Solent University

Faculty of Business, Law and Digital Technologies

BSc Software Engineering

2021

Kieron Gillingham

"GLAD – A Voice Assistant for People Living With Dementia"

Supervisor : Prins Butt
Date of submission : May 2021

Acknowledgements

With great gratitude to my parents for their patience and understanding; to my supervisor Prins Butt for his kind advice; and to my friend Mr Matthew Dear for inviting me to sit at his table that day.

Abstract

Dementia is among the world's leading health concerns, affecting approximately 50 million people and rising worldwide. It primarily affects the elderly and causes degeneration of cognitive functioning which inhibits their ability to live independently. As the condition is irreversible, interventions to limit the rate of cognitive loss are the only course of treatment.

This paper describes the implementation of a voice assistant – GLAD – targeted at users living with dementia and related conditions with the aim of assisting them in their daily lives to improve their independence and reduce the rate of cognitive decline. Following a systematic literature review, the architectural design of GLAD is presented and implemented in accordance with an Agile software development methodology. An evaluation of its capabilities is then completed and areas of further work suggested.

The presented voice assistant is shown to be a capable foundation with potential for extensions to improve its capabilities.

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1 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 (Alzheimer's Disease International *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] (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 caregivers 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

[1] There is no consensus on a general term for this class of products. Alternative terms include "intelligent virtual assistant", "intelligent personal assistant", and "smart speaker".

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 evaluates the potential of VA technology in supporting elderly persons living with dementia by attempting to answer the question: “Can a VA help reduce the rate of loss of cognitive functioning?” This question will be addressed through the development of a VA called the *General Living Assistance Device* (*GLAD*) that is tailored for users living with dementia. *GLAD* includes features common to current VAs as well as ease-of-use considerations made for elderly users in general. A shortlist of features designed to maintain user independence, monitor wellbeing, and reduce the effects of cognitive decline was decided following a review of best practices for dementia care and the viability of implementing these features will be assessed.

In this paper, current literature surrounding the challenges caused by dementia for sufferers and carers is reviewed. 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.

2 Literature Review

2.1 Method

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 (Appendix A.1) 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 which were then collated and had exclusion criteria applied (Table 1; Appendix A.2). One additional paper was included 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**

Table 1. Literature review exclusions.

2.2 Dementia

Dementia is the impairment of higher brain functions such as memory and cognitive processing and is commonly caused by Alzheimer's disease (AD). 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 (World Health Organization 2019). 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.

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).

2.3 Assisted Living

As technologies such as robotics, the internet-of-things (IoT), and machine learning are developed worldwide, these innovations have been applied to improve the QoL for both the fully cognitive elderly and those suffering from cognitive decline (Li, Lu, and McDonald-Maier 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 (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 VA. 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 such robotics projects can be integrated with smart homes.

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).

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 by Dodd *et al.* (2020) as the desired outcomes of care solutions. 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 and Hersh (2014) developed a framework for assessing the outcomes of ICT support.

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

2.4 Digital Divide

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.

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 and 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. Hawley-Hague *et al.* (2014) found that concern for their own safety was another crucial factor in elder's adoption of AL technology and a review by Song and van der Cammen (2019) was concerned with how AL technology affects elders living alone.

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, Lu, and McDonald-Maier 2015).

2.5 The State of VAs

Recently, consumer VAs such as Google's *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 (NLP), however, privacy concerns are a common factor restricting their usage (Ho-Sam-Sooi, Pieters, and Kroesen 2021).

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 NLP computers have been used for various healthcare services (Adamopoulou and Moussiades 2020).

Trust in a VA is an essential factor in determining whether carers and family members will be willing to entrust their dependent's well-being to it. Poushneh (2021) explored the perception factors of artificial personalities in mobile voice assistants and 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. Instead, 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 language in its terminology, intonation, speed, and context makes this a difficult task that is accomplished typically 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).

Mulfari *et al.* (2021) approached the task of designing a NLP 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.

2.6 Implications

The literature review provided insight into the difficulties people living with dementia and their carers face, and revealed key concerns of users regarding AL technologies; many of which were considered when designing GLAD. The most desired traits were simplicity of operation, robustness of understanding and NLP, and competence and trustworthiness.

The literature also showed a disparity between traditional health-care and technological interventions. There is repeated evidence of successful trials of voice interfaces for elderly HCI, and difficulties interacting with AL devices. A robust VA could serve as the critical link between these two fields.

3 Methodology

3.1 Objectives

In this project a VA intended to reduce the rate of cognitive decline in people diagnosed with dementia was created with the aim of answering the research question: Can a VA help reduce the rate of loss of cognitive functioning?

3.2 Development Methodology

The project was structured using elements of Agile development practice. It was broken down into stages (Appendix B) each focusing on a particular feature in line with the Agile principal of continuous delivery. Because of the limited timeframe of the project, each stage is aligned with a single sprint. Development took place between February and May of 2021. Each stage of the project would also feature its own research into the specifics of that feature to determine how best to implement it.

Unlike typical Agile development, which is designed to facilitate good collaboration between team-members and stakeholders in projects with changing requirements, this project was an independent effort with fixed requirements.

3.3 Management

The development of the project was managed using GitHub tools to track required tasks and milestones. For each stage of the project, the tasks within that stage were outlined as GitHub Issues. These Issues were assigned to Milestones for each sprint and tracked in a GitHub Projects Kanban board. The repository for the code and management is available at: https://github.com/KieronGillingham/DementiaVA.

The key metrics of success for software development projects are velocity and effort (Kupiainen, Mäntylä and Itkonen 2015). Effort accounts for the time required and difficulty of a task and velocity covers the frequency of updates, usually delivering small improvements to the product regularly.

Time management was handled by a burndown chart (Appendix C.1). Although this approach assumes equal effort is required for each stage, it ensured that time was distributed evenly throughout the project, and no stage would reduce the quality of another.

3.4 Evaluation

3.4.1 Software Evaluation

Ideally, the VA would be tested by users with cognitive impairment over an extended period to ascertain a change in their rate of cognitive decline, however there are several issues with this approach. Elders with cognitive decline are vulnerable persons and obtaining ethical clearance to work with these individuals is beyond the scope of this project; additionally, people living with dementia may not be able to provide informed consent of participation. The results of this evaluation would also be questionable as the benefits of dementia care technologies are often only perceivable with longer follow-up times and the timeframe of this project would not allow such an extended study. As cognition loss is inevitable with or without intervention, identifying whether a change in cognition is attributable to the VA would also require a large sample size.

Instead, a list of voice commands covering the use of the implemented features was created after the development stages to measure the speed and accuracy of the VAs responses. These commands were spoken to the VA for evaluation at the end of the project. Each command was repeated five times to collect a range of results and reduce the impact of outliers.

These commands were decided following development as the number and nature of the included features was unknown beforehand.

The time-to-process (TTP) of each command was measured from the output logs of the VA beginning with the timestamp where the VA detected the user had begun speaking to the timestamp when the VA finished processing the command (including the time to compose a response, but not including the time to speak it).

The accuracy of transcription was measured using Levenshtein distance, a metric commonly used for calculating the "edit distance" between two strings (Rane and Sun 2010), to compare the difference between the phrase the user knowingly spoke and the automatic transcription of the phrase that was heard. The expected outcome of each command was also compared to the actual outcome.

Additionally, each new feature is informally evaluated throughout development. This recurring evaluation falls under the iterative development ideology of Agile and highlights inadequacies of design, poor usability, and poor performance as quickly as possible so they can be rectified.

An automated test-suite for chatbots and VAs, *Botium* (Botium GmbH 2021), was considered to evaluate the VA. *Botium* is able to simulate human input errors which could be adapted to represent unclear speech inputs from people with cognitive decline. Ultimately, *Botium* was not used for testing as it was not feasible to develop a custom adaptor for the VA in addition to developing the VA itself within the project timeframe. It was also considered to compare GLAD with existing VAs, however this would have been unproductive because of their varying functions and capabilities (Jiang *et al.* 2015).

3.4.2 Process Evaluation

The project management was evaluated using the burndown chart to confirm that the assigned hours were completed at a consistent rate. Additionally, by comparing the developed software to the requirements initially set out, it can be determined that the time was spent appropriately by measuring the number of requirements that were met.

3.5 Ethics

3.5.1 Data Collection

The developed artefact constantly collects auditory samples of users' voices and coincidental background sounds while active. Although the software does not request sensitive information, it may inadvertently collect such data if spoken aloud in proximity to the attached microphone. Any information collected is only parsed for keywords relating to the VA and is not transmitted outside of the software or persisted in memory after processing.

3.5.2 Testing

There are no ethical requirements related to evaluating *GLAD* as it will not involve user testing. An ethics approval was obtained for the project (Appendix D).

3.6 Legal

The project has been created under a GNU GPLv3 license allowing open modification and redistribution of the software, provided any derivative is not closed-source. Any third-party technologies or other software used within this project are provided under a license that allows these same permissions.

4 Planning

4.1 Requirements

Following the initial literature review, a concept map based on common keywords found in the literature was created (Appendix E). This concept map supported the definition of the key needs and possible features for the proposed VA.

The needs and features were initial divided into functional and non-functional (Table 2), and then further sorted using MoSCoW prioritisation (Figure 1). This helped to plan the development stages.

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)
FR6	Data Privacy
Non-functional	
NFR1	Set Reminders
NFR2	Cognitive training exercises
NFR3	Music therapy
NFR4	Consistent personality
NFR5	Independent Action
NFR6	Extendable

Table 2. Functional and non-functional requirements.

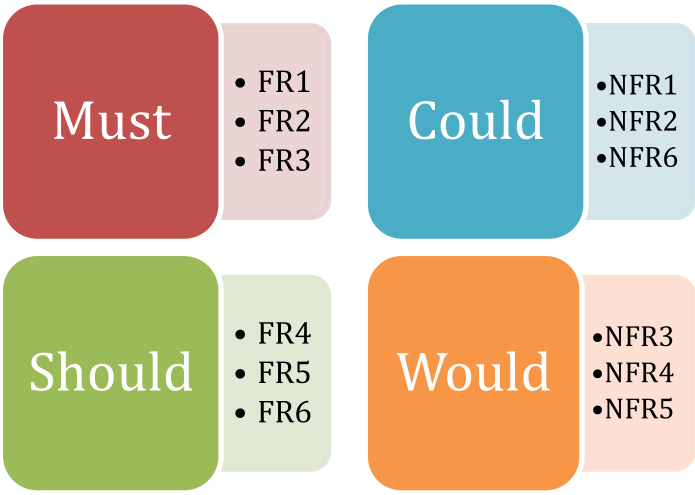

Figure 1. MoSCoW prioritisation of the requirements.

