The Future of Assistive Technologies for Dementia

Carrie Beth Peterson [1,2]*, Neeli R Prasad [1,2], Ramjee Prasad [1,2]

1 Department of Electronic Systems, Aalborg University, Aalborg, Denmark
2 Center for TeleInFrastruktur (CTiF), Aalborg, Denmark
* Corresponding author (cbp @es.aau.dk)

Purpose The use of Assistive Technologies (ATs) for residential dementia care is increasing, yet there is a gap between what individuals want, what developers design, and how outcomes are evaluated. Despite widespread acceptance that ATs improve quality of living (QOL), there is relatively little data to support such claims. This article discusses the current state-of-the-art AT-design, its use and assessment in relation to dementia care and projected future trends that can be incorporated into research now. **Method** By reviewing a history of ATs used in residential dementia care, incorporating societal and healthcare trends and applying theories of science, a futuristic view of AT-development and use is presented. The theoretical foundation is rooted in phenomenology, universal design, aging in place and gerontechnology. This research is supported by results from a European Commission-funded project where ATs were integrated and tested in real life conditions and evaluated qualitatively and quantitatively by older adults with dementia as well as their formal and informal caregivers. **Results & Discussion** The results shows the need for future ATs to be more integrated into the environment, combined with ambient and intelligent technologies, the Internet of Things (IoT), and the potential of cloud computing. They will also become more personalized to individual needs and user requirements.

Keywords: Assistive Technology, Quality of Life, dementia, Ambient Intelligence, Internet of Things, gerontechnology

INTRODUCTION

Assistive Technologies (ATs) are often presumed to increase Quality of Life (QOL) and improve health and social care services for many older adults, yet there is inadequate data to support these hypotheses. It appears that, at least in health services provision and clinical research, performance evaluations of the technological devices, services and psychosocial outcomes is becoming a central paradigm in AT development. The evaluations should be built upon the perceived needs and wants of the end users (i.e. user requirements) so that the development, use and evaluation of the ATs have clear social impacts. Some of the primary barriers to this development are in defining parameters and the correlations between QOL domains and care interventions outcomes.

Persons with dementia are the subjects of the research presented here as there is no current cure for dementia and the primary care goal is in maintaining or increasing QOL. They are a particularly interesting population to work with due to the effects of their syndrome. Being a syndrome means that there are groups of characteristic symptoms, rather than a disease process (with the exception of some types of dementia, such as Alzheimer's Disease). The most common symptoms are a progressive loss of cognitive functioning, including decision making, mathematics, communication, memory and spatial reasoning. However, each person (and those who work with them) experiences it uniquely. This is why it is so highly individualized and this is where knowing the person makes a world of difference in the quality of the care. Any nurse or caregiver can tell you that they adjust to the dementia, noticing changes in the person throughout the day and over longer spans of time. It is common that people with dementia communicate through their behaviors; this may be due to decreasing communication capabilities (i.e. aphasia or apraxia). Caregivers reach a certain quality of care when they are able to interpret behavioral symptoms (e.g. agitation as a reaction to care) and in turn communicate with the person in an appropriate manner. People with dementia are ideal nominees for benefitting from context-aware technologies and, from an engineering standpoint, they are an ideal challenge to design for. The best, currently known method to intuitively and seamlessly change and adapt the environment to the fluctuations of the user is through technologies associated with Ambient Assisted Living (AAL).

The theoretical basis of this article is rooted in phenomenology[1,2], aging in place[3,4], gerontechnology[5] and exponential growth[6]. Gerontechnology research currently applies four modules of technology impact (prevention and engagement, compensation and assistance, care support and organization, and enhancement and satisfaction) to five elements of activity (health and self-esteem, housing and daily living, mobility and transport, communication and governance, and work and leisure) to relate technology, activity and health and self-esteem[7,8]. Further research in this area is needed as we are just starting to be able to interpret information on how older adults interact with and perceive (assistive) technol-

ogies. This article gives a forward-thinking perspective on where these technologies and services are headed in residential care with dementia.

STATE OF THE ART

A full State of the Art on ATs for dementia care is beyond the boundaries of this article so current high-tech ATs are presented. Low-tech interventions would include grab bars in the bathroom or ergonomic tools, and are not expanded upon in this work. This section ties in current best practices for residential caregiving for dementia to technologies that can achieve the same goals. It is emphasized that the person's level of need alone does not describe how the ATs are perceived, used or the resulting outcomes. If ATs are disproportionate to the user's needs, they are less likely to be utilized, which impedes the fulfillment of care goals. This entails assessing the safety, health and care needs to tailor the individualized dementia care plan.

