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Remotely Monitoring and Preventing the Development of Pressure Ulcers with the Aid of Human Digital Memories

Chelsea Dobbins, Paul Fergus, Madjid Merabti, David Llewellyn-Jones

School of Computing and Mathematical Sciences

Liverpool John Moores University

Liverpool, UK

C.M.Dobbins@2006.ljmu.ac.uk, {P.Fergus, M.Merabti, D.Llewellyn-Jones}@ljmu.ac.uk

***Abstract* – There is growing concern, among senior personnel in the National Health Service in the UK, over the increased development of pressure ulcers. The occurrence of pressure ulcers has been attributed to prolong sedentary behaviour. Providing care, for this preventable condition, is costly and time-consuming for patients and medical practitioners. Extra bedside assistance is needed; however, with the workload of medical staff increasing, this is not always practical. In order to prevent the occurrence of pressure ulcers new and novel ways of remotely monitoring patients is essential. An interesting approach worth considering is the use of human digital memories, which provide visual life logs of a patient’s physiological and environmental data. This paper discusses some of the current technologies used within the area and how they might be applied to the management and prevention of pressure ulcers. We have successfully developed a working prototype system to demonstrate the applicability of our approach.**

***Index Terms*—Life logging, Sedentary Behaviour, Human Digital Memory, Sensor, Pressure Ulcer**

I. Introduction

Pressure ulcers or bedsores are a debilitating and chronic wound, often occurring in elderly patients and those with physical impairments [1]. They form when sustained pressure is placed on a particular part of the body and interrupts the blood supply, eventually leading to infection [2]. This group is particularly at risk because of their increase in sedentary behaviour. Patients are often bedbound and unable to move their body around as freely and frequently as required. In previous research, monitoring and preventing sedentary behaviour is considered essential to improve a patient’s quality of life, particularly as they grow older [3].

As well as being extremely painful, pressure ulcers can cause severe social and financial consequences for individuals, health services and the community [4]. Extended hospital stays and/or extra nursing care is often needed. This results in severely increasing the healing time and cost of care. Dealing with pressure ulcers is estimated to cost between £1.4 and £2.1 billion annually (4% of the total NHS expenditure) [5]. In most cases pressure ulcers are preventable, with the correct amount of patient assessment and monitoring. However, given that the workload placed on nurses has increased [6], dedicating a set amount of one–on–one time is not feasible. In a recent survey [6], it was revealed that 98% of UK nurses stated time constraints prevented them from spending as much time with individuals as they thought necessary. With 97% thinking that more time with patients would have a significant impact on their health. In order to reduce the risk of patients developing pressure ulcers, remotely monitoring and measuring their behaviour is important.

The area of human digital memories has focus on documenting the things we do, the places we visit and the thoughts we think [7]. This outlet allows us to capture rich information about ourselves and our surrounding environment [3]. Monitoring a patient’s behaviour and movement patterns, via digital memories, provides a visual depiction of their habits. It can also illustrate the state of their health, at any time. It is proposed that using digital memories in this way presents a new and novel way to monitor patients remotely. This method would allow some of the pressure to be lifted off nursing staff. Viewing a patient’s memories would give doctors and carers a direct insight into how the patient was feeling. It would also provide an accurate interpretation of their movements. In this sense, alerting them to the fact that the patient has been in the same position for an extended amount of time. Providing visual illustrations and behavioural patterns of a person’s body movements could result in the prevention of pressure ulcers, and would be a great benefit to caring staff.

With the development of “smart” mobile devices, and their prevalence within our environment, it is safe to assume that they would be a useful tool to use in creating human digital memories. Technology has enabled us to capture a multitude of data, from distributed sources, and reason over this information accordingly. Mobile devices currently fit into our environment, instead of forcing humans to enter the machine's environment, a concept first envisioned by Weiser [8]. Memories are often impulsive events and are better suited to being captured and shared on these portable devices. These devices are adequately compact to be carried around and are sophisticated enough for sharing content amongst users [9].