The *must*-have requirements for *GLAD* include the defining elements of a VA: Speech-to-text (STT), NLP for intent detection, and text-to-speech (TTS). The requirements that *should* be met cover the features that distinguish *GLAD* from other VAs, specifically its ability to function offline and minimal interaction. *Could-have* requirements cover the main features that are intended to be included: Reminders, cognitive training, and extendibility. The remaining requirements - music therapy, consistent personality, and the ability to take independent actions - are sorted under *would-have*, meaning they will only be included as supplementary features if feasible but are of the lowest priority.

4.2 Risk Assessment

Risks to the project completion were also evaluated at this stage (Appendix F), and mitigation strategies were considered and implemented for the most severe risks.

4.3 Development Environment

An Ubuntu 20.04.2 virtual machine (VM) was set-up for development and testing through Oracle VirtualBox 6.1.16. This machine had 4GB of RAM and 10GB of storage. Development of the Python program was done using PyCharm Community 2021.1. During development, as a result of memory issues that arose, the machine was recreated with 20GB of storage.

A second VM with 2GB of RAM and 8GB of storage running Debian GNU/Linux 10 to simulate a Raspberry Pi for testing the VA on limited hardware. Problems installing the required python libraries prevented this VM from being used.

4.4 Prototype

An initial prototype for the VA (Figure 2) was created to evaluate the use of a self-hosted back-end for Mycroft (Mycroft AI Inc. n.d.) – an existing open-source VA – with the intention of developing further features as skills. The back-end services required too much disk space and processing power to run on low-performance hardware and would have done so at a considerable disadvantage. As this could not be completed in a timely manner and would have negatively impacted performance, the Mycroft-based prototype was not used for the full development.

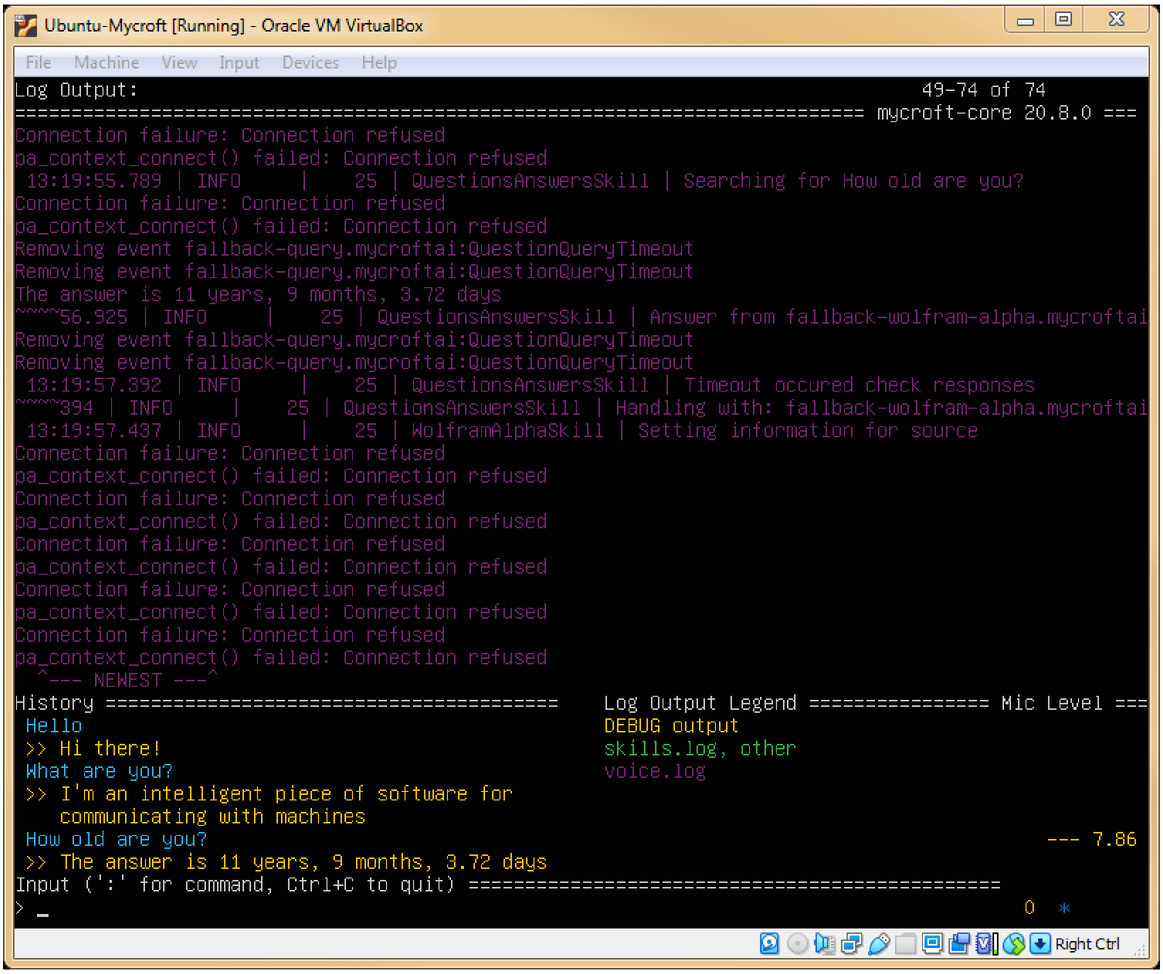

Figure 2. Mycroft instance running in a virtual machine.

5 The Voice Assistant

5.1 Components of a Voice Assistant

The principal components of a voice interaction system are STT, NLP, and TTS. Together, these technologies are able to register a spoken command, identify and act upon it, and vocalise a response; allowing for conversational software interfaces. These components may operate programmatically or utilise machine learning techniques. Open-source implementations of these components were evaluated and selected to create the basis for *GLAD*.

5.2 Technologies

5.2.1 Voice Assistants

Although there are many familiar consumer VAs such as Amazon's *Alexa*, Google's *Google Home*, Apple's *Siri*, and Microsoft's *Cortana*, digital privacy concerns have prompted the development of a number of open-source alternatives.

Mycroft (Mycroft AI Inc. n.d.) is an open-source VA comparable to most popular consumer products and designed to run on a range of devices including desktops, *Raspberry Pi*s, or on specialised hardware – the *Mycroft Mark I* and *Mark II*. It features an existing library of installable skills and its back-end consists of a suite of cloud-hosted services for STT, NLP, and TTS, and supporting infrastructure such as account management.

Open Assistant (Open Assistant n.d.) is designed for controlling computer operations using voice commands. It is written in Python and is capable of running entirely self-contained and without requiring internet access. Unlike other VAs, it does not respond to a wake word and instead is "always on", listening constantly for any of its pre-defined commands. Its key-phrase-based intent detection and strict pattern matching limits its effectiveness.

The *Jasper Project* (Jasper Project n.d.) is an open-source voice interface for *Raspberry Pi*s. As with *Open Assistant*, *Jasper* is always-listening but has few native capabilities. It was considered for the initial *GLAD* prototype but was rejected as it is written in the now unsupported Python 2.

5.2.2 Speech-to-Text

Modern STT technology takes advantage of machine learning techniques to effectively identify spoken words. *DeepSpeech* is deep learning STT engine developed by Mozilla Corporation (2020) that uses Google *TensorFlow*. There are pre-trained models available for *TensorFlow* covering many languages and these can be easily integrated into *DeepSpeech* clients.

Most STT technologies are designed around users with an average level of diction; however this assumption cannot be made when designing for the cognitively impaired. Mulfari *et al.* (2021) demonstrated the use of AI-driven speech detection for users with staggered speech. A keyword spotting model was trained on audio samples of ten users with speaking impediments caused by cerebral palsy and similar conditions. The principal difficultly encountered was the limited sample audio available on which to train the model, resulting in a model only capable of identifying specific keywords.

5.2.3 Natural Language Processing

Automated intent detection through NLP is generally used in marketing feedback to ascertain customer opinions on products and services. For VAs, NLP is the component that determines how to interpret a spoken sentence and can include identifying the phrase as a command, identifying parameters of the command (such as the time to set an alarm for), or determining whether a spoken utterance is directed at the VA.

Consumer VAs typically employ Machine Learning (ML) techniques for NLP as in Firdaus et al. (2019) and Lin and Xu (2019). In other cases such as Mulfari *et al*. (2021), keyword matching can be an effective low processing approach.

5.2.4 Text to Speech

Voice synthesis or TTS involves generating audio clips from input text. Historically this was accomplished by deconstructing the text into syllables and concatenating phenome samples from a given library into a sentence. While these results were comprehensible, they were distinctly non-human. ML and improved algorithms have led to modern projects such as *Resemble.AI* (Resemble.AI, 2020) being able to produce lifelike voices in real-time.

For VAs, the chosen TTS implementation should produce a clear voice in a quick manner. In addition to the clarity of the chosen voice, the personality of a VA can impact its success (Poushneh 2021). The personality is affected by the sound of the voice and the tone of the language it uses. From their experiment with cognitively impaired and unimpaired individuals, Chattaraman *et al*. (2019) found that users with cognitive impairment found an informal tone in VAs more difficult to understand because of its indirect nature, instead preferring instructions to be clear and brief.

5.3 Design

As mentioned previously, an initial prototype was created based on running an offline version of the *Mycroft* back-end services, although the concept was not successful. This would have allowed a *Mycroft* instance to serve as the interface for *GLAD* by connecting to a local back-end and the other features would then be created as skills for *Mycroft*. This idea was discarded because the required back-end services were too memory intensive for a self-contained offline version and the prototype was not completed.

GLAD was instead developed based on *Open Assistant*, which has a modular architecture comprised of the following components: Ear – refers to the module responsible for receiving auditory data; Speech Recognition – refers to the STT module that processes the data; Minds – simple intent detection modules that compare the text with known commands; Abilities – modules that are triggered by commands to perform a task and generate a response; Voice – the STT module; and Sound – the audio playback module. Each component operates on a separate thread, allowing concurrent processing of audio, intents, and any feature the user has activated. Each thread listens to its own input queue on a loop and can output messages to the input queue of another thread. A central “hub” is responsible managing the messages between components (Figure 3).

