Developing a Voice Assistant for Users with Dementia

# Introduction

Dementia is one of the leading causes of disability among the global elderly population which causes the deterioration of cognitive functioning. As modern advances in healthcare cause the average age of the world’s population to rise, so too is the number of elderly persons living with dementia that require care and support (World Health Organization 2019). There are estimated to be over 885,000 people in the UK diagnosed with dementia (Wittenberg *et al*. 2019) and over 50 million worldwide (Prince *et al.* 2015). People living with dementia require constant care and, although the nursing care industry is growing, training care-workers is difficult, time-consuming, and expensive. As a result, the number of care-workers is not sufficient to match the growing number of dementia cases.

There is great promise for voice assistants[[1]](#footnote-1) (VAs) such as Apple’s Siri and Amazon’s Alexa to support care-workers and patients by managing routine tasks such as setting medication reminders, carrying out mental stimulation exercises, and alerting human carers when needed. These products are operated through voice commands and can run on existing internet-enabled devices or dedicated hardware. They are capable of monitoring the wellbeing of vulnerable people at a lower cost of time and money than training a care-worker. Such devices could serve as a buffer on the workload placed on care-givers and enable persons living with dementia to have more independence. Unfortunately, current consumer products are not sufficiently reliable enough to provide support in this capacity. Despite being marketed as easy-to-use, these products still require a degree of technical understanding to be used effectively. While younger users (“Digital Natives”) of these products may find it easy to adapt to their use, older generations (“Digital Immigrants”) have more difficulty learning the technology. Furthermore, as these products are intended for general use, they are not suitable for users with special needs.

This project aims to develop a prototype VA that is tailored for users living with dementia. This prototype will include features common to current VAs such as setting reminders, performing search queries, and calling contacts, as well as ease-of-use considerations made for elderly users in general. A shortlist of additional features designed to maintain user independence, monitor wellbeing, and reduce the effects of cognitive decline will be created following a review of best practices and the viability of implementing these features on limited hardware will be assessed.

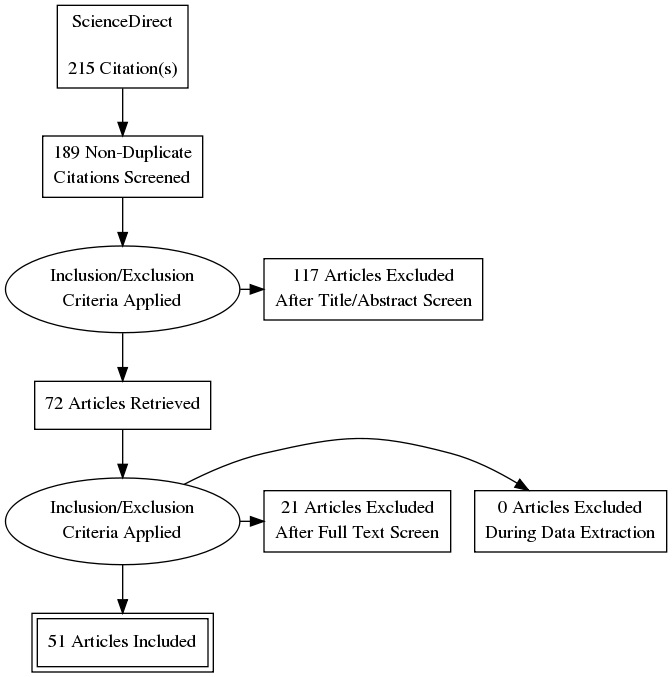
In this paper, I review current literature surrounding the challenges caused by dementia for sufferers and carers and review the current state of VA technology including its shortcomings. This research is used to list potential features and requirements of a VA to assist people living with dementia. Next, a simple VA that will serve as the foundation of the selected features is designed and presented. This paper then describes the research and implementation of each feature, the difficulties faced, and evaluates their effectiveness. Finally, an evaluation of the feasibility of the entire developed prototype is given and future areas of work are considered.