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This paper explores how human digital memories can be created and applied to the field of monitoring sedentary behaviour, with the aim of preventing pressure ulcers.

II. Creating Human Digital Memories

Digital memories can be created at any time and can be composed of a variety of information. From purposely taking pictures, to more sophisticated systems that automatically collect a multitude of data, our lives can be reconstructed from our digital artefacts. Nowadays, these moments are not being captured on 'traditional' cameras and camcorders but increasingly on mobile devices and sensor equipment. The data that we are able to capture is also shifting in content. Currently, researchers are exploring ways in which physiological data can be captured and incorporated into our memories. Sensor–based systems are quickly emerging as a new way to capture our every move and to monitor our health and well-being. The development of smaller sensing devices and wireless communications is revolutionising the way in which a subject's health can be monitored, ubiquitously [10]. This increasing trend of capturing content is one that will only strengthen over time; presenting us with new and novel ways data can be encapsulated and interpreted.

Mobile devices are the ideal candidate to create human digital memories. This is due to their increase in sophistication and decrease in size [9]. One such approach, which has been leading the way in this area, is Microsoft's *SenseCam* [11]. The device is a sensor augmented wearable stills camera that automatically captures a digital record of the wearer's day [11].

Many research projects use *SenseCam* for reminiscing and creating life logs. However, the application of the technology to healthcare is relatively unexplored. One approach that has used the device is Lindley *et al.*'s [12] study on creating 'small stories.' Stories are used to reflect upon the daily lives of people and help them to identify periods of sedentary behaviour. The study is supported by Doherty *et al.* [13] who stated that "after participants looked at their images, they were prompted to change their lifestyle by, for example, cycling instead of driving, taking up exercise, and spending more time interacting with their children".

The technologies discussed can be used to monitor patients with limited mobility. For instance, strategies for dealing with the management of pressure ulcers can exploit digital memory technologies. They can be used to help overcome the problems associated with over–reporting and prolonged sedentary behaviour, as we shall see in the following section.

III. Monitoring Behaviour

In order to monitor and measure the physiology of patients accurately, sensing technologies can offer real–time analysis of movements and pressure areas. One such methodology is Yousefi *et al.*'s [14] proposed smart bed platform. This approach collects information from various sensors incorporated into the bed, analyses the data to create a time-stamped, whole-body pressure distribution map. It then commands the bed's actuators to adjust its surface profile periodically to redistribute pressure over the entire body [14]. In a similar approach, Yip *et al.* [15] have developed a flexible pressure monitoring system, consisting of 99 pressure sensors on a 17–cm x 22–cm sheet. The results from both studies indicate that the use of sensing technologies can accurately measure the pressure that is being sustained on the body.

In other works, Manohar and Bhatia [16] have used ZigBee and bend sensors to create a low power, micro-controller based patient bed monitoring system. The goal of their work is to "periodically estimate the pressure points and to maintain a database." However, this approach is not flexible enough and is deemed "mattress specific." In a similar study, Wang *et al.* [4] developed a remote monitoring and caution system. Like Manohar and Bhatia [16], their system also uses the ZigBee network infrastructure. They have used sensors to monitor pressured positions for mobility-impaired persons on the bed [4]. Four sensors are attached to potential ulcer areas, and a ZigBee sensor is integrated with several of the sensors. If a certain position is sustained over a 30-minute period, an alarm is triggered, and a message is sent to the caregiver's mobile device [4]. This work is of particular interest due to the alarm feature.

As well as measuring the pressure sustained on a patient's bed, body sensors can also be used to measure movement. The activPAL system uses a single–axis accelerometer [17] that can distinguish between sitting or lying, standing, and walking transitions. The activPAL accelerometer has also been used to determine habitual behaviour, whilst also determining the interplay between sedentary behaviour and periods of physical activity [18]. However, both studies have indicated the limitation of this system is its inability to recognize slow steps, due to the small amount of amplitudes that are produced. Nevertheless, for monitoring a patient who is susceptible to developing pressure ulcers, this device is useful. Prolonged periods of a particular position could be measured to establish how long the patient has been in the same state. For example, the system could determine that for 10 hours; the patient was constantly lying down.

