Agents and Dementia — Smart Risk Assessment

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Abstract This paper describes an early stage of applied research primarily concerned with the development of mobile, wearable and other smart technology to assist people with mild to moderate symptoms of dementia. With safety and security paramount, the primary objective is to prolong independence of the person with symptoms and provide an element of relief to families from what can become a full-time burden of care. Intelligent agents recognise activity, its context, risk and subsequently, in the worst case act to recover persons who wander or become lost. Initial results indicate that constant activity monitoring without ethically controversial tracking is possible without the necessity of invading privacy. The small-scale participatory study will incorporate real-world needs of a recruited user group into the design of a research prototype.

Keywords: Dementia, Assistive technology, Activity recognition, Multiple Agents, Ambient Healthcare, Ambient Assistive Living

1 Introduction

'Dementia' describes a collection of symptoms that result from damage to the brain due to a number of conditions, the most common of these is Alzheimer's disease [1]. Only 43% of persons with dementia (PwD) are diagnosed [2], but in 2015 the number of people affected was estimated as 850,000 in the UK [3] and over 46.8 million globally. This is predicted to double every 20 years [4].

With an immense impact on PwD and their families [5], common symptoms include memory loss, difficulty remembering routes and becoming confused in unfamiliar places [6]. Wandering and getting lost is common and can happen during any stage of the disease [7]; it is reported that 40% get lost at some point and about 5% get lost repeatedly [8]. PwD who wander can be in mortal danger, 1% of PwD die while lost and half of those who are missing for more than 24 hours die or are seriously injured. [9,10].

With the emergence of connected smart-devices a unique opportunity to provide individualised care in the community is imminent. Although not well suited to the whole spectrum of symptoms or to all stages of the disease, Assistive Technology (AT), in the right circumstances has the potential to improve the quality of life for PwD and their families [11,12]. The first phase of the project examines selected smart-phones, wearable technology and devices that may, when made bespoke, be made useful to PwD with mild to moderate symptoms

[13]. The project initially focuses on 5% of the affected population who are aged below 65 [14], that is with early onset symptoms.

The hypothesis is that smart technology for monitoring PwD may be used to preserve independence, allow a reduction of carer burden and thus increase the time that they may be cared for in the community. This, it is thought will provide benefits for the PwD, their family unit and the healthcare provider. PwD should be supported to remain independent in their communities for as long as possible [15]. The cost of full time care is significant [16] and this, among other things, can lead to ad-hoc measures being put in place. A full-time burden of care sometimes leads to ill health and a poor outcome for the carer [15,17]. A study in 2010 shows that its particular AT solutions prolonged the ability of PwD to continue living at home by an average of 8 months [18]. In the last 5 months a project test-bed has been established to develop agents on multiple platforms that seek to address what is now a mature ethical and privacy debate.

2 Ethics and barriers to the use of AT

Ethics. Monitoring those who may be considered to be vulnerable has been debated for decades[19,20,8,9,21]. Many people emphasise benefits such as safety, independence and peace of mind [22,23], while others [11,24,25], are concerned that systems that monitor and record an individual's location present ethical and privacy issues. In 2013, when Police in the UK used GPS tracking to recover lost PwD this resulted in an outcry in the media [26], Sky News called it barbaric [27].

In relation to dementia, one dilemma is this: Where is the greater breach of rights? Is it a locked door resulting in the loss of liberty or is it monitored autonomous movement using AT that could lead to loss of privacy [25]? Landau et al. in 2010 [22] made a preliminary analysis of the thoughts of cognitively intact older people that concluded that they favoured the use of AT. McKinstry, in 2013, states that research is required to find the most suitable people that this technology is best suited [28]. In a small participatory study PwD disliked remote monitoring and surveillance, while carers pragmatically prioritised safety [29], it depends upon the 'locus of responsibility' says Landau [22]. With smartphones, the risk of broadcasting the user's location is known [30], but large parts of society are unaware or appear not understand [31]. A lack of digital privacy gives an opportunity for surveillance, 'which may confer control' [32], to a level possibly worse than Orwell predicted [33,34].

