Cardiff University

School of Computer Science and Informatics

CM3203 One Semester Individual Project

A Low Cost IoT Prototype To Evaluate Sit-To-Stand Exercises For Older Adults

Author:
Joshua Tucker
C1739307

Supervisor:
Dr. Katarzyna Stawarz
Moderator:
Dr. Hantao Liu

Abstract

Maintaining an active lifestyle is key to sustained health in older adults, and current technologies such as the Mircosoft Kinect are often too expensive and complex for many older adults to integrate into their daily lives.

This project implements an internet-of-things prototype tailored towards strength exercises for older adults, using a computer vision approach in order to evaluate sit-to-stand exercise, that is lower in cost, and oriented specifically towards older adults.

The prototype is evaluated through a usability study, in which 5 participants test the functionality of the prototype and provide feedback in the form of a usability questionnaire and post study interview.

with an average system usability score of 80 out of 100, results show that the prototype is able to maintain usability and functionality despite the lower costs through the use of more up to date computer vision techniques with less demanding hardware requirements.

Contents

List of Figures

List of Tables

1 Introduction

With the release of consumer home exercise technologies such as the Microsoft Kinect in 2010, exercise assistance coaches and games utilising computer vision were brought to a wide audience. Maintaining an active lifestyle is key to sustained health, however, for certain members of the public such as older adults and those on a fixed income, the technology was often too expensive or imposing to be used as part of daily life. Especially for those older adults, countrywide lockdown restrictions due to the global COVID-19 pandemic has meant that many common ways in which people exercise are currently unavailable. This project aims to utilise advancements in computer vision since the 2010 release of the Microsoft Kinect, in order to build an IoT device to assist older adults in exercising in the home, which is cheaper, smaller and easier to use than previous solutions.

2 Background

2.1 Importance of Sit-To-Stand exercise in Older Adults

The sit-to-stand process is one of the most simple strength exercises, however, it plays a crucial role in allowing older adults to stay mobile and in dependant. Sit-to-stand ability is linked with functional mobility and dynamic balance, and so maintaining fitness in this area is key if older adults are to remain mobile and is the first step towards further exercise and fitness (Fujita *et al.*, 2019). While the role that strength exercises play in reducing falls in older people more generally has recently been reviewed and no longer recommend, regular sit-to-stand exercises are shown to be an important way to improve and maintain mobility for older adults (Chaovalit *et al.*, 2020).

Now that the importance and impact of sit to stand activity in older people has been discussed, I will provide a more detailed overview of what these exercises entail, and elaborate on the common variations.

Figure 1: Assisted Sit-To-Stand Exercise Demonstration

Figure 2: Un-assisted Sit-To-Stand Exercise Demonstration

Figure 1 shows the basic, assisted form of the Sit-To-Stand strength exercise. Sit to stand exercises take two main forms: assisted, and unassisted. The assisted form allows the participant to support their weight using their arms, either by pushing up against an armrest or from pushing upon their knees. In the unassisted form, seen in figure 2, the participant performs the exercise with their arms crossed against their chest so that their arms do not assist them in the exercise (Shrift, 2018).

The assisted form would be used initially for weaker participants who may struggle to perform the exercise unassisted, progressing to the unassisted form once they have progressed enough to be able to perform the exercise without the support needed from their arms for strength and balance.

These two forms, therefore, correspond to the two separate positions that the prototype will need to be able to differentiate between. In addition to the positions of the hands to tell between these two forms of the exercise, the prototype will first need to recognize the correct positioning for the start and end of each repetition of the sit to stand. Thus giving 3 positions required for the prototype to function:

- Arms crossed
- Sitting
- Standing

With these 3 positions being recognized the prototype will be able to count repetitions of the sit to stand exercise and recognize which variation is being performed.

2.2 Blocking Factors in Exercise for Older Adults

Table 1: Common Barriers to Exercise in Older Adults. (Nied RJ, 2002)

Common Barriers to Exercise in Older Adults	
Barrier	Approach
Self-efficacy	Begin slowly with exercises that are easily accomplished; advance gradually; provide frequent encouragement.
Discomfort	Vary intensity and range of exercise; employ cross-training; start slowly; avoid overdoing.
Disability	Specialized exercises; consider personal trainer or physical therapist.
Poor balance/ataxia	Assistive devices can increase safety as well as increase exercise intensity.
Fear of injury	Balance and strength training initially; use of appropriate clothing, equipment, and supervision; start slowly.
Habit	Incorporate into daily routine; repeat encouragement; promote active lifestyle.
Fixed income	Walking and other simple exercises; use of household items; promote active lifestyle.
Environmental factors (e.g., inclement weather)	Walk in the mall; use senior centers; promote active lifestyle.
Cognitive decline	Incorporate into daily routine; keep exercises simple.
Illness/fatigue	Use a range of exercises/intensities that patients can match to their varying energy level.

Table 1 shows the most common barriers to exercise identified for older adults (Nied RJ, 2002). These must be the main considerations in designing a solution to appeal to older adults and so must be taken into account at each stage of the development process. Through a critical analysis of current solutions against these barriers, we will be able to identify the factors that are underrepresented in current solutions and so develop a prototype that aims to target these concerns more specifically.

2.3 Review of Previous Solutions

Now that we have identified the main barriers to exercise in older adults, we will review previous solutions which have met similar requirements in measuring strength activity and identify how they altered their approach to accommodate older adults, comparing against the blocking factors discussed above to identify areas in which improvements can be made.

One such application used a Microsoft Kinect to create a game targeted towards older adults, encouraging exercise Ganesan and Anthony (2012). This study focused on arm movement through displaying shapes on a screen in which the participant would need to reach to touch each shape in order to increase their score. The study concluded that while making the game fun was the most important factor, making the game easy enough to do was also important in building habit to encourage continued use. Social elements such as adding high scores were also identified as important, as this would allow participants to compare and compete with their peers. Limiting factors to this type of exercise game lie in the cost of systems like the Kinect, which may not be affordable for many older adults, with fixed income being one of the barriers identified in figure 1. Additional limitations identified in the study were in the feedback provided to the participant. As previously mentioned a high score system was suggested so that participants can compare with others, and immediate feedback on the points scored for each activity were brought up as a suggested improvement.

A different study explores assistive robots for exercise training in older adults Lotfi *et al.* (2018). The system designed in the study uses a Kinect to track the positioning of the participant and a moving robot with a tablet attached to act as the training coach, which would allow them to decide on the exercise and provide feedback in the form of smiley faces. The robot was found to be engaging for participants, however, there was criticism about the size of the system, which required the Kinect to be mounted on a tripod in addition to the coach robot. Similar to the previous Kinect prototype discussed, the study stresses the importance of feedback in encouraging continued use of the product, which in this case took the form of both visual smiley faces and audio feedback for each exercise, including feedback on what the participant can do to improve.

2.4 Conclusion

Through comparing the barriers to exercise in older adults identified in table 1, with the feedback given by users of the previous solutions discussed above, we can identify specific barriers that have not been previously addressed, in order to design a solution that will address these issues. The two barrier this project will am to address will therefore be:

- *Fixed Income:* Previous solutions used expensive equipment such as the Microsoft Kinect (Ganesan and Anthony, 2012). These systems may not be affordable for older adults on a fixed income

- *Habit:* The system in the Lotfi *et al.* (2018) robot trainer study was critisized for its large size, which may inhibit the incorporation of the system into a daily routine

These two blockers, therefore, will be the main barriers that the system will aim to overcome, while also incorporating and maintaining the positive features identified in previous solutions such as the use of real time feedback identified as a positive in both studies covered.

3 Approach

This section will give an overview of the requirements gathering process used in defining a specification for the system, followed by the subsequent design approach taken to meet these requirements.

3.1 Requirements Gathering

The main goal of the project is to implement a low-cost IoT prototype to evaluate sit-to-stand exercises in older adults. Thus in developing a specification for the system, the requirements have been split along the three main themes that make up the project brief.

- Low-cost hardware
- Pose estimation (evaluating sit-to-stand exercises)
- User experience tailored to older adults.

3.2 Low-Cost Hardware

One blocker for exercise in older adults identified in the background research for the project was fixed income (see figure 1). This was a barrier that was not found to be addressed in previous solutions, which used mainly more expensive hardware such as the Microsoft Kinect (Ganesan and Anthony, 2012). The current cost for this sensor is at the time of writing is £355.00 (Microsoft, 2021). Thus the feasibility of older adults being able to afford a system using the device is questionable, as in addition to the Kinect sensor they would also require a computer in order to run any software associated with the device.

Therefore for this project, the aim is to develop a lower-cost prototype that would be feasible for a person with a fixed income to afford. In order to meet this requirement, instead of a sensor such as the Microsoft Kinect, which uses an array of both RGB and depth cameras, the prototype will use a low-cost single RBG camera as input. In addition to the cost savings in using a less expensive sensor, this more basic input will aim to reduce the processing power required to analyse the video feed, and thus remove the need for a powerful computer to run the software and allow the system to run off of a single board computer such as the Raspberry Pi.

