A minimally intrusive monitoring system that utilizes electricity consumption as a proxy for wellbeing


Abstract

The purpose of this work was to test the hypothesis: 'Off-the-shelf domestic electricity meters can be utilised to assist in monitoring the wellbeing of elderly people'. Many studies have shown that it is, in theory, possible to use domestic electricity consumption to determine activities of daily living but the availability of systems for actual use is very limited. This work followed the Design Science Research Methodology to create a Java application running on the Google App Engine cloud service that interfaced with both electricity meters and voice and text services. The system was implemented and tested over a three month period with one older person and their carer. Results demonstrated that the technology readily succeeds in meeting the study's initial objectives. The need for more sophisticated decision logic was apparent and a method to determine whether a home is currently occupied is likely to improve the ability to create more timely alerts.

Keywords

independent living, assisted living, wellbeing, electricity monitoring, Google App Engine

1. Introduction

Many countries are dealing with reduced birth rates whilst at the same time managing the increased aging of their populations. This raises problems for their ability to provide quality care (Lai, 2008; van Nimwegen & van Est, 2010). There is a call to action on a global level to change the current care system to one that is better suited for the elderly (Health and Welfare Information Association & Japan National Council of Social Welfare, 2013). The cost of providing such care is widely seen as being a large burden on many countries (van Nimwegen & van Est, 2010), whether state or privately funded. Disabled people (both physically and cognitively) are another sector of society who require care services to be delivered (Barker & Glendinning, 2011). It is likely that as industry and society find new ways to deal with the growing needs of the elderly, so the needs of the disabled may also be addressed.

This work describes the design, development and deployment of a novel minimally intrusive monitoring system (hereafter referred to as MIMS) that utilises the monitoring of domestic energy monitoring devices and cloud computing. MIMS has been designed to work with individuals or organisations that wish to monitor vulnerable people living alone, so that alerts are generated when there is a deviation from the person's normal behaviour.

2. Methodology

2.1 Research

The Design Science Research Methodology (DSRM) has been followed in this work (Hevner, March, Park, & Ram, 2004). DSRM provides a framework that is well suited to the creation of artefacts in the Information Systems arena. The main activity of the methodology are: 1) Problem identification and motivation, 2) Definition of the objective for a solution, 3) Design and development, 4) Demonstration, 5) Evaluation and 6) Communication. The methodology allows for retrospective application to a piece of research that has already occurred - as perhaps often happens in practice. The last activity of Communication is, of course, partly happening in the writing of this paper, but has also occurred through the involvement of interested parties.

2.2 Software

In the initial stages of this, the roles of client, designer and developer were performed by the same person. The Unified Process (UP) for software development utilisation was constrained by this fact. Once the work was introduced to third parties, the UP allowed for resolving earlier stages of the cycle, such as requirements gathering, so that the artefact being developed could be modified to meet the needs of the intended audience. This is consistent with "The evaluation of the artefact then provide feedback information and a better understanding of the problem in order to improve both the quality of the product and the design process." (Hevner et al, 2004).

Object Oriented (OO) Design and Analysis is often used along with the UP as a modern technique for creation of software artefacts and was adopted in this work. In addition, the Unified Modelling Language (UML) was used to document the stages of the work where appropriate.

3. Problem Identification and Motivation

As mentioned in the introduction, the big picture problem has been identified as the issue of an aging population that will require affordable care. However, this paper focusses on a narrower question: "Is it possible to use current and next level developments in computer science and technology to create an acceptable system for helping to "keep an eye on" and to check on elderly people's wellbeing?" The definitions of "vulnerable" and "intrusive" should take into account the needs of the individual and what is appropriate for each person. The more care that a person requires, the more intrusive may be acceptable to keep that person safe. More intrusive solutions may be not acceptable for independent elderly people who are able to manage their lives in normal circumstances, but for people with social isolation and communication impairments (for example autism), intrusive solutions may be necessary to prevent self-injurious behaviours.

3.1 Options for care

The traditional method that a society uses to look after its older people is to have them live in the same residence as their adult children. A variation of this is the 'granny annex' (Wapner, Demick, Yamamoto, & Takahashi, 1995) where the elderly parents live in a closely located but fully self-contained home. Here the adult children can easily monitor the wellbeing of their parents.

Either the older person or their adult children may not be, or want to be, in a position to closely share the living arrangements just described. If there is a need for care then a popular option is to use a residential care facility (Dudman & Meyer, 2012). Various levels of care can be provided and can change as the needs of the older person change. Nursing homes are able to provide a high level of care at that would be very difficult for most elderly people to provide, although this level of care is expensive (Neffen et al, 2001; Szczepura, Rehman, & Holt, 2008).