Ear uses a peripheral microphone to listen for audio. When the audio reaches a volume threshold, it begins recording until the volume drops below the threshold for an extended duration. A buffer is also used to capture leading audio before the recording. The volume threshold dynamically adjusts by monitoring background noise. When a complete recording is assembled, the data is forwarded to the input queue of Speech Recognition.

Speech Recognition takes the recorded audio and processes it to detect spoken words using *PocketSphinx* (cmusphinx n.d.); however this implementation is limited to detecting words from a pre-defined list.

A mind is a program running within the VA. Each mind is a python script with functions that are run when a tagged keyword is detected by Speech Recognition. Only one mind can be active at a time, and speech input is only checked against the active mind's keywords. The active mind can be swapped during runtime by functions that may be triggered by other minds. Functions may send system events, run external programs (such as a media player), shutdown the VA, or activate the audio out modules: Voice and Sound.

Voice uses *pyttsx3* (Bhat 2017) to generate a synthesised voice from an input string. *pyttsx3* is a wrapper library for TTS engines that works offline.

The Sound module can be used to play local MP3 sound files. It is used to provide audio cues in addition to the vocal responses given by Voice.

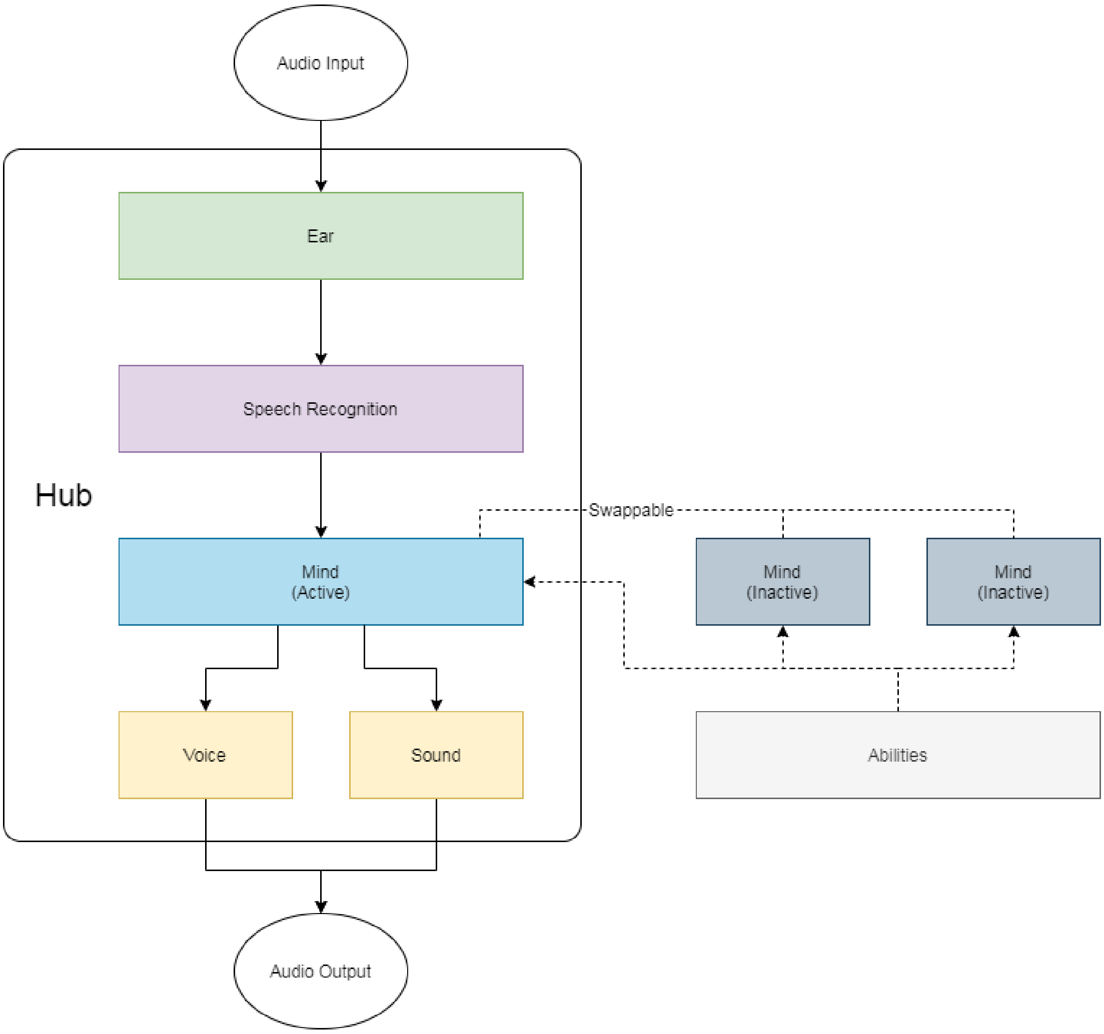

Figure 3. Open Assistant architecture.

5.4 Implementation

GLAD, being based on the *Open Assistant* architecture, is written in Python 3. The modular design allowed for some components to be replaced as needed.

The included speech recognition module was insufficiently robust for GLAD's needs as it was only capable of understanding words which were specified as keywords in the loaded minds. As a consequence, all spoken words were interpreted as the closest matching keyword. While this was suitable for recognising pre-defined phrases, it gave inaccurate results with single words; resulting in frequent misunderstandings. Additionally, the intent detection algorithm required that spoken commands must exactly match the pre-defined phrases, severely limiting the VAs adaptability and suitability for cognitively impaired users.

To address the robustness concern, the Speech Recognition module was modified to instead implement Mozilla *DeepSpeech* (Mozilla Corporation 2020). A pre-trained model was included in the VA that *DeepSpeech* uses to recognise a larger vocabulary than the *PocketSphinx* implementation. Additionally, the intent detection algorithm was improved to be more lenient when matching phrases by searching the strings for keywords rather than complete matches.

5.5 Evaluation

The basis for *GLAD* was completed within the allotted timeframe of the first sprint, although further work would later be done to improve elements of its implementation.

The default voice synthetisation for *Open Assistant* is less sophisticated than other available options; however it was sufficiently clear for the needs of *GLAD* and was not changed.

The pre-trained model for *DeepSpeech* is intended for general use and clear voices. Although it may not be suitable for the intended users, it was not feasible to obtain the data necessary and train a new model within the timeframe of this project. The design allows the model to be easily replaced at a later point with a more suitable one.

Being fully self-contained, the VA fulfils the requirement of being offline and *Open Assistant*'s minds and abilities – comparable to skills in Amazon's *Alexa* – fulfils the extendibility requirement.

Open Assistant is licensed under GNU GPLv3, and Mozilla *DeepSpeech* is licensed under the Mozilla Permissive License. Both technologies are open-source and their licenses provide the required level of restriction.

6 Cognitive Exercises

6.1 Introduction

Because dementia and related conditions are largely irreversible, the only course of treatment is to slow the rate of cognitive decline. To this end, efforts have been made to incorporate cognitive exercises in the form of serious games into *GLAD*. Additionally, music therapy has been shown to have positive effects on people living with dementia, and a radio feature has been developed for the VA.

6.2 Exercises

6.2.1 Serious Games for Dementia

Serious games can be an effective tool for improving cognition as they promote engagement and exercise perception and memory functions through an enjoyable medium. Although typically used in educational environments, serious games have seen successful applications in many fields including dementia care. These games have been developed specifically for individuals with cognitive impairment with the aim of exercising their short-term memory, planning skills, spatial awareness, and reactions.

Chi, Agama, and Prodanoff (2017) created a *Smart Thinker*, a suite of four games to improve player attention and memory including *High-Low,* which has players compare two numbers; *Color Game* in which players must select squares matching a given colour; *Rock-Paper-Scissors*, a popular hand game; and *Find Me*, a text game of keeping track of objects.

Serious games have also found use as a tool for screening people for cognitive impairment through emulating ADLs and scoring players on their success (Zucchella *et al*. 2014; Tong, Chan, and Chignell 2017).

Imbeault, Bochard, Bouzouane (2011) highlight the importance of serious games being adaptive and supportive for users with cognitive impairment. They apply AI techniques to evaluate user performance during a cognitive skill test and adjust difficulty accordingly.

6.2.2 Music Therapy

Music therapy is suggested as another means of reinforcing memory skills by triggering old memories. Music therapy is effective and enjoyable, with benefits to the recipients' memory; however it carries a risk of triggering unpleasant memories. Unfortunately, this risk cannot be practically anticipated. Music therapy has also been successful in improving patient relationships with caregivers.

6.2.3 Physical Exercise

In addition to brain-training, there is evidence of the effects of physical exercise on cognitive functioning (Heyn, Abreu, Ottenbacher 2004); however the results of such studies have found only a moderate correlation between physical exercise and improved cognition. There are other psychological benefits to physical exercise (Thuné-Boyle *et al*. 2012) such as improved confidence and mood, and a VA could potentially provide guidance for a physical exercise routine to encourage active behaviour in users.

6.3 Implementation

6.3.1 Number Game

A simple number recognition game inspired the *High-Low* game by Chi, Agama, and Prodanoff (2017) was created for *GLAD*. This game tests short term memory and basic numeracy by tasking players with recalling a number spoken by the VA and identifying whether a second number is larger than, smaller than, or equal to the first. This game uses the VAs voice detection to receive commands and responses from the player, eliminating the need for graphical interfaces or physical controllers which can be challenging for older adults.

There a five levels of gameplay in the number game with increasing ranges of possible numbers and lengthening delays between the numbers given. To maintain simplicity of design for elder users, players are automatically progressed to the next level of difficulty when they are performing well, and regressed to an easier level if they appear to be struggling. User profiling would allow tailoring the difficulty for specific individuals; however this would require storage of personal information that could be considered sensitive.

6.3.2 Radio

GLAD was given a digital radio player that is programmed to the URLs of *m4d Radio* (m4d Radio, n.d.), a collection of five digital radio stations designed for people living with dementia. These stations are available from streaming URLs and feature popular music from different decades of the 20th century with the intention of stimulating positive memories from listener's youth and young adult years.

The radio can be triggered by the keywords *music* or *radio*. To reduce the user input required, the possible stations are hard-coded and one is selected at random whenever music is requested. The user is however able to request a different station, prompting another station to be randomly selected. The radio stations are streamed using a Python library for *VLC media player*.

6.3.3 Challenges

To facilitate these features, the VA required more robust interaction capabilities. A mechanism was integrated into the intent detection module to allow users to provide an answer to a prompt, and adjustments to the keyword search algorithm allowed keywords with wild card characters.

