Telehealth for our Ageing Society 75 M.E.L. van den Berg and A.J. Maeder (Eds.), IOS Press, 2018

Supporting Diverse Challenges of Ageing with Digital Enhanced Living Solutions

John GRUNDY [a,1], Kon MOUZAKIS [a], Rajesh VASA [a], Andrew CAIN [a], Maheswaree CURUMSING [a], Mohamed ABDELRAZEK [a] and Niroshine FERNANDO [a]

[a] *School of Information Technology, Deakin University, Victoria, Australia*

Abstract. By the 2050, it is estimated that the proportion of people over the age of 80 will have risen from 3.9% to 9.1% of population of Organisation for Economic Cooperation and Development countries. A large proportion of these people will need significant help to manage various chronic illnesses, including dementia, heart disease, diabetes, limited physical movement and many others. Current approaches typically focus on acute episodes of illness and are not well designed to provide adequately for daily living care support. In our rapidly ageing society, a critical need exists for effective, affordable, scalable and safe in- home and in-residential care solutions leveraging a range of current and emerging sensor, interaction and integration technologies. Key aims are to support the ageing to live longer in their own homes; make daily challenges associated with ageing less limiting through use of technology supports; better support carers - both professional and family - in providing monitoring, proactive intervention, and community connectedness; enable in-home and in-residential care organisations to scale their support services and better use their workforces; and ultimately provide better quality of life. Deakin University researchers have been investigating a range of emerging technologies and platforms to realise this vision, which we in broad terms coin Digital Enhanced Living, in the ageing space but also supporting those with anxiety and depression, sleep disorders, various chronic diseases, recovery from injury, and various predictive analytics. A Smart Home solution, carried out in conjunction with a local start-up, has produced and trialled a novel sensor, interaction, and AI- based technology. Virtual Reality (VR) solutions have been used to support carers in the set-up of dementia-friendly homes, in conjunction with Alzheimers Australia. Activity and nutrition solutions, including the use of conversational agents, have been used to build dialogue to engage and change behaviour. Predictive analytics, in conjunction with major hospitals, have been applied to large medical datasets to better support professionals making judgements around discharge outcomes. A set of lessons have been learned from the design, deployment and trialing of these diverse solutions and new development approaches have been crafted to address the challenges faced. In particular, we found that there is a need to consider user emotional expectations as first-class citizens and create methodologies that consider the user needs during the creation of the software solutions. We find that quality and emotional aspects have to be engineered into the solution, rather than added after a technical solution is deployed.

Keywords. Ageing population, smart home, elderly, independent living, emotions, digital enhanced living, emotion-oriented development approach

1. Introduction

The need to provide assisted care for the ageing population has been a cause of concern for most developed and developing countries, including Australia [1]. As life expectancy increases, the challenges of aged care are becoming more immediate and pronounced [2, 3]. The supply of well-regulated, well-structured and suitable aged care facilities and communities will not be able to keep up with demand [1, 4]. As such, there are strong socio-economic reasons to encourage and assist older people to live at home for as long as possible. Additionally, studies show that many people prefer to prolong their stay at

[1] Corresponding author, Maheswaree Curumsing, School of Information Technology, Deakin University, Victoria, Australia; E-mail: m.curumsing@deakin.edu.au.

home, as long as they can, a concept known as aging-in-place [2, 4], and maintain their control over their environment and activities to improve their autonomy [5]. However, given their physical and mental circumstances, many elderly people require constant care and assistance in their daily activities.

Recent reports suggest that well-chosen and designed digital technology can help the elderly in prolonging their stay at home [3, 4]. Technologies and tools that can assist with this have the potential to drive social, structural and economic change in this area [6, 7, 8, 9, 10]. For more than a decade, several technologies, including sensor enabled monitoring devices, wearables and mobile apps, have been developed to support the growing number of elderly people [4, 5]. However, many elderly people still do not accept the idea of being supported by technology rather than by human beings. Evidence suggests that one of the main issues linked to the adoption of smart home technologies, in particular by the elderly, are linked to the way people perceive the technology, for instance, concerns around privacy and confidentiality are recurrent in many studies [1, 11, 12, 13]. In some studies [12, 13], people even referred to wearable devices, such as emergency alarm pendants, as being a stigma and a sign of old age.

Digital Enhanced Living is a fairly new concept and the technology supporting this concept is still emerging. One of the research areas that is currently being explored by researchers at Deakin University is *how can technology be better designed to address the users' social and emotional needs?*

In this work, we highlight the key challenges linked to supporting elderly people in home and in care; current progress and trial outcomes from in-home technologies including sensors, interaction, monitoring, data analysis and proactive intervention; key lessons learned about these approaches from design and conducting trials; and briefly outline current research projects including data integration platforms, remote monitoring, wearables, greater use of AI; and sustainability and scalability issues.