[Roadmap of project]

# Literature Review

To assess the difficulties caused by cognitive decline and potential technologies that could mitigate them, a review of existing literature was conducted. The literature was gathered through multiple search queries on ScienceDirect using combinations of the following keywords: *dementia*, “*caring* *for*”, “*home* *care*”, *palliative*, *helping*, *challenges*, *difficulties*, *needs*, *prevention*, *independence*, *enabling*, *preferences*, “*assistive* *technology*”,“*smart* *home*”, *capability*, *voice*, *assistant*, “*consumer* *product*”, *adoption*, *elderly*, “*digital* *immigrants*”, *design*, “*early* *onset*”. Studies mentioning “*social* *media*”, *student*, or *diagnosis* were excluded. Each search query was refined until it produced 30 or fewer results and exclusion criteria were applied.

|  |
| --- |
| **Inclusion Criteria** |
| English |
| Academic Papers |
|  |
| **Exclusion Criteria** |
| Inaccessible |



## Dementia

What is Dementia? What causes it?

Dementia is the impairment of higher brain functions such as memory and cognitive processing and is commonly caused by Alzheimer’s disease (AD).

How widespread is the problem? What is the impact of Dementia?

The World Health Organization (2019) estimated 50 million people worldwide living with dementia burdening individuals, caregivers, and healthcare services with an approximate global cost of US$ 818 billion in 2015. Dementia cases are expected to reach 82 million by 2030 and 152 million by 2050. This inflation is the result of a global aging population caused by increased life expectancy worldwide. Galende *et al.* (2021) assessed the social impact of dementia to advise healthcare policies in Spain, concluding that robust healthcare programs were essential. Their review found between 4% and 9% of people in Spain over 65 affected by dementia with rates increasing proportional to age. These proportions are typical of other countries.

What challenges are faced by sufferers / carers?

The decline of cognitive functioning causes difficulties in safety, autonomy, and quality-of-life (QoL) affecting both patients and carers; and various focus groups, interviews, and workshops have attempted to formalise the design requirements of care services based on these concerns (Morgan *et al.* 2002; Thoma-Lürken *et al.* 2018; Lockerbie and Maiden 2020). Focus groups with formal and informal caregivers conducted by Thoma-Lürken *et al.* (2018) revealed 6 recurring domains of problems preventing aging-in-place for people living with dementia: Self-reliance, safety, social, behavioural, formal Services, and cognition; however they did not address the causal relationships between these domains. The most common issues raised were patients suffering a loss of independence and inability to perform activities of daily living (ADL). In a review by Alexopoulos *et al.* (2002), mid- and late-life depressions were found to exacerbate cognitive decline, and the increased loss of independence produced further depression. One study that focused on support for informal caregivers found that many felt they could continue to provide sufficient care for their dependant for longer if they were given better education and relief as they lacked appropriate training and were hindered by time constraints (Chi *et al.* 2020).

## Assisted Living

What attempts have been made to address these challenges?

As technologies such as robotics, the internet-of-things (IoT), and machine learning are developed worldwide, these innovations have been applied to improve the quality-of-life (QoL) for both the fully cognitive elderly and those suffering from cognitive decline (Li *et al.* 2015). Traditionally, caring for people living with dementia would be performed at home by family members until they were unable and the dependent was moved into formal care (Kemp, Ball, and Perkins 2013); however financial pressure placed on both individuals and healthcare services has motivated research into assisted living (AL) technologies to promote “aging-in-place” and allowing dependents to maintain their autonomy. These advances aim to relieve pressure on healthcare services and informal carers.

Telecare refers to technologies that provide remote healthcare directly to patients in their own homes such as monitoring sensors and direct communication channels (Barlow, Bayer, and Curry 2006; Roberts and Mort 2009). These approaches are also referred to as telemedicine and telehealth inconsistently across different authors. Some of the earliest telecare solutions include the EU-ACTION project that began in 1997 ­– a system intended to introduce ICT into home environments to educate home carers and dependants in correct care techniques (Magnusson *et al.* 2002).