The prompt-answer interaction works by keeping a global dictionary of user options relating to a previous response. Minds are able to set the content of this dictionary to include options the user may select and functions to run for each answer. For example: when asking the question "Do you want to play the number game?", the mind would set the dictionary to include two answers - "yes" and "no" - and provide functions to run when each answer is detected. If these options are set, then there is an outstanding question and any detected command is first checked against the dictionary. If no match is found, or there are no options set, the normal flow of data (from Speech Recognition to the active mind) continues. When an answer is given, the dictionary is cleared until needed again. This mechanism of question and response provides a more conversational interface for the VA.

With an increasing number of features, the limitations of using keywords for intent detection became more apparent. A function for parsing wild card characters in keywords was included to enable more versatile pattern matching. This new interpretation of spoken commands had the consequence of a spoken command matching the pattern of multiple functions. In these cases the most common function found is accepted as the user's selection.

6.4 Evaluation

The benefits of each of these features on user cognition have not been tested. The number game is very simple and unengaging. The entertainment factor of the game has not been evaluated. The difficulty of the game has not been evaluated.

Use of the radio requires an internet connection to receive broadcasts. This is in violation of the offline-usage requirement. To rectify this, a catalogue of songs could be included. The operation of the radio has been kept simple for elderly users.

7 Considerations for Elderly Users

7.1 Introduction

As dementia and related conditions are most prevalent among the elderly, it should be assumed that the primary users of the VA will include digital immigrants with limited technological expertise and early-stages of cognition loss. The VA should therefore make efforts to support this unique subset of users by following guidance on designing technology for both the elderly in general and those with limited cognition.

7.2 Research

7.2.1 Software Design Principals for Elderly Users

When designing software for users unfamiliar with IT, it is important to make clear the options available and consider appropriately identifiable images, auditory cues, and terminology (Castilla *et al*. 2013). For a VA, this applies to the choice of language used, avoiding technical words in favour of metaphors that may be familiar to elderly users, and sound cues to strengthen mental connections between tasks and a goal. Guidance pertaining to the design of user interfaces such as image selection and interactive element positioning are not relevant to a VA.

Limited hand-eye co-ordination makes traditional computer interfaces unsuitable for elderly users, making alternative methods such as touch screens, eye-tracking, gesture control (Hsiao *et al*. 2017), and voice control desirable.

As noted by Iancu and Iancu (2020), it is imperative in designing software for the elderly that user goals should be achievable through a single pathway of action. Having circuitous navigation around the software with backtracking links and multiple ways of accomplishing the same task often confuses elderly users and makes the application more difficult to learn.

It should not be overlooked that some key issues preventing continued aging in place relate to caregivers (Thoma-Lürken *et al*. 2018). A VA is in a unique position among AL technologies in that is can additionally provide support to the caregiver themselves; and whom should be considered potential users. These caregivers are likely to be more competent with technology than their care-recipients, although they may lack formal training. 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.

7.2.2 Future of Elder Tech Use

There is also a population of early adopters and innovators of IT who have now matured into elder age. The interviews Kania-Lundholm and Torres (2015) did with this population found that many of them still maintain a competence with technology. This suggests that current younger tech users may also preserve a measure of technological competence as they mature, and a growing number of elderly people adopting technology has been observed (Fischer *et al*. 2014).

7.3 Implementation

7.3.1 Speech Speed

To account for elderly and cognitively impaired user's needs, the speed of voice used by the VA to communicate should be selected accordingly. The voice speed was lowered to 100 words-per-minute to allow adequate time for cognitively impaired users to process the statement. Commands were also included to adjust this speed during use. Changes to this option are persisted in a configuration file. Similarly, the audio detection module was configured with longer pause times to support users with staggered or slow speech when responding to the VA.

7.3.2 Affirmations

Yes-no questions were possible with question-answer mechanism implemented previously, however their prevalence required a more uniform way of creating them. A function was created that standardised the options of yes-no questions. As part of this it included extra affirmations (“sure”, “okay”), denials (“nah”, “don’t”), and homonyms (“shore”, “know”).

7.3.3 Sound Cues

To encourage better use of the VA, several sound cues were created and included. These include jingles for when the VA starts and stops, and confirmation and denial sounds for use in the number game when a player gives a correct or incorrect answer. The sound cues were created in a digital audio editor using soft piano and bell synthesisers to evoke a comforting atmosphere for users. The sound module is used to play the effects when called.

7.3.4 Improvements

The bulk of this stage of development saw improvements and modifications to the existing architecture including the removal of excess features from *Open Assistant* that were not required for *GLAD*, and stability improvements. A configuration file, and a mechanism for reading from and writing to it, was created to store local settings. In addition to the speech speed setting, the configuration file includes the path to the speech recognition model.

7.4 Evaluation

Needs of elderly users were considered during the early stages of development and played a part in selecting the technologies that would form the basis of *GLAD*. Only a few changes to the existing architecture were required at this stage. As *GLAD* was designed from the beginning to keep complexity to a minimum, there were no implementation obstacles in this regard.

The capacity for GLAD to independently act was considered at this stage of design, however it was not implemented. The VA does not attempt to engage with the user without prompting, requiring the user to initiate any interaction. The VA could be improved with a feature in which it suggests playing music if it detects a prolonged silence. This unprompted response could be intrusive and would need to be configurable.

8 Companionship

8.1 Introduction

Companionship and social relationships have been consistently shown to be very important for maintaining both physical and mental health, however for the elderly, social relationships are hampered by difficulty communicating. The proposed VA could help overcome this obstacle and assist early-stage dementia sufferers with maintaining their social relationships and provide a degree of companionship itself.

8.2 Research

Real and popular TTS voices were evaluated by Cambre *et al*. (2020) to identify those that were considered preferable for reading long content. While more “human-like” voices were rated highly by listeners, they note that no generalizable metric for determining the quality of a TTS voice could be created. Hu *et al*. (2021) explain that human-like voices do not contribute to the level of trust in voice interfaces if the quality of the underlying intent detection and perceived competence of the device is poor.

Users, including the elderly, have shown the capability of relating to AI and robots (Obi, Ishmatova, and Iwasaki 2013; Hu *et al*. 2021). This stems from human nature to engage socially with others and is strong evidence that a VA could provide a similar form of stimulation for users; particularly those with limited social contact because of challenges caused by their cognitive impairments.

Lord *et al*. (2020) express the need for dementia support technologies and 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, and support the idea of social activity prolonging patient cognisance.

8.3 Implementation

8.3.1 Name and Personality

At this stage of the project, a name and personality were selected for the developed VA. These aspects of the device were critical to developing a sense of trust and reliability in the device, a key factor affecting adoption of voice technologies (Poushneh 2021). Additionally, further improvements to the intent recognition were made, reducing misunderstandings and errors that could jeopardise user's opinion.

In creating a personality for the VA, the name "GLAD", an acronym for "General Living Assistance Device", was decided upon. The word "glad" also evokes a helpful tone.

As even advanced voice synthesisers struggle to believably introduce emotion to generated speech, it was considered preferable to not fake a human voice and personality for *GLAD*. Instead, *GLAD* speaks politely and clearly in a formal manner akin to a professional assistant. *GLAD*'s simple voice synthesis was also preferred to keep it portable and suitable for installation on an independent device such as a *Raspberry Pi*. Raspberry Pi OS includes *eSpeak*, the voice engine used for *GLAD*, as standard.

To further improve the interaction between the user and *GLAD*, the VA was programmed to respond to the user thanking it. This was accomplished by tracking the time since *GLAD* last spoke to the user and listening for the word “thank” within ten seconds. After this time, it is assumed that the user was not addressing *GLAD*, and the keyword “thank” is ignored.

8.3.2 Alarm

It was the intention to include a timer/alarm function for the VA allowing it to provide assistance in other ADLs such as cooking or medication scheduling at this stage. Two obstacles were encountered during this implementation: The existing architecture not being able to extract parameters from given commands; and the grammatically complex task of translating a spoken time (such as “quarter-to-eight in the evening”) into a computer-readable time (19:45). The necessary changes were made to the architecture to support custom parsing of a spoken command during the function that it called; however there was insufficient time to implement the parsing function for time selection.

8.3.3 Time and Day

Open Assistant originally included the ability to speak the current time and day of the week when prompted. The commands for these features were part of a mind that was removed from *GLAD* during the first sprint but the logic for the ability was not. These functions were reinstated at this stage, with unsuccessful efforts made to improve the format of the spoken time.

8.4 Evaluation

GLAD is limited in its ability to offer companionship without user profiling. As this would require data gathering that could negatively impact the user’s perception of their privacy and violate FR6, *GLAD* was not able to adequately address the user’s need for companionship.

Without user testing, it is not possible to gain insight into the effectiveness of *GLAD*'s personality, or to assess how it compares to the findings of Chattaraman *et al.* (2019) regarding the use of task-oriented interactions.

An early concept for *GLAD* included the ability to contact friends, family, and carers and have spoken conversations. Unfortunately, this feature was not able to be included because of time restrictions. Furthermore, any practical implementation of this would have required an internet connection and the local storage of contact details to operate. It is also possible that users may prefer to communicate through more familiar means such as a telephone.

9 Evaluation

9.1 Developed System

9.1.1 Requirements

At the completion of development, the overall system was considered against the requirements set-out initially. The following requirements were met: FR1, FR2, FR3, FR4, FR5, FR6, NFR2, NFR3, NFR4, and NFR6. NFR1 and NFR5 were not met.

As discussed previously, the alarm feature that would have covered NFR1 was not implemented within the timeframe because of unforeseen complexity in parsing spoken times. NFR1 was prioritised as a "could have" requirement and was not critical to the operation of the VA.

Autonomous action was also not able to be implemented in the VA because of delays caused by issues arising in earlier sprints, missing requirement NFR5. As NFR5 was a lowest-priority requirement, its omission is not a considerable loss.

9.1.2 Speed and Accuracy

33 voice commands covering the developed features of the system (including greetings, the number game, the radio, and affirmations) were decided upon. In some cases, multiple phrasings of the same command were tested to ensure the VA can process a range of inputs. These commands were then spoken to the VA (with each repeated 5 times) and the response speed, transcription accuracy, and correctness of intent detection were recorded (Appendix G).

117 of the 165 total commands were correctly transcribed without error. 48 commands had some error (<100% accuracy) with 18 having considerable

errors (<50% accuracy). 144 of the 165 commands resulted in the expected response, regardless of transcription accuracy. Of the 21 that were not accurately processed, no command was misinterpreted as another command.

