A Framework of Real-time Wandering Management for Person with Dementia

Ashish Kumar
Joint NTU-UBC Research Centre of Excellence in Active Living for the Elderly (LILY)
Nanyang Technological University
50 Nanyang Avenue, Singapore
(65) 8679 7268
ashish007@e.ntu.edu.sg

Maode Ma
School of Electrical & Electronic Engineering
Nanyang Technological University
50 Nanyang Avenue, Singapore
(65) 6790 4385
emdma@ntu.edu.sg

Chiew Tong Lau
School of Computer Science and Engineering
Nanyang Technological University
50 Nanyang Avenue, Singapore
(65) 6790 5047
asctlau@ntu.edu.sg

Syin Chan
School of Computer Science and Engineering
Nanyang Technological University
50 Nanyang Avenue, Singapore
(65) 6790 5748
asschan@ntu.edu.sg

ABSTRACT

Recently, several solutions have been designed to detect and identify the wandering patterns for Person with Dementia (PwD). Thus, many applications have been developed which collects Spatio-temporal and contextual information from the environment. These data have not been fully utilized to its potential. The data were mainly used for the simple pattern recognition. The long-time benefit which can arise by properly managing, storing and analyzing these data has not been realized. We propose a framework for wandering data management and analytics tool which can be beneficial to the patients, caregivers as well as researchers. In this paper, we first present a novel system architecture and then discuss its key components with the integration into the system. We use web API standard for the implementation of the services. Security also forms an integral part of our design in dealing with sensitive medical data. We also demonstrate the feasibility of the system with sample analytics such as "*trend in the wandering pattern*" which has been done on the real-world dataset. We have done the analysis on the daytime movement data of a patient residing in Assisted Living Facility (ALF).

CCS Concepts

•**Human-centered computing~Ubiquitous and mobile computing systems and tools • Software and its ngineering~Development frameworks and environments** • Information systems~Spatial-temporal systems • Applied computing~Bioinformatics • Computing methodologies~Feature selection

Keywords

Wandering in dementia; Wandering management; Spatio-temporal data analysis; System design for wandering management; Web API design framework for wandering; Features of wandering

1. INTRODUCTION

Dementia is a group of symptoms which is associated with impaired human memory, difficulty in communication and reduced cognitive ability. Wandering behavior is a frequent characteristic of persons with dementia. Over the age of 60 years, more than 5% of the people are estimated to suffer from dementia [5]. Wandering is becoming a significant issue now, given the large numbers of adults entering old age. Even at the early stages of dementia, a person can become disoriented and confused for a period. It may result in wandering and getting lost, elopement or injuries and in some cases death due to falling [1].

Detection and management of wandering forms the active part of research recently. A system to detect wandering from the GPS traces of a person in real time is quite accurate and can be ubiquitous [8]. The device does not provide any contextual information about wandering e.g. place and time of the wandering. This information can give extra insight into the nature of wandering and proper management techniques can be implemented. Navigation traces also have features such as intensity of randomness, average path length and total time spent in wandering, etc. Randomness intensity can be captured as the measure of tortuosity (Fractal-Dimension), which is a significant predictor of dementia [6]. iWander [12], is an Android based application which predicts wandering from the data collected from a mobile sensor and sends the notification to the caretakers. Here, there is no provision that these valuable data can be stored for future use and data mining techniques can be applied to find some wandering trends. There is also no provision for report generation of navigation pattern for the dementia patients.

We have reviewed several wandering management tools and propose the following improvement which can be applied to the existing solutions:

- **Improvement I1**: Management of spatio-temporal and contextual information collected from sensor devices for future use.
- **Improvement I2**: Development of algorithms to generate the exhaustive list of features of wandering for the task of data mining and analysis.
- **Improvement I3**: Development of reporting tool which can produce a long-term report on wandering, and generates actionable interpretation from the data.

Relating to our first proposed improvement **I1**, we have found that in the last two decades, significant progress has been made in pervasive computing technologies which have made possible the fast, easy and efficient deployment of sensor devices in the environment. Recently, there has been a flood of available sensor data due to the widespread use of these devices. But the management of these critical data is still not explored to its full potential. Apart from the navigational data each patient also has clinical report such as Mini Mental State Examination (MMSE) or Revised Algase Wandering Scale (RAWS), which are updated periodically based on the suggestion of the physician. Combining these two types of data to give us insight into the dementia progression is the goal for our future research.