Barriers. In 2015 research funded by the UK's Department of Health reported on the case for investment in technology to manage the cost of dementia, they recognised barriers, such as under-developed technologies, a weak evidence base, cost, staff skills and AT awareness [35]. The literature paints a fragmented picture of acceptance of AT by health professionals and shows that potential users are often making their own decisions on this. Lack of evidence [36,35], patient-led learning; the 'DIY' approach and a lack of a single point of access or an authority on the subject to give advice and support are key problems [11,36]. Addressing the issue of a weak evidence base, in 2013 a randomised controlled trial commenced in the UK. It is assessing whether AT will significantly extend the time PwD continue to live independently and safely in their own homes [37].

For PwD, human relationships are the most important thing and AT should only be seen as an aid [11,18]. While it may ease the burden of care and enable independence, a solution should encompass any moral or ethical concerns. We set out to do this through user-centred design and then model validation.

3 Bespoke Prototype Development

Adopting the principles of beneficence and non-maleficence a debate is necessary, but it is currently thought that if the PwD gets into a situation that is not safe, ethical arguments change. A morally acceptable solution is being researched where human rights of privacy and autonomy are pre-eminent, but safety and security are paramount. In the simplest use case, if a PwD is walking outside at midnight and it's $-3°$C, the risk to health is high. The computing capacity of mobile devices and a home-base 'hub' will be used to assess risk of the circumstance in which activity is taking place, activity patterns will be compared those that have been 'learnt' or are otherwise known to be acceptable. Data is gathered and processed directly, initially on a phone, but the mechanisms developed in this research will be applicable in future miniaturised wearable devices. Multiple agents will interact, and location information will only be shared externally if a clear instance of recovery necessitates this.

Invasive tracking of movement by another person is not advocated, but in recovery GPS and Wi-Fi location may be made visible, these sensors will also be used internally to contextualise activity. All data such as activity patterns and location are kept private. Minimal data propagation and encryption will be used to reduce the risk of interception or abuse.

4 Ubiquitous Assistive Technology

Technology develops quickly, but if a solution fails once in this scenario or if it gives false alerts trust will be lost irrevocably. Likewise, if intrusive or unacceptable in use it will not be adopted. Capabilities, strengths and weaknesses of cognitive aids and sensors have been reviewed; concluding that evaluation of these should be evidence based and be carried out in real world settings [38]. Technology, as discussed in expansive studies of Ambient Assisted Living (AAL) and Ambient Intelligence discuss health, safety, security, peace of mind, independence, mobility and social contact. Technical systems that support elderly people and people with special needs in activities of daily living (ADL) are available across Europe [39].

Mark Weiser, often referred to as the father of ubiquitous computing said: "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it"

[40]. In 2016 it may be argued that mobile and wearable technology is already part of everyday life. Tractica in 2015 predicted 12 million 'smart' patches would be shipped in 2020 [41], so technology may in fact become inconspicuous, it may even become part of our clothing [42].

5 Activity Recognition (AR)

The developing field of activity recognition has recently brought about first commercial attempts at wearable devices fuelled by the popularity of keeping fit and healthy. Currently available products are used to inspire and motivate users to live a healthier lifestyle. For this project, selected smart-phones, wearables and suitable in-home products have been evaluated with the potential to those with dementia in mind.

5.1 Activity recognition on a smart-phone

Experiments have shown that the accelerometer on some smart-phones are capable of being used as sensor devices for activity recognition [43]. Software may be used to sense movement [44] and the use of a gyroscope can improve accuracy [45] while other sensors in the phone may contextualise input [46]. The Android Activity Recognition API was selected using a Nexus 5 phone to evaluate these capabilities. Collected data was analysed using PHP and JavaScript leading to very encouraging results. Fig. 1 visualises data from our own experiments using the Google charts API. An agent may analyse this activity on the phone, and on return data is uploaded to a trusted hub on the LAN where learning of 'normal' activities will take place. Visualisation of sequences of events is purely for the purposes of explanation and to assist in the study.

In Fig. 1, initially there was a period of walking and then sitting down. From 17:13 onward, there was a short walk to a car, then driving to a shop and just before 18:00 a return trip back home. Clearly, a sequence of events can be recognised and – when compounded with map data – if the context of the walking between 17:34 and 17:56 is a shop, the whole sequence may be recognised as an instance of 'going shopping'. Since this is not an event that requires intervention (the user successfully did the shopping and returned home), there is no need for an alert and no information will be made visible, hence privacy is preserved.