3.2 A Technical solution

There is an increasing use of technology to assist with the care of the elderly (Hyysalo, 2004). A major driver for this is to reduce the costs of providing care. In some cases technology is being used to provide older people with companionship. Although the aim of using technology is to provide a level of care that would be too costly if the market labour rate had to be used, many of the technical solutions are still likely to be relatively costly for many people and societies (Zapf, Nenmäki, & Hartog, 2011). Kerbel (2012) discusses the term tension that uses management, ICT and service networks to provide health and social care in the home. He discusses three generations of takeover from safety-alert systems that can be manually activated, to intelligent systems that use sensors to determine if a person is acting in a typical manner (Kankanaskis & Nenmäki, 2007) and finally to the third generation that enhances the "quality of this user's life rather than his independence and safety".

3.3 Security and ethical considerations

There are many concerns around the type of technology that is being used for Assisted and Independent Living schemes (Herszog & Lind, 2003; Rauhala & Topo, 2003). Although the terms are not always clearly defined, one interesting proposal is, "that users of AT [Assisted Technology] should be able to have a say in what is being monitored and when to turn a monitoring device off." The ability to cancel false activations of a fall detector was seen as a positive feature of one device (Brown & Havel, 2004) and this feature could be implemented in all situations where alerts are being sent, thereby increasing the level of autonomy.

3.4 Electricity monitoring

In parallel to the situation of the aging population is the growing awareness and interest in reducing energy use (Murphy, 2011). There is a growing market in devices that monitor the electricity usage of homes with the intended outcome being that if a person can easily see the correlation between appliance usage and electricity charges they will reduce their energy consumption. A number of devices have now become available that can easily be installed by the average user (AlertMe, 2013; Blue Line Innovations, 2010; Current Cost, 2013; Enertis, 2012; NetRC Systems Inc, 2013; P3 International Corporation, 2013; Rowhammer Dynamics, 2013; Sahas Electronics, n.d.; Thinkspon, n.d., saillife.com, 2013).

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A person's electricity usage is likely to give an indication of the wellbeing of that resident and some of the available devices can be configured to allow remote access to the data. However, the current devices for measuring electricity usage are not usually configured to automatically alert a concerned adult or other care giver (henceforth referred to as a Carer) of a possible need to intervene (for example, call them to ask if they are alright). In addition to the alerts that can be sent are aimed at informing an individual rather than being a tool an organisation could use as a central means of monitoring a number of people. For example the e-friend from Powerhouse Dynamic does allow the creation of best and email alerts when "your electric bill has passed a certain threshold" (Powerhouse Dynamic, 2013) and the device from wattvision allows you to "track your graph as well as the graphs of your friends and family" (wattvision, 2013), although to do this it appears that you need to make the data available on a public website.

A common scale used to measure the health of the elderly is the Activities of Daily Living (ADL) (Katz, 1983) and some studies have used electricity usage as an attempt to measure this. Franco, Gollub, and Berenguer (2008) measured the electricity used by room lights and individual domestic appliances and concluded that "Eating was the most accurately measured ADL, toileting and bathing results were less accurate. The system also has a promising component of home telecare". Tang, Cheng, and Xiong (2005) monitored water, electricity and gas usage monitored and reported that "A model of the changing amount of the elderly's activities can be built with the inferential arithmetic and the accumulated data. And based on this model, the health and security status can be predicted and abnormality can be inferred".

### 3.5 Making electricity usage data available

Although the literature has reported the successful use of electricity monitoring for determining ADL, there still is a lack of actual services that exist outside of the research field. Given the recent advances in technologies previously discussed, this study aims to show that the time is now right to implement a low cost and readily accessible service.

The EnviR electricity meter from Current Cost (Current Cost, 2013) enables users to view their electricity usage on a display that they can locate in a convenient location. The company also sells devices that automatically send the data to a secure website where users can graphically view current and historical electricity usage, (see Figure 1 and 2). It is now possible for a third party to access it for the purpose of determining if the usage is typical. As maladaptive usage may be an indication that the person is in need of support. The ability to view consumption data on a website is a feature of many of the devices referenced earlier. However, a better solution for the Carer is to be sent alerts when a situation has occurred, or even a daily alert just to say that everything looks normal. Current Cost provides the ability to pass data onto the Xively service (Xively by LogmeIn, 2014) from where it is possible to create alerts that are triggered when the current electricity usage matches a particular condition for example above 2000W or below 50 W. When a trigger occurs, the software makes an HTTP POST request to a URL that the user will have had to setup previously to receive such requests.

This service is provided for a technical audience rather than the layperson and only limited functionality is available for creating alerts based on historical data. However an Application Programming Interface (API) provides access and retrieval of data which allows another program to analyse the data and create these alerts.

![Figure 1. The lower plot shows the electricity use for a single day for the entire house being monitored. The upper plot shows the room temperature.](image1)

**Figure 1.** The lower plot shows the electricity use for a single day for the entire house being monitored. The upper plot shows the room temperature.

