Improving The Well-Being of Older People by Reducing Their Energy Consumption Through Energy-Aware Systems

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Abstract-Fuel poverty is becoming a problem amongst the older community in the UK. We propose an assistive technology for reduced energy consumption in aid of active aging. We introduce how the well-being of older people within the community can be improved by reducing anxiety associated with fuel poverty. A recommender and behavioural change system will be introduced, which enables older people to improve their energy footprint through energy-aware systems. Using systems to help reduce fuel poverty will invariably improve their general well-being. Results show how this technology can be accepted and act as an enabler in improving the overall well-being of older people.

Keywords- ***energy-efficiency; energy-awareness; intelligent sensor systems; recommender systems; well-being.***

I. INTRODUCTION

At present, older people within the community face a host of technological and perceptual problems, which can inhibit their interaction and well-being while using information and communications technology (ICT) solutions to improve their lives. This is especially relevant when considering Internet of Things (IoT) based systems to improve their well-being within their home environment, dealing with heating and reducing costs. Fuel poverty is a key societal problem that impacts on large numbers of the older community within the UK [1] as older people tend to fall into the low-income range due to low pensions and rising energy costs. The worry and anxiety concerning their limited financial resources results in 20,000 – 25,000 deaths in the UK [3]. This is due to reducing their dependency on heating their homes as they are not financially secure enough to afford or pay for their monthly house hold heating or cooling bills [4]. The use of technology to help older people reduce costs is constrained by their fear and distrust of technology. To enable older people to accept ICT solutions, the UK government has a number of initiatives in place to help reduce this fear (e.g., digital by default [2]), which aims to provide them with skills to use modern technology. However, figures show that high numbers of individuals are still susceptible to fuel poverty which is not only reducing their well-being but also putting their lives at risk [3].

Compounding the issue of fuel poverty, older members of the community also fear the use of technology which can impact on the successful deployment and adoption of technology to address the issue of fuel poverty. Other issues relating to the acceptance of technology and the security of personal information also factor into the distrust of ICT, which is there to help improve their well-being.

In this work we intend to provide a prototype system to show how unobtrusive and intelligent technology can help reduce the energy consumption of older people and how this can impact on their behaviour by adopting more energy conscious patterns through a real-time responsive recommender system. We will therefore examine whether an *intelligent recommender system can reduce the energy consumption of older people by predicting and modifying their daily patterns and behaviours so that they minimise their energy needs*. The rest of this paper is structured as follows: Section 2 provides an insight into existing systems; Section 3 discusses the design considerations that need to be taken into account when considering energy-awareness as a whole; Section 4 introduces our proposed system and its key components; Section 5 discusses user interaction issues and factors that can deter engagement; Section 6 provides initial results; and finally, in Section 7, we present our conclusion.

II. RELATED WORK

Reducing the energy consumption of individuals has been widely tackled by a variety of commercial and academic systems. An approach taken by some commercial systems is to view each room as a separate entity and give contextual information regarding the state of the room. Some systems require user intervention in the control of the ambient energy consumption. For example, with the *Hive* system [10], to adjust or improve the heating within a room, a separate mobile based application is required which can lead to problems when considering older people. Although additional sensors and smart plugs are available to provide the ability to turn on and off devices, these still need to have some form of user intervention. Voice control or a mobile phone application is required to govern their operation. However, this forces the user to actively monitor, respond and modify temperatures rather than allow the system to proactively shape the energy use of the home. IFTTT (IF This, Then That) [11] is another system which allows IoT integration within the home by providing users with a simple rule-based approach for governing the operation of smart devices. Devices are linked to a web based system

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which can then control the devices within the home. Systems like this would fail to address the needs and anxiety encountered when older people interact with technology [5] due to mobile technology and applications not being accessible to all older people which also increases their fear of technology. Another similar system is the Honeywell *evoHome* [12] system provides users with contextual information about the room temperature and provides them with a digital thermostat to control ambient temperatures. The *Heat Genius* system [13] is another commercial product which uses motion control to determine whether heating is required in a particular room. This system also provides the ability to learn and adjust room temperatures based on the life style of the users. However, these commercial systems do not address the issue of reducing energy consumption as a whole but instead focus on one specific problem - heating.