The average time to respond to a command was 3.574 seconds, with the fastest response being 2.204 seconds and the slowest being 8.931 seconds. Overall, the VA had an 86.8% accuracy of transcription and 87.3% accuracy of intent detection. It should be noted that 27 commands were incorrectly transcribed but produced the expected response.

Variations in processing speeds can be attributed to either computational delays (such as parallel background processes and threading locks) or as a result of slow user speech (as processing time was measured from when the user speech is first detected). The processing speed measurements do not account for cases where a sound-effect plays before a response is given, which inflated some readings.

It was found during development that the STT component of GLAD can take noticeably longer to process longer spoken phrases. Although no excessively lengthy commands were used during this test, there is a correlation between the length of the transcribed phrase and the processing time (Figure 4).

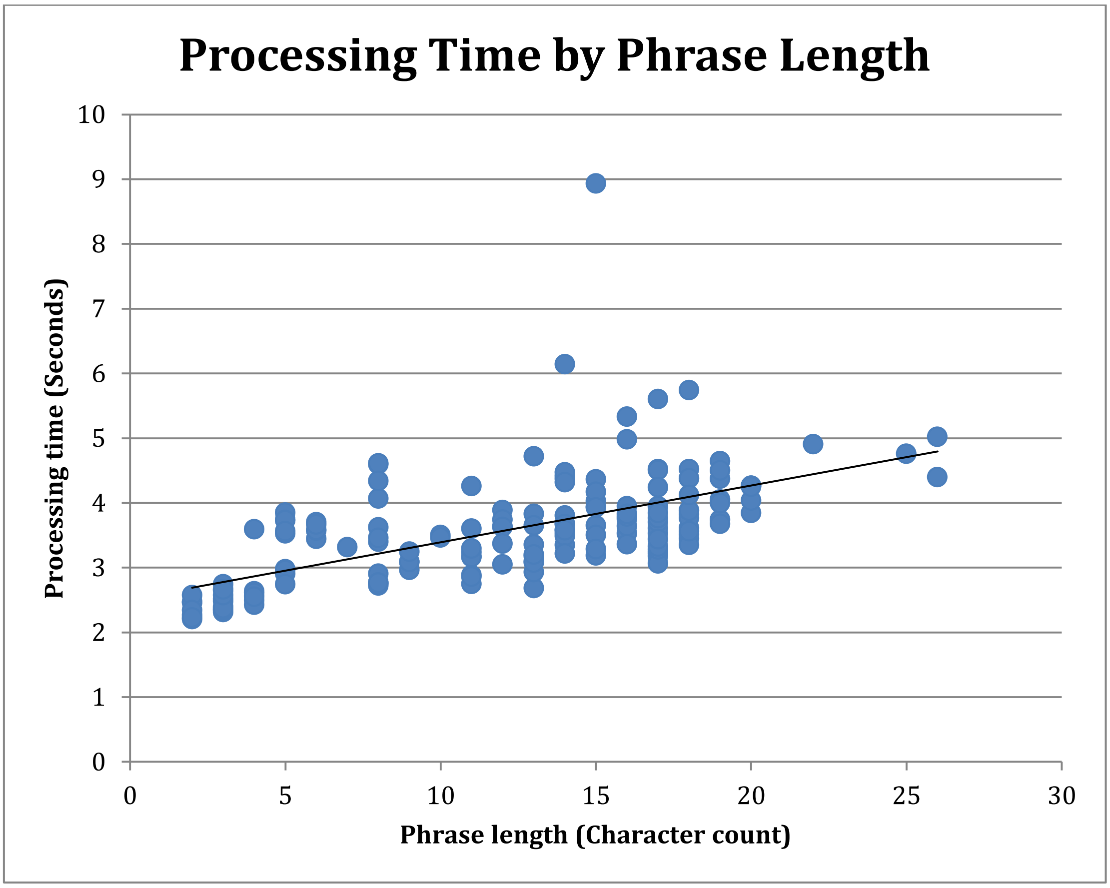

Figure 4. Chart of processing time by length of phrase.

9.2 Development Process

Despite efforts to divide time between each stage of development evenly, it was necessary to devote time to bug-fixes and improvements for the first two sprints during the third and fourth sprints. These unanticipated difficulties and a misjudged complexity of tasks (such as the alarm) prevented some features from being completed. Furthermore, the day-to-day breakdown of hours was not strictly followed because of delays caused by other commitments despite these being considered during planning.

Gkouskos and Burgos (2017) and many AL technology projects such as those reviewed by Jacelon and Hanson (2013) strongly recommend developing the system alongside potential users including both carers and people living with dementia. This co-development approach ensures that the desires of end-users are incorporated more effectively, and improves the relationship between developers and users making the ultimate adoption of the technology more likely. Although this would have been ideal, it was not possible with this project because of the aforementioned restrictions working with vulnerable persons in this scope.

9.3 Discussion

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.

Comparing the capabilities of the developed VA to existing commercial products would be an unproductive evaluation as they are designed to operate on an extensive infrastructure and can deliver superior performance.

Most dementia cases are present in countries with low income. Sufferers in these countries would not directly benefit from the deployment of the presented VA; however reducing the dependency on human care-workers in developed countries will open the possibility of aid for lower income countries. Additionally, studies on dementia are often done in high income countries, how effective the techniques developed are for low income countries is uncertain.

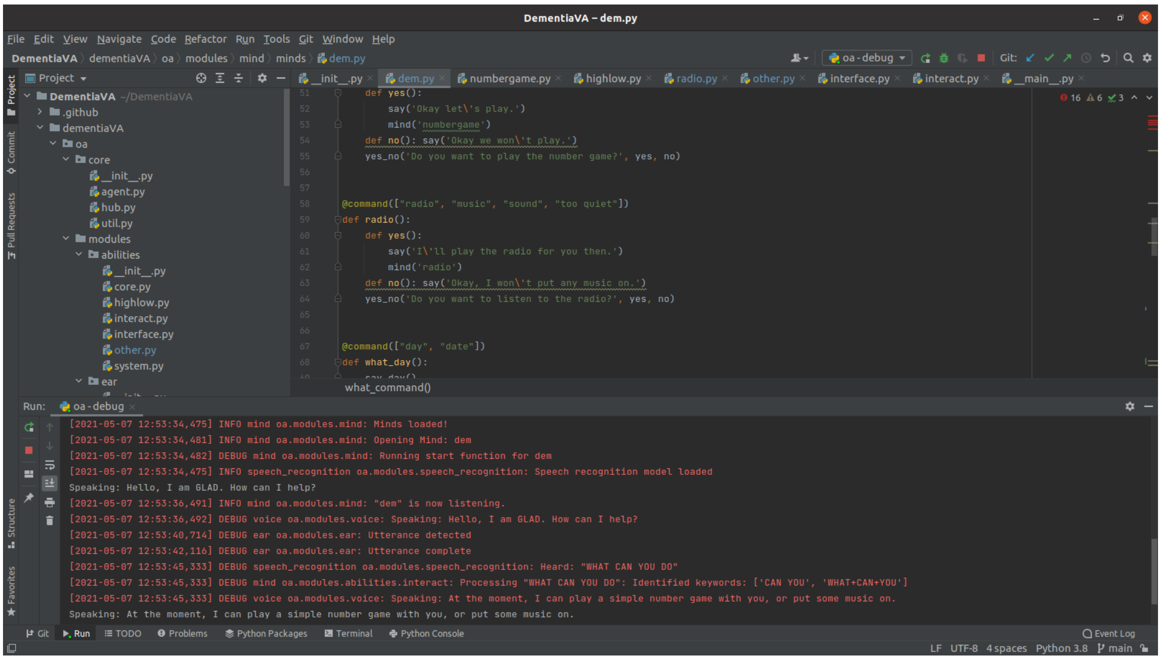

Figure 5. GLAD running in PyCharm on the VM.

10 Further Research

Having created an acceptably robust and extendable core, more features for the VA could be developed including additional games and cognitive exercises (possibly utilising A.I. for more dynamic experiences). Efforts could also be made to provide localisation or language options by moving command declarations and responses to external files to be selected at runtime and to include more sound cues.

A completely auditory assistant requires the user to have a good short-term memory to track the state of the VA and tasks. As this is a notable weakness for people living with dementia, a visual display may provide clearer feedback to complement the voice interface. Additionally, integrating the VA into an existing smart-home environment as a physical device or dedicated platform would allow for greater range of functions and features.

11 Conclusion

This project involved the design and creation of a VA to assist people living with dementia with the aim of slowing their rate of cognitive decay. During this project a systematic literature review was conducted to assess existing dementia care technologies. From this review, possible features of the VA were considered and the requirements for the system were outlined. The design and development process of the project was then explained; describing each stage of development and highlighting the features created, supporting technologies, and challenges faced. The finished artefact was then compared to the requirements initially set-out and evaluated. Finally, suggestions for further work to prepare the VA were given.

This project has shown that it is feasible to create a lightweight VA for people living with dementia that does not require an internet connection to operate its core functionalities. However, this VA lacks many convenience features and provides only limited functionality compared to existing products. It is apparent that more effective functionality, such as smart-home connectivity, would still require an internet connection.

GLAD has not been tested by potential users and it cannot be confirmed that it or its features are suitable for the intended usage. Nevertheless, the core of the VA shows an acceptable level of robustness, with the possibility of improving the functionality available.