Assistive Technologies for Dementia

Gerontechnology concentrates on four classes of technology[8]. Prevention and engagement technologies strive to delay or defer restrictions in functioning and promote user engagement in their environment. This would range from safety features to interactive interfaces. Compensation and assistance technologies are closely related, but are more fine-tuned to adapt to the user, such as increased lighting when reading and robotics-assisted cleaning. Care support may include devices for physical support, such as lifts for caregivers to transfer a person, or organization, like records of medications administered during the day. Finally, enhancement and satisfaction are like the icing on the cake; they provide services that include ambient lighting and music or virtual reality to enhance the enjoyment of activities. Some of the standard high-tech ATs[9] consist of:

- *Communication* (e.g. e-mail, real-time alarms, access to telecare and medical networks and social support networking).
- *Robotics* can perform household maintenance (e.g. vacuum), as a butler (e.g. assistance with bathing or eating) or companionship activities.
- *Home automation* technologies could monitor and ensure home safety features (e.g. fire and smoke alarms, ventilation, sensors for water temperature, power control).
- *Sensors* for monitoring, initiating alarms and data collection. The most common types of AAL sensors are environmental (e.g. motion detection, PIR, water usage, thermostats), radiofrequency transmitters (e.g. RFID tags) and computer-vision (e.g. webcam, user recognition, motion analysis).
  - o *Radio Frequency* Identification (RFID) technology is used to locate items in the home and GPS/GSM for navigation or locating the person outside the home.

The sensors detect and generate alarms through several techniques and activities are usually divided into event-based and clock-based parameters. For example, motion detectors relay if the user has entered the bathroom, signaling a new event. Say the user has turned on the tap 3 times, which the system interprets as hand washing sub-activities. Fuzzy logic and pattern recognition consolidate the data to identify activities and interpret if there has been variance in the normal daily pattern. Furthermore, machine learning allows computer algorithms to automatically improve experience. The basic idea is for the system to learn a function that maps between some inputs (e.g. sensor readings – water tap turned on in bathroom) and some outputs (e.g. categories of human behavior – washing hands or deviation of activity). Additionally, many of the technologies used for dementia care in the home are or can be connected through the Internet. Internet-based services can provide several benefits to the dementia care plan, such as remote access to system data.

Dementia Care

Now we can combine the technologies and the best practices for caregiving. A main function of formal caregiving is in assessing when modifications to the care are needed and again if they are proven beneficial. This is under the hypothesis that the best care is provided when the individual symptoms of dementia are understood. The following is from the Alzheimer's Association manual, "Dementia Care Practice Recommendations for Professionals Working in a Home Setting"[10]. To allow for a transfer of tasks from caregivers to Assistive Technologies, they at least need to characterize the tasks that were previously performed by humans. The Alzheimer's Association states that the fundamentals of quality in dementia care consist of:

1. *The ability to recognize the signs of dementia and behavioral indicators and to detect changes.* Through Machine Learning, Smart Home systems that build upon patterns of interaction in the home can be fine tuned to notice changes in behavior (e.g. increased night wandering).

2. *Communication with the person with dementia and their family as well as coordination with other care providers.* This can be accomplished through mobile devices (e.g. PDA, mobile phones) as well as stationary computers (e.g. email, video conferences); however, this may still be difficult for a person with dementia, particularly those who have little experience with technology use.

3. *Apply and assess nonpharmacological methods (i.e. environmental interventions) to the care plan through person-centered techniques.* AT

systems can integrate new technologies and functions can be tailored to the personal care management plan. Sensors can gather information on how the services are utilized.

4. *Encourage proper nutrition and hydration.* Electronic calendars and reminders are some of the most common used technologies, along with ambient lighting features to draw attention to meals. Refrigerators can monitor weight in the contents to evaluate if food is being eaten regularly[11] and water taps can register how often the tap is used.

5. *Medication management.* Electronic calendars with reminders and electronic medication dispensing systems are used, but this is more challenging when meds are not in pill form.