A number of approaches have been explored. However, in order to monitor patients accurately, incorporating sensing and life logging technologies are essential. The limitation of current systems is that they either record visual or physiological data. In order to form a complete snapshot of our lives these technologies need to work together. This will allow us to recap our experiences visually, and the physiological changes in or body such as those associated with happiness and sadness. For example, a doctor remotely monitoring a patient's digital memory can "see" exactly how they are feeling, and if they are being moved around enough. Another drawback is that physiological data can be ambiguous and can require extensive data analysis. Automatic analysis of this data would have to be performed in order to discern meaningful information to enhance our memories.

Current research aims to address these limitations by automatically gathering a variety of data, from distributed sources, to form a "memory box". In this context, a memory box could contain visual items, i.e. photos, as well as various sensor readings, ranging from the temperature of the room to changes in physiological data. These "boxes" are of particular use for monitoring patients, which are inclined to develop pressure ulcers. By granting their doctor remote access to their memories allows the patient to be reassured that someone is always watching over them. The care they are receiving can also be improved. For staff, knowing that a patient is being monitored continuously and that this information can be accessed at any time, acts as a reminder and may prompt the improvement of the level of care provided. The following section outlines the current system that is being developed to create these "boxes" and how it can be used for monitoring and preventing pressure ulcers.

IV. Pressure Ulcer Management System

Several technologies are used to prevent the occurrence of pressure ulcers. Many of these are proprietary, expensive and highly restrictive. Researchers operate within the operational functions provided by certain devices, which do not always fulfil the requirements for measuring sedentary behaviour. Solutions include a specific focus on acceleration, inclination and aspects of physiological computing, such as monitoring ECG, galvanic skin response and respiration. Furthermore, data is used in isolation, thus providing little or no contextual information.

To understand sedentary behaviour multiple data sources are required to determine the context under which the behaviour occurred. For example, an increase in heart rate due to someone breaking into your home, or you being attacked, whilst producing the same or similar results, would produce a different classification to say a person who is playing a boxing game on a game console. This information, used in conjunction with other information (obtained from other data streams), may provide contextual information about why this is happening [19–21].

The idea of creating memory boxes fits well within this field. Memory boxes are composed of a variety of data, from distributed sources, and contain vivid structures and varied information sources that emerge through the semantic clustering of content and other memories [9]. Linking data from a variety of sources provides a greater level of detail in the creation of human digital memories. Adding as much detail as possible enables the execution of "smart" queries, which have the ability to search data in a multi–dimensional fashion. Thus enabling the user to see exactly where they were, what they were doing and how they felt, at the time. Memory boxes are distinctively useful within the healthcare field because they provide a way for carers to monitor patients remotely. They are particularly beneficial to patients with conditions, like pressure ulcers, where the problem does not present itself until it's too late. Monitoring patients 24 hours a day to establish how often they move is unrealistic and an alternative method is required. Memory boxes offer a way of providing this information remotely.

For these reasons the approach posited in this paper considers an alternative solution that is open, extensible and fully configurable, to accommodate the specific needs of applications.

The design goals provide the system requirements for a suitable scheme. The principle goals are as follows.

- To use an open, cheap and extensible sensor platform, capable of sensing a rich set of sedentary behaviour data.
- Provide a set of open source software tools to support existing sensing functionality and the addition of custom developed sensors and functionality.
- A framework for sedentary behaviour practitioners to access and process data, using a rich set of commercially and open source tools.
- Enable the incorporation of memory boxes into the framework to allow a greater level of detail to be recorded and reasoned upon.
- Build additional middleware services, to achieve the memory structures required. Thus, enabling a plug and play platform for memory data sources that can be exploited by any digital life memory middleware service.