Smart energy meters have been used extensively in the home and in some cases targeting low-income and older users. In [15], a number of smart energy systems and the interactions with users are discussed. Here, users used the *Duet* and *Trio* devices in a bid to monitor their real-time energy consumption over a one year period. Smart home and assistive technology can also play an important part in monitoring and adapting the environment to best suit an older person. Kim et al [14] discuss the *U-Health* system for monitoring and supporting the older person within their home. Wireless sensor technologies embedded within appliances in the home allow for the collection and mining of information regarding the habits of the older user, as well as providing decision-making capabilities to allow the system to adapt to the users' needs.

The issue of fuel poverty is a multi-dimensional one which covers more than just the heating of homes. To provide a representative picture of how energy-awareness impacts older people, all aspects of energy consumption needs to be considered. When looking at the problem of fuel poverty, any savings of an older person's energy expenditure must yield in financial benefits. In turn, for a technological solution to fully address the issue of fuel poverty it must holistically look at energy-awareness as a whole and provide ways in which behaviours and usage patterns can be altered to improve energy expenditure through an unobtrusive and proactive system which does not require constant user interaction to govern the control of the environment.

III. DESIGN CONSIDERATIONS

Older people face a number of challenges in today's society which can impact their lives and well-being. Fuel poverty is a major societal challenge which affects significant proportions of the society. With limited financial resources available to older people who are reliant on state pensions, paying for fuel (i.e., electricity and gas) becomes a major concern for their well-being [3]. Within the UK alone, a high number of unnecessary deaths are caused each year due to weather concerns [1]. This can be due to excessively hot weather during the summer months or excessively low temperatures during the winter. In circumstances like this, which require a higher expenditure, it is common for the older person to go without basic heating or cooling due to limited financial resources, which enables them to focus on other costs (e.g., food and rent) [4]. However, this has a detrimental impact on their well-being due to the suffering involved, and possible death, during low or high temperature times during the year. Not only does it impact the older people, but the costs to healthcare for dealing with emergencies relating to the admission and care of older patients at these times, places stress on services which are already over-stretched.

Communities and community care offer care services where carers or social workers visit the older person to ensure that they are coping and not suffering. However, with finite resources, only so much is able to be done. To help in the care of older people, smart technology has been employed quite extensively. For example, in [15], smart devices help monitor the older resident. However, relying on technology can introduce other challenges. More specifically, older people distrust and fear the use of technology [5]. This often leads to technology being ineffective due to the lack of engagement from the older person, especially if they are required to interact and engage with the technology in some way. Davis [5] introduces the Technology Acceptance Model which impacts on the perceived usefulness of technology by the older person which can introduce barriers for adoption. However, older users also encounter problems with a general lack of understanding of ICT which introduces barriers to the user as it impedes them from making strategic decisions when managing fuel costs [9]. This lack of understanding needs to be addressed for the system to be effective and allow seamless interaction with the user. For instance in [14][15] mobile technology is used but can introduce problems with engagement due to the fear of technology whereby the older person has to interact not only with an unknown and unfamiliar device but also some form of application and visual interface. If the interaction between the system and older person is perceived to be too difficult then a lack of engagement usually results [5][9]. Therefore, intelligent devices need to be unobtrusive as well as the system offering a less technological way of interacting with the older person to minimise the impact of the fear of technology.

Behavioural change is another key consideration for such systems as the technology would also have to monitor and determine if there are better behaviour patterns when interacting with energy-reliant devices within the home. For example, making a cup of tea or cooking dinner relies on some form of energy consumption (either electricity or gas) to complete the task. However, energy tariffs can change through the day and can impact on the total expenditure over a month. By modifying the behaviour of the older person to a more cost-conscious time can have benefits in the long term.

Therefore, when designing effective systems for reducing the energy consumption of older people, a number of design considerations have to be taken into account. Namely, the use of unobtrusive technology which is embedded within the environment; simple interaction devices which promote trust; behaviour modification and prediction to reduce or better manage the use of energy reliant devices within the home; and, systems to recommend changes to patterns.