This paper is organised as follows: Section 2 presents the key challenges involved in designing technology for the elderly and the emotion-oriented development approaches to designing technology for the elderly. Section 3 outlines three research projects involving the elderly people. Section 4 highlights the key challenges linked to supporting elderly people and the lessons learned throughout the development of these three research projects.

2. Related Work

2.1. Challenges in Designing Technology for the Elderly

Even though several smart home technologies, wearable devices and mobile apps have been designed to support the elderly population in their day-to-day activities, evidence suggests that many of these technologies have not been fully accepted by the targeted audience [12, 13, 14]. A growing concern described in the literature [12, 13, 14, 15, 16, 17, 18] is that software engineers fail to give adequate consideration to user's emotional needs when designing systems, leading to unhappy and unaccepting end-users. Software engineers who are trained to design products from a set of desired functional and non-functional goals often end up developing an end-product that fails to fulfill the actual needs of its intended users.

Pedell et al. [13] presented a field study involving users of an emergency alarm pendant where they highlighted the users' reactions regarding the use of the emergency pendant. Their findings revealed that many users viewed the pendant as a sign of old age, a stigma if worn in society and even referred to it as a cowbell. This is a classic example showing that even though the emergency alarm system is functionally correct and serves its purpose, it fails to meet the social and emotional needs of the user.

Given that user emotional goals are a critical determinant to the acceptance of a technology, they should therefore be treated as first-class citizens during the development process. Even though the consideration of emotion is becoming predominant in the area of design, including human-computer interaction, this consideration has not transcended to the software engineering field [14]. However, including user emotional needs within the software engineering processes entails a number of challenges.

Emotional needs, such as to feel empowered, to feel in control and to feel safe cannot be easily converted into functional or non-functional requirements using existing software engineering methodologies. Hence, unsurprisingly they are very often ignored. In some cases, even though these goals, which we refer to as emotional goals are identified during the early stages of the project [19] they are very often forgotten at a later stage of the software development life cycle with the pressure of meeting deadlines [20]. One of the major reason for this little consideration given to emotional goals is linked to the shortcomings of the existing software methodologies in addressing user emotional goals within software design and development.

2.2. Emotion-Oriented Methods

In telemedicine studies, several works have identified emotional issues in take-up of the technologies [21]. Buck et al [21] describe nine human factors impacting on the update of telemedicine technologies. Djamasbi et al [22] describe the uptake of telemedicine technologies including challenges with applying a standard IT Technology Acceptance Model to digital health solutions without considering user mood and emotional responses. Several studies have looked into affective computing design approaches to telemedicine and medical educational technologies [23, 24, 25]. These indicate the importance of considering user emotions in the design of solutions.

Recent work in the digital enhanced living area [17, 26, 27] emphasised on the need to incorporate user emotional goals within the different phases of the software development life cycle. One such work Kissoon Curumsing [17] proposes a set of emotion-informed techniques to capture, represent and evaluate user emotional expectations. In this section, we briefly present these emotion-oriented techniques. A complete description of these techniques and their applications within three real-life case studies are avail- able in [17]. At the early conceptual phase of the project, an emotion-informed elicitation method is proposed to capture the key functional, quality and emotional goals of the end- users of the system. This method is based on a brainstorming session and brings together the key stakeholders of the system. The participants of the brainstorming session are led through a set of steps and throughout these processes, they are encouraged to list out and prioritise the key functional, quality and emotional goals of the system.

At the data analysis level, an emotion-informed analysis technique is proposed which is based on two well established techniques namely, *content analysis* [28] and *affinity diagram*. Content analysis is a well-established technique used for analysing content that may consist of words, meanings, pictures, symbols, ideas, themes, or any message that can be communicated [28]. It is usually applied to analysing text in transcriptions or documents [29] whereby the text is searched for recurring words or themes to identify core consistencies and meanings. The affinity diagram is a tool used to organise the identified patterns of words, identified during the content analysis process, into a hierarchy to draw higher-level concepts out of the data [30, 31]. The patterns are grouped together by related themes to create a story about the topic studied [32]. This emotion- informed analysis technique is applied to interview transcripts or used during literature review to identify terms relating to user emotional expectations or user emotional concerns.

In order to represent the users and systems goals identified during the elicitation and analysis phases, Kissoon Curumsing [17] proposed a set of agent-oriented models. The emotional concerns of users, for example, *privacy issues*, *social stigma* and *burden on others*, which we refer to as "emotional threats" are translated to "emotional goals" through an emotional model (refer to Figure 1 for an example). In previous works [17, 33], we described how an emotion model can be used to map the emotional threats to a set of functional, quality and/or emotional goals. The legend within Figure 1 represents the set of icons that are used to represent the different types of goals. Emotional threats are represented through ‘spades’, emotional goals are portrayed through ‘hearts’, functional goals are shown within ‘parallelograms’ and quality goals are represented through ‘clouds’. The output from this emotion model is then used to generate the goal model which provides an overview of the system in terms of its different goals (refer to Figure 2 and Figure 3).