Sensor devices can also capture the contextual information such as spatial, temporal or vital signs relating to the situation. The information such as place, time and intensity of wandering can play a crucial role in the design of the environment which can restrict wandering. Researchers have found that certain geographical layout can intensify wandering [10]. If some physical layout in ALF shows abnormal wandering episodes, sign card can be used to help patients to prevent wandering. For some patients, wandering episodes intensify at a time of day. This information is also critical in the diagnosis of dementia.

The improvement **I2** and **I3**, suggest improving the system from the data analytics perspective. We could identify some features in the navigation which correlate significantly with the dementia progression. Calculation of these features over a period and then analyzing the trends can be very insightful in deciding the course of medication for the physician. It will also help in identification of abnormal situation which might not be readily detected without the aid of proper analytics tool. It forms the part of our ongoing research. We also propose to create a reporting tool for wandering which the physician or caretakers can generate on the fly. Finally, a toolbox which can be coupled to location tracking data to facilitate analysis will be of great help in hastening research in this area.

In our preliminary study, we have collected the indoor/outdoor navigational data of real patients and classified them into navigation patterns as suggested by Martino-Saltzman [9]. This classification is based on the geographical region and is the prevailing strategy used by researchers studying wandering. For the latter part of our study, we are analyzing the navigational patterns of PwD over a longer duration of time, e.g. one year, to isolate trends in the features associated with wandering such as path-efficiency, and fractal-dimension of the path. If significant differences in the trends between PwD and non-PwD patient groups are found, then these features can be monitored longitudinally to gain a better understanding of the progression of dementia. Our preliminary analysis of the trends in the statistical features of navigation for PwD suggests the existence of such differentiation.

Our goal is to develop a framework for the real-time wandering management and analytic tool for dementia patient (RT-WMAT). This can alleviate the pain in elderly care. It aims to help doctor, caregivers and family member by providing a tool to understand the nature of wandering. We also aim to make it easy for physicians to study the change in patterns of wandering by trend analysis over a longer duration. This information can be very useful in deciding the course of medication in future and can add an extra dimension to the care of dementia patients. We will propose the key design components of the framework. This is the part of our ongoing project and the detail implementation and evaluation of the system will be left for our future work.

2. PRELIMINARIES

Using the typology of travel pattern as devised by Martino-Saltzman [9], navigation episodes can be divided into four basic categories direct, random, lapping and pacing. Out of these four, all the patterns except direct is considered as wandering. The random pattern has been associated with the loss of cognitive function [2] but still there is no enough empirical evidence to characterize lapping and pacing pattern. Lapping is less related to the loss of cognition and followed by a short span of rest after the episodes. It occurs when the distance between targets is more and these patterns vanishes once this distance is reduced. Pacing is perceived as a sign of agitation or anger and correlates very poorly with cognitive loss. It may be a considerable point of interest to know, how these patterns for a person changes over time.

Wandering correlates significantly with the cognitive factor [4]. Due to the loss in cognition person lose track of place and time. The spatial and temporal disorientation aids to the onset of wandering movement. Some tool restricts wandering by generating alerts when a person moves out of the permissible area. These devices are restraining in nature and do not allow the person to move freely. There are adverse effects of restraints on nursing home residents, which include agitation, infections, and physical deconditioning [3]. Another set of devices is in the form of video/camera surveillance, where the patient is monitored round-the-clock. Implementation of this technology will overshadow their right to privacy [11]. With the onset of the inertial sensor for monitoring wandering, the privacy concern is less, but it still does not comply with all the wandering management requirements.

We have used grid-based layout representation to represent the navigation path and have used the algorithm as described in [7] to identify these patterns. A grid-based representation of the layout provides us the flexibility to calculate many features such as path efficiency, speed, angle turn per unit distance, etc. The algorithms have shown promising results in terms of identification accuracy, speed and performance on a real-world dataset.

3. SYSTEM ARCHITECTURE

To achieve the goal, we propose the solution as a server-client distributed architecture. The server acts as the providers of resource and services and a client is the requester of these services. The architecture allows the multiple clients to connect simultaneously. It is highly scalable and role based security in terms of authentication and authorization can be easily implemented. It also provides better data sharing opportunity.