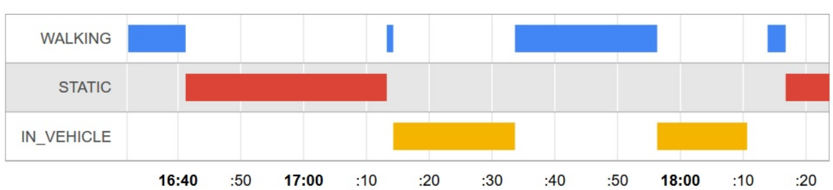

Figure 1. AR Timeline using data from a Smart-Phone

5.2 Activity recognition using Wearable Technology

Technology, in this area is fast moving, commercially available wearable devices such as Fitbit, Basis Peak, Jawbone and Garmin Vivofit, amongst many others allow monitoring of activity and vital signs. Many of the devices come with an open API which means that they may be used for bespoke software development. The Apple ResearchKit and Android Wear SDK are expansive tools that may be used in the creation of a research system.

In 2016 Fitbit have the most significant 'wearable' market share [47], a Fitbit Blaze, Jawbone UP-3 and Motorola 360 '2nd Generation' smart-watch were used for evaluation of the proposed methodology. The sensors within these devices are used to recognise human activity when worn. A comparison of these devices showed significant quantitative discrepancies of, e.g., heart rate and step count. Despite this inaccuracy, the fundamental activity was reliably detected on all devices. Heart rate and sleep are monitored automatically and heart rate may be broadcast from the Moto-360 to a tethered phone giving live measurements. This may be important since agitation is linked with heart rate [48]. Agitation and anxiety are the second and third most common behavioural abnormalities in persons with Alzheimer's disease [49] and this represents a particularly burdensome problem for caregivers, increasing the risk of transition to full time care [50]. Future human stress monitoring may be done with a patch [51].

Sleep disturbances are a common behavioural symptom associated with Alzheimer's Disease [52,53], Increased walking at night corresponds with disruption of diurnal rhythm and is disruptive to ADL [54], it is a major reason for nursing home admission [55]. Over five months of activity was collected using the Fitbit and just over one and a half month's information was gathered using a Jawbone Up3. The recorded sleep activity from both was an accurate representation of actual behaviour. Data, that includes quality of sleep, is available retrospectively to the registered user and can be accessed programmatically through the manufacturer's API. Long term trends in sleep activity may be useful in assessing the risk of night time wandering. Both devices use Bluetooth Low Energy (BLE) [56] for data transfer between the device and a tethered phone, the Fitbit Blaze can be used to track movement outside via the GPS sensor on the phone, but this requires user interaction, hence will not be used in this project.

The Moto-360, a fully programmable Android smart-watch, was selected for its sensors and the possibility of bespoke development. Step count was found to be different from the other devices, but this does not impede the intended use that only requires qualitative AR. It is possible to trigger alerts or reminders, e.g., if it is out of range of a phone, it can be used to find the phone and it responds to voice commands. It can display graphics, photos, or text, and alerts may be with vibration and/or audible. If necessary, the watch may access the internet via a Wi-Fi network.

5.3 Activity recognition in the home

It was envisaged that 'smart-home' equipment may be used to monitor activity while indoors, but due to prohibitively high cost of commercially available

Figure 2. In-home Activity recognition

products and unavailability of APIs, there is currently little prospect of low-cost bespoke development. The Internet of Things (IoT) has for a long time promised to help to meet a considerable number of current challenges such as an ageing society [57]. An extension of this concept, the Physical Web [58], enables seamless interactions with physical objects. 'Nearables' [59] are small and portable BLE devices built on beacon technology [60], information they emit is read by a suitable receiver. Nearables and beacons were evaluated with very good results when placing them on everyday items (see Fig. 2).