6. *Manage home safety issues.* This has been one of the fastest areas of gerontechnology to develop as electronically detecting and preventing safety issues is a major user requirement for older adults living alone. Gas and water sensors can turn the appliance off if it has been left on for too long. Gait analysis employs motion sensors and accelerometers can predict falls before they occur[12]. Electronic keys and door sensors can accommodate for entry and exit of the home and fall detectors can alert caregivers or emergency personnel when an incident occurs[9,12-14]. It is also important to recognize that wandering can serve to keep the person physically active and allow them to express needs or emotions that they otherwise might not be able to communicate (e.g. pain, too much stimulation, desire for more stimulation, need to toilet, anxiety, adjustments to care, etc.)[11]. Wandering is really only considered dangerous when the person is alone or incapable of recognizing safety issues (e.g. outdoors alone, risk of disorientation, doesn't recognize traffic, not appropriately dressed for the season, etc.). GPS/GSM technologies can localize a person if they do go out or would become lost, and notify the proper authorities.

Although the application of these technologies to care practices is sophisticated, there are some important goals for continued development that are imperative to the future of ATs for dementia care. We are still in need of a common system concept to seamlessly integrate devices and service functions through secure networks. The technologies themselves need continued development, particularly intelligent products that aggregate and integrate contextual data to extrapolate situational user requirements. And we also need continued development in how to interpret the outcomes of the care interactions to make meaningful information out of accrued data.

Functioning, Device and Service Classification
One hindrance to the cohesive assessment of ATs

with dementia lies in the lack of a standardized ontology. The benefits of having a common language to describe disease, disability and therapeutic outcomes are seen in clinical use (i.e. determining functional ability, goal setting, care plan management, assessing intervention impacts) and policy (i.e. disability evaluation for services provision, anti-discrimination laws, building codes). Several major classification systems are in current use; it is expected that these will be more unified, centralized and integrated into development and evaluation tools in the future. While establishing standardized ontologies in AT and QOL classification is obviously difficult to realize, an agreed ontology will promote the discourse necessary to develop and evaluate the ATs and their outcomes.

The American Psychiatric Association's Diagnostic and Statistical Manual of Mental Disorders (DSM)[15] assigns a uniform language and evaluation criteria for clinical diagnosis, research and legal use. The coding of the DSM is to be congruent with the coding used in the International Classification of Diseases and Related Health Problems (ICD)[16]; however, they are not revised at the same, and discrepancies exist. The ICD is one of the most prominent classification systems used for coding diseases, symptoms, conditions and causes of injuries and diseases.[17] conducted an international survey of psychiatrists and found that the DSM was considered more valuable in research and the ICD was most used for clinical diagnosis. Additionally, the WHO's International Classification of Function, Disability and Health (ICF) is a framework that categorizes health-related subjects into bodily structure and functions, and activities and participation[18]. However, the ICF it is not adequate to neither match nor evaluate abilities with technologies alone. The Patient-Reported Outcomes Measurement Information System (PROMIS)[19,20] group is creating a domain framework that can be used in their computerized system to collect and interpret therapeutic effects that cannot be currently assessed. The PROMIS group and the Patient–Reported Outcome and Quality of Life Instruments Database (PROQOLID) group are both trying to make cohesion of the thousands of items relevant to QOL domains[21]. In PROQOLID, the domains are divided among working groups that focus on their specific domain. This is beneficial in determining the weight of sub-domains, such as anxiety on emotional affect; but it is worrisome that each work-group devises their own strategy to accomplish this.

Work in this area involves engineers, sociologists, gerontechnologists, psychologists, social and health care professionals and citizens (i.e. caregivers and elderly with dementia), so a common language to define and describe the technology must be applica-

ble to several tiers of understanding of technologies and dementia care. Once the language is agreed upon, definitions, goals and indicators will be streamlined and these will bring about social impact. The values of the definitions and outcomes have the power to change the lives of citizens in their understanding, use of and evaluation of the ATs. It is expected that with a greater understanding of these values, they will become part of the public communication. In this way, the end user feedback will more efficiently play a role in the continued development of AT systems and outcomes indicators. It will become easier to distinguish the effects of a behavior (e.g. use of an AT) and, hopefully, how those further affect other behaviors (i.e. QOL). Another area of research would be in reliably incorporating the continued changes in science and technological solutions as they develop. At present, the WHO Family of International Classifications (FIC) Development Committee is pioneering plans towards this end.

Evaluations of Systems and Services

In the field of evaluating ATs, most of the literature is on educational settings (e.g. with learning disabilities) or on people with physical handicaps (e.g. wheelchair users). Understandably, evaluations in these dimensions allow for defined outcomes as indicators (i.e. increased test scores in schools or increased mobility with the wheelchair). Although this seems far from investigating Smart Homes and dementia care, the methodology used can be applied to the development of outcomes indicators in this field. Evaluations in this context are important because if we can assess QOL outcomes, we can also assess AT as a treatment intervention.