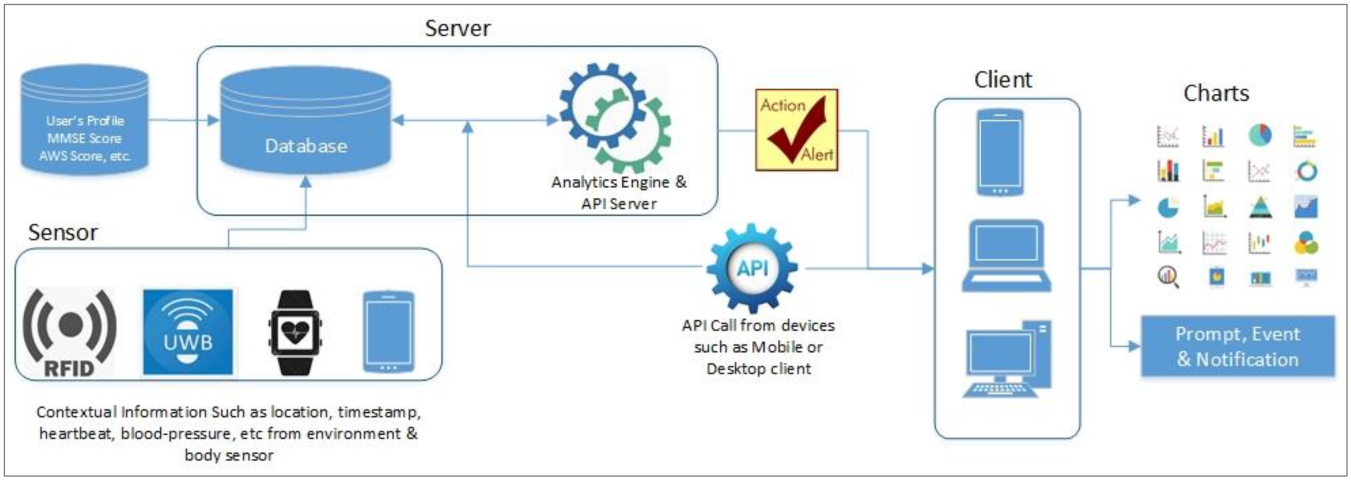

Figure 1: Overall System Architecture (RT-WMAT)

We propose to develop an end-to-end system for all the operations associated with wandering management. Figure 1 shows the overall system design. There are three components of the system. Sensor devices provide the way to collect spatio-temporal and contextual data from the environment. The centralized server is the place where all the processing takes place. The client requests for services to the centralized server.

3.1 Sensor

Sensor technologies used in this field are RFID, UWB, Inertial sensor, etc. These sensors can be either embedded in the environment or can be carried by the individual in the form of smartwatch or smartphone.

Sensor devices used for the indoor and outdoor devices are different. Outdoor logging device such as GPS does not act well in the indoor environment. For outdoor scenarios, we have collected data from GPS and cell tower using GPSLogger for Android. The app can stream data in real-time. The indoor navigation data was gathered by a Ubisense, Inc. Ultra-wideband (UWB) radio research pack. Before the data is stored in database initial processing such as noise removal and compression is done. Initial processing on the data has been discussed in the paper [7].

3.2 Centralized Server

This forms the heart of our system. We can divide the server into three major sub-components:

3.2.1 Data Store:

Data store is a central repository for the profile of the patient. It contains the user's demographic information and various dementias/wandering-related test results. These records are updated based on suggestions by doctors. A stream of locomotion data along with contextual information is stored in corresponding patients' profile. Locomotion data from the sensor can either be streamed in real time or in batches. To study the feasibility of the system, we have used batch processing. This method has been preferred as it is very easy to implement and preserves the computing power of the server. Sensors do not have to be connected to the server at all the time. We have used MongoDB NoSQL database to store all the information. It is fast, secure, reliable, and highly scalable.

3.2.2 API Engine:

An Application Programming Interface (API) allows the client such as smartphone or desktop to make use of the functionality of user authentication and authorization, database query and call to essential services. It provides a consistent, programmatic method for accessing a resource; it is a structured way of exposing algorithmic functionality to be used by a client.

We have identified the key services which are necessary for the wandering management. We abstract the service from the internal implementation of the algorithm. The API calls are made using HTTP methods such as GET, POST, UPDATE, DELETE etc. If there is a requirement to add new services, it can be easily done on the fly without affecting the older services. The analytics engine hosts the services for identification of wandering pattern, calculation of statistical features and analysis of trends. All services are handled through the API call from a client to the server.

3.2.3 Webhooks for Alert generation:

One of the important aspects of wandering management is to be aware of the abnormal and critical situation of the patient. Services running on the server can alert of any discrepancy in a situation or in cases of abnormality in the wandering pattern. It can generate alerts to caretaker and doctor and it may also suggest some clinical test such as MMSE to better understand the situation. The alerts have been implemented in the form of webhooks, these are URL address which a client can subscribe to and server can push the alerts and notification on this address.