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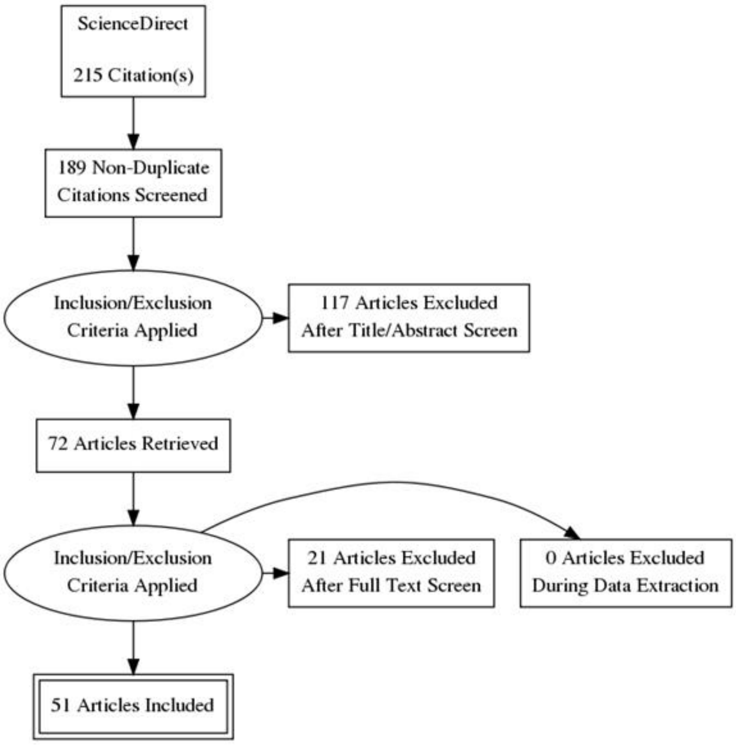
Appendix A. Literature Review

A.1. Search Queries

Query	Results	Performed on
dementia	168,250	22/01/2021
dementia helping	5,728	22/01/2021
dementia helping challenges	2,993	22/01/2021
dementia helping challenges caring	2,501	22/01/2021
dementia helping challenges needs	2,214	22/01/2021
dementia helping challenges needs palliative	439	22/01/2021
dementia helping challenges needs palliative independence	124	22/01/2021
dementia helping challenges needs palliative independence preferences	91	22/01/2021
dementia helping challenges needs palliative independence preferences care	91	22/01/2021
dementia helping challenges needs palliative independence preferences enabling	26	22/01/2021
dementia "assistive technology"	408	22/01/2021
dementia "assistive technology" difficulties	239	22/01/2021
dementia "assistive technology" interaction	264	22/01/2021
dementia "assistive technology" difficulties independence	136	22/01/2021
dementia "assistive technology" difficulties independence preferences	64	22/01/2021
dementia "assistive technology" difficulties independence preferences enabling	30	22/01/2021
"digital immigrants"	327	22/01/2021
"digital immigrants" usability	0	22/01/2021
"digital immigrants" design	264	22/01/2021
"digital immigrants" design NOT "social media"	171	22/01/2021
"digital immigrants" design NOT "social media" NOT student	27	22/01/2021
"digital immigrants" needs	244	22/01/2021
"digital immigrants" voice	72	22/01/2021
"digital immigrants" voice NOT student	15	22/01/2021
dementia "caring for"	64,046	22/01/2021
dementia "caring for" elderly	26,733	22/01/2021
dementia "caring for" elderly difficulties	10,586	22/01/2021
dementia "caring for" elderly difficulties "early onset"	817	22/01/2021
dementia "caring for" elderly difficulties "early onset" independence	159	22/01/2021
dementia "caring for" elderly difficulties "early onset" independence prevention	99	22/01/2021
dementia "caring for" elderly difficulties "early onset" independence prevention "home care"	22	22/01/2021
"voice assistant"	153	22/01/2021
"voice assistant" capability	46	22/01/2021
"voice assistant" capability adoption	23	22/01/2021
"smart home" assistant	990	22/01/2021
"smart home" assistant "consumer product"	20	22/01/2021
"smart home" assistant dementia	78	22/01/2021
"smart home" assistant dementia NOT diagnosis	52	22/01/2021
"smart home" assistant dementia support NOT diagnosis	50	22/01/2021
"smart home" assistant dementia independence NOT diagnosis	26	22/01/2021
"voice assistant"	163	08/02/2021
"voice assistant" "language processing"	57	08/02/2021
"voice assistant" "language processing" technology	50	08/02/2021
"voice assistant" "language processing" technology features	40	08/02/2021
"voice assistant" "language processing" technology features comparison	26	08/02/2021

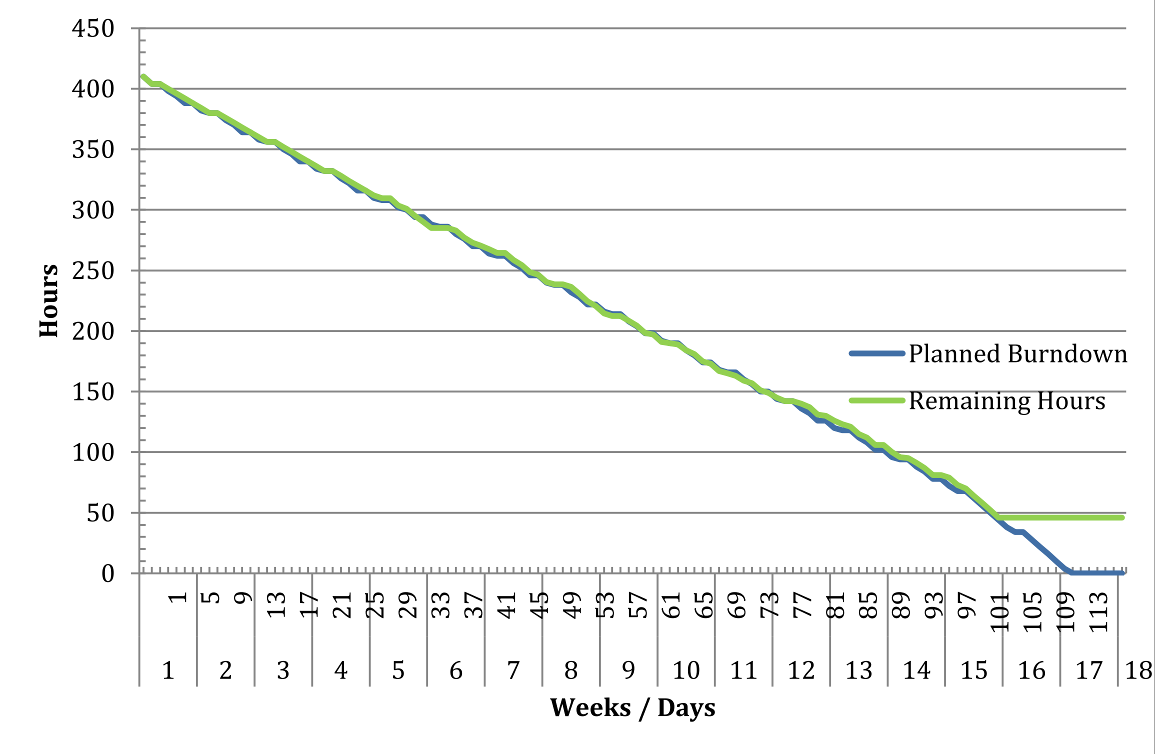
A.2. PRISMA Flow Diagram



Appendix B. Project Roadmap

Appendix C. Project Management

C.1. Burndown Chart

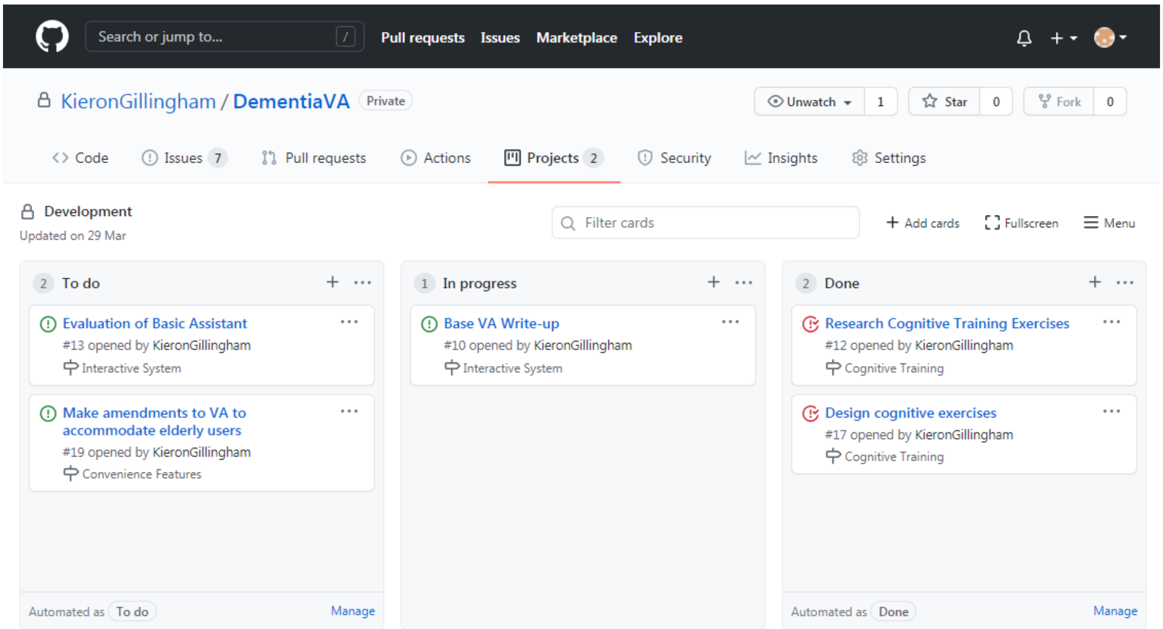


C.2. Breakdown of Hours

			Week	Day	Plan	Planned Hours	Total	Actual Hours	Total
January	18	Mon	1				0		0
	19	Tue					0		0
	20	Wed					0		0
	21	Thu					0		0
	22	Fri		1	Paper Gathering	6	6	6	6
	23	Sat		2		6	12	6	12
	24	Sun		3		0	12	0	12
	25	Mon	2	4	Lit Review	6	18	4	16
	26	Tue		5		4	22	4	20
	27	Wed		6		6	28	4	24
	28	Thu		7		0	28	4	28
	29	Fri		8		6	34	4	32
	30	Sat		9		2	36	4	36
	31	Sun		10		0	36	0	36
February	1	Mon	3	11	Lit Review	6	42	4	40
	2	Tue		12		4	46	4	44
	3	Wed		13		6	52	4	48
	4	Thu		14		0	52	4	52
	5	Fri		15		6	58	4	56
	6	Sat		16		2	60	4	60
	7	Sun		17		0	60	0	60
	8	Mon	4	18	Requirements/Plan	6	66	4	64
	9	Tue		19		4	70	4	68
	10	Wed		20		6	76	4	72
	11	Thu		21		0	76	4	76
	12	Fri		22		6	82	4	80
	13	Sat		23		2	84	4	84
	14	Sun		24		0	84	0	84
	15	Mon	5	25	Prototype	6	90	4	88
	16	Tue		26		4	94	4	92
	17	Wed		27		6	100	4	96
	18	Thu		28		0	100	4	100
	19	Fri		29		6	106	4	104
	20	Sat		30		2	108	2.5	106.5
	21	Sun		31		0	108	0	106.5
	22	Mon	6	32	Progress Report	6	114	6	112.5
	23	Tue		33		2	116	2.5	115
	24	Wed		34		6	122	6	121
	25	Thu		35		0	122	5	126
	26	Fri		36		6	128	5	131
	27	Sat		37		2	130	0	131
	28	Sun		38		0	130	0	131
March	1	Mon	7	39	Sprint 1	6	136	2	133
	2	Tue		40		4	140	6	139
	3	Wed		41		6	146	4	143
	4	Thu		42		0	146	2.5	145.5
	5	Fri		43		6	152	3	148.5
	6	Sat		44		2	154	3	151.5
	7	Sun		45		0	154	0	151.5
	8	Mon	8	46	Sprint 1	6	160	6	157.5
	9	Tue		47		4	164	4	161.5
	10	Wed		48		6	170	6	167.5
	11	Thu		49		0	170	2	169.5
	12	Fri		50		6	176	6	175.5
	13	Sat		51		2	178	2	177.5
	14	Sun		52		0	178	0	177.5
	15	Mon	9	53	Sprint 2	6	184	2	179.5
	16	Tue		54		4	188	6	185.5
	17	Wed		55		6	194	6	191.5
	18	Thu		56		0	194	4	195.5
	19	Fri		57		6	200	6	201.5