3.3 Pose Estimation

In order to track and analyse the positions of the user, the system will need to integrate some form of pose estimation. This is an area of computer vision focused on identifying objects from an image and determining their orientation from one another. In the case of this project, the objects being identified would be human body parts and their orientation from one another. This is known more specifically as *Human Pose Estimation*.

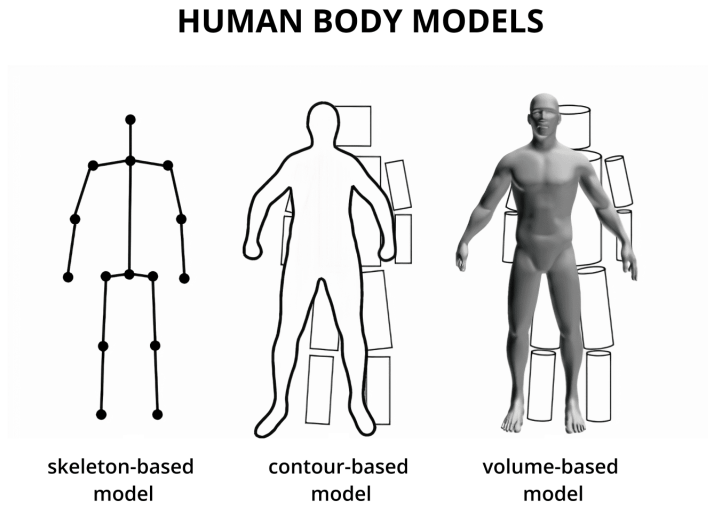

Figure 3: Human Body Model Types (Chen *et al.*, 2020)

Human Pose Estimation can be split into categories based on the type of human body model, and by the dimensions that are being modelled, 2-Dimensional or 3-Dimensional. There are three common types of human body model; skeleton-based, contour-based and volume-based (see figure 3) (Chen *et al.*, 2020).

While a volume-based model can only be applied in 3-D, the remaining two types can be applied to either a 2-D or 3-D model. When taking into account the aim of the project in creating a lower-cost system that will be required to run on a single board computer, a 2-D model seems more appropriate here due to the reduced processing cost. Therefore the decision is made between the skeleton-based model and the contour-based model. While the skeleton model lacks the width element of the limbs offered by the contour-based model, for the requirements of the project these won't be needed, as for the Sit-to-Stand exercises outlined previously (see section 2.1), we are only interested in the position of specific points on the body, for example, the position of the hands. Therefore the skeleton model is able to meet this requirement while being simpler than the contour model, and so will be the model implemented in this project.

3.4 User Experience Tailored to older Adults

Much of the functionally of the user interface seen in precious solution will be required for this project, for example in showing the user a count of their repetitions and a live feed of the video capture, will also be required for the prototype. The user interface must also be appropriate for the intended target audience of older adults.

Barnard *et al.* (2013) establishes a set of interface design guidelines for IoT and mixed reality products aimed at elderly people, which will be utilised to ensure that the various elements of the user interface for the prototype are appropriate and usable. While not all of the guidelines are applicable to this project, a number of the guidelines will impact the design of the user interface. These guidelines and their impact on the design are covered below:

- *Facilitate elderly people's accuracy and precision:* The UI uses large input buttons and provides enough space between buttons to reduce fine finger movements.

- *Provide simple UI with reduced complexity:* The UI has a simple, clear and understandable structure. In addition, the information is arranged with its importance.

- *Be consistent with older adults' expectations and intuition:* The UI is designed to be interactive. In addition, consistent mapping between tasks and their responses is maintained throughout the system.

- *Maximise legibility of essential information:* Digital information characteristics (font size, colour contrast)

- *Promote mobility for elderly people:* ATs should promote mobility for elderly people by placing UI controls near IoT devices instead of allowing to control them remotely

3.5 Specification

With the above design considerations in mind, a list of requirements for the prototype has been defined, which can be found in the appendix section 11.1. These requirements fit with the three above design areas and are split into two categories; functional and non-functional requirements(Altexsoft, 2018).

The functional requirements, which define *what* functions the system will perform, are made up mostly of requirements relating to pose estimation functionality, the main feature of the system, with the addition of requirements relating to user interface functionality and user's ability to select various options within the system and receive real-time feedback when exercising.

The non-functional requirements cover *how* the prototype will function, and requirements of the properties of the system. They are split between requirements defining the characteristics of the hardware, and usability requirements for older adults ,following the guidelines discussed previously.

With these design considerations and system requirements in mind, the next section will cover the implementation of the system, as well as discussing the blocking factors and design compromises that occurred during the development process.

4 Implementation

This section will cover the implementation of the three main elements identified as part of the approach, listed below.

- Hardware
- Pose Recognition
- User Experience

4.1 Hardware Implementation

The hardware that will make up the prototype consists of three separate components:

- Raspberry Pi 4
- Camera Module V2 for Raspberry Pi
- Adafruit BrainCraft HAT

For each of these components, I will now discuss the reasons for choosing these for the prototype, as well as a discussion around the assembled prototype and how the hardware functions when put together.

4.2 Raspberry Pi 4

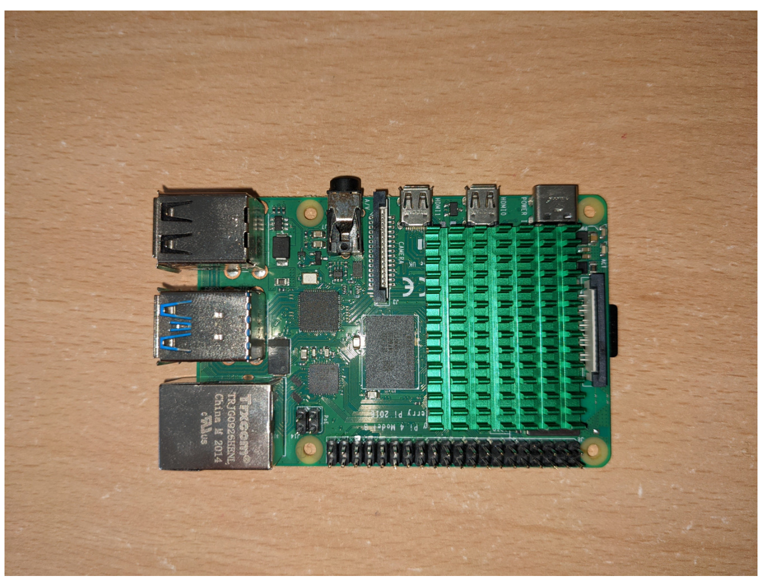

Figure 4: Raspberry Pi 4

The Raspberry Pi (RaspberryPiFoundation, 2021b) is a credit-card sized computer widely used for IoT projects and thus is ideally suited for this project. It has a wide range of support for both additional hardware add-ons and software packages and so is suitable in meeting the requirements of the project, which will require the use of a camera add on and I/O for use of the prototype by the user. The small size of the computer is additionally beneficial in addressing the issue identified in previous studies in which the hardware used (for example the Microsoft Kinect) was seen as large and intrusive to participants, and so by using this computer the footprint of the prototype is greatly reduced.

4.3 Camera Module V2 for Raspberry Pi

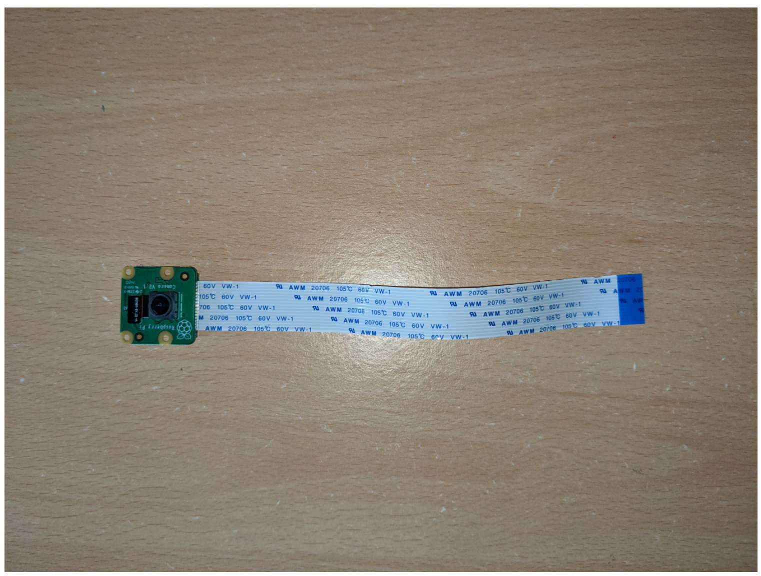

Figure 5: Camera Module V2 for Raspberry Pi

This camera module (RaspberryPiFoundation, 2021a)is required to record the video used by the prototype in order to analyse the user's technique when performing the sit-to-stand exercises. An additional reason as to why this particular camera module has been chosen is that it is the most widely supported camera module for the Raspberry Pi and so will be easy to integrate with the rest of the components which make up the prototype.