3.3 Clients

A host of devices such as desktop or smartphone can act as a client for generation of charts using API calls to the server or receiving prompts through webhooks. The client is authenticated, and access permission is granted based on the user privilege. This prevents the data abuse from unauthorize the user. We propose to use OAuth 2.0 for users credential management. For the new client to connect to the server, profile for the client must be created by a user having administrative privilege.

4. IMPLEMENTATION AND EVALUATION

4.1 Implementation

For this experiment, we have used the navigational data of a single patient (MMSE: 6) residing in day care facility over a period of one year. During daytime when in motion, tags transmitted x, y, and z coordinates in centimeters at 0.43-second intervals with a time-stamp. The source of the data has been described elsewhere [6]. The Institutional Review Board (IRB) of the University of South Florida approved the study protocol #106249 'Locomotor Variability in ALF Residents with A/D MCI', after determining it qualified for expedited review and constituted no more than minimal risk to human subjects.

We have conducted a preliminary experiment to ascertain the feasibility of the system. In this experiment, we aim to show some of the important aspects of wandering which can be generated from the analysis of the navigational data. These results can be generated on the client side through API call to the server. With our novel approach to the wandering pattern detection and development of a new set of the grid-based algorithm, it is now possible to detect wandering with high accuracy and to calculate the statistical features automatically in real-time. Contextual information about wandering such as place, time, and environmental factors which are likely to trigger wandering can also be identified.

We have developed three categories of algorithms specific for the purpose. I*ntensity-analysis* algorithm on the features can report the quantitative aspects of these features. Suppose we want to generate alert for the person whose amount of wandering increases above certain limits, these algorithms can generate a report on the intensity of selected features. The second categories, called *trend-analysis* algorithm can identify linear trends in the features derived from navigation pattern. An example of the trend can be a study of increase/decrease of random motion over a long duration of time. The third categories of the algorithm can perform *cause-effect analysis.* For this analysis, we perform the chi-square test on the mean of the features to find any significant change. It can be useful if we want to check the efficacy of some procedures by analysis the change in some features before and after the application of the procedure.

4.2 Results and Discussion

For the first part of the analysis, the spatio-temporal data has been categorized into four navigation patterns as shown in Table 1. The daytime has been divided into four time-slots and percentage of the patterns have been calculated for each time-slot. For total of a 302 days of data, mean has been calculated corresponding to each time-slot and represented in the tabular form.Figure 2 shows the corresponding plot of these patterns. The plot shows that as the day progresses, the percentage of the direct pattern decreases whereas random patterns increase. Lapping and pacing are minuscule fractions of all the navigation motion and does not change significantly.

For the next part of the analysis, we grouped days into months and calculated four features of navigation namely, *ambulation fraction*, *speed of movement*, *path efficiency* and *angle turn* per unit distance traveled for each month.

Table 1. Percentage of navigational pattern during time of day (ToD)

Pattern\ToD	00:08-11:59	12:00-15:59	16:00-19:59	20:00-23:59
Direct %	72.16	55.14	51.16	45.42
Random %	22.51	39.96	43.95	49.05
Lapping %	05.07	02.60	02.93	02.60
Pacing %	00.25	02.30	01.96	02.93

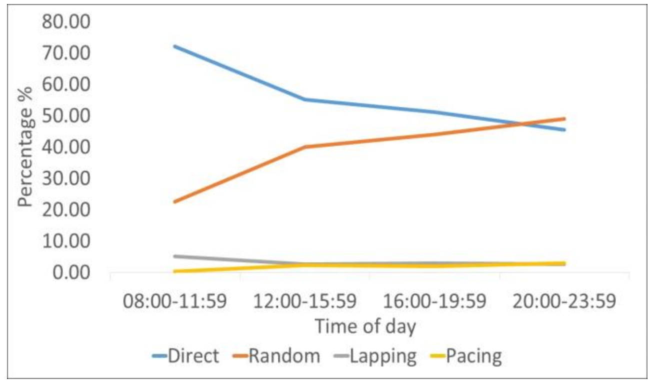

Figure 2: Trend in navigation pattern

Figure 3 shows the plot of the mean of these features along with trend line. We have used one-way ANOVA to compare means of these parameters, grouped in months in chronological order. We have used linear contrast to find the existence of trend if any. It has been found that there is a significant linear trend in features *ambulation fraction, path efficiency* and *angle turn* (Figure 3.a, 3.c, 3.d). While linear trend saw not significant for *speed of movement* (Figure 3.b). *Ambulation fraction* and *angle turn* were found to be increasing over time. It may be that the person's dementia condition has deteriorated over this period, this can be confirmed from the MMSE score at the later stage.