A set of guidelines is also provided on how to generate emotion-informed personas. A persona is defined as “a description of a fictitious user, who does not exist as a specific person but who is described in such a way that the reader can recognise the description and believes that the user could exist in reality” [34]. Although fictitious, personas bring users to life by giving them names, personalities and often a photo [35]. The approach proposed by Kissoon Curumsing [17] included representing users in terms of their emotional expectations from the system.

Lastly, Kissoon Curumsing [17] proposed the use of an emotion-oriented assessment tool, namely a questionnaire to evaluate the extent to which emotional goals have been addressed by the system from the end-users’ perspective. This tool is an adaptation of the Attrakdiff questionnaire [36], which consists of 28 items whose poles are opposite adjectives, for instance, “confusing-clear”. The emotion-oriented questionnaire is designed with a similar approach whereby for each emotional goal, a corresponding emotional threat is placed at the other end of the pole, for example “I feel that I am a burden on my loved ones versus I feel that my loved ones care for me”.

The validity of these techniques was explored within three real-life case studies in Kissoon Curumsing [17] and are currently being applied to some projects at the Deakin Software and Technology Innovation Lab.

3. Exemplar Research Projects

In this section, we provide an overview of three projects that have been designed and developed by a group of Deakin researchers with user emotional goals as a first-class priority. SofiHub is a smart home technology designed to promote independent living among the elderly. EDIE is a virtual reality smartphone app, designed to create empathy amongst the carers of patients suffering from dementia. Cardiac Care Chatbot is a chatbot system designed to promote positive behaviour change amongst people suffering from cardiovascular diseases.

3.1. SofiHub - A Smart Home Technology

The term ‘smart home’, or ‘smart house’ was first used in 1984 by American Association of House Builders [37]. Since then, it has been given a number of definitions, including “a residence equipped with computing and information technology which anticipates and responds to the needs of the occupants, working to promote their comfort, convenience, security and entertainment through the management of technology within the home and connections to the world beyond” [37]. At its inception, the focus of the smart home research was to provide ambient intelligence for the home. However, in recent times, there has been a growing interest in utilising smart home technology to provide various assistive services to elderly people living at home. Case studies in aged care suggest that many senior adults prefer to continue living in their home as long as possible to maintain one’s independence [38, 39, 40].

SofiHub is an “in-home” solution designed to provide a passive monitoring and interactive advice for the elderly, assisting with a range of ageing challenges. A base station provides a point of interaction including reminders to take medication, fluids, conduct tasks, communicate with friends and family, remember important events e.g. birthdays and appointments and visitors, and ask for confirmation of status, for example, if no movement is recorded in an expected time period. A set of wirelessly networked sensors can include movement/motion, use of appliances, for example, fridge, stove, use of taps and doors, weight, blood pressure, temperature readings, use of things such as cups, chairs, food preparation. Various devices can be wirelessly controlled, for example, lights, heating and appliances.

A critical feature of SofiHub is the collection of a wide range of monitored data that paints a picture of expected behaviour of the elderly person. Machine learning is used to develop an aggregated, comprehensive view of this expected behaviour and deviations from this expected behaviour can be identified, for example, too long using the bathroom, late arising or early going to bed, not using tap, not taking medication or food, etc. SofiHub can then proactively remind or query the elderly person, for example, “Hi Jim, you have been in the bathroom for a long time - please move to the next room to show me you are OK” or “Hi Sally, it is time to take your lunchtime medication”. A carer or emergency service can be alerted if, for example, a suitable response or action is not received in required time. Different sets of sensors, dialogue and alerts can be configured for different homes and people. The technology of SofiHub differentiates itself from other smart home technologies in its use of a configurable, expandable network connected low-cost sensors, having an IoT platform with an aged-care component and built-in AI capability that can learn and adapt to a user’s behaviour.

Prior to the design and development of SofiHub, a review of the current approaches used for smart homes for elderly care was undertaken by the research team. This revealed that there was lack of theoretical foundation from which to derive what services are required by target end users, how they perceive IT enabled digital enhanced living, how the technology needs to be designed for their services to be accurately visible to and be actualised, and consideration of the emotional reaction and acceptance of such approaches. In particular, there are many documented issues with privacy, fear of becoming dependent on technology, stigma of being viewed as disabled/dependent by others, complexity of the system, invasiveness, cost and, loss of control [41]. As a result, SofiHub was designed with user emotion as a first-class citizen to address many of these issues.