This is not a new concept [61], but quantitative measurement of proximity, location and movement may be captured inside and also outside the house. Temperature of a kettle, fridge and cooker for example may be measured through their thermal sensor, as well as the movement of doors or other objects using the built-in accelerometer. A myriad of use cases and activity recognition opportunities may be developed, sensor data can be combined to make compound assertions about the context the person is currently acting in. E.g., if the front door moves, a person goes out of range of a hub and the phone is not moving, it is likely that the person is outside without the phone. Beacons can be placed outdoors or in shops, and can store longitude and latitude. For the purpose of in-house monitoring, a home hub was developed running JavaScript on a low cost single board computer, approximate distance from beacons to the hub may be calculated using received signal strength. These beacons are powered by batteries that have an expected life of up to 12 to 60 months depending upon the type, they are unobtrusive, require no installation apart from placement and are relatively low cost.

Long term data is being collected with a view of learning individual activity patterns and then using these to assess the risk of actions in real time. One example of risk is when cooking takes place, for example the gas is left on [62]. Findings will be discussed with a recruited user group, including PwD, carers, health professionals and an ethics panel. Together they will assist in prioritising real-world needs and will be invited to collaborate in the design of the final prototype that may then be deployed for testing.

6 An Agent-based Architecture

Activity recognition and assessment described above are implemented as a multi-agent system. Depending on the size of the home, there will be a number of hubs, each with its own hub agent. All agents communicate securely on the LAN. Mobile agents are currently implemented on smart-phones. They communicate directly with the hubs when they are within reach of the respective Wi-Fi signal. All agents contextualise sensor data and run algorithms to assess the current risk potential of the person being monitored. It is expected that there will be agents on wearables, this is possible using programmable smart watches and similar wearables due to the possibility of application development for these devices.

A schematic architecture of our system is given in Fig.3. This shows zones in the home, some sensors, hubs and mobile devices. We have modelled this using the Renew tool [63] for Petri nets following the nets-within-nets paradigm [64]. Hub agents and mobile agents are modelled by nets that reside in the Petri net representing the environment, i.e., the respective zone in the home or the current outdoor location. The agents' decision-making components can themselves be modelled as nets within the agent net and data can be transmitted from the mobile agents to the hub agents through channels that become available when the agents are within the reach of a hub.

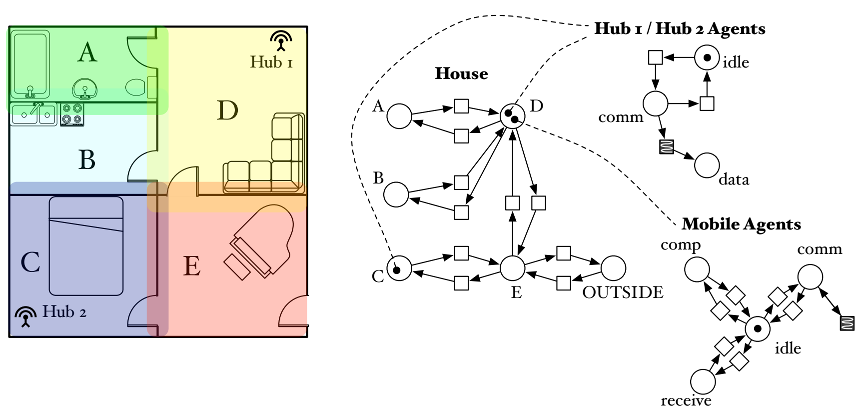

Figure 3. Agent-based design for a home comprising five zones

7 Conclusion

Initial results suggest that, not only is it possible to monitor activity with socially accepted and widely available devices it may also be carried out in an unobtrusive way. Furthermore it is clear already that activity monitoring without invasive tracking is possible without invading privacy. Another key to success is the reliability of agents and their implementation on low energy devices. The former is addressed by formal models for validation of processes involving the agents (such as Petri nets), while the latter is achieved by optimisation of algorithms with respect to the frequency of sensor polling. The user acceptance of any final device will heavily rely on the success of these considerations. Though the current prototype requires the individual to carry a smart-phone, it is thought that advancement in sensors and battery technology will make a final product even more wearable and unobtrusive. Future work is expected to concentrate on the following areas:

- Clarify user requirements within the scope of the project and what is morally acceptable.
- Algorithms for agents to effectively determine risk situations from comparison with normally experienced activity, and dealing with dynamic changes to normal activity due to the nature of the progression of the disease, still considering boundaries to what is safe and ethical.
- Address key viability issues such as reliability, battery consumption, and user acceptance.

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