4.4 Adafruit BrainCraft HAT

Figure 6: Adafruit BrainCraft HAT

The Adafruit BrainCraft HAT (Adafruit, 2021) is a hardware add-on for the Raspberry Pi that is designed for use in IoT computer vision prototypes specifically. It features ports for a multitude of sensors, in addition to a small LCD screen and 5-way joystick and button which allows for user interaction without the need for a keyboard and mouse to be plugged into the Raspberry Pi. This piece of hardware has been chosen due to its versatility and number of features, which provides the prototype with the I/O functionality required to allow the user to navigate through the menus and functions of the prototype, via the 5-way joystick featured on the board.

4.5 Assembled Prototype

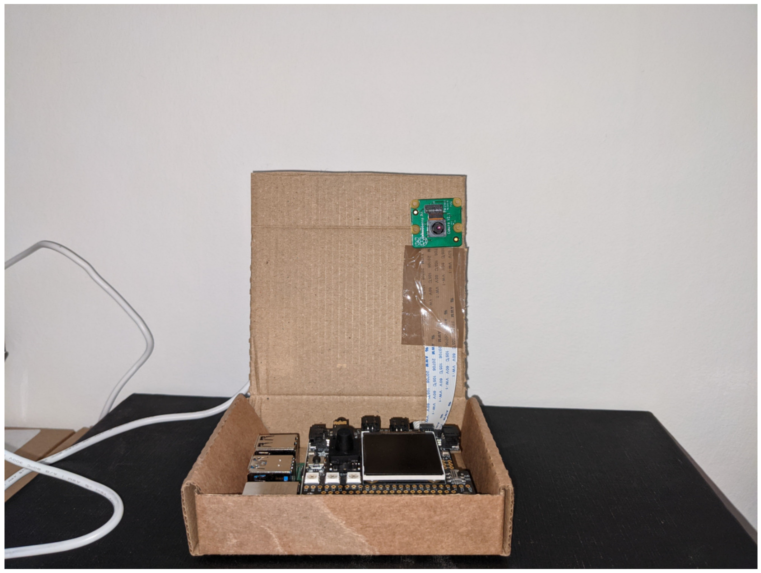

Figure 7: Assembled Prototype

The Assembled prototype is contained within a cardboard case which holds the parts in place such that the camera module is held steady and upright. A low fidelity prototyping approach was taken as part of the project due to cost and time limitations that would be involved in designing and building a more high fidelity enclosure (Stickdorn *et al.*, 2018). The use of cardboard prototyping also allows for a greater degree of freedom in changing the form and assembly of the prototype as the project progresses. For example, the cardboard flap seen holding the camera in place, seen in figure 7, allows the angle of the camera to easily be tilted up and down, which is useful in framing the video image correctly.

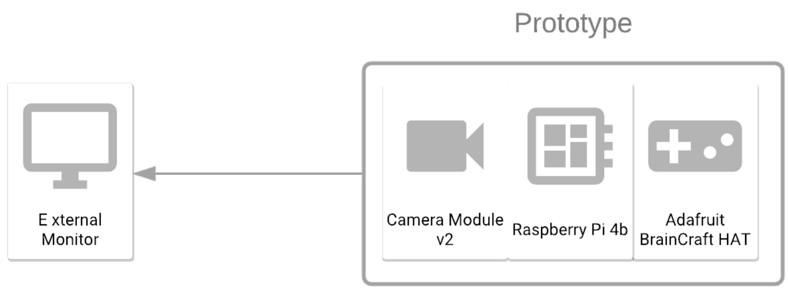

Figure 8: Prototype Overview

Figure 8 shows an overview of the assembled prototype as previously described, with the camera sensor, Raspberry Pi processing unit, and BrainCraft HAT I/O device assembled as a single unit, attached via HDMI to an external monitor.

While the LCD screen attached to the prototype was originally planned to be used as the primary display for the prototype, upon early testing it became clear that while performing the exercises, a user would need to be at least 2-3m away from the camera in order for their whole body to be in the frame, which was required for the pose estimation to function correctly. At this distance, the screen attached to the prototype was too small to see clearly and any text displayed was illegible. Therefore in addition to the components described above, the Raspberry Pi was connected to an external monitor to display the user interface at a larger scale such that it was readable from a distance.

4.6 Software Implementation

4.7 Technologies used

All code for the project was written in python. This language was chosen primarily due to its compatibility with the variety of libraries required to integrate the hardware components. Libraries for the BrainCraft HAT are all python libraries, as well as the camera module which is operated via the 'picamera' python module. In addition to its wide compatibility, python was also chosen due to my own familiarity with the language, which would therefore reduce development time and give a greater chance to implement all features in order to meet the requirements set out for the project.

Library	Justification
picamera	Used to integrate Camera Module v2 Hardware to receive video feed
digitialio / board	Used to integrate 5-way Joystick attached to BrainCraft HAT
cv2	Open Computer Vision, used to display video feed from camera, and for UI display elements.
tensorflow	Machine learning platform used for pose recognition (more detail in following section)

Table 2: Table Showing Key Libraries Used

Table 2 gives an overview of the main python libraries used as part of the system. The following sections will describe each of these in greater detail, as we run through each element of the software implementation.

4.8 Software Implementation Overview

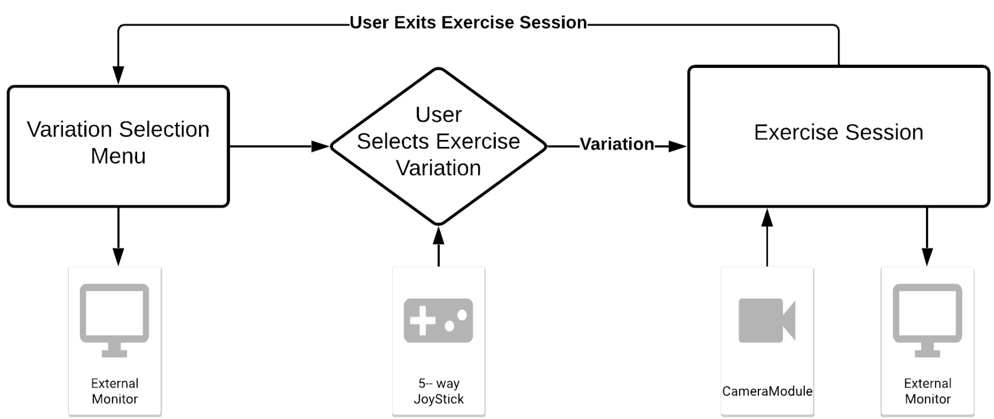

Figure 9: Software Process Overview

Figure 9 shows an overview of the user journey through the system. The system is made up of two main loops, the Variation Selection Menu, and the Exercise Session.

The user is first presented with a menu containing the 3 variations of the sit-to-stand exercise they wish to perform. Using the joystick they then select a variation, and the exercise session starts. The following two sections of the report will detail the implementation of these two parts which make up the system, starting with variation selection, followed by the main element of the system, the exercise session.

4.9 Variation Selection

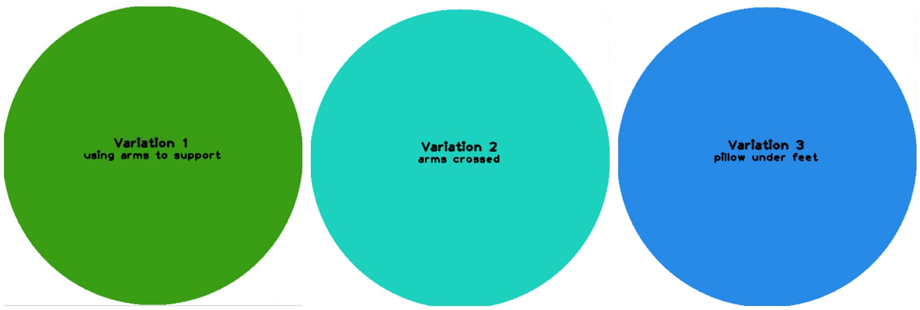

Figure 10: Variation Menu Screens

Figure 10 shows the three screens available for the variation menu the user sees upon launch of the program. Each variation is numbered with a brief description indicating which variation of the Sit-To-Stand exercise it relates to. The user is then able to cycle through each menu item by moving the joystick left or right. Upon selecting the desired option the joystick is pressed down to launch an exercise session with the selected variation.