The discussion so far highlights a number of ways to extract relevant information about sedentary behaviour, for preventing pressure ulcers. Solutions like ActiGraph[1] and activPAL[2] have helped to provide a moderate assessment of engagement in sedentary behaviour. The ActiHeart [3] combines accelerometer and heart rate monitoring to provide rudimentary context. Whilst this system is useful, it is proprietary, and as such a closed system that does not allow functionality to be changed or extended. Nonetheless, it is appropriate to build on these technologies to address this limitation. In the next section, a scheme is provided that moves towards a fully extensible platform for measuring sedentary behaviour. It explains how the principal goals have been incorporated within the framework and highlights the novelty of the approach.

A. *Technical Details*

The DigMem application [9] provides services to access the hardware of ubiquitous devices and to process the data streams that they provide. Information abstracted from these data sources enhances the development of human digital memories.

The system utilizes a P2P network to abstract device functionality as independent network discoverable services. DigMem is run as a middleware service on different kinds of device, i.e. sensors, smart phones and household appliances, like televisions and media centres. DigMem instances are collected together, via the P2P interface, allowing the capabilities that each mobile device has to offer to be discovered and utilized, in an ad hoc and environment dependent fashion. For instance, in the home, devices such as mobile phones, entertainment systems and game consoles

[1] http://www.theactigraph.com/

[2] http://www.paltech.plus.com/products.htm

[3] http://www.camntech.com/cnt_actiheart.htm

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can all be accessed via the DigMem P2P interface. In other words, this means that any of the functions they provide can be used, via their service interfaces, within different types of application. For example, this would be particularly useful in hospitals and residential care homes where children and the elderly remain in sedentary positions for long periods. By accessing the appropriate services, a picture of the memory can be built to measure activity and directly support the management of pressure ulcers.

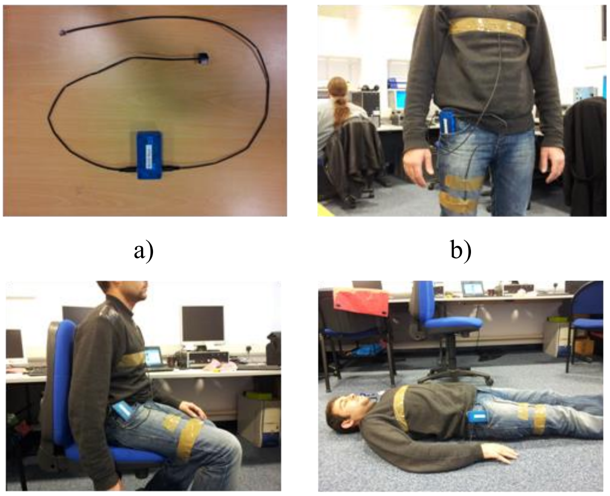
In this paper, we incorporate sensors and sensor networks to enrich the camera and GPS services, demonstrated in our previous work [9]. In this way, activities and sedentary behaviour can be described, pictorially, to track a patient's movements outside of medical or residential facilities [3]. The sensors allow us to determine if a patient is sitting, standing or lying down, whilst the sensor network allows us to triangulate a patient's location. These additional features allow us to monitor activity and the location in which it occurs. Using the sensors alone, whilst providing useful information about activities, does not provide a clear picture of what a patient is doing. Using the camera service provides time stamped images, collated together, with activity data. The camera service has been accessed, via DigMem, from the user's mobile phone that is worn around their neck. This provides a better understanding of patient's activities. In other words, if a person is standing, using the sensors alone does not show what they are doing. The camera service allows us to provide the missing details.

Sensor networks installed in medical, residential and home environments are used to track the location of people (using triangulation, i.e. by calculating the RSSI values between three points). The TelosB sensor used to measure the sedentary behaviour has been extended to include two additional sensing features for detecting, sitting, standing and lying down positions. Figure 1 shows the complete system.