We propose to address the question of whether an intelligent recommender system can reduce the energy consumption of older people by predicting and modifying their daily patterns and behaviours so that they minimise their energy needs to ensure an improvement in their general well-being by reducing anxiety associated with fuel poverty. Anxiety has a clear detrimental effect on the well-being of an older person [8], which will hinder their interactions and acceptance of technology. Improving the quality of life of older users is difficult to gauge as different people assign different values to things [7]. For that reason, the proposed system aims to reduce the fear of poverty and improve the quality of life for older users by providing them with guidance and options on how to change their behaviour so that they are more energy-conscious and aware of what they are doing through a simple house model interface. More detailed feedback can be given to those users who feel comfortable with technology or to carers, or family members who are actively helping the older user. By providing them with a more holistic and wide-ranging understanding of the energy-consumption which takes into account not only their heating but also their activities during the day can help them improve their overall energy consumption. By looking at the whole, more substantial savings can be made which in turn reduce their chances of falling into the fuel poverty trap.

Therefore, in summary we intend to address the issue of the acceptance of technology as well as factors relating to the trust of intelligent systems and improving well-being by reducing fuel poverty. This will be through simple, trusted and unambiguous human-computer interfaces, behaviour and activity analysis; and, recommender systems to help promote more informed energy-aware decisions. This will allow older people to consider all aspects of their energy consumption, rather than focusing on one single aspect (e.g., heating) as their overall energy-footprint will be made out of many different components. For example, heating, cooking, recreation, etc., which complements their potentially sedentary life-style.

IV. PROPOSED SYSTEM

From a conceptual perspective, the system (see figure 1) will process sensor telemetry from devices located within the environment, determine if the behaviour of the person can be changed based on the task activity they are performing, which includes using tariff information gathered from energy suppliers through IoT and then facilitate in providing feedback to the older person.

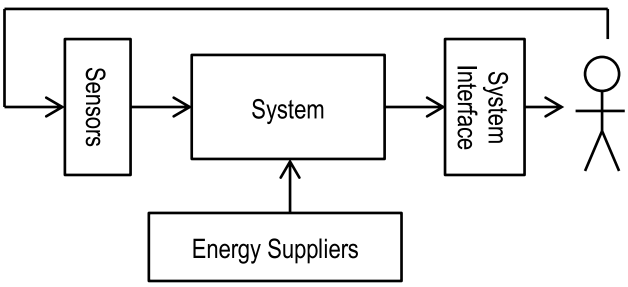

Figure 1. System overview.

The guiding principle in the design of the prototype is to determine if the energy consumption of the user can be reduced by determining the behaviour and patterns they are exhibiting. The system relies upon a number of key components that deal with the interactions with energy suppliers to provide information, which informs the recommender system; activity/task detection and interfacing with the user through an unobtrusive interface. A system prototype has been developed which allows the seamless interaction with an older person, which could reduce their energy consumption. For this prototype iteration the full system was implemented but deployed within an idealised test environment to capture telemetry. The system was also able to save and playback telemetry for user evaluation.

A. Sensors

A variety of off-the-shelf sensors have been used to provide contextual information regarding the state of the environment, the location of the older person, and what they are interacting with in the home environment. Sensors that provide telemetry on light, motion, pressure, electricity use, sound, as well as other sensors providing contextual state information of the environment, have been used. Sensors were typically subsumed within the appliances which consumed energy. This was mostly electrical appliances but scope for gas based appliances will be incorporated in a later iteration. Sensors can be added seamlessly to the system by simply plugging them in and informing the software that a particular type of sensor has been added. Different sensors can be dynamically added, along with information which provides contextual information regarding how telemetry can be analysed and interpreted during the behavioural analysis phase. Environmental and power usage sensors were based on Phidgets' technology and were used to record and forward telemetry using an event system that had been developed (details in section IV. B). For the next phase of the work, smart Wi-Fi enabled energy plugs and other Wi-Fi enabled technology, will be used.

B. Behavioural Analysis

To aid in the process of determining how much energy is being consumed within the house and whether a better alternative is available, telemetry from sensors are aggregated and processed within the behavioural analysis component of the system. An overview of the activity, behaviour and recommender stages is outlined in figure 2.