### 3.6 Using a cloud resource to provide an always on service

As previously stated, the intention of this work is to provide an alert when the electricity usage is abnormal. A simple way to achieve this would be to constantly monitor the power usage and send an alert when the value went above or below a predetermined trigger value. The trigger value could be different for different times of day.

An alternative method would be to compare the current value with historical values to try to determine if the current value deviates from the normal. This means that the program that will provide the alert needs to be continuously running and have access to the historical data. A large number of providers of various cloud services exist (Vaquero, Rodero-Merino, Caceres, & Lindner, 2009) with the major providers being Google App Engine (GAE) (Google, 2012), Windows Azure (Microsoft, 2013) and Amazon Web Services (Amazon web services, 2013).

**Table 1**

<table>
<thead>
<tr>
<th>Cloud Service</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAE</td>
<td>Reliable, low cost, good for small-scale applications.</td>
</tr>
<tr>
<td>Windows Azure</td>
<td>Scalable, robust infrastructure.</td>
</tr>
<tr>
<td>Amazon Web Services</td>
<td>Large-scale, high reliability.</td>
</tr>
</tbody>
</table>

### 4. Defining Objectives of a Solution

The following objectives have been identified.

#### 4.1 Low cost

Solutions to monitor people already exist but they are often too expensive for individuals or organizations to implement. This work aims to create a solution that is affordable for individuals on low incomes or organizations that are involved with providing community services.

#### 4.2 Low intrusion

Current solutions are often not acceptable due to their intrusion into people's lives. The use of cameras in someone's home is obviously invasive to most people, but even devices of much lower intrusion are also not satisfactory for example, requiring someone to wear a device may be too high an intrusion, due to the person not wanting, or not remembering, to wear it.

#### 4.3 Globally available

A solution that is globally available has the potential to help more people than a more locally focused one: the more users, the lower the potential cost per user. The availability of hardware and cloud services that work in all developed countries means that there is no need to develop a local specialised service, any service developed will have to be tested locally to determine any potential issues.

#### 4.4 End user acceptable

Intrusion and cost and their impact on the likelihood of acceptance have already been discussed. Other aspects that may have a bearing are the ease of setup and ease of monitoring, as well as safety.

#### 4.5 Highly reliable

Given the seriousness of the service that the project wants to provide, high reliability is crucial. The project wants a service that not only alerts Carers when there is a problem, but also does not cause unnecessary concern through false positives.

#### 4.6 Ethical

Monitoring of vulnerable people has the potential for abuse if not performed in an ethical manner. We want to produce a system that allows automatic monitoring of people without the need for the Carer to be aware of the daily habits of the person being monitored. We also do not want the system to be seen as a replacement for human contact, but rather as augmenting an acceptable level of social involvement. However, this paper does not enter the debate of how society should care for their vulnerable citizens.

### 5. MIMS Design and development

The design was based on the idea of using off-the-shelf (OTS) sensors and globally available cloud services. We did not want to build bespoke devices that would not be easily available for others to acquire; we did not want to get into the business of manufacturing. An advantage of using OTS devices is that they have already been approved for domestic use and are unlikely to be a safety concern or affect a person's house or contents insurance. To an extent the design of MIMS depended on the actual choice of sensors and cloud services as each product offered different capabilities.
5.1 Sensor choice

Although there are many types of devices available for monitoring domestic electricity usage, there were a limited number that met all our needs. In evaluating these devices it was obvious that the setup from Current Cost (discussed in section 3.2) best met the requirements of low cost, ease of installation and access to data.

5.2 Choice of cloud service provider

In this project, both GAE and Windows Azure were trialed to determine if they were suitable. It was considered that the Windows Azure development environment was easier to use and more stable than GAE; however the lack of a maximum monthly charge was found to be unacceptable and made this service unusable. The main issues with GAE were the difficulties in setting up the development environment but once set up, the actual service has so far proved very reliable.

5.3 Data flow overview

The Current Cost system measures electricity use either through a current clamp or by in-line wall socket sensors. Both methods send electricity usage data wirelessly (433MHz) from the sensor to a central receiver that also displays the usage on a display, see figure 3. The receiver/display has a wired connection to another device (called the HubSmart) that is in turn wired into the home’s internet modem/broadband connection. The data is then automatically sent to the company’s cloud service where it is eventually made available via a RESTful API interface provided by Xively.

6. Demonstration and Evaluation

6.1 Testing in researchers’ homes

MIMS was developed in an iterative manner using the home of one of the authors. During this time the system went through a number of iterations as various parts of MIMS were built. At the end of the process MIMS was then deployed to two other homes belonging to other researchers to verify that it worked in a variety of home situations.