The ubiquity of IoT devices has led to the notion of intra-connected smart homes in which multiple sensors and devices can communicate and be controlled through a unified interface such as a voice assistant. Cooper *et al.* (2008) describe “intelligent environments” similar to the newer idea of smart homes, noting how they could assist individuals with cognitive impairments using reminders, directional guidance, or monitoring. They recognise the importance of technology understanding the context of a situation (such as a user’s location or task), an issue that has been addressed more recently with machine learning. Other early work on smart homes also foresaw their use in telecare for elderly and disabled people including those with cognitive impairment (Chan *et al.* 2008; Chan *et al.* 2009). Belley *et al.* (2015) present a practical algorithm for detecting erratic behaviour in people with cognitive decline by analysing power usage of smart devices. Liu *et al.* (2016) also focused on the benefits of health monitoring of elderly in smart homes, however they conclude that smart homes were not capable of completely supporting the elderly. Rumeau *et al.* (2020) investigated co-living spaces for elders to reduce isolation with a tangential experiment related to smart home technology.

Shishehgar, Kerr, and Blake (2018) outline a variety of robotics projects for supporting elders including companion robots, mounted mechanical arms, electronic wheelchairs and walking assistants, domestic cleaning robots, and health and time management robots. Wilson *et al.* (2019) discuss how these robotics projects can be integrated with smart homes.

What are the limitations of these AL technologies/services?

Despite the number of care projects that have been created, few have seen widespread adoption or made it past early pilot stages due to poor evidence of cost-effectiveness (Obi, Ishmatova, and Iwasaki 2013; Clarkson *et al.* 2017). The effectiveness of these solutions is difficult to measure because the majority of studies use qualitative means of assessment or failed to apply their findings to a formal framework (Siegel and Dorner 2017). Dodd *et al.* (2020) were also unable to find an existing measure for assessing the effectiveness of care solutions with respect to the key desired outcomes of stakeholders. Limited study sizes also question the validity of any positive findings in these studies. Among those projects that were deployed, adoption is likely hindered by the deep-rooted social stigma related to dementia and AL technologies; particularly in rural areas (Morgan *et al.* 2002).

How should these solutions be approached?

End-of-life care should preserve an individual’s dignity and QoL. Östlund, Brown, and Johnston (2012) reviewed palliative care studies to assess how well recipient’s dignity was addressed. Palliative care includes solutions to ease the pain of conditions without addressing the cause of the problem. Dementia care is considered palliative as it improves the comfort of the patient and may reduce deterioration, but cannot reverse any existing damage. None of their reviewed studies addressed patients concerns regarding the impact of their own death on their surviving friends and family. Rich relationships, autonomy and control, knowledge, and improved mental health were identified as the desired outcomes of care solutions (Dodd *et al.* 2020). Lockerbie and Maiden (2020) created a model for defining the QoL goals for people with dementia through workshops with four experienced UK care workers, also concluding that improving independence and social connectivity were desirable outcomes of support. Gómez (2015) discusses the nature of autonomy for elders and the sustainability of solutions that support their independence, arguing that autonomy should not be accepted as a guaranteed improvement to QoL. Hersh (2014) developed a framework for assessing the outcomes of ICT support.

## Digital Divide

What limitations are faced when designing technology for the elderly?

The concept of a digital divide between elderly (digital immigrants) and younger (digital natives) users of technology is well documented. Digital immigrants are characterised by their struggle or resistance to adopt technology because of decreased learning capabilities, a rapidly changing industry, limited or poor experiences, or lack of confidence; instead using technology only when necessary.

Mobile phones have the capability of improving QoL for elders (Plaza *et al.* 2011). Many applications are available for encouraging personal health and wellbeing.

What prevents technology from fulfilling this role?