During the early requirements gathering phases, user emotional goals were also captured along with the functional and quality goals. Interestingly, during the elicitation process, many end users expressed their needs in terms of what they did not want to feel, for instance, they commented on how wearables make them feel old and dependent on others. Carers noted that the elderly often forget or deliberately do not put on wearable solutions including pendants and heart rate monitors.

We developed an emotion model as shown in Figure 1, to document and map out the emotional threats, identified during the elicitation process, to a set of functional, quality and/or emotional goals. For example, emotional threats such as ‘dependent on others’, ‘monitored’ and ‘controlled’ were mapped to the functional goal (represented as parallelograms) ‘support independent living’ and emotional goals (represented as hearts) ‘independent’ and ‘in control’.

The outputs from the emotion model were then used to generate the goal model, shown in Figure 2, to represent the key goals of the system. The goal model refines the key high level goals and relates these subgoals, for example, messaging, movement detection, reminders, etc, to key quality and emotional goals. We used these models to gain feedback from carers and target end users around the suitability of SofiHub to maintain these key emotional goals for each detailed functional component of the solution.

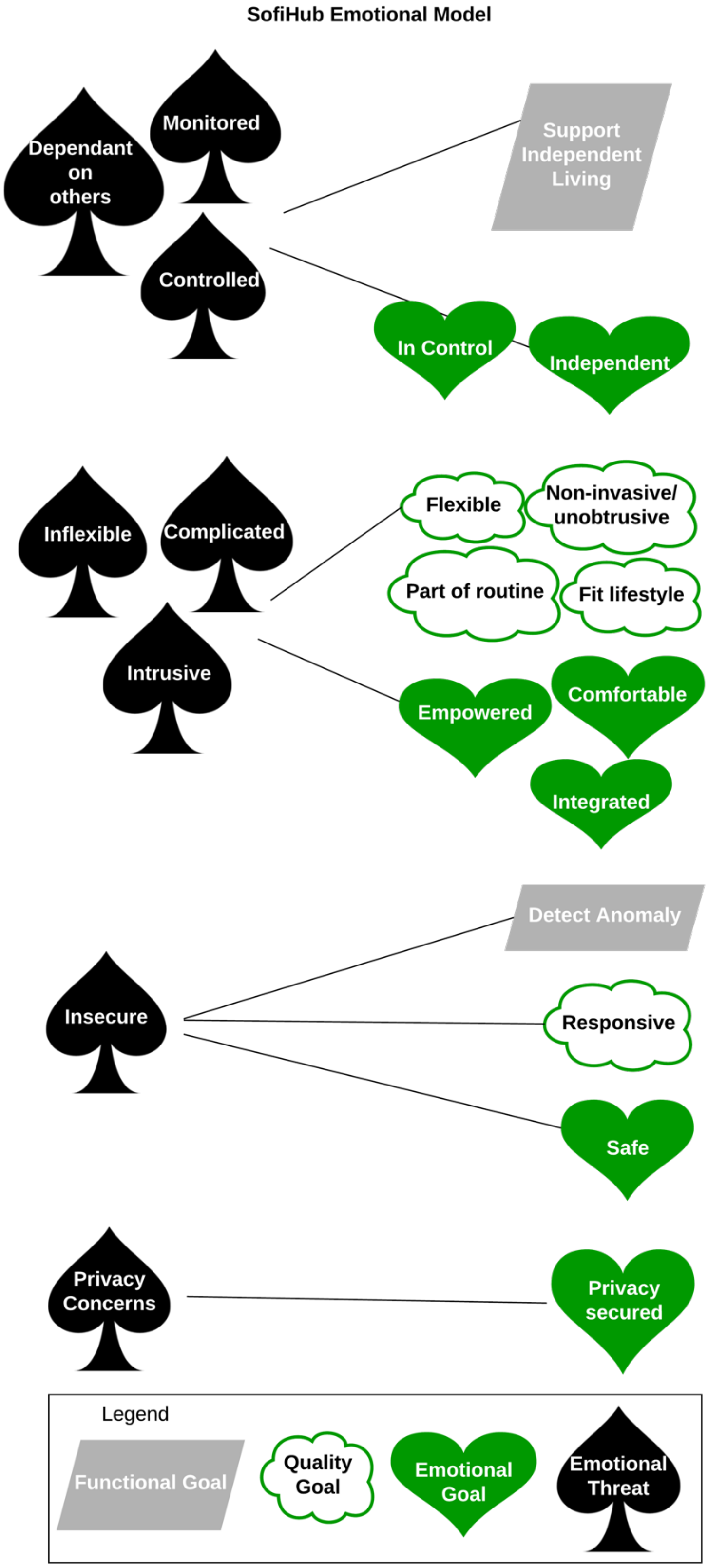

Figure 1. SofiHub's Emotion Model

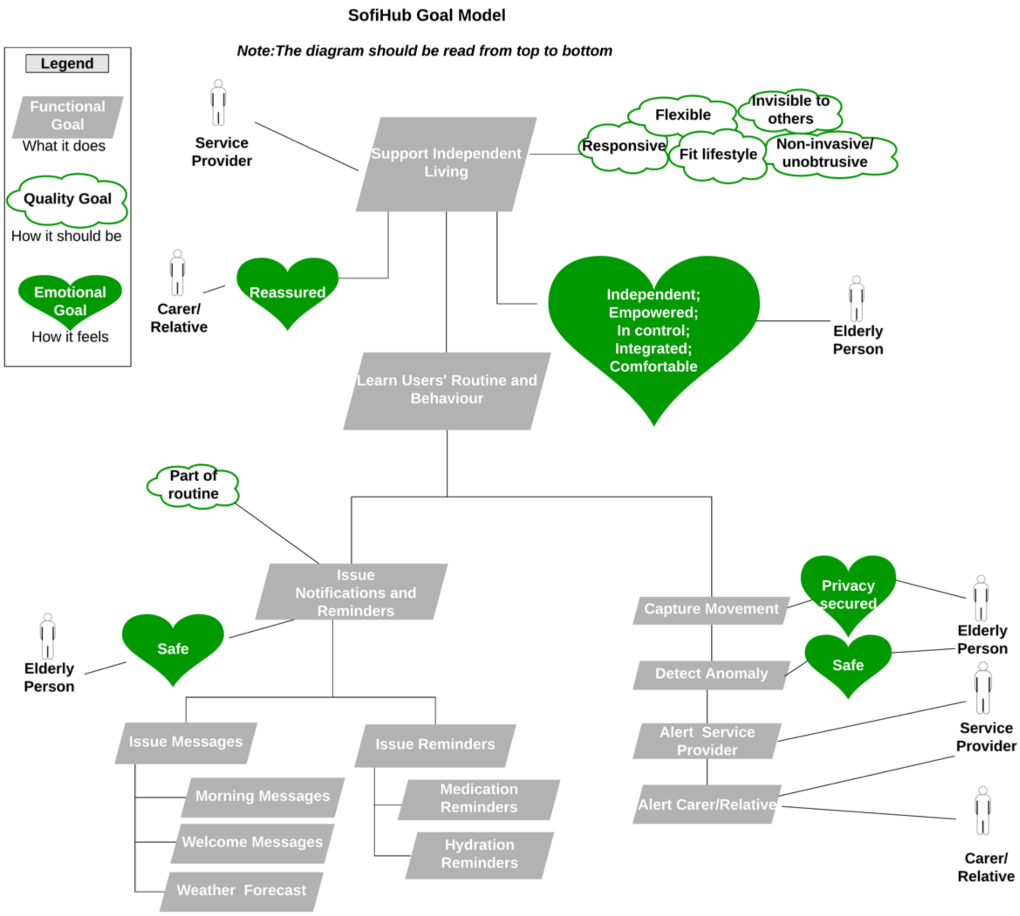

Figure 2. Goal Model for SofiHub

The goal model was then used during discussions with the designers and developers of SofiHub. Each emotional goal was mapped to functionality or design feature of the system. For example, in order to ensure that the system fit in the lifestyle of people, the system was designed to be non-intrusive with small devices (sensors) installed within the house and requiring very limited input from the user. It is similar to a smoke alarm detector within a house.