In the previous study [6], it has been found that parameters such as Fractal-Dimension correlate significantly with the cognitive state of dementia patients. *Trend analysis* of these parameters over a longer duration of time can be used to ascertain the efficacy of medication or procedure to restrict wandering and it can also help in deciding the proper intervention process. It can also help in better decision-making capability using *cause-effect analysis* on each individual subject.

5. CONCLUSION AND FUTURE WORK

Dementia not only affects the person diagnosed with the disease but also the entire family and caregivers. There has been a surge of wandering management tools and navigational data, most of them work on methods to prevent or restrict wandering, but there has been no tool which can analyze the various factors which may lead to wandering. Analysis of these factors tailored to the individual cases can give more insight into the very nature of wandering.

In our future study, we intend to test our system in real-time with more number of cases and examine the overall performance of the system across multiple individuals with different patient characteristics. This will also advance the science of wandering management by giving researchers a tool to understand its nature and giving them flexibility in the design of their research processes. Hospitals, nursing home and assisted living facility would be the primary beneficiaries of this research. Our aim is to provide a tool which can be reliably used by medical and data scientist to understand the nature of wandering better.

6. ACKNOWLEDGMENTS

This research is supported by the National Research Foundation, Prime Minister's Office, Singapore under its IDM Futures Funding Initiative.

The authors also gratefully acknowledge contribution of Dr. William D. Kearns from College of Behavioral and Community Sciences, University of South Florida for providing the data.

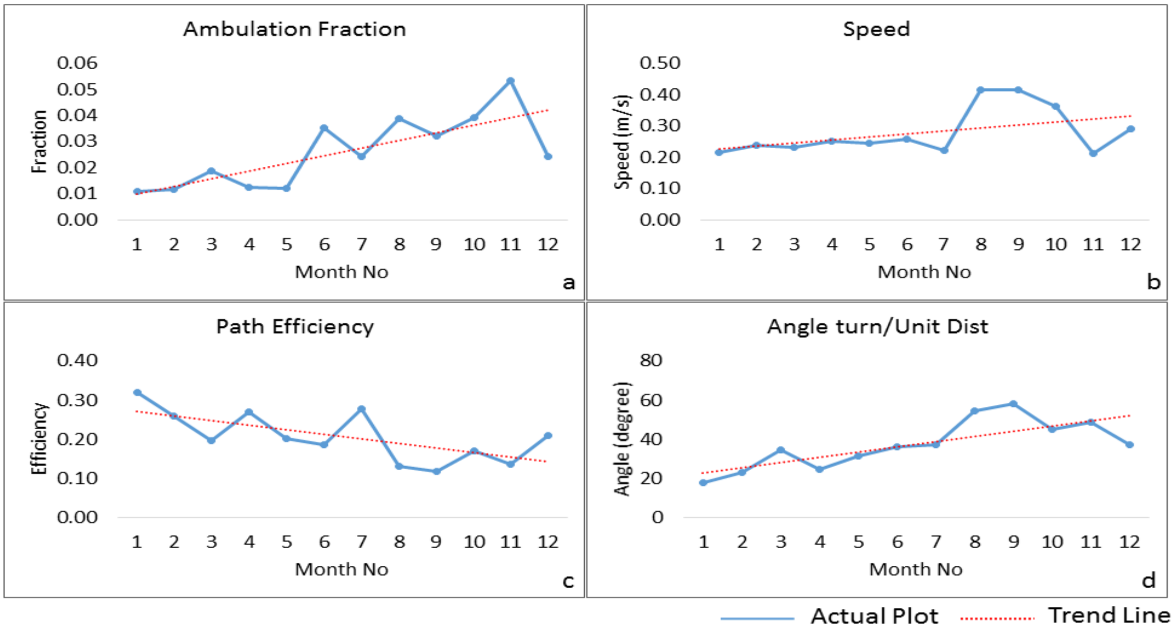

Figure 3: Plot of the important features of navigation along with linear trend line