	20	Sat		58		2	202	2	203.5
	21	Sun		59		0	202	0	203.5
	22	Mon		60		6	208	4	207.5
	23	Tue		61		4	212	4	211.5
	24	Wed		62	Sprint 2	6	218	6	217.5
	25	Thu	10	63		0	218	1.5	219
	26	Fri		64		6	224	6	225
	27	Sat		65		2	226	1	226
	28	Sun		66		0	226	1	227
	29	Mon		67		6	232	5	232
	30	Tue		68		4	236	3	235
	31	Wed		69	Sprint 3	6	242	6	241
	1	Thu	11	70		0	242	2	243
	2	Fri		71		6	248	6	249
	3	Sat		72		2	250	2.5	251.5
	4	Sun		73		0	250	2	253.5
	5	Mon		74		6	256	4	257.5
	6	Tue		75		4	260	2	259.5
	7	Wed		76	Sprint 3	6	266	6	265.5
	8	Thu	12	77		0	266	2.5	268
	9	Fri		78		6	272	4	272
	10	Sat		79		2	274	3	275
	11	Sun		80		0	274	0	275
	12	Mon		81		6	280	2	277
	13	Tue		82		4	284	2	279
	14	Wed		83	Sprint 4	6	290	6	285
April	15	Thu	13	84		0	290	1.5	286.5
	16	Fri		85		6	296	4	290.5
	17	Sat		86		2	298	2	292.5
	18	Sun		87		0	298	2	294.5
	19	Mon		88		6	304	6	300.5
	20	Tue		89		4	308	3.5	304
	21	Wed		90	Sprint 4	6	314	6	310
	22	Thu	14	91		0	314	0	310
	23	Fri		92		6	320	6	316
	24	Sat		93		2	322	3	319
	25	Sun		94		0	322	1	320
	26	Mon		95		6	328	4	324
	27	Tue		96		4	332	4	328
	28	Wed		97	Catch-up	6	338	6	334
	29	Thu	15	98		0	338	0	334
	30	Fri		99		6	344	2	336
	1	Sat		100		4	348	6	342
	2	Sun		101		0	348	3	345
	3	Mon		102		6	354	6	351
	4	Tue		103		6	360	6	357
	5	Wed		104	Finish Report	6	366	6	363
	6	Thu	16	105		6	372	6	369
	7	Fri		106		6	378		369
	8	Sat		107	Presentation	4	382		369
	9	Sun		108		0	382		369
	10	Mon		109		6	388		369
May	11	Tue		110		6	394		369
	12	Wed		111	Presentation	6	400		369
	13	Thu	17	112		6	406		369
	14	Fri		113		6	412		369
	15	Sat		114		4	416		369
	16	Sun		115		0	416		369
	17	Mon		116			416		369
	18	Tue		117			416		369
	19	Wed	18	118	Presentation		416		369
	20	Thu		119			416		369
	21	Fri		120			416		369

C.3. Project Kanban Board



Appendix D. Ethics Release

Ethical clearance for research and innovation projects

Project status

Status

Approved

Actions

Date	Who	Action	Comments
16:37:00 31 March 2021	Prins Butt	Supervisor approved	
15:31:00 31 March 2021	Kieron Gillingham	Principal investigator submitted	

Ethics release checklist (ERC)

Project details

Project name:	Dementia Voice Assistant
Principal investigator:	Kieron Gillingham
Faculty:	Faculty of Business, Law and Digital Technologies
Level:	Undergraduate
Course:	BSc Software Engineering
Unit code:	COM616
Supervisor name:	Prins Butt
Supervisor search:	
Other investigators:	

Checklist

Question	Yes	No
Q1. Will the project involve human participants other than the investigator(s)?	○	◉
Q2. Will the project involve sensitive materials or topics that might be considered offensive, distressing, politically or socially sensitive, deeply personal or in breach of the law (for example criminal activities, sexual behaviour, ethnic status, personal appearance, experience of violence, addiction, religion, or financial circumstances)?	○	◉
Q3. Will the project have detrimental impact on the environment, habitat or species?	○	◉
Q4. Will the project involve living animal subjects?	○	◉
Q5. Will the project involve the development for export of 'controlled' goods regulated by the Export Control Organisation (ECO)? (This specifically means military goods, so called dual-use goods (which are civilian goods but with a potential military use or application), products used for torture and repression, radioactive sources.) Further information from the Export Control Organisation '	○	◉
Q6. Does your research involve: the storage of records on a computer, electronic transmissions, or visits to websites, which are associated with terrorist or extreme groups or other security sensitive material? Further information from the Information Commissioners Office '	○	◉

Appendix E. Concept Map

Appendix F. Risk Assessment

ID	Risk	Likelihood 1 – Unlikely 4 – Very Likely	Consequence	Impact 1 – Low 4 – High	Risk Factor Likelihood x Impact	Mitigation Strategies
1	Poor planning	3	Project overruns / Fails to meet milestones	4	12	Use project management software / Follow a planning process
2	Loss of work	3	Work must be repeated	4	12	Use back-ups / Cloud storage / Version Control
5	Difficulty integrating technologies	4	Chosen technologies must be reconsidered	3	12	Create prototypes and integration tests
14	Persistent programming bugs	3	Tasks take longer to complete than planned	3	9	Provide lenient development time to address bugs
6	Unclear goals	2	Unnecessary work may be completed	4	8	Clearly define needs and scope of project
7	Chosen technology is insufficient	2	Chosen technologies must be reconsidered	3	6	Create prototypes and integration tests
11	Developed solution is not suited to live environments	2	Solution may require rework	3	6	Ensure requirements are clear
13	Digital developer environment is not suitable	2	Tasks take longer to complete than planned	3	6	Ensure environment is set-up beforehand and is comfortable
15	Underestimated difficulty of task	2	Tasks take longer to complete than planned	3	6	Allow time near end of project to catch-up
16	Solution is cost in-effective	2	Solution may require rework	3	6	Ensure requirements are clear
3	Loss of back-ups	1	Work must be repeated	4	4	Use multiple back-ups
9	Users unavailable for testing	4	Solution cannot be verified by real users	1	4	Select evaluation strategy that does not require live users
10	Requirements are insufficient	1	Solution may require rework	3	3	Ensure requirements are clear
8	Project requirements change	1	Previous plans may become irrelevant	2	2	Follow an adaptable workflow such as Agile
12	Prolonged loss of access to online resources	1	Supplementary research cannot be completed	2	2	Complete research sub-stages early
4	Unclear commit messages	1	Reviewing code later may become difficult	1	1	Follow a standard or convention for commit messages