To verify and validate the approach taken to achieve the SofiHub smart home, two sets of trials have been carried out to date. The initial deployment of SofiHub was installed and tested in ten homes of elderly people, for twelve weeks. A set of questionnaires and interviews were used as data collection tool prior to the trial, mid trial and at the end of the trial. The data collected throughout the trial was analysed using our emotion-oriented content analysis approach.

This provided insight into SofiHub's technical functions as well as its ability to meet users' emotional goals. From this trial, we learned that the participants had a positive response to having SofiHub in their home.

In particular, users reported that they felt safer, cared about, reassured, supported, less lonely and that the technology was well integrated in their lives. Key features that assisted these feelings were the periodic dialogue initiated by SofiHub, contextual reminders, re- minders and checks on wellbeing using learned behaviours, and the sense that SofiHub "knew" about the elderly person's key needs and activities, rather than being a one-size- fits-all solution. The refinements made to SofiHub from this first trial have been used to implement further refinements and the second iteration is now being trialled in another set of thirteen homes of elderly people living independently.

3.2. EDIE - A Virtual Reality Smartphone App

A key challenge in providing support to people living with dementia and their carers is understanding the perception of the dementia patient. Feeling and seeing the world from the dementia patients' viewpoint can greatly help in this aspect. For example, at night time a person suffering dementia may perceive shadows and shapes very differently to someone without, resulting in heightened anxiety, fear and confusion. Those without dementia, including close family and carers, often have no idea how the living environment is actually being perceived and may be impatient or intolerant of the sufferers' behaviours.