The sedentary behaviour system includes several static TelosB sensors that are used at fixed points in an environment being monitored. A base station TelosB plugged into a TrimSlice™ Linux box, and a mobile TelosB with two tilt switch sensors that is worn by the person being monitored.

Fig. 1: Complete Sedentary Behaviour System

Figure 2 a) shows the mobile TelosB sensor with the two tilt switches attached to it via mono jacks, directly wired to the TelosB general IO. In Figure 2 b) the encased TelosB device is attached to the person's hip, a tilt switch attached to the chest and the other to the thigh of their right leg. In this position, the system can determine the standing position, the unique id of the person, via the RIME address assigned to the TelosB (note that multiple people might be monitored as the case would be in a nursing home), and the location within the environment the person is in. Figure 2 c) and d) demonstrate the further two positions captured by the system, sitting and lying down respectively.



a) b)

c) d)

Fig 2: Measuring Standing, Sitting, and Lying Positions

Accessing the data available, via DigMem and the sensor platform, allows a vast array of dynamic information to be discovered. This allows a vivid snapshot of our lives and well-being to be constructed, at any particular time. Once the data has been obtained it is stored as RDF triples, within a MySQL database, and can be searched. Intelligent queries are then performed, and through linked data, can create memory boxes illustrating exactly what you were doing on a certain day. By utilizing the Dropbox software, memories can be distributed and shared with anyone across the globe.

B. *Discussion*

There are several notable features that make this system viable alternative. A custom interface to the TelosB sensor is provided that allows additional functions, such as an inclinometer or accelerometer, to be used. Secondly, the sensing platform is built on the open-source Contiki operating system. This allows the software to be freely accessed, changed and extended to meet the unique requirements of individual applications.

The Mobile DigMem application has been developed using the open-source Android platform and as such allows access to the hardware features of any device. While DigMem has been developed using the Java language, which is compatible with Android. DigMem and its mobile counterpart allow data to be accessed from any device, in order to build a memory. Constructing memories in this fashion is novel in itself and provides a finer level of detail, previously unseen before.

The data is created using an open format and is stored using an open-source database technology. It is not encoded in a proprietary format. The reason to store the data as standard SQL was a design decision, based on the flexibility, to allow users to choose the data processing tools that they are familiar with. For example, it is relatively easy to extract

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the data from MySQL and import it into Excel, SPSS, MatLab or indeed, any other data processing application.

The development of this framework allows human digital memories to be created, in any environment. The incorporation of the sensing platform and the ability to extract information, from distributed resources, enables a more "complete" representation of our lives to be constructed. The development of this system allows the user to keep track of their entire lives and to reflect on how experiences made them, and others, feel. This work is of particular benefit to the healthcare field, as we shall see in the next section.

V. Conclusion and Future Work

Technology is rapidly changing the landscape of our environment, and the information that we have access to. Creating human digital memories is not only useful for reminiscing but can significantly improve the level of care we receive. Preventing the onset of pressure ulcers by monitoring sedentary behaviour and our environment, through the channel of human digital memories, has been the focus of this paper. A solution has been presented that gathers and incorporates a multitude of data in order to generate rich human digital memories. As it can be seen, the system has the potential to revolutionize the healthcare industry.

Future work aims to build on the ideas presented in this paper so that rich and dynamic memory boxes can be formed and reasoned over. Once created, the memory boxes can then be clustered together and linked, forming an endless stream of memories, that can be accessed anytime. The creation of the memory boxes is the fundamental aspect of future work because they are the representation of our memories. Careful consideration will need to be taken into how the data will be reasoned on and how the boxes will "look." This work raises many questions, such as, what does a memory look like? What is the best way to structure this data? Can a true representation of our memories ever exist? These are significant arguments to consider, and ones that will be propelling this research forward.

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