6.2 Independent participant

The next stage of the testing was to deploy MIMS to the home of a participant from the cohort of target system users. We presented MIMS to a group from a local organisation (Age Concern) that provides services for older people. Although the uptake of participants was low (only one eventuated) we were able to proceed with testing in a more realistic environment. The Google Authentication Service uses a Google email address as the means of authentication. Screens were developed for four levels of access: Owners, Administrators, Carers and System Users (the people being monitored). The owner of the MIMS (the person who installs the application) only has the ability to create Administrators. Administrators can setup Organisations and Carers. The information for the Organisation includes the details on its associated Twilio account (for text and voice calls) as well as an account balance that can be used for charging and billing purposes (if required). Each Carer is assigned to an organisation and the contact details for the Carer entered. Carers can then log in to set up System Users, Meters and Triggers.

Each System User has contact information entered so that the system can contact them and allow them to log in. The options are given for the method of contact (email/text/voice) and whether the System User is to be notified before the Care. Meters are software representations of the electricity meter and record the authentication details of the electricity meter to allow the MIMS to automatically gather the required data. The MIMS logic is an application running on GAE that uses a regularly timed process (known as a ‘cron job’) to request the data from Xively every 5 minutes. As data arrives it is stored in the database and then analysed to see if any conditions have been met to cause further data processing. Depending on the logic configuration, the application may first contact the person being monitored and if the person fails to answer or requires assistance, then MIMS can contact the Care via email, voice or text message.

6.3 Low cost

The ultimate cost of MIMS will depend on the operating profit that a company providing the service aims to achieve. However it is possible to calculate the costs of the system before profit is added. The major difference between this project and other systems is the use of off-the-shelf equipment that is being produced for domestic power consumption monitoring and avoid the use of a dedicated call centre. The services listed are not a direct comparison with the system developed, do give an indication of the market pricing of monitoring services.

Table 1. A selection of currently available home monitoring services. Costs are higher in New Zealand than elsewhere. * See text below for explanation of additional costs.
The system developed in this work between NZ$268 to NZ$515 to purchase the hardware, depending on how many sensors are used. Current Cost state that a qualified electrician is not needed to install the device, but they do recommend using one if the power is going to be monitored at the switchboard. We estimate the cost of an electrician to do this work to be $100. On top of this cost, there are costs associated with the countless connections of GAE and Twilio services, a cost that is incurred every time the device is used. If more than 50,000 units are purchased, it is likely that this time could be significantly reduced when not in a research setting and when the installation procedure becomes routine. The location of the user's modem meant that the network connection was beside the user's interface, which resulted in the monitor being inconveniently placed on the bedside table. This was also changed because of the cost of the electricity being used to power the equipment and the user's considerations withdrawing from the study due to cost. Although we felt that the costs were less compared with her TV system on standby, it was still a cost for a person on low income and so these costs were covered by the research.

We are greatly indebted to Age Concern Hamilton who gave us a platform for recruiting participants and even more so to the anonymous users of the system - thank you.

8. Acknowledgements

MIMS has been designed so that the degree of control given to the end user can be varied: more autonomy for more independent and higher functioning System Users and less autonomy for more dependent persons. The nature of the data being collected is always using it unintrusively and therefore helps to create an ethical means of monitoring. MIMS has been designed so that the degree of control given to the end user can be varied: more autonomy for more independent and higher functioning System Users and less autonomy for more dependent persons.

9. References


9. Conclusions and discussion

We have shown that the availability of ‘off-the-shelf’ consumer devices for domestic electricity measurement along with cloud services can form the basis of a low cost, minimally intrusive system for monitoring the wellbeing of people living independently. The system developed (MIMS) has potential to be used in a global setting.

Further work needs to be done on the development and implementation of more useful and robust logic for determining if the person being monitored requires assistance - especially in a timely manner. Also, addressing the ‘false positives’ problem is important. MIMS can also be improved, in part by using an energy monitor that is capable of calling the System User first to see if they need assistance. This now seems obvious but it does highlight the need to create robust logic for determining when an alert should be raised. Further it also highlighted the fact that it would be very useful if the System User was informed at the point of installation. However, there were still instances of ‘false positives’. The concept of using ‘off-the-shelf’ devices along with cloud services gives our system the potential of being globally available. The Current Cost device can be bought through a number of websites and the Current Cost website also lists partners in 17 countries in Europe, three in the Americas (including the US), two in Africa as well as Australia and New Zealand. Use in other countries may depend on the available power supply and a lawful available radio frequency.

We believe that we have built a flexible system that can be used in an ethical manner and the current trail has been implemented with due consideration of ethical concerns. The reasons for this may have been partly due to our requirement for the users to have an internet connection as only half of the group did. It was also felt that we were not able to explain clearly to the particular group what the purpose of the trial was. Ongoing work is looking at using a 3G network connection and also involving the Carers more in the recruitment process.