To address this need, we developed EDIE, a virtual reality smartphone app using Samsung Gear VR, in collaboration with Alzheimer Australia Victoria [42], a not-for-profit organisation providing support and education for dementia sufferers and their careres. EDIE has been designed to provide an immersive Augmented Reality-based experience of how a dementia patient may perceive their living environment and give some insight into how they react to these perceptions. The EDIE app includes taking a visualisation of a room and adding in distorted shadows and moving walls to mimic what a dementia patient typically experiences. The app has an 'anxiety system' that emulates how anxiety builds up in a patient, and uses the sound of an increasing heartbeat to demonstrate how anxious the person is, as he/she experiences various aspects of dementia.

We designed the app and its AR-based features in conjunction with Alzheimer's Australia experts with a view to providing an educational experience in terms of mimicking emotional threats that typically impact the person with dementia. The functional aspects of the AR visualisation and its associated heart rate simulation generate a set of confusing, anxious, fearful, and disoriented negative emotional "goals" in the wearer that closely align with dementia sufferer experiences under the same circumstances. This generates better awareness in how these negative emotional experiences within the to the non-sufferer normal-seeming - environment are actually problematic to the dementia sufferer.

We trialled EDIE with a set of experts and carers to determine how well our app produces negative emotions in the user that align with an actual dementia sufferer. The feedback received from the interviews conducted during these trials with EDIE revealed that EDIE is successful in generating empathy amongst the carers of the dementia patients and a better understanding of anxiety and confusion that can be generated by living environments. Through the use of EDIE, carers can better understand what the dementia patients are going through and feel their emotions, explaining their behaviour and guiding carers in ways to mitigate these.

3.3. Cardiac Care Chatbot - Digital Health Platform

We developed a digital health platform to improve the heart health and wellbeing of people diagnosed with cardiovascular diseases. It aims to retain users' interest in the program by learning from the users' context, behaviour and lifestyle, to adjust their habits with beneficial nutrition and physical activity plans.

Patients diagnosed with heart problems or who are at risk of cardiovascular diseases are usually advised by doctors to follow special nutrition and physical activity plans that are often strict, complex, and hard to follow [43]. The increase in the number of people affected by cardiovascular diseases and the rise in the number of deaths related to cardiovascular diseases [44] indicate that the success rate of such plans is very low.

Most of the time, when people hear about their diagnosis, they feel various negative emotions about their condition, including shocked, confused, teary, lonely, worried, stressed or even angry and guilty [43]. At the same time that they are still digesting the information about their failing health and dealing with their emotions, they are provided with a treatment plan by the health specialist. Under these circumstances, patients very often get overwhelmed with the amount of information being provided to them, feel frustrated and lose motivation in following their doctor's treatment plans.

One of the main focus of this project is therefore to take into account users' emotions and their emotional expectations around using digital aids to assist them in implementing required heart health management plans and to improve the acceptance and adoption of such a tool. We used our emotion-oriented techniques [17] in the design and evaluation phases for this project to capture and model the users' emotional goals. The emotional, functional and quality goals identified for this tool are presented in the goal model in Figure 3. This shows a breakdown of the key functions of the cardiac care system, linked to the key emotional goals including feelings of safety, empowerment, control and, critically, reduction of stress. When designing and implementing the chatbot, developers were required to ensure for each of the functional features, their related functional goals and hence related emotion goals were realized in the tool.

We have begun informal trials of this cardiac care tool. To assist us in its evaluation with target end users we have adopted an emotion-oriented evaluation model, developed in line with our emotion-oriented requirements engineering method [17], that enables us to assess whether the cardiac care chatbot is actually meeting each of the required functional goals and their associated emotional goals.

4. Discussion

4.1. Lessons Learned from SofiHub

Unlike many smart home for ageing approaches, we developed a comprehensive emotion-oriented requirements goal model to inform our development team of key functional features, functional goals, emotional goals to achieve, and negative emotional goals to avoid. This was validated in consultation with literature review and target end users and carers.

We then went through multiple prototypes when designing SofiHub using different kinds of sensors and wearables. It was clear that an ambient, non-intrusive solution that does not get in inhabitants' way was the right direction for the set of emotional goals that we identified. SofiHub works a bit like a smoke detector - it passively monitors inhabitants' behaviour, and only triggers when there is an anomaly or when the inhabitant needs assistance - for example, medication reminder, dehydration reminder, etc. Our trials showed a wide-acceptance of the technology compared to intrusive solutions available in the market. In most cases, these solutions offer basic capabilities - for example, IF-This-Then-That IFTTT rules - and mostly not targeted for this market segment elderly people. The trials also showed interesting findings - for example, it was reported that SofiHub helped in alleviating participants' loneliness as they liked the periodic reminders and interactions, especially those relating to family and appointments.