7. REFERENCES

1. D L Algase, D Helen Moore, C Vandeweerd, and D J Gavin-Dreschnack. 2007. Mapping the maze of terms and definitions in dementia-related wandering. *Aging & mental health* 11, February 2015: 686–698. https://doi.org/10.1080/13607860701366434
2. Donna L Algase, Elizabeth R A Beattie, and Barbara Therrien. 2001. Impact of cognitive impairment on wandering behavior. *Western Journal of Nursing Research* 23, 3: 283–295.
3. Elizabeth Capezuti. 2004. Minimizing the use of restrictive devices in dementia patients at risk for falling. *Nursing Clinics of North America* 39, 3: 625–647.
4. Roee Holtzer, Ming-Xin Tang, D P Devanand, Steven M Albert, Domonick J Wegesin, Karen Marder, Karen Bell, Marilyn Albert, Jason Brandt, and Yaakov Stern. 2003. Psychopathological features in Alzheimer's disease: course and relationship with cognitive status. *Journal of the American Geriatrics Society* 51, 7: 953–960.
5. Thorlakur Jonsson, Jasvinder K Atwal, Stacy Steinberg, Jon Snaedal, Palmi V Jonsson, Sigurbjorn Bjornsson, Hreinn Stefansson, Patrick Sulem, Daniel Gudbjartsson, Janice Maloney, Kwame Hoyte, Amy Gustafson, Yichin Liu, Yanmei Lu, Tushar Bhangale, Robert R Graham, Johanna Huttenlocher, Gyda Bjornsdottir, Ole A Andreassen, Erik G Jonsson, Aarno Palotie, Timothy W Behrens, Olafur T Magnusson, Augustine Kong, Unnur Thorsteinsdottir, Ryan J Watts, and Kari Stefansson. 2012. A mutation in APP protects against Alzheimer/'s disease and age-related cognitive decline. *Nature* 488, 7409: 96–99. Retrieved from http://dx.doi.org/10.1038/nature11283
6. William D. Kearns, James L. Fozard, Vilis O. Nams, and Jeffrey D. Craighead. 2011. Wireless telesurveillance system for detecting dementia. *Gerontechnology* 10, 2: 90–102. https://doi.org/10.4017/gt.2011.10.2.004.00
7. Ashish Kumar, Chiew Tong Lau, Syin Chan, Maode Ma, and William D Kearns. 2016. A Unified Grid-based Wandering Pattern Detection Algorithm. 5401–5404.
8. Qiang Lin, Daqing Zhang, Xiaodi Huang, Hongbo Ni, and Xingshe Zhou. 2012. Detecting wandering behavior based on GPS traces for elders with dementia. *2012 12th International Conference on Control, Automation, Robotics and Vision, ICARCV 2012* 2012, December: 672–677. https://doi.org/10.1109/ICARCV.2012.6485238
9. D Martino-Saltzman, B B Blasch, R D Morris, and L W McNeal. 1991. Travel behavior of nursing home residents perceived as wanderers and nonwanderers. *The Gerontologist* 31, 5: 666–672. https://doi.org/10.1093/geront/31.5.666
10. Lynne Mitchell, Elizabeth Burton, Shibu Raman, Tim Blackman, Mike Jenks, and Katie Williams. 2003. Making the outside world dementia-friendly: design issues and considerations. *Environment and Planning B: Planning and Design* 30, 4: 605–632.
11. Alistair R Niemeijer, Brenda J M Frederiks, Ingrid I Riphagen, Johan Legemaate, Jan A Eefsting, and Cees M P M Hertogh. 2010. Ethical and practical concerns of surveillance technologies in residential care for people with dementia or intellectual disabilities: an overview of the literature. *International Psychogeriatrics* 22, 7: 1129–1142.
12. Frank Sposaro, Justin Danielson, and Gary Tyson. 2010. IWander: An Android application for dementia patients. *2010 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBC'10* 2010: 3875–3878. https://doi.org/10.1109/IEMBS.2010.5627669

Columns on Last Page Should Be Made As Close As Possible to Equal Length

Authors' background

Your Name	Title*	Research Field	Personal website
Ashish Kumar	PhD Candidate	Pattern detection, Machine Learning, Activity Recognition	
Maode Ma	Associate Professor	Wireless Networking, Network Security	
Chiew Tong Lau	Associate Professor	Wireless Communications, Cognitive radio network	
Syin Chan	Associate Professor	Multimedia information retrieval, web information extraction, ontology applications and multimedia understanding	

***This form helps us to understand your paper better, the form itself will not be published.**

***Title can be chosen from: master student, Phd candidate, assistant professor, lecture, senior lecture, associate professor, full professor**