4.10 Exercise Session

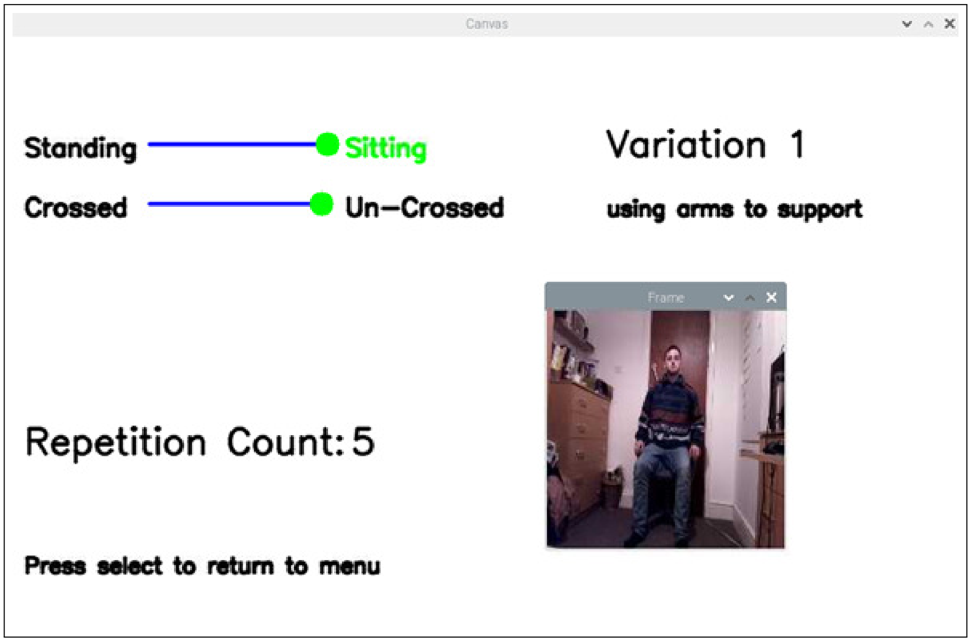

Figure 11: Exercise Session Screen

Figure 11 shows a screenshot from the Exercise session interface. The screen is made up of three main elements:

- Classification Sliders

  The sliders shown move from side to side as the user completes each repetition of the Sit-To-Stand exercise. This is further illustrated in figure 12. the point along the slider is a representation of the system's confidence in the current pose of the user. As seen in figure 11, once the slider has gone all the way to one side, the colour of the corresponding position changes to green. To complete one repetition, the user must start from a sitting position, then move the slider across to the standing position until it lights up green, before returning to the sitting position.

  The Crossed to Un-Crossed slider works in the same fashion, however as the user must maintain the arms crossed pose for the duration of the exercise, they do not need to move the slider, but keep the green dot to the left 'Crossed' position for the duration of each repetition.

- Video Feed

  This element shows a live video feed to the user as they perform the exercise. This allows the user to view their own form as they perform the exercise, as well as allowing them to see what the system is seeing to ensure that they are within the frame of the camera.

- Variation Description

  The variation description provides a prompt to the user as to which variation they have chosen during the exercise session.

- Repetition Counter

  The repetition counter allows the user to keep track of the number of exercise repetitions performed in order to track whether they have met their goal.

During the approach section of this report (see section 3), a set of guidelines in designing interfaces for IoT devices for older adults were identified (Barnard *et al.*, 2013). For each of the guidelines identified, we will now see how these were implemented as part of the design for the exercise session screen.

- *Provide simple UI with reduced complexity:* The UI has a simple, clear and understandable structure. In addition, the information are arranged with its importance.

  The UI displays the minimum required information in order for the user to operate it. Previous iterations mapped the key points identified by the system over top of the video feed. However, in this case it was not clear to the user the mechanism the prototype was using in order to classify whether they were sitting or standing. Instead, a simpler slider system was used, which shows clearly the confidence level the system has of whether a user is sitting or standing. As this is the main activity of the exercise, it is placed in the top left of the screen.

  The second most important screen element for the user is the live video feed. In earlier iterations of the prototype, this element was larger and took up the entire bottom right quadrant of the screen. However due to performance issues, the size of this element had to be reduced in order to increase the framerate of the system. This will be discussed in more detail in the limitations section of the report (see section 7).

- *Be consistent with older adults' expectations and intuition:* The UI is designed to be interactive. In addition, consistent mapping between tasks and their responses is maintained throughout the system.

  In order to maintain consistency throughout each exercise variation, the exercise session screen has the same layout for each variation, the only change being in the variation description in the top right. Further, the indicators for sitting and standing, and for the arms being crossed or uncrossed, operate in the exact same way, in order to meet the expectations of the user.

- *Maximise legibility of essential information:* Digital information characteristics (font size, colour contrast)

The font size was kept large throughout all screens of the prototype. This was primarily due to the guidelines established, but also furthered by the need to view the screen from a distance, as users operating the system would be sat at a distance from the screen, and so the display elements are enlarged to accommodate this. Due to the size restrictions of the video feed, however, this element was not as clear as I would have liked when designing the user interface due to its small size when viewed from a distance.

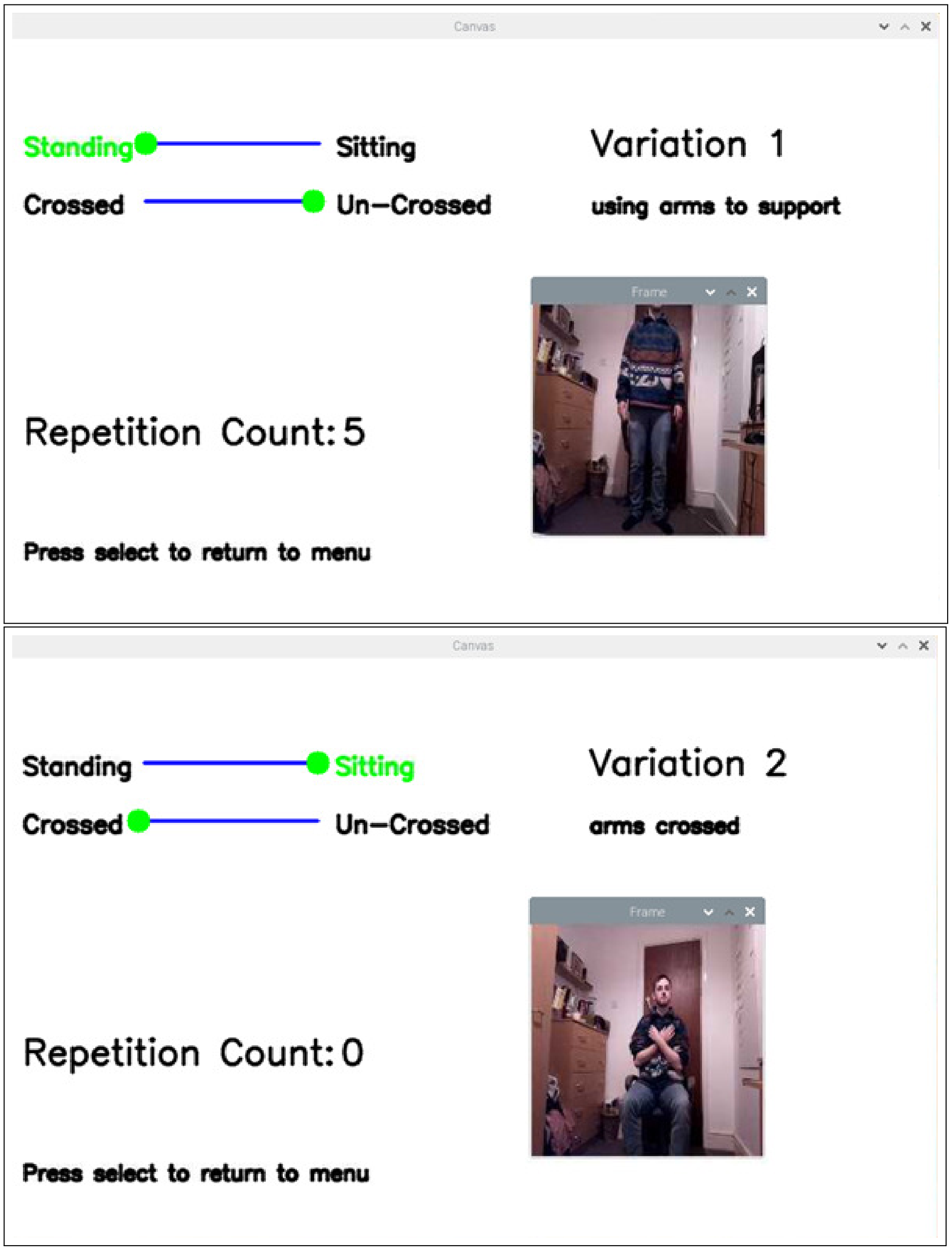

Figure 12: Exercise Session Screenshots Showing Slider Movement

4.11 Pose Estimation

In this subsection, I will detail the approach taken in the design and implementation of the pose estimation portion of the prototype. I will first give an overview of the technologies used in implementing the pose estimation, before sections outlining how these technologies were leveraged to perform the classification of the Sit-To-Stand exercises required for the project.

4.12 Pose Estimation Technology Overview

The program utilises the PoseNet MobileNet model (Papandreou *et al.*, 2018), a pose estimation model implemented through the Tensor Flow Lite platform (Google, 2021). This ML model utilises a convolutional network in order to detect the individual key points in human pose estimation. The model takes an input image and outputs a heat map representing the probability of the location of 18 key points representing key points on a human model. Figure 13 Shows a visual representation of the key points generated. Note, for this project the first 4 keypoints, which represent locations on the face (eyes position etc), were not used and so will be excluded from any key point diagrams throughout this section.