Appendix G. Results

ID	Prerequisites	Spoken Phrase	Heard Phrase	Accuracy of Transcription	Average Accuracy	Time to process (TTP) [seconds]	Average TTP [seconds]	Expected outcome	Outcome success	Outcome Accuracy
1.1	VA is active	Hello	HELLO	100%	100%	03.850	03.087	Respond "hello"	Yes	100%
1.2			HELLO	100%		02.973			Yes	
1.3			HELLO	100%		02.907			Yes	
1.4			HELLO	100%		02.961			Yes	
1.5			HELLO	100%		02.742			Yes	
2.1	VA is active	What time is it	WHAT TIME IS IT	100%	100%	08.931	04.982	Respond with current system time	Yes	100%
2.2			WHAT TIME IS IT	100%		04.025			Yes	
2.3			WHAT TIME IS IT	100%		03.651			Yes	
2.4			WHAT TIME IS IT	100%		03.939			Yes	
2.5			WHAT TIME IS IT	100%		04.362			Yes	
3.1	VA is active	What is the time	BOYS THE TIME	62%	92%	04.717	04.462	Respond with current system time	Yes	100%
3.2			WHAT IS THE TIME	100%		05.331			Yes	
3.3			WHAT IS THE TIME	100%		03.527			Yes	
3.4			WHAT IS THE TIME	100%		04.981			Yes	
3.5			WHAT IS THE TIME	100%		03.756			Yes	
4.1	VA is active	What day is it	WHAT DAY IS IT	100%	100%	04.373	04.029	Speak the day of the week	Yes	100%
4.2			WHAT DAY IS IT	100%		04.415			Yes	
4.3			WHAT DAY IS IT	100%		04.472			Yes	
4.4			WHAT DAY IS IT	100%		03.350			Yes	
4.5			WHAT DAY IS IT	100%		03.533			Yes	
5.1	VA is active	Who are you	WHO ARE YOU	100%	91%	03.602	02.956	Introduce self	Yes	60%
5.2			HOW ARE YOU	82%		02.746			No	
5.3			WHO ARE YOU	100%		02.887			Yes	
5.4			WHO ARE YOU	100%		02.860			Yes	
5.5			WHERE ARE YOU	73%		02.684			No	
6.1	VA is active	What is your name	WHAT IS YOUR NAME	100%	100%	03.937	03.328	Introduce self	Yes	100%
6.2			WHAT IS YOUR NAME	100%		03.246			Yes	
6.3			WHAT IS YOUR NAME	100%		03.215			Yes	
6.4			WHAT IS YOUR NAME	100%		03.179			Yes	
6.5			WHAT IS YOUR NAME	100%		03.065			Yes	
7.1	VA is active	What can you do	WHAT CAN YOU DO	100%	96%	04.172	03.692	List functionality	Yes	100%
7.2			WHAT CAN YOU DO	100%		03.927			Yes	
7.3			WHAT CAN YOU DO	100%		03.502			Yes	
7.4			WHAT CAN YOU DO	100%		03.187			Yes	
7.5			BUT CAN YOU DO	80%		03.674			Yes	
8.1	VA is active	Put some music on	PUT SOME MUSIC ON	100%	90%	04.519	04.182	VA receives command to play the radio	Yes	100%
8.2			BUT SOME MUSIC ON	94%		03.528			Yes	
8.3			BUT SOME MUSIC ON	94%		03.609			Yes	
8.4			THAT SOME MUSIC ON	82%		03.513			Yes	
8.5			THAT SOME MUSIC ON	82%		05.743			Yes	
9.1	VA is active	Play the radio	PLAY THE RADIO	100%	99%	03.488	04.095	VA receives command to play the radio	Yes	100%
9.2			PLAY THE RADIO	100%		03.214			Yes	
9.3			PLAY THE RADIO	100%		03.805			Yes	
9.4			LAY THE RADIO	93%		03.828			Yes	
9.5			PLAY THE RADIO	100%		06.140			Yes	
10.1	VA is active	I want the radio on	I WANT THE RADIO ON	100%	100%	04.642	04.096	VA receives command to play the radio	Yes	100%
10.2			I WANT THE RADIO ON	100%		04.049			Yes	
10.3			I WANT THE RADIO ON	100%		04.375			Yes	
10.4			I WANT THE RADIO ON	100%		03.739			Yes	
10.5			I WANT THE RADIO ON	100%		03.674			Yes	
11.1	Radio is playing	Change the station	JANE THE STATION	83%	77%	03.642	03.488	Change the radio station	Yes	100%
11.2			CHANGE THE STATION	100%		03.822			Yes	
11.3			CHANGE THE STATION	100%		03.448			Yes	
11.4			CHANGE THE STATION	100%		03.348			Yes	
11.5			CAN TESTATION	0%		03.178			Yes	
12.1	Radio is playing	Put a different station on	BUT A DIFFERENT STATION ON	96%	65%	04.397	04.716	Change the radio station	Yes	100%
12.2			CARTERET STATION ON	0%		04.502			Yes	
12.3			TO A DIFFERENT STATION ON	88%		04.757			Yes	
12.4			PORTENDUERE STATION ON	62%		04.905			Yes	
12.5			THERE DIFFERENT STATION ON	81%		05.018			Yes	
13.1	Radio is playing	Put the volume up	BUT THE VOLUME AT	82%	70%	03.699	03.693	Turn the radio volume up	No	40%
13.2			BUT THE VOLUME UP	94%		03.281			Yes	
13.3			BUT THE VOLUME UP	94%		03.327			Yes	
13.4			BUT THE VALET	0%		03.650			No	
13.5			BUT THE VOLUME AT	82%		04.507			No	
14.1	Radio is playing	Lower the volume	HERE THE VALLEY	50%	85%	03.285	03.730	Turn the radio volume down	No	80%
14.2			THE LOWER THE VOLUME	75%		04.265			Yes	
14.3			LOWER THE VOLUME	100%		03.949			Yes	
14.4			LOWER THE VOLUME	100%		03.361			Yes	

14.5			LOWER THE VOLUME	100%		03.788			Yes	
15.1	Radio is playing	Stop the music	STOP THE MUSIC	100%	96%	03.581	03.877	Stop the radio	Yes	100%
15.2			STOP THE MUSIC	100%		03.673			Yes	
15.3			STOP THE MUSIC	100%		03.576			Yes	
15.4			STOP THE MUSIC	100%		04.316			Yes	
15.5			STOPPED THE MUSIC	79%		04.241			Yes	
16.1	Radio is playing	Turn off the radio	TURN OFF THE RADIO	100%	93%	03.881	04.044	Stop the radio	Yes	80%
16.2			TURN OFF THE RADIO	100%		04.521			Yes	
16.3			TURN OFF THE RADIO	100%		04.377			Yes	
16.4			TURN OFF THE RADIO	100%		03.614			Yes	
16.5			THEN OTHER RADIO	67%		03.829			No	
17.1	VA is active	Play the number game	FLAY THE NUMBER GAME	95%	95%	03.843	04.077	VA receives command to play the number game	Yes	100%
17.2			PLAY THE NUMBER GAME	100%		04.037			Yes	
17.3			PLAY THE NUMBER GAME	100%		04.265			Yes	
17.4			PLAYS A NUMBER GAME	80%		03.995			Yes	
17.5			PLAY THE NUMBER GAME	100%		04.247			Yes	
18.1	VA is active	Let's play a game	LET'S PLAY A GAME	100%	100%	03.439	04.120	VA receives command to play the number game	Yes	100%
18.2			LET'S PLAY A GAME	100%		03.766			Yes	
18.3			LET'S PLAY A GAME	100%		03.949			Yes	
18.4			LET'S PLAY A GAME	100%		03.846			Yes	
18.5			LET'S PLAY A GAME	100%		05.601			Yes	
19.1	Game has started	What are the rules	WHAT ARE THE RULES	100%	100%	03.764	03.940	Explain the number game rules	Yes	100%
19.2			WHAT ARE THE RULES	100%		03.879			Yes	
19.3			WHAT ARE THE RULES	100%		03.560			Yes	
19.4			WHAT ARE THE RULES	100%		04.377			Yes	
19.5			WHAT ARE THE RULES	100%		04.122			Yes	
20.1	Game has started	Higher	HIGHER	100%	100%	03.443	03.593	Accept "higher" as answer for question	Yes	100%
20.2			HIGHER	100%		03.574			Yes	
20.3			HIGHER	100%		03.582			Yes	
20.4			HIGHER	100%		03.700			Yes	
20.5			HIGHER	100%		03.664			Yes	
21.1	Game has started	Lower	LOWER	100%	80%	03.530	03.403	Accept "lower" as answer for question	Yes	80%
21.2			NO	0%		02.459			No	
21.3			LOWER	100%		03.736			Yes	
21.4			LOWER	100%		03.732			Yes	
21.5			LOWER	100%		03.560			Yes	
22.1	Game has started	The same	THE SAME	100%	100%	03.624	04.246	Accept "the same" as answer for question	Yes	100%
22.2			THE SAME	100%		04.065			Yes	
22.3			THE SAME	100%		04.594			Yes	
22.4			THE SAME	100%		04.609			Yes	
22.5			THE SAME	100%		04.338			Yes	
23.1	Game has started	Stop playing	STOP PLAYING	100%	100%	03.048	03.587	Stop the game	Yes	100%
23.2			STOP PLAYING	100%		03.638			Yes	
23.3			STOP PLAYING	100%		03.886			Yes	
23.4			STOP PLAYING	100%		03.738			Yes	
23.5			STOP PLAYING	100%		03.627			Yes	
24.1	VA is active	Talk faster	TALK FASTER	100%	100%	03.170	03.426	Increase VA talking speed	Yes	100%
24.2			TALK FASTER	100%		03.238			Yes	
24.3			TALK FASTER	100%		03.164			Yes	
24.4			TALK FASTER	100%		03.296			Yes	
24.5			TALK FASTER	100%		04.261			Yes	
25.1	VA is active	Talk slower	TAKE ALL OUR	36%	44%	03.371	03.438	Decrease VA talking speed	No	40%
25.2			TAKE OUR	0%		03.398			No	
25.3			TO LOWER	0%		03.458			No	
25.4			TALK LOWER	91%		03.502			Yes	
25.5			TALK LOWER	91%		03.462			Yes	
26.1	User has been asked to confirm an action	Yes	YES	100%	80%	02.310	02.458	Action is confirmed	Yes	80%
26.2			YES	100%		02.342			Yes	
26.3			YES	100%		02.513			Yes	
26.4			THE	0%		02.648			No	
26.5			YES	100%		02.478			Yes	
27.1	User has been asked to confirm an action	Okay	OKAY	100%	100%	02.494	02.780	Action is confirmed	Yes	100%
27.2			OKAY	100%		02.612			Yes	
27.3			OKAY	100%		02.567			Yes	
27.4			OKAY	100%		03.592			Yes	
27.5			OKAY	100%		02.634			Yes	
28.1	User has been asked to confirm an action	Sure	SHE	0%	25%	02.743	02.529	Action is confirmed	No	20%
28.2			SHOW	25%		02.425			No	
28.3			SHE	0%		02.398			No	
28.4			SO	0%		02.471			No	
28.5			SURE	100%		02.610			Yes	
29.1	User has been asked to confirm an action	No	NO	100%	80%	02.267	02.348	Action is denied	Yes	100%
29.2			NO	100%		02.204			Yes	
29.3			NOW	0%		02.352			Yes	
29.4			NO	100%		02.572			Yes	
29.5			NO	100%		02.343			Yes	
30.1	User has been asked to confirm an	Nah	NO	0%	20%	02.227	02.478	Action is denied	Yes	80%
30.2			NOT	33%		02.373			Yes	
30.3			NOT	33%		02.574			Yes	

30.4	action		THAT	0%		02.549			No	
30.5			NOT	33%		02.665			Yes	
31.1	User has been asked to confirm an action	Don't do that	DON'T DO THAT	100%	100%	02.931	03.133	Action is denied	Yes	100%
31.2			DON'T DO THAT	100%		03.354			Yes	
31.3			DON'T DO THAT	100%		03.098			Yes	
31.4			DON'T DO THAT	100%		03.080			Yes	
31.5			DON'T DO THAT	100%		03.202			Yes	
32.1	VA is active	Turn off	TURN OFF	100%	100%	02.907	02.782	VA receives command to shut down	Yes	100%
32.2			TURN OFF	100%		02.724			Yes	
32.3			TURN OFF	100%		02.746			Yes	
32.4			TURN OFF	100%		02.767			Yes	
32.5			TURN OFF	100%		02.767			Yes	
33.1	VA is active	Shut down	SHUT DOWN	100%	87%	02.963	03.140	VA receives command to shut down	Yes	20%
33.2			SO DOWN	67%		03.314			No	
33.3			SHOT DOWN	89%		03.090			No	
33.4			SHOT DOWN	89%		03.086			No	
33.5			SHOT DOWN	89%		03.248			No	