarity we include an example of the results obtained with a real patient. In Figure 5 (left) we show a trajectory followed by a patient during 3 days in the area of Tarragona. Figure 5 (right) depicts the graph created by our system. This graph is analysed to determine the number and length of cycles and the results are shown in Figure 6 (20x20 meters cells are considered).

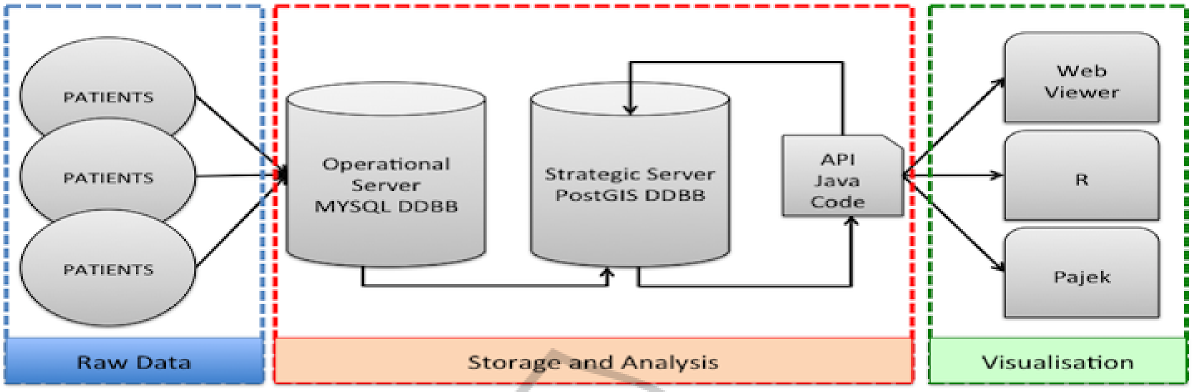

Figure 4: Data flow scheme of our proposal. First the raw data are collected from patients, then they are stored and analysed in our servers, and finally the data are visualised in Open Street Maps, R and Pajek.

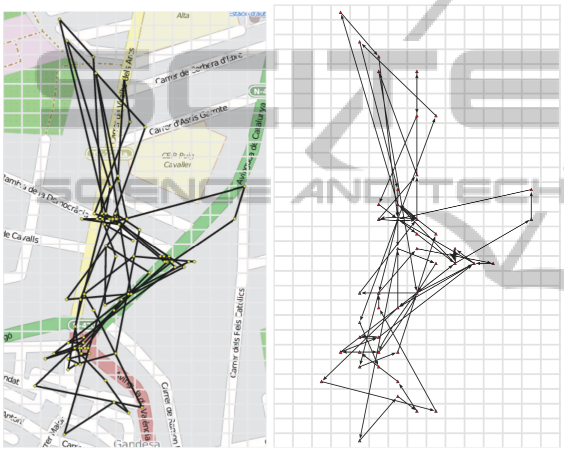

Figure 5: Trajectory and graph of a real volunteer patient of the SIMPATIC project pilot test.

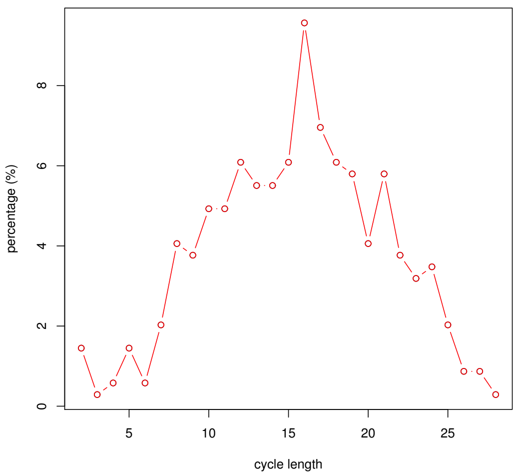

Figure 6: Results of the cycles analysis of the above trajectory/graph.

It can be observed that the percentage of short cycles (under 7, 8 steps) is very low and most of the detected cycles have lengths between 12 and 18 cycles. These results indicate that the patient behaved normally during the analysed days, which was confirmed by directly asking the patient.

At the time of writing this article, we are still collecting data and the pilot test is ongoing. However, to the date, the system has been able to properly identify alarms and the initial results for wandering detection (as stated in this article) seem very promising.

5 CONCLUSIONS AND OPEN RESEARCH LINES

Wandering is a serious problem for people suffering from MCI and first stages of dementia. In this article we have proposed the idea of studying the existence of wandering behaviours by means of analysing the randomness of the trajectories by counting the number of Eulerian cycles and their lengths.

Although there are still many techniques to be studied and compared (Lin et al., 2014), the experimental results support our claim that there is a relation between the amount of randomness and the presence of wandering. Also, it has been shown that there is an initial evidence to think that the percentage of short-cycles in a graph might be a good indicator of the randomness of a trajectory.

Currently, the presented solution is used in a pilot test within the context of the SIMPATIC project with volunteers in the Tarragona area. Although the project is already providing interesting results and a good service to patients and carers, there are many open research lines that will deserve further study in the years to come and are briefly listed as follows:

- **Tuning the System.** Although the proposed solution is operative and is currently being tested with real patients, there is still a lot of work to do to improve its resilience. Also, there are a number of parameters that have to be carefully tuned. It would be desirable to have an automatic system that determines the values of these parameters and adapts them to the needs of each patient.

- **The Smart Health Paradigm.** The process of urbanisation is concentrating most of the population in cities. Those cities that are hosting a very demanding population need to improve their way of managing resources to guarantee a proper and sustainable living. As a result, smart cities have appeared (Pérez-Martínez et al., 2013). The use of ICT in smart cities aiming at improving a variety of services and providing new solutions has gained importance. It seems natural that also health services might be offered within the context of a smart city: intelligent systems fed with data collected from sensors, users and mobile devices, etc, pave the way for the emergence of new services related to health and well-being. Hence, the concept of smart health (s-health) arises (Solanas et al., 2014). Using the sensing and context-aware infrastructures of smart cities allows the collection of personalised data that will help to improve our system.
- **Recommender Systems.** Using the experience of other users/patients to predict the behaviour of new patients is an interesting new approach that will be used by our system in the near future. Collaborative Filtering (Casino et al., 2013b)(Casino et al., 2013a) systems are good candidates to be studied and we plan to use them to predict possible erratic behaviour of patients.
- **Psychological Analysis.** Although our system is centred in patients. We are very much interested in the benefits that it can provide to carers and relatives. At the time of writing this lines, we are analysing which are the effects of using our system on the reduction of anxiety and stress of carers and relatives. Preliminary results indicate that carers feel less stress because they trust the system that allows them to locate patients if they get lost or disoriented. Further studies have to be carried out to confirm these initial findings.

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