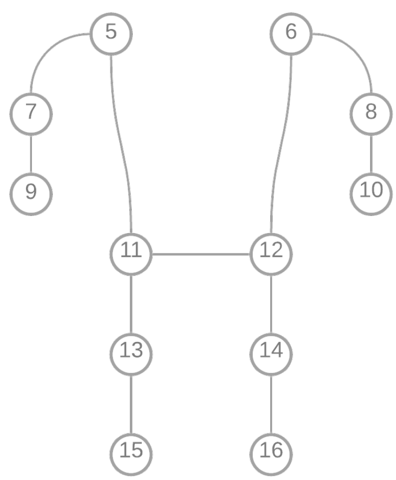

Figure 13: Diagram of PoseNet Key Points

This model was chosen in particular as it is available as a pre-trained model to be run on the TensorFlow lite platform (Google, 2021). This platform is a spin-off of the TensorFlow platform specifically designed for deploying machine learning to mobile and IoT devices. The main benefit of using this platform for the project is in its high performance, in which models are optimised to run without the use of a GPU on low-end hardware, allowing them to perform well on hardware such as the Raspberry Pi used for the prototype.

The program first processes a frame of the video and runs the frame through the PoseNet MobileNet pre-trained pose estimation model. This results in a set of 18 coordinate points on the image, each relating to a point on the human body, as seen in figure 13.

Once these key points are generated from the video frame, we take subsets of the points in order to perform individual analysis of various key elements which determine the position of the exercise (sitting or standing) and the variation (arms crossed or uncrossed).

4.13 Sitting or Standing

In order to determine whether or not the user is sitting or standing, the change in the relation of the shoulder, hip, and knee key points, are analysed. (5,6,11,12,13,14 see figure 13).

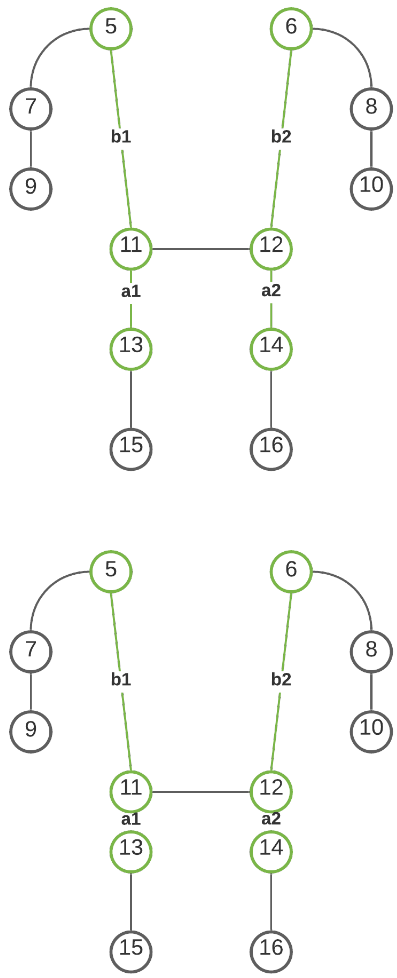

Figure 14: Diagram of Sit-Stand Key Points

By using the height difference between each hip (points 11,12) and shoulder (points 5,6) key points, represented by values b1 and b2, the two distances between these points can be compared to the height difference between the hips (points 11,12) and the knees (points 13,14), represented by the values a1 and a2. By comparing these values to one another it can be determined whether or not a user is likely to be sitting.

```python
def check_Standing(kps):
  sittingAddition = 0

  if kps[11,2] and kps[13,2] and kps[5,2]:
    a1 = abs(int(kps[11,0])-int(kps[13,0]))
    b1 = abs(int(kps[11,0])-int(kps[5,0]))

    if a1 < b1/1.3:
      sittingAddition += 1


  if kps[12,2] and kps[14,2] and kps[6,2]:
    a2 = abs(int(kps[12,0])-int(kps[14,0]))
    b2 = abs(int(kps[12,0])-int(kps[6,0]))

    if a2 < b2/1.3:
      sittingAddition += 1


  if sittingAddition == 0:
    sittingAddition -= 2

  return sittingAddition
```

Figure 15: check_standing Function

Figure 15 Shows the check_Standing function, which implements this check to see whether a user is standing or not. The function takes the set of key points (kps) and outputs an integer 'sittingAddition', which ranges between -2 and 2. sittingAddition represents the change in the confidence value for sitting used by the system to classify whether a user is sitting or standing, where a lower value indicates a sitting position, and a higher value represents a standing position.

A similar confidence value method is used in evaluating both the sit-stand classification, and for the arms crossed or un-crossed classification, and so these will be explained in detail together later in the implementation section.

4.14 Arms Crossed or Uncrossed

In order to determine whether the arms are crossed or not we analyse the position of the elbow (points 7,8) and wrist (points 9,10) key points in relation to the shoulder key points (points 5,6). If the wrists are positioned within the distance between the shoulder key-points and the elbows are below both the wrist and shoulder key points, then the arms are determined as being crossed, as shown in figure 16.

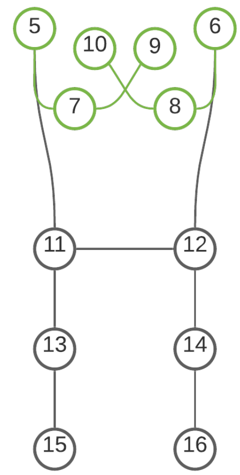

Figure 16: Diagram of Crossed Arms Key Points

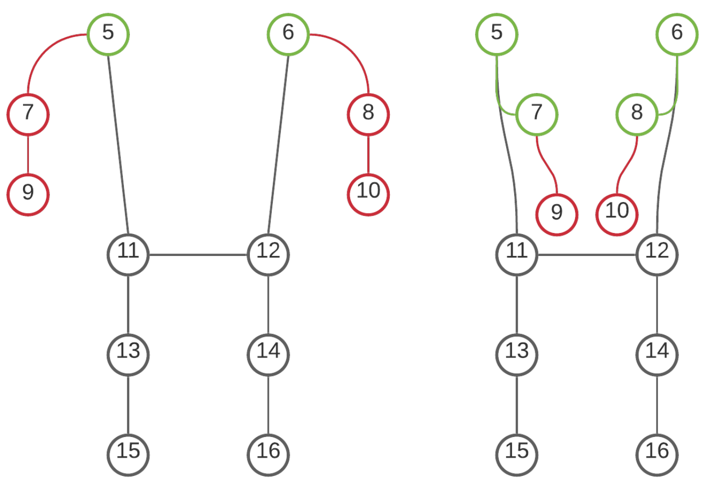

Figure 17: Diagram of Un-Crossed Arms Key Points

This classification will permit both having arms crossed, and also having them tucked into the chest but not crossed. This is the case as during testing it was shown that users would not always place their hands upon each opposite shoulder, but also clasp their hands together and press them to their chests. Both of these techniques have the indented effect of restricting the use of the arms for balance, and so this weaker classification was deemed suitable.

```
1  def check_arms(kps):
2
3  crossedAddition = 0
4  if (kps[6,1] < kps[10,1])
5  and (kps[10,0] < kps[8,0])
6  and (kps[8,0] > kps[6,0]):
7
8      crossedAddition += 1
9  else:
10     crossedAddition -= 1
11 return crossedAddition
```

Figure 18: check_arms Function

Figure 18 shows the implementation of the check_arms function which implements this classification, as seen in the figure, lines 4-6 classify the positions of the relevant key points to one another in order to meet the arrangements shown in figures 16 and 17.

Similar to the check_standing function (see figure 15), this function returns an integer value 'crossedAddition', which is used to modify an overall confidence value used to classify whether the user has their arms crossed or not.

4.15 Pose Confidence Values

Taking input from the check_arms and check_standing functions, the system modifies two confidence values, 'sittingConfidence' and 'crossedConfidence'. Upon meeting the threshold value for each, the user is classified as sitting or with arms crossed. These values are also displayed as the confidence sliders previously shown in the excersise session screenshot (see figure 11). Figure 19 shows the implementation of these classifiers, as they are updated for each frame of the video. On lines 14-15, figure 19 also shows the trigger for a new repetition to be counted. for each frame in which the user meets the sitting threshold, the system will check whether they were standing previously, in addition to checking whether or not their arms have been crossed throughout the duration of the repetition.

```
    sittingAddition = 0
    crossedAddition = 0
    crossedAddition = check_arms(kps)
    sittingAddition = check_Standing(kps)

    sittingConfidence = max(min((sittingConfidence + sittingAddition), sittingThreshold),0)
    crossedConfidence = max(min((crossedConfidence + crossedAddition), crossedThreshold),0)

    if crossedConfidence == crossedThreshold:
      Crossed = True
    if crossedConfidence == 0:
      Crossed = False

    if sittingConfidence == sittingThreshold:
      RepetitionCount += check_repetitionCount(Standing, Crossed, variation)

      Standing = False
      Sitting = True

    if sittingConfidence == 0:
      Sitting = False
      Standing = True
```

Figure 19: Repetition Classification

4.16 Pose Estimation Implementation Limitations

In order to ensure that the analysis is effective no matter where the user is seen within the frame of the video, the analysis takes into account only the relations between key points, thus eliminating any issues of scale. For example in determining whether the user is sitting or standing, an early approach was to calculate the distance of the participant's head from the top of the frame. However when testing this was found to be problematic, as the analysis would only work effectively if the user was in an optimal position, with their entire body in the frame, and if the user were to move too close to the frame such that either their head or feet key-points were put of view, the program would fail to recognise their position correctly.