Social stigma around assistive technology is noted as a barrier to use. The interviewed elders expressed a desire for devices to feature in a range of discreet styles that avoid the appearance of hospital machinery.

Despite the existence of tech-savvy elders and the inevitable generational shift as digital natives continue to age with technology, it is crucial to consider the difficulties caused by natural aging and late-life disabilities that are barriers to assistive technologies (Fischer *et al.* 2014). The results of a survey into motivations behind elder’s technology adoption by Sintonen and Immonen (2013) found that prior experience with technology their own physical limitations are key deciding factors for frail elderly. Their population had an approximately 1:2 split of frail and well-coping elderly. A review by Song and van der Cammen (2019) was concerned with how AL technology affects elders living alone.

What can be done to mitigate these problems?

The needs and preferences of elderly users should be considered before designing any AL technology. Jacelon and Hanson (2013) discuss the benefits of involving elders in the design process for smart homes to ensure they meet the practical needs of this specialist group. Gkouskos and Burgos (2017) also highlight the importance of involving elders in the design process of any AL technology.

Detweiler and Hindriks (2016) formalised a taxonomy for value sensitive design of AL technology and raise the issue of limited coverage of research into all permutations of their identified values, technologies, and contexts.

After interviewing elders who consider themselves technologically savvy, Kania-Lundholm and Torres (2015) question the importance of age as a factor in the Digital Divide; instead finding socio-economic explanations. The elders interviewed were generally highly educated and had used computers as early as the 1970s.

Castilla *et al.* (2013) created a software tool for the elderly that streamlines common computing features such as email and telecommunication. They realised that simply enlarging icons and text was insufficient for making software accessible. To better aid user’s synchronous learning of what capabilities were offered and how to perform them, they concluded that no more than three options should be available at any time. Similarly, Iancu and Iancu (2020) suggest principals to be considered when designing mobile phones for Elders and found that multiple paths of completing the same action were confusing to users. They recommend familiarity and consistency in the design of tasks. Alternative human computer interaction (HCI) technologies have been considered to facilitate digital immigrant’s engagement with modern devices.

Hsiao *et al.* (2017) present natural hand motion controls for desktop applications with limited success. Other means of natural HCI that have been used include voice control and eye tracking (Li *et al.* 2015).

## The State of VAs

What is a VA? What are the capabilities of current VAs?

The concept of natural language interaction with computers is thought to begin with Turing (1950). More recently, consumer VAs such as Google Assistant and Amazon’s Alexa have become familiar presences in households and on mobile devices (McLean and Osei-Frimpong 2019). These consumer VAs are frequently tasked with performing web queries and making online purchases. Current VAs are still somewhat limited, despite considerable advances in natural language processing.

How will VAs address the problem of care?

VAs are able to integrate with Smart Home technology and provide a conversational means of controlling the devices within. Conversational controls are accessible even for elders with cognitive decline. Chatbots and natural language interaction computers have been used for various healthcare services (Adamopoulou and Moussiades 2020).

What needs to be improved first?

Trust in the VA is an essential requirement as carers and family members will be unwilling to place their dependent’s well-being in jeopardy. Poushneh (2021) explored the perception factors of artificial personalities in mobile voice assistants. Hu, Lu, and Gong (2021) investigate how user interactions with and trust of AI are affected by human-like qualities, determining that the humanness of voice output does not impact competence-related trust. However, Hu *et al.* (2021) found evidence that improving the perceived intelligence of VAs results in more frequent use. Chattaraman et al. (2019) conducted a usability experiment with elders and found that for users with cognitive impairment, an informal personality in a VA was less effective and caused difficulty.

Intent detection involves translating a natural language command into a digital instruction and is a crucial component of a VA. The varying nature of natural language in its terminology, intonation, speed, and context makes this a difficult task that is accomplished only through machine learning such as the multi-layered neural network used by Firdaus *et al.* (2019) or the deep neural network used by Lin and Xu (2019) to learn new intents.