Current criticisms in the field are that when reviewing AT outcomes in dementia, no comprehensive conclusions can be drawn as data is not collected or assessed in a unified way, study sample sizes are small, the disease and outcomes are highly individual and the majority of reporting is through descriptive studies[22-24]. The WHO is working on an International Classification of Health Interventions (ICHI), which will be a tool to statistically report and evaluate the allocation and development of health interventions[25]. This is where we currently are now in the state of the research. The next step is to demonstrate how effective ATs are by evaluating them in the context of longitudinal real-life.

Both objective and subjective evaluations provide important information on the understanding of end user interactions and outcomes. The subjective evaluations are given by, e.g. the person with dementia themselves, their informal caregivers or by formal care providers. Objective evaluations are collected through biomedical data (e.g. blood pres-

sure, physical functioning tests). Martin[26] refers to these models of QOL as *s*QOL (subjective), *o*QOL (objective) and proposes a new model to investigate, *f*QOL (functional). The administration and scoring methods are still largely conducted by humans, can be costly and time consuming and are outdated to the mode that services are provided (e.g. pen-and-paper testing of cutting-edge technologies). The increasing interest in developing individualized measures[27] reflects the paradigm that life quality is unique to individuals and thus cannot be adequately assessed with measures that ask every patient the same questions and require the same, preset responses. Personalized systems will essentially need personalized assessments. One strategy would be to have the assessment as a software component of the AT system, a type of software-as-a-service. The authors in[28,29] discuss a prototype assessment that would have intelligence to adapt to the user, adjusting to how they define and act out what the quality of their life is to them. What's more, collecting information on ATs and QOL outcomes via the Internet allows for meta-analyses involving multiple groups and diverse locations to compare, for example, treatment *x* versus treatment *y*. This has remarkable implications for Randomized Controlled Trials (RTCs) in accruing participants for longitudinal and ethnographic studies and how we can ascertain care needs by increased ability and reliability in detecting statistically significant factors. An anticipated cohesion strategy would be to connect the classification systems mentioned above with the home AT system, including the QOL assessment itself[29].

We have increasing ability to optimize healthcare but the technology is not perfect yet. We haven't worked out all the bugs in making innovative technology platforms that can seamlessly sense and integrate itself into the context, collect and interpret data and respond intelligently. The implications of achieving this would allow for monitoring and treating in real time, at the point of care. This leads us to look further into the possibilities of Ambient and Artificial Intelligences and their role as ATs for dementia care.

INNOVATION IN TECHNOLOGIES FOR DEMENTIA CARE

In the era of the digital divide, we are just starting to learn how to gather and interpret information on how older adults interact with technologies. The Law of Accelerating Returns implies that with the exponential growth of technology, we realize more effective and efficient ways to do execute activities and achieve knowledge[6]. Even though this is largely correlated with technology, it is not hard to imagine how other elements of life are affected as a result (i.e. health care and socialization). It is expected that future generations will be more familiar with technology; there will be more homogeneity as everyone

has lived their entire lives with the influence of technology. The technology will also become more personalized to individual needs and user requirements and social and health care services will have streamlined electronic records and communication. By then, we will have a better understanding of how humans interact with technology which can help researchers to better distinguish between individual changes (e.g. preferences, needs and mood states). Some projected future trends in technology development discussed here are in anticipation of developments in context awareness, intelligent data processing, Ambient Assisted Living (AAL), robotics, the Internet of Things and Cloud Computing.

An intelligent home will be better equipped to predict and minimize safety hazards in the home as well as contact help when needed. The best way to arbitrate this is by gathering information on user patterns, environmental hazards, assessing the individual's needs and initiating an action plan to alert when a safety threshold has been breached. Homes in general will have more electronic features, such as keys, window and door locks and sensors. Gait sensors and accelerometers will not only be able to predict falls, but to determine the physiological root and recommend training or rehabilitation (e.g. greater flex of hips to compensate weak ankles)[12]. Context-aware systems have the capacity to be cognizant of environmental activities and characteristics through networked equipment, such as mobile, pervasive and ubiquitous computing components.

Minimizing interaction required by the user is especially important with dementia as declines in procedural memory hinder the user's capabilities. Zero Effort Technologies (ZETs) use algorithms to collect, analyze and apply data autonomously and unobtrusively[30]. Likewise, AAL systems interlink individual components to assist with household and daily activities[31]. As part of an AAL environment, ZETs could automatically clean surfaces or items, water plants, open and close windows or curtains and perform other functions that ensure safety in the home while maximizing personal privacy and freedom. The applications can extract environmental information (tag the captured data), interpret information (adjust to the dynamic context) and apply large amounts of varied information (execute a function). Intelligent home systems will be able to collect biosignals and physiological data which helps detect behavioral changes as well as interaction fluctuations in the home's integrated devices or appliances. These will also be able to identify indicators of change in communication or cognition in the user and possibly differentiate them from outcomes of care management or comorbid conditions (e.g. depression, pain). Innovation in smart materials[32] may mean that tex-

tiles such as clothing, bandages and wallpaper can detect if the person has an infection or monitor vital signs and respond appropriately.

Simultaneous to ZET development, there is also expansion in research that promotes user interaction. The work in robotics is a good example of this as there is a strong connection between companionship and caregiving[33]. In[34] and[35], the authors report that older adults who were involved in testing robotic technologies became socially and emotionally attached to the robots, talking to them, naming them and anticipated missing them when the trials would be over. Borka and SARAH[36,37] are examples of robotic technologies that perform tasks while providing companionship. SARAH is a virtual presence, so the software (user-perceived personality) can be integrated into other system agents in the home (e.g. tablet, robot, stove). The LIREC group is also striving to make robots more companion-like by observing canine behaviors[37]. It is envisaged that robots will be able to detect human expressions (facial and body language), adapt accordingly and even mimic them through the interface; Feelix Growing[38] is working towards this direction. It will be interesting to see how users will build personal relationships with their technologies and how this effects how they shape their environments and define quality over time.

The increase in micro and personal devices (i.e. wearable medical instruments, RFID tags, smart phones) allows for the user to extend context beyond the walls of the home by integrating biomedical, mechanical, electrical and information and communication technologies (ICTs). The increase in the number and capabilities of devices to be connected is one of the central themes in the Internet of Things (IOT); smart devices can communicate with smart homes and smart cities via the Internet[39]. Wireless communication networks (i.e. cell phone networks, mesh networks, WiFi networks) essentially connect end users with a city's network to provide assistance in public transportation, medical appointments and socialization activities, for example. This leads us to consider the role that Cloud Computing will play in connecting the Internet of Things for the future of dementia care. Cloud computing is basically a distributed computing model that delivers services over the Internet. Internet-centric software that can be accessed globally, and is scalable for multiple users, platforms and networks is one of the newest models of service delivery. Currently, the services are categorized as Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS) and Software-as-a-Service (SaaS)[40]. Amazon Web Services is the largest public cloud provider; the public services are essentially available to anyone on the Internet. Private cloud services are available to a limited number of vendors behind a firewall, (i.e. US Department of Defense). If

a tenant would use public cloud resources to make their private cloud, they have created the third type of cloud computing, the virtual private cloud. There are also hybrid clouds and mission-critical clouds, and it is expected that these will continue to evolve in the coming years. However, because cloud computing is still quite new, key areas still need to be addressed. A legal framework needs to be in place to protect the privacy of users and to cooperate with international regulations. Technical services also need to reach a point where they are secure and accessible; this involves technical standardization and service level agreements. For more details on research related to Cloud Computing in Europe, please see[41].

DISCUSSION

Although some strides have been made in assessing AT outcomes with dementia, we are still far from our goals of understanding how end users interact with the technologies and the intricacies of the effects. This article has discussed recent trends in technologies for dementia care. Assistive Technologies alone as well as AT systems have strong potential to positively influence QOL. Context-aware technologies that utilize sensing and machine learning can autonomously perceive the environment, learn from and adapt to the user, and carry out predefined, goal-directed tasks in real-time. Particularly in dementia, they can aid in tasks that require learning and decision making (two of the primary limitations characteristic of dementia). Furthermore, there is potential for communities (Smart Cities) to play a role in the future of living with dementia by connecting the user and their devices (Internet of Things) to services through Cloud Computing. Of course, there are major issues in data storage, system integrity, privacy and security, networked architecture and service provision, but it is worth starting a dialogue on these issues and setting forward-thinking, goal-directed research ambitions for the future of dementia care. We can imagine what the future holds, now we need to create it.

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