Therefore in the final approach used, analysis is done via the relation of key points and not via any absolute distances in relation to the user's position in the frame. This approached worked much better as it does not rely on the user's position in the frame or distance from the prototype, so long as the pose recognition is still able to detect the key points. By abstracting away from the video itself and working with only co-ordinate points the calculations required to analyse each frame were also simplified which helped to improve the frame rate of the video feedback displayed to the user.

5 Results

5.1 Study Methodology

In order to evaluate the prototype, a usability study was conducted. This study followed the System Usability Scale framework (Brooke, 1995), which is used to measure the usability of a system through a 10 question questionnaire. In addition to filling in the questionnaire, participants provided feedback in a post-study interview, in which participants discussed their answers to the questionnaire and provided additional feedback. Further detail and justification of the Software Usability Scale will be given in the following section covering analysis methodology, with this section detailing how the study itself was conducted.

Five participants were recruited for the study. Due to national lockdown restrictions in place at the time of recruitment, participant recruitment was limited to members of my own household. This was due to the nature of the study requiring participants to interact with the physical prototype, preventing the study from being conducted remotely. This limitation and its impacts on the study are discussed further in section 7.

All participants recruited were current undergraduate students at the time of the study. Table 3 shows the background of each participant. Two of the participants, 3 and 5, had some background in software engineering and so were familiar with using prototypes such as this one. However, having participants from a range of backgrounds meant that the study was able to cover a range of experience levels with similar technologies.

Participant	Area of Study	Gender
1	Sociology	Female
2	Economics	Male
3	Computer Science	Male
4	Economics	Male
5	Engineering	Male

Table 3: Table Showing Study Participant Backgrounds

1. To begin the study, participants were given a 5-minute explanation of the prototype including a demo of how to perform a sit to stand exercise. Participants were informed that the system they were using was a low-fidelity prototype, and were asked to ignore the cardboard housing when considering their feedback as it was not representative of what a complete product would look like (Stickdorn *et al.*, 2018).

2. Once familiarised with the system, participants tested the prototype, selecting an exercise variation of their choosing, and performing ten repetitions of the Sit-To-Stand exercise.

3. Once their testing was complete, participants filled in the ten question Software Usability Scale questionnaire (see appendix section 11.4).

4. Once they had filled in the questionnaire, participants took part in a post-study interview, in which they were asked to discuss their answer to each of their answers to the questionnaire, as well as providing any additional feedback on the prototype.

Once the study was completed, the results were analysed following the methodology detailed in the following section.

5.2 Analysis Methodology

The analysis of the results of the study are split into two sections.

The first is a quantitative analysis of the questionnaire answers (1-5, from strongly agree to strongly disagree), following the system usability scale framework Brooke (1995), in which a score from 0-100 is generated based on a function of all the answers given by a participant.

The second analysis method utilises a framework analysis approach (Parkinson *et al.*, 2016), in which key themes from the background research and prototype requirements are used to develop a code in which to classify participant feedback. The feedback is then grouped along with these headings in order to accommodate comparisons of feedback across these predefined themes.

5.3 System Usability Scale

As described in the previous overview, the questions presented to participants followed the System Usability Scale framework (Brooke, 1995). This framework aims to measure the usability of a system and is appropriate for this study as it is shown to be reliable even with smaller sample sizes than other questionnaires, and measures both learnability and usability. Measuring usability is important as the intended audience for the prototype, older adults, value greater usability in software more than the average population (Barnard *et al.*, 2013).

The System Usability Scale consists of 10 questions in which the participant gives an answer on a scale of 1 to 5. A full list of the questions can be found in the appendix (see section 11.4). Once collected the answers to each questionnaire are converted into a single usability score, and the usability scores of all participants averaged out in order to give an overall score for the system.

Once the usability score for the system is calculated, We can plot our score on a 7-point adjective scale, in order to convert the score from a number into a descriptor of the usability of the system (Bangor *et al.*, 2009).

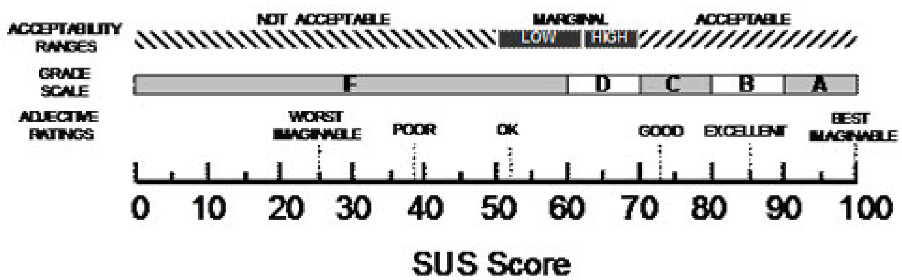

Figure 20: Adjective Rankings of SUS Scores (Bangor *et al.*, 2009)

5.4 Framework Analysis

The data gathered in the form of transcripts from the post questionnaire interview are analysed following a Framework Analysis approach (Parkinson *et al.*, 2016). This approach tackles the analysis of the qualitative interview results through the process of identifying a priori themes from the background research and requirements of the project, then identifying these themes within the transcript results. This allows for a predefined and structured approach in analysing these results in a way that aligns closely with the aims of the project. The framework analysis is split into three parts:

- ### 5.5 Identifying a framework

  Identifying headings to group data around. These are based broadly on the aims defined for the project, with some being taken from blockers identified as part of the background research, and others based on the requirement specification for the prototype.

- ### 5.6 Indexing

  The interview transcript data is indexed, with relevant excerpts from the interviews being labelled to the relevant framework heading

- ### 5.7 Charting

  Once each interview is indexed, transcript excerpts are grouped together by theme in order to allow comparison on each heading in order to identify general themes.

The below sections outline the results of the System Usability Scale questionnaire and Framework Analysis of the post-study interview. There were 5 total participants, all of whom took part in all parts of the study; use of the prototype, filling in a SUS questionnaire, and participating in a post-study interview.

5.8 System Usability Scale Results

Table 4 shows a breakdown of the usability scores for each question in the questionnaire. The lowest average score was for question 1 with an average score of 2.2, while the highest average score given was for question 7, which had an average score of 4.

Question	P1	P2	P3	P4	P5	Average
1	2	1	3	3	2	2.2
2	2	4	4	4	3	3.4
3	3	3	3	4	3	3.2
4	1	2	4	3	1	2.2
5	3	4	4	4	3	3.6
6	3	3	3	4	3	3.2
7	4	4	4	4	4	4
8	4	3	1	3	4	3
9	4	4	4	3	3	3.6
10	3	4	4	4	4	3.8

Table 4: Table Showing average usability scores per question

Table 5 shows the SUS score from 0-100 of each participant and an average of all scores given in order to identify an overall usability score for the system, which was found to be 80.5. By comparing this to the adjective ranking table presented in figure 20, we can see that this score falls into the 'Good' category, with a grade scale ranking of B, and well into the acceptable range.

Participant	SUS Score
1	72.5
2	80
3	85
4	90
5	75
Average	80.5

Table 5: Table Showing SUS Totals Per User

5.9 Participant Interview Findings

The key themes of the study, seen below, were drawn from the main sections of the specification for the project, which were in turn based on key themes identified as part of the background research. These themes cover all elements of the prototype that participants interacted with as part of the study, with the addition of feature suggestions, which will be discussed further in the 'Future Work' section of this report.

- Usability of Hardware
- Pose Recognition Performance
- Usability of User Interface
- Feature Suggestions

After identifying the key themes in evaluating the usability and feasibility of the project, The participant interviews were analysed following the framework analysis method previously described. The below quotes detail feedback received on each topic during the course of the interviews.

Repeated words from the interview transcripts have been removed from participant quotes for clarity.

5.10 Usability of Hardware

Participants gave positive feedback on the use of the joystick in navigating the menus of the system. This was the main piece of hardware the participants interacted with when using the prototype.

> *"It was really easy, just left-right to select ... it was really easy to choose which variation I wanted to do"* - Participant 2

> *"Once you get a hang of it once you see it it's just really simple and straightforward. I feel like anyone could get used to it because I'm not very technical and I just picked up almost straight away."* - Participant 1

Participant 2 also gave positive feedback to the on-screen prompt which explained how to use the joystick to exit the exercise and return to the menu.