From an engineering perspective, we faced many challenges while developing the solution due to the instability of many existing IoT devices (sensors). Moreover, it was very challenging to extract semantic understanding of the house using few, simple, off-the-shelf sensors that only send binary signals (motion or no-motion) while keeping the total cost of the technology down to make sure that it is affordable. Compliance with Australian Standards is very important. Some of the sensors that we used in our initial prototypes turned out to be not compliant with the local standards, which meant that we could not use these sensors in a commercial product.

The Sofihub smart home for ageing solution, at different stages, has been in trials in the last 18 months. Engaging with potential users of the solution at this early stage was very useful to tune, pivote and plan features based on real priorities.

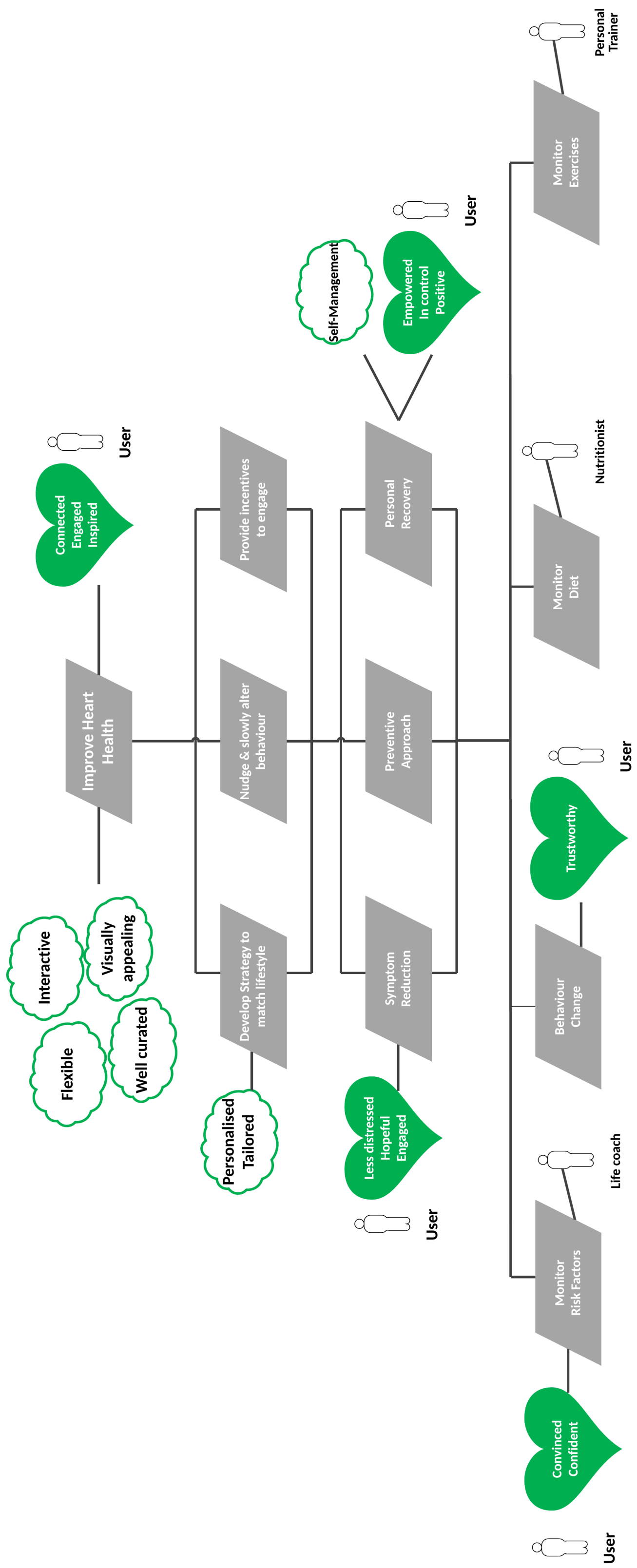

Figure 3. Goal Model for the Cardiac Care System

4.2. Lessons Learned from EDIE

EDIE is not designed to directly support ageing people with Dementia but rather to place carers (who interact with people suffering with Dementia) into the shoes of a person living with dementia. This then gives carers a first-hand look and feel at what the world seems to be like through their eyes as they progress through a living scenario. This helps increasing awareness, appreciation and understanding of the problem. We used a set of NEGATIVE emotional goals to exacerbate the key feelings a dementia sufferer typically has in a living environment due to their cognitive decline: seeing shadows, flashes, "things" that are not there; becoming confused as these changes unexpectedly; becoming anxious and then fearful; and forgetting the purpose of tasks as these unexpected visions confuse them.