Mulfari *et al.* (2021) approached the task of designing VA system for users with speech disorders by using keyword spotting algorithms for intent detection. Kumar, Deepak, and Santhanavijayan (2020) propose an efficient emotion detection algorithm, although limited. As dementia significantly impacts speech, an appropriate method of understanding a user’s request or inferring their need is crucial.

Grześ *et al.* (2014), POMDP, Designing assistive tech for Dementia

# Working Notes

A major factor that will dissuade use of the VA is incapability. Patients cannot be expected to understand the limitations of the VA, meaning a robust and capable tool should be created initially to encourage adoption.

Companionship and social relationships have been consistently shown to be very important for maintaining both physical and mental health. For the elderly, social relationships are hampered by difficulty communicating (A. Palmer et al. 2016). The proposed VA could help overcome this obstacle and assist early-stage dementia sufferers with maintaining their social relationships and health. The VA could also provide a degree of companionship itself. Improved voice synthesis will make VA’s more relatable.

Alexopoulos *et al.* (2002) describe the relationship between depression in the elderly and comorbidity with other ailments including Alzheimer’s and dementia. They found evidence in literature that early to mid-life depression increases the risk factor of Alzheimer’s and that late-life depression is a potential indicator of dementia.

Kemp, Ball, and Perkins (2013) examine the boundary between formal and informal care, noting the conflicting viewpoints in literature regarding how the two interact. They suggest a complementary and evolving “convoy” of care that adapts to changing needs as opposed to a supplanting model wherein formal care assumes responsibility when informal care cannot.

Even healthy elderly users have difficulty using these products comfortably (A. Reis*et al.* 2018). These products are primarily cloud-based, leaving users unable to utilize many of their features if disconnected from the internet.

In addition to aiding fully cognitive elders in daily life, the discussed technologies have many benefits for people living with dementia and AD.

Few participants in the studies reviewed by Siegel and Dorner (2017) expressed concerns over digital privacy.

It has been extensively shown that non-pharmacological approaches to treating dementia such as cognitive behavioural therapy, reality orientation, and validation therapy are prospective solutions.

Before considering the needs of users living with dementia, it is important to consider the challenges faced by all elderly users of technology. Elderly users of technology are often referred to as digital immigrants.

Any AL technology should also involve the design inputs of caregivers to ensure that the product mollifies their concerns. As caregivers may be called upon to intervene when AL technology malfunctions, it should be designed to be as intuitive as possible during these critical scenarios.

Damant *et al.* (2016) categorise technologies as Mainstream ICT – consisting of mobile phones, the internet, and other technology used by the general public – and Remote Care – vital sign monitors, cognitive and physical fitness trackers, and other assistive technologies.

A review by Koumakis *et al.* (2019) found recurring evidence of the benefits of technology in improving the lives of people living with dementia and their care-givers. They found examples of mobile applications for diagnosing and monitoring patient conditions, supporting patient daily activities through reminders, location tracking, and educating care-givers.

The global aging population is a common motivator of research into the needs of elders. The prevalence of Dementia in this population has placed dementia care at the forefront in the design of these care solutions.

(Dixon *et al.* 2020)

Galende *et al.* (2021) conducted a literature review with unknown parameters.

(Lockerbie and Maiden 2020) The created framework was designed to be interpretation of existing dementia quality of life work by Lawton (1994).

Inclusion Criteria: English, Academic Papers only

Additional commonly referenced material was found manually.

|  |  |
| --- | --- |
| Results | 215 found |
| Duplicates | 26 exclusions |
| English language only | 0 exclusions |
| Relevant title/abstract | 88 exclusions |
| Accessible | 21 exclusions |
| Academic Papers | 29 exclusions |
| Final count | 51 papers |

Lord et al. (2020) build a theoretical model to describe the requirements of any home-based dementia support from a systematic review of studies up to August 2018. The concepts identified fall under: Values and Approaches, Strategies, and Delivery. Within these categories, they express the need for treatments to be personal, respectful, and consistent for both patients and carers. They also highlight two successful interventions in line with their model that enabled extended autonomy and home-care of persons living with dementia: Maximising Independence at Home (MIND) and the New York University Spouse Caregiver Intervention (NYUCI). These interventions focus on group education and therapy for patients and family, supporting the idea of social activity prolonging patient cognisance.

* The current state of voice synthesis is also lacking and can be hard to relate to for users who require companionship
  + Research shows that companionship is important
  + Historically, users have been able to relate to even less advanced AI.
* Virtual assistant can offer brain-training exercises that could help elderly users keep focused
* Ethical concerns – Collecting and storing data
* Product implementation?: Raspberry Pi or Mobile

Considerations to make for users living with dementia:

* Poor speech makes speech detection difficult
* Poor understanding of technology and confusion means commands may be complex or indirect
* Certain terminology or phrasing should be used
* The current state of voice synthesis is also lacking and can be hard to relate to for users who require companionship
  + Research shows that companionship is important
  + Historically, users have been able to relate to even less advanced AI.
* VA can offer brain-training exercises
* The ability to perform critical tasks without requiring an internet connection. Current options are primarily cloud-based, leaving vulnerable users unable to utilize them if web connection goes down.
* Be able to infer a task from a less explicit statement. For example, a confused question such as, “Where did Alice go?” while Alice is not present should be treated as a command to call Alice.
* a clear description of the stages of the life cycle undertaken
* a description of how verification and validation were applied at these stages
* a description of the use of tools to support the development process
* a description of any research hypothesis

Themes:

* Dementia
* Challenges
* Quality of Life
* Independence
* Usability
* Carer

# Requirements of a VA / Potential Features

Many studies of dementia care make note of the burden placed on informal care-givers. As such, this group is often considered when developing frameworks for dementia care plans. The proposed VA could offer benefits and relief to this group as part of its design.

|  |  |
| --- | --- |
| Functional | |
| FR1 | Speech to text for staggered speech |
| FR2 | Natural language processing |
| FR3 | Text to speech output |
| FR4 | Offline functionality |
| FR5 | Minimal user input needed (i.e. yes or no questions) |
| Non Functional | |
| NFR1 | Set Reminders |
| NFR2 | Cognitive training exercises |
| NFR3 | Music therapy |
| NFR4 | Consistent personality |

# Project Plan

Outline of project

# Basic Voice Assistant

## Introduction

* Short paragraph explaining how an extendable VA will be developed

## Research

* VA technology

## Implementation

* Process of selecting the technology and creating the VA

## Evaluation

* Address limitations of implementation

# Feature 1

## Introduction

## Research



## Implementation

## Evaluation

# Feature 2

## Introduction

## Research



## Implementation

## Evaluation

# Feature 3

## Introduction

## Research



## Implementation

## Evaluation

# Physical Product

## Introduction

## Research



## Implementation

## Evaluation

# Evaluation of Developed System

While persons suffering with late-stage dementia will likely still require constant support, this system should allow persons with early stage dementia and pre-dementia to continue living independently for a longer period before requiring more consistent care.

A critical appraisal of the project, indicating the rationale for any design/implementation decisions, lessons learnt during the course of the project, and evaluation (with hindsight) of the project outcome and the process of its production (including a review of the plan and any deviations from it)

# Further Research

Most dementia cases are present in countries with low income. Sufferers in these countries would not directly benefit from the development of the proposed voice assistant; however reducing the dependency on human care-workers in developed countries will open the possibility of aid for lower income countries.

Studies on dementia are often done in high income countries, how effective the techniques developed are for low income countries is uncertain.

# Appendices

## References

## Bibliography

1. There is no consensus on a general term for this class of products. Alternative terms include intelligent virtual assistant (IVA), intelligent personal assistant (IPA), and smart speaker. For this document the term voice assistant (VA) will be used. [↑](#footnote-ref-1)