> *"The joystick was intuitive and explains how to exit the activity yeah so happy with that"* - Participant 2

However, participant 3 struggled somewhat in pressing down the joystick, as it was not clear to them that you are able to use the joystick as a button, and suggested having a separate button on the device to confirm the selected items. Participant 4 suggested adding a prompt on the device to explain the usage of the joystick more clearly.

> *"Maybe a thing saying press down on the joystick for you, maybe if there's something there."* - Participant 4

> *"We talked about with, instead of pressing the joystick down, having a separate button."* - Participant 3

5.11 Pose Recognition Performance

The pose recognition performed well generally for all participants, with the majority of repetitions being recognised. Participants found that they had to adjust their position slightly when pose recognition was lost in order for it to re-register.

> *"I think it was just once or twice of the 10 standing times, but it was easy to fix so I think it was consistent, I just had to wiggle about a bit sometimes."* - Participant 2

> *"just when I sat down sometimes the thing wouldn't detect that I sat down so that was all really, it was just that and that's only inconsistency really and yeah, that's the only thing I could fault it for though."* - Participant 1

Not all participants chose a variation of the exercises which required arms to be crossed, however, those that did found that when arms were crossed, recognition of sitting and standing was affected slightly. When disturbed the camera would also wobble slightly, which would affect the focus of the video feed and led to pose recognition being lost.

> *"The camera quality which might affect the wobbliness in the registering thing, yeah particularly the arm crossing wasn't it, but yeah but apart from that good."* - Participant 5

5.12 Usability of User Interface

Participants found the layout and colour scheme of the user interface clear, as well as positive feedback on the progress bars for tracking what the system was detecting.

> *"I like the progress bars you had and the colours were good as well yeah"* - Participant 4

> *"I have no computer science background at all and you explained it in 10-15 seconds and I knew what I was doing"* - Participant 4

However, some participants found the low frame rate of the video feed and user interface to be detrimental. They also mentioned the low resolution of the video feed as being difficult to see.

> *"The image and sliders are choppy and the resolution of the model is small yeah so would you be fine if it was a big image and some of just bits smoother yeah 100%"* - Participant 2

5.13 Feature Suggestions

Two participants mentioned that they would want further instructions as part of the system before being able to use it. As part of the study, participants were given a short demo of the user of the prototype before they used it themselves, however, they felt that a user manual or video clip would have been helpful for them in using the system.

> *"Yeah, it's stuff that like a quick sort of instruction manual probably yeah cover anyway."* - Participant 5

> *"I needed someone to explain to me the first time or if there was perhaps an audio clip or a video even images might be fine."* - Participant 1

In addition, one participant who found the use of the joystick unclear suggested using a separate button for selecting menu items.

> *"We talked about with, instead of pressing the joystick down, having a separate button."* - Participant 3

Overall the results showed that the participants found the prototype clear and easy use, giving positive oral feedback and good usability scores via questionnaire feedback. Negative feedback came mostly around inconsistency in pose recognition, and in low frame rates of the user interface. each of these points will be discussed in more depth in the next section.

6 Evaluation

In light of the results gained from the study, we can now evaluate the main aims of the project. In the previous approach section of the report (see section 3), three main themes were identified which were then taken to create a specification for the prototype (see appendix section 11.1). Along these same themes, we can now identify how these were met and areas where they were not. Limitations will be addressed in greater detail in the limitations section (see section 7), however, these will first be identified as part of the evaluation.

6.1 Hardware Evaluation

Of the 3 requirements attributed to hardware, 2 two were met fully and 1 was met partially. The most important requirement here as in developing a system that was of lower cost than those identified in the background section (see section 2.3). Fixed income was identified as one of the main barriers to exercise in older adults (Nied RJ, 2002), and so a cost reduction of over 1/3 means that that the prototype is able to address this concern, and improve over previous solutions.

The requirement for the prototype to be fully self-contained was attempted during implementation through the use of the LCD screen attached to the Adafruit Braincraft HAT (see figure 4.4), however, it became clear early on during the development of the prototype that this screen was much too small to be seen clearly at the distance required for a user to be in the frame of the camera. Therefore instead the Raspberry Pi was plugged into an external monitor to use as a display for the prototype. This requirement has been classified as partially met, however, as the remaining elements of the prototype are all self-contained within the unit.

Functional Requirement	**Requirement Met?**	**Description**
6. UI controls must be near the IoT device	Yes	5-way joystick used is attached to prototype
Non-Functional Requirement	**Requirement Met?**	**Description**
1. The overall cost of components for the prototype must be less than £355.00	Yes	Total cost of prototype components £109. Raspberry Pi 4b: £54, Adafruit Braincraft HAT: £35, Camera Module v2: £20
2. All prototype components must be part of a single integrated system, with no separation between sensor, UI and processing unit.	Partial	While the camera sensor, processing unit, and I/O are all part of a single unit (see figure 7), the UI was displayed via a connected monitor.

Table 6: Table Showing Hardware Requirements Evaluation

6.2 Pose Recognition Evaluation

Feature implementation of the pose recognition was completed, with all positions being able to be classified by the system. However, during the user study, nearly all participants encountered at least one instance in which their position was not registered correctly. While this did not impact the majority of exercise repetitions, it was picked up upon by all participants in the study. There did not appear to be any consistency in which position was not able to be classified; for participant 5 it was in the detection of arm crossing, for participant 1 it was in sitting recognition and in participant 2 is was in recognising the standing position. Due to time limitations no further testing has been done in order to identify the root cause of this, it may be due to the resolution of the camera used in the prototype, or in the quality of the pose recognition model used. These are good topics for further investigation and will be expanded on further in the future work section of the report (see section 8).

Functional Requirement	Requirement Met?	Description
1. The prototype must be able to detect the following body positions:	Partial	
1. a) Sitting Position	Yes	
1. b) Standing Position	Yes	
1. c) Arms Crossed	Yes	
1. d) Arms to the sides	No	Functionality not required, as in the case of the variation not requiring arms to be crossed, the user may place their arms wherever they choose in order to balance.
Non-Functional Requirement	**Requirement Met?**	**Description**
2. The prototype must recognise correctly whether the user is sitting or standing for 90% of exercise repetitions	No	As part of feedback, multiple users noted that once or twice the system failed to recognise their position. As users performed 10 repetitions each, more that once instance per user means that this target has not been met. *"I think it was just once or twice of the 10 standing times, but it was easy to fix so I think it was consistent, I just had to wiggle about a bit sometimes."* - Participant 2

Table 7: Table Showing Pose Recognition Requirements Evaluation

6.3 User Experience Evaluation

During the approach section of this report, a set of usability guidelines (Barnard *et al.*, 2013) were discussed and applied to the user experience design of the system (see section 3). These guidelines were then taken into account in the implementation of the user interface as shown in 11. From feedback gained from the SUS questionnaire, the implementation of these features was successful, and received positive feedback from all participants, with an overall usability score of 80.5, which is classified halfway between 'good' and 'excellent' on the adjective ranking of SUS scores (Bangor *et al.*, 2009). However, due to restrictions in recruiting participants during national lockdown due to the COVID-19 pandemic, I was only able to recruit participants from my own household, which did not include and participants that fit into the target audience of older adults. As the guidelines used in developing an interface specifically for older adults did not then apply, it is not possible to say whether these we beneficial specifically for this audience. This limitation in the scope of the study will be discussed in greater detail as part of the limitation section (see section 7).

Functional Requirement	**Requirement Met?**	**Description**
2. The prototype record each of sit-to-stand exercise performed	Yes	Repetition counter implemented (see figure 11)
3. The prototype record which variation of the sit-to-stand exercise is being performed	Partial	Repetition counter only displays the count, however variation number and description is shown in top right of UI (see figure 11)
4. The prototype must display in real-time the following evaluation criteria: 4. a) Position of user; either sitting or standing 4. b) Position of arms; either crossed or uncrossed	Yes Yes Yes	Progress sliders are displayed to the user in top left of UI (see figure 11)
5. The prototype must allow the user to select which variation of the sit-to-stand exercise to perform	Yes	User is able to select which exercise to perform in menu before exercise launch (see figure 10)
Non-Functional Requirement	**Requirement Met?**	**Description**
4. The prototype should be fully understandable after a tutorial of no more than 5 minutes	Yes	Participants gave positive feedback that the prototype was easy to use *"I have no computer science background at all and you explained it in 10-15 seconds and I knew what I was doing"* - Participant 4

5. The prototype must usable without any technical support	Partial	Participants gave a mixed response to the question 'I think that I would need the support of a technical person to be able to use the prototype.', mentioning the need for explanation being required before using the prototype. *"I needed someone to explain to me the first time or if there was perhaps an audio clip or a video even images might be fine."* - Participant 1
6. The prototype must have a consistent visual style	Yes	All participants strongly disagreed with question 7 'I thought there was too much inconsistency in the prototype.' *"I like the progress bars you had and the colours were good as well yeah"* - Participant 4

Table 8: Table Showing User Interface Requirements Evaluation

6.4 Conclusion

Overall 16 of 18 requirements established for the system were met, and the results of the usability study conducted were very positive with a score of 80.5 out of 100. The two main barriers to exercise in older adults that the project aimed to address, identified at the start of this report in section 2.3, were to develop a low-cost system to address the barrier of fixed income and to reduce the size of the system in order to accommodate the incorporation of the system into the daily routine to promote habit building. These two issues have been addressed by the prototype, however with some effect on the ability of the system to perform as well as it could using a more powerful sensor such as the Microsoft Kinect, as there were some irregularities in the pose estimation functionality identified during the study.