Our studies of using EDIE with dementia experts and carers have demonstrated that such an AR-based emersion tool provides a highly accurate and realistic scenario of dementia confusion and anxiety. This in turn helps carers to better understand these problems in the people they are caring for, in turn increasing their empathy and understanding, and ideally improving their ability to care for the dementia sufferers as these challenges manifest.

We faced many technical and usability challenges in developing EDIE. Some of these include making sure that the user does not get lost when navigating through a scenario and, hence, we had the user interface moving around with the user's gaze. Current VR interfaces need hardware buttons for interaction. We introduced "stare buttons" to capture user virtual interactions. In our trials, we found that some users did not navigate through the scene as we wanted them to do, and did not getting the full experience we expected. We ended up introduced instruction screens to help users interacting with the app and guide them through the game.

4.3. Lessons Learned from Cardiac Care Chatbot

The Cardiac care tool is meant to change the negative behaviours of those who are suffering from chronic heart disease, mainly through an intuitive and engaging chatbot. Our idea was to give the user a very simple interface that they can interact with, while being able to streamline interactions based on previous interactions, target goals, and other relevant, contextual information - e.g. time of the day, location, etc. We developed an emotion-oriented goal model to better assist our developers in ensuring key challenges for this target group - including safety, control and stress reduction - are being met by the functional features related to these goals.

While the concept of chatbots is widely spreading with the advancement in natural language process (NLP) and deep learning, we have found in our work that the current platforms are not supportive when it comes to developing a highly personalised chatbot with deep machine learning model generating bi-directional conversations. This is necessary in the domain of cardiac advice as the conversations must be highly personalised, contextualised, related closely to the exercise and nutrition care plans prescribed, and manage the highly-agitated state of mind most patients are in when adopting the tool. Our emotion-oriented evaluation framework is being used in current trials to determine when our prototype chatbot is meeting the key emotional goals required and when it is not. In the later case, our developers refine both the chatbot interface and behaviour to ensure these are met.

Table 1. Comparison of our three studies

Study	Technology	Users	Key Outcomes
Sofihub	Smart home with sensors e.g. movement, cupboard, fridge, doors, voice and button interaction Passive AI monitoring	Aged family Carers	+ successfully prototyped and trialled + most emotional goals met - many technical challenges to build - challenges with multiple people with different goals
EDIE	VR/AR tool for dementia training	Dementia carers	+ identified key negative dementia sufferer goals to show carers + mitigated most -ve goals in design - navigation challenges - learning to use challenges
Cardiac Care	App with chatbot to support caridac incident recovery	Cardiac patients	+ meets most emotional goals + emotional evalution approach useful - dialogue challenging to build - personalisation hard

5. Conclusion

In this paper, we have described three exemplar projects developed by our team in the area of digital enhanced living using cutting edge technologies including Internet-of-Things (IOT), VR, Machine Learning and Chatbots. We applied an emotion- oriented approach to better capture the target end user emotional needs, both positive and negative, when using the applications and relating them to key application quality and functional goals. These projects were all successfully deployed and evaluated with end users, resulting in considerable feedback to developers.

Across the three applications that we have presented we have made several key findings:

- Using emotion-oriented requirements engineering, development and evaluation approaches has greatly assisted us in identifying and staying focused on what matters to the end user in a wide range of contemporary Digital Enhanced Living solutions
- As a reference model, this has helped us in evaluating the technology we built and making sure that it satisfies critical end user functional, emotional and quality goals
- Further work is needed in the increasingly popular areas of chatbot technologies in terms of users' emotional reaction, appropriate language, area of use, and effecting behaviour changes
- Immersive reality interfaces hold much promise in the digital enhanced living domain but still suffer from challenging navigation, instructional and accessibility issues
- While our Sofihub smart home solution has proved very promising, issues of multiple co-located users, further use of emerging sensors and AI techniques, and appropriate interaction to suit different user emotional goals and circumstances are very challenging

Based on our observations, these emotion-oriented approaches could be applied and further extended to incorporate user emotional goals at different stages of the software development life cycle. While applying these emotion-oriented approaches within these three projects, we identified a major gap between the requirements engineering phase and the design/development phases. While our techniques have proven to be successful in identifying the key requirements of the system, in particular, the emotional goals of the users, we are still working on generalising the process of mapping the identified emotional goals to the design and implementation of the system. The field of digital enhanced living is still under-developed. One of the key gaps we identified through our engagement with industry and researchers is eHealth, especially in the area of rehabilitation.

Acknowledgements

We would like to thank the SofiHub, Cardiac Care Chatbot and EDIE team who allowed us to use their technology to acquire the data for this work. We would also like to acknowledge the efforts put forward by the DSTIL team at Deakin University to develop the smart home technology, chatbot and VR technology.

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