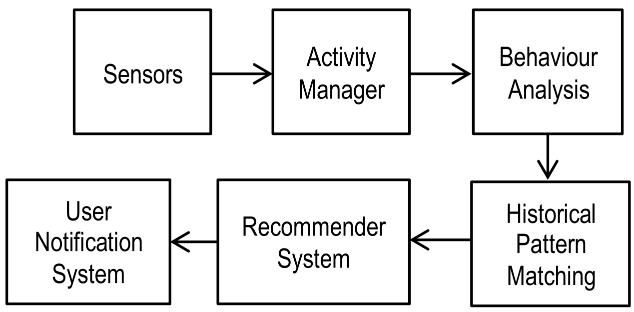

Figure 2. Activity, behavioural and recommender stages.

Activities are used to identify what task the user is performing within the home. For example, making a meal would involve using a variety of sensor equipped devices within the kitchen, each of which will be generating telemetry. In a typical use case, the oven, along with the cooker and supplementary devices (e.g., kettle) could be used. Combined with environmental state information originating from embedded sensors in the home, additionally telemetry regarding light, sound and motion information would be generated and be contextualised within the kitchen environment.

Activities are generated by end-users and allow the association between different telemetry and sensors and a given activity. The approach that has been taken is to offer a simple means for users to define an activity and then to associate sensor combinations to that activity. These activities will then form the basis of the behavioural analysis and pattern-matching functionality whereby the system will be able to determine what type of activity is being performed by the user.

Raw sensor telemetry is tagged with additional meta-information regarding the sensor type, timestamp and location and transmitted around the system within an event message. Events are captured and processed within the behavioural component during the activity identification process. To aid in providing an environmental snapshot of what is happening within the environment, a window of applicability is used which allows events to be received over a short period of time. This populates activity states which are triggered when all associated sensor telemetry has been received during a set period. When this has been satisfied, activities trigger notifications, which are in turn, processed by the analysis component. At this point, a decision can be made on what to do next. The first option is to process an associated action which causes the system to perform some form of real-world action which impacts the end-user. Alternatively, notifications can be used to build up composite events which provide more complex combinations of activities to be associated with each other. This allows the system to provide a richer and more complex activity detection process.

Historical information regarding past activities is used to provide the ability to determine if activities have occurred during similar times in the past. For example, cooking food at specific times; use of kettle to make drinks; and activities that relate to their life-styles. This information is used by the recommender system to determine if user activity patterns can be modified to help improve the energy use within the home based on their occurrences. For instance, when coupled with tariff information, the recommender would be able to inform the user that by changing their pattern to do a particular activity by a few minutes could result in a tangible energy cost saving over a period of time.

C. Recommender System

The purpose of the recommender system is to provide end-users with feedback on their energy consumption performance or provide alternative actions. To best inform end-users of any energy cost savings, tariff information is used from the electricity supplier that they are signed up with. By analysing their past behavioural patterns, the recommender system will determine if any energy savings can be made by suggesting to the end-user how best to alter their habits. For instance, as a profile of the user is generated, any patterns or behaviours they exhibit will be identified and any improvements will be suggested. This information can be conveyed in a number of ways to the end-user. Notification messages detailing the current cost and potential savings can be shown to the user, whilst real-time feedback is given through a physical prototype system, which allows users to instantly see how much energy they are consuming within different rooms in the house.

An administrative component is provided which allows carers or family members to configure the system and provide guidance on what levels of energy expenditure the older user should use on average. This information is used to inform the older user that targets are not being met and to keep the carer or family member informed and involved in the care of the user. Additionally, these set targets also allow carers/family members to closely monitor that the older user is using a minimum threshold amount of energy, thereby ensuring that they are not suffering from the lack of heating or cooling.

V. USER INTERACTION

Compounding the problem of fuel poverty, older users also suffer from technology acceptance. This adds additional constraints in which electronic systems subsumed within the home impact the experience and engagement of the older user. If the technology with which the older user has to interact is complicated or non-intuitive, this can lead to users disengaging with the system put there to improve their well-being and causes an opposite effect so that the user is even more isolated and stuck within the fuel poverty trap. The issue of reducing a lack of understanding and purpose of the system [9] needs to be considered to allow the prototype to be effective with users. In turn, Leonardi [6] highlights that the interactive medium needs to take into account the "*motor and cognitive capabilities*" [6] of the older user. When considering the perceived usefulness of the system [5] to promote older users to engage and trust the system and recommendations, a clear simple interface is required. These issues are important when considering how the older person interacts with the prototype system. However, it does pose challenges when considering the acceptance of the interface as it must not rely on something that might cause confusion or anxiety when interacting with the system. Therefore, some form of mobile device or interface would pose significant challenges to older people.

Different interfaces were constructed and evaluated to determine which one offered the older user with the best way to interpret energy usage information. One method of conveying information was through a clock metaphor where LEDs indicated the general energy usage within the home. However, this did not prove to be too useful or popular with older-users.

The approach, which ended up being taken, was to provide the older user with a simple, non-technical interface which does not rely on any interactive technology (e.g., mobile phones or smart televisions) but instead uses a simple traffic light metaphor. A mock-up miniature house was provided which uses a traffic light system located in each of the rooms within the model. Instant visual feedback is provided to the older end-user by indicating their power consumption in each room. Red indicates that they are excessively using energy within that room, amber indicates they are using more than they should but there is room for improvement with a few recommendations, while green indicates that they are using energy within the guidelines, or what the carer/family member might have specified.

Figure 3 shows the model house prototype interface. Each room of the house contains a set of LED's which indicates the real-time use of energy within that room. This was found to be the more successful of the prototypes for conveying straight forward energy usage information to older users.

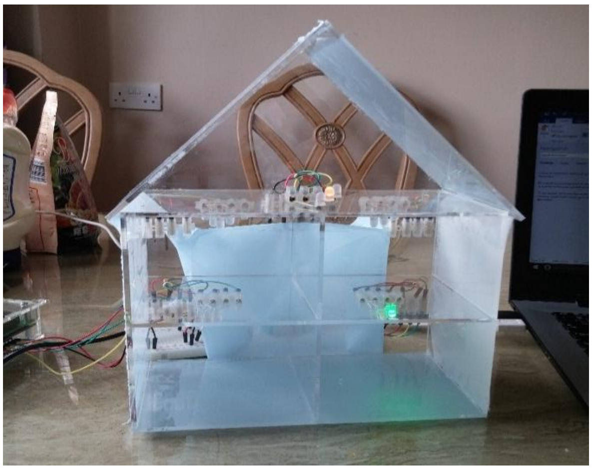

Figure 3. Model house prototype.

A. *Administrative interfaces*

The administrative interface provides carers or family members with cost saving's information either on a day-by-day basis or over a projected month. If older users felt comfortable with the technology they were also provided access to this information, rather than simply relying on the model house. For example, figure 4 shows the costs incurred for a number of monitored appliances within the home environment. Information is outlined, based on the activities that have been detected during the day and shows a comparison of their energy use. Both carers/family members and the more technically confident older user can utilise this information to determine how many times a day they perform specific activities with a view to reducing the frequency over time or to more suitable times which reduces their energy costs.

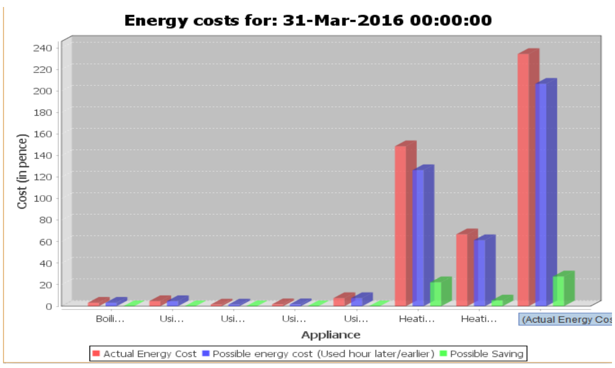

Figure 4. Savings graph.

Another way in which financial information can be conveyed to the user is through a monthly chart outlining the costs that have been incurred for each of the activities during that particular time period. Figure 5 shows how information can be presented to end-users regarding the total costs incurred and by activity.

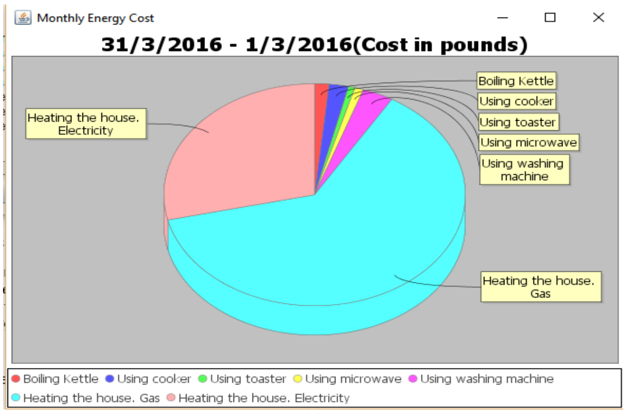

Figure 5. Monthly energy costs.

Recommendation notifications were also provided to end-users and carers/family members to allow them to determine where savings could be made by changing habits. For example, recommendations could be made to change the time of morning snacks and eating times to make best use of energy costs by moving these occurrences by a few minutes.

VI. INITIAL RESULTS

To combat fuel poverty, older users have to overcome issues with anxiety caused from the distress of lack of finance to pay for energy bills and also the fear of technology, which impedes the adoption of technology to help them become more energy efficient. Data was collected from an idealised test environment and played back through the system for evaluation purposes. The prototype was evaluated by 10 older users, whose ages ranged between 50 and 70 and were used to measure their technological fear and acceptance of using this technology. This was to determine whether monitoring energy use and recommending more efficient use of energy through modifying activity patterns, would improve their well-being by reducing their overall energy costs.

Preliminary testing has been conducted using 10 users to determine the effectiveness of the model house prototype. Older users were asked to answer a questionnaire after evaluating the usefulness of the interface. The data collected represented activities spread over several days from the test environment and was played in compressed form for them to evaluate the prototype. Activities were highlighted and explained during the playback of telemetry to help identify what was being done. 100% of the respondents identified with what the model house prototype was attempting to do by making them more aware of their energy consumption patterns. It was found that 80% of users were able to interpret the real-time information with ease while 20% of the respondents experienced difficulty at times when the system detected an increase or decrease in the energy use and notified them through flashing LED's. When addressing the question of technology acceptance and the fear of using new technology which can beset an older user, 100% of respondents said that they did not feel

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anxiety or fear regarding accepting information generated through the model house prototype. When asked if the prototype provided them with a way to monitor and adjust their habits during the day to make better use of energy, all respondents replied favourably (100%). In fact, it was discovered at this point that a number of users would like even more information presented to them on improving their energy expenditure. This proved to be encouraging and a validation that the model house improved their energy awareness and reduced their anxiety from worrying about fuel costs. Another group of 10 users (aged between 20 and 50) were used to evaluate the usability and functionality of the backend functionality of the system. This type of functionality would be used by carers or family members to help advise the older end-user on how to improve their energy-use by exposing them to fine-grained data regarding which activities were done and how potential savings could be made. The type of questions asked to these participants were predominantly focused on activity management, savings information, monthly projections and recommendations. The results from this evaluation showed that 100% of participants understood what the activities were and how they related to the system and data while 70% of participants were able to deal with, and manage, activity related features. The remaining 30% required extra guidance before they felt fully comfortable with the back-end system. When addressing the usefulness of the recommendations and potential financial savings, all participants agreed that the system was easy to use and offered important and helpful information on how to improve energy usage.

VII. CONCLUSION AND FUTURE WORK

Our intention was to produce a simple ICT system which would attempt to reduce the anxiety that older people experience in relation to fuel poverty as well as address the issue of accepting technology. It was found that the prototype system promoted the perceived usefulness of the system to older users. This is in addition to other areas of our research into energy-aware programming languages and runtime systems.

By focusing on the energy-awareness of everyday use from the start, the prototype system was able to successfully improve the energy use of a user over the initial trial period. The behavioural analysis and recommender systems were found to accurately identify activities which in turn aided in recognising and highlighting the cost awareness of what users were doing in association to their activities. By increasing this cost awareness of their actions, users were found to be more aware of how to reduce their energy costs by changing times or common activities to more cost effective times of the day. Carers/family members would be able to help by raising awareness of what the older user was doing on a day-to-day basis by showing them how simple changes to their daily patterns could result in tangible cost savings as well as improved health.

Following on from our preliminary results and prototype system we intend to expand trials for longer periods of time as well as integrating other technology dealing with energy-conservation within IoT devices populating these homes. Experiments on how the system affects the overall well-being of the older person will also be conducted as well as the impact of gender, disability (both physical and cognitive related), living status and age on their acceptance and use of the technology.

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