7 Limitations

There were a number of limitations encountered during the design, implementation and testing of the project.

- Delays in Acquiring Hardware

  In the initial plan for the project, there were two cycles of development and user testing. However, the delivery of the Adafruit BrainCraft HAT took two weeks which delayed the development of the prototype initially. This meant that there was no time to perform the first user study as development had not progressed far enough. While delays were to be expected, this did mean that some features suggested by participants, such as the addition of a user manual and the addition of separate buttons for selecting menu items, could not be implemented due to these time constraints.

- Video Stream Performance

  A major limitation found during the development of the user interface for the prototype was with the rendering of the live video stream. At higher resolutions, the frame rate of the video would be so low that the prototype was unusable, and so the size and resolution of the video had to be reduced considerably. Even after the resolution was lowered, the prototype's performance was sluggish, and this was picked up upon by participants during the study. This issue was further exasperated, as a lot of development time was wasting investigating the route cause of the slowness, which was assumed to be not in the video, but in the speed of the pose estimation processing. This meant that time was lost that could have been put towards improving other features.

- Low Fidelity Prototype

  Due to time and cost restrictions in building the prototype, a cardboard prototype approach was taken in which the enclosure for the prototype was built from cardboard and held together with packaging tape. While participants during the study were informed of this limitation as part of the study, a more user-friendly enclosure for the hardware would have likely improved usability and been more representative of a complete product.

- Limited User Study Participant Pool

  Due to the nature of participants needing to interact with a physical prototype, under lockdown restrictions throughout the duration of the project user testing was restricted to members of my own household. This reduced the number of potential participants, but more importantly, it meant that the target audience of older adults could not be recruited to partake. This meant that the user study was not truly representative of the feedback that could have been received if this was possible.

8 Future Work

This section will provide suggestion on future work that might be carried out to improve the existing system, or to apply findings gained from the project to different areas.

- Expanded User Testing

  One of the limitations identified for this project was the restricted user testing performed. Future projects could expand upon the work done by testing with a greater number of users, and by testing with users who are members of the system's intended audience.

- Expand Exercise Pool

  This project aimed only to evaluate one type of strength exercise. However, the same approach could be applied to a wide variety of such exercises to provide a much richer experience.

- Improved User Feedback

  For this project, a 5-way joystick was used to allow the user to interact with the system. However, the BrainCraft Hat used has support for speakers and a microphone. Therefore future work could look at implementing this way of interacting with the prototype. Additional verbal feedback could also be provided to users as encouragement.

- Pose Estimation Based Interaction.

  Previous solutions looked at allowed the user to navigate the menus of their systems via the same pose estimation technology used in evaluating the exercises. future projects could implement this in a similar fashion.

- Key Point/Pose Codification.

  For this project, the arrangement of key points which classified a certain position such as having your arms crossed were manually coded into the system. One avenue of future work could be in developing a standardised way of encoding different postures that would be easy to implement by non-technical people. This would allow the number of exercises recognised to be expanded upon more easily.

9 Conclusions

The aim of this project was to develop a low-cost IoT Prototype to evaluate sit-to-stand exercises for older adults. I believe this aim was met, with an overall usability score of 80.5 and 16 of 18 requirements met, the main goals of the project were successful. Users are able to perform the three variations of the exercise, and the prototype is able to recognise these activities and record them. This functionality has been implemented in a system that is both much smaller in size and lower in cost than previous solutions.

There is still much room for improvement, however. There were limitations to the performance of the prototype, and an improvement in the frame rate would have improved the overall experience greatly. The scope of the project was also limited. While the prototype provides good proof of concept, a lot more work would need to be put into polishing the performance of the pose recognition to prevent irregularities, and a greater number of exercises would need to be implemented before the prototype would be useful on a daily basis, as while this project focused on implementing only the sit-to-stand exercise, a larger range would be needed in order to build a complete exercise regime.

10 Reflection on Learning

Throughout the process of conducting this project, I have expanded my learning in a variety of areas not previously explored as part of my studies so far at university.

Previous to tackling this project, the largest project I had undertaken was in developing a chatbot as part of the group project module in my second year at university. This was a large piece of work, however, due to the group working nature of the project, there were many areas in which I did not take an active part in. Conducting this project lead to a greater understanding of planning and carrying out a large piece of work in which I had to cover all areas myself. This lead to the need to develop a much more thorough work plan, with many more variables which could be delayed or present issues. While in hindsight I can see that the initial plan of conducting two cycles of development and user testing was two ambitious under the time constraints, I am happy that I had considered this originally and proposed an alternate plan, which I was then mostly able to follow, conducting only one user study at the end of development of the prototype.

The development of the prototype allowed me to both combine existing knowledge of developing on Raspberry Pis with new technologies I had not previously encountered depth such as in development of computer vision techniques. When I first set out on development it was not clear to me whether I would be able to succeed in integrating both the hardware and the software elements as this had proved challenging when developing projects on the Raspberry Pi in the past. However the wide variety of libraries available that I utilised in the project has given me a much better understanding of how these two elements integrate with IoT systems and has given me a good grounding for further development of IoT system in the future.

Conducting proper user testing was also something that I had not done previous to this project. This was something that I found very rewarding as it gave concrete results in order to evaluate the project and I found it to be very satisfying to see others use a system I had designed and created. This has given me a greater appreciation for the importance of user testing and shown how many things you might miss that others can pick up on and provide insightful feedback about.

In addition to the large scale of the development and testing, writing the report itself was also a challenge as I had not previously written such a large report and so to manage the amount of writing my supervisor suggested use of the Overleaf platform and use Latex in order to ensure I was able to properly manage formatting and referencing. This has been one of the highlights of conducting the project as after the initial learning curve it has allowed me to manage all elements of the report much easier than would have been possible using Microsoft Word. Now that I am able to utilise this technology any future reports will be much easy to manage and so this will be something I am able to apply to any future projects undertaken.

11 Appendices

11.1 System Requirements

11.2 Functional Requirements

1. The prototype must be able to detect the following body positions:
   (a) Sitting Position
   (b) Standing Position
   (c) Arms Crossed
   (d) Arms to the sides
2. The prototype must record each sit-to-stand exercise performed
3. The prototype must record which variation of the sit-to-stand exercise is being performed
4. The prototype must display in real-time the following evaluation criteria:
   (a) Position of the user; either sitting or standing
   (b) Position of arms; either crossed or uncrossed
5. The prototype must allow the user to select which variation of the sit-to-stand exercise to perform
6. UI controls must be near the IoT device

11.3 Non-Functional Requirements

1. The overall cost of components for the prototype must be less than £355.00
2. All prototype components must be part of a single integrated system, with no separation between sensor, UI and processing unit.
3. The prototype must recognise correctly whether the user is sitting or standing for 90% of exercise repetitions
4. The prototype should be fully understandable after a tutorial of no more than 5 minutes
5. The prototype must usable without any technical support
6. The prototype must have a consistent visual style

11.4 System Usability Scale Questionnaire

1. I think that I would like to use the prototype frequently.
2. I found the prototype unnecessarily complex
3. Please explain the reason(s) why you have chosen to select this option
4. I thought the prototype was easy to use.
5. I think that I would need the support of a technical person to be able to use the prototype.
6. I found the various functions in the prototype were well integrated.
7. I thought there was too much inconsistency in the prototype.
8. I would imagine that most people would learn to use the prototype very quickly.
9. I found the prototype very cumbersome (awkward) to use.
10. I felt very confident using the prototype.
11. I needed to learn a lot of things before I could get going with the prototype.
12. Do you have any further feedback or suggestions for improvement after your time using the prototype? If so please write them below:

References

Adafruit. 2021. *Adafruit braincraft hat*, [Online]. Available at: https://www.adafruit.com/product/4374.

Altexsoft. 2018. *Functional and nonfunctional requirements: Specification and types*, [Online]. Available at: https://www.altexsoft.com/blog/business/functional-and-non-functional-requirements-specification-and-types/.

Bangor, A., Kortum, P. and Miller, J. 2009. Determining what individual sus scores mean: Adding an adjective rating scale. *Journal Of Usability Studies* 4, pp. 114–123.

Barnard, Y., Bradley, M. D., Hodgson, F. and Lloyd, A. D. 2013. Learning to use new technologies by older adults: Perceived difficulties, experimentation behaviour and usability. *Computers in Human Behavior* 29(4), pp. 1715–1724. Available at: https://www.sciencedirect.com/science/article/pii/S0747563213000721.

Brooke, J. 1995. Sus: A quick and dirty usability scale. *Usability Eval. Ind.* 189.

Chaovalit, S., Taylor, N. F. and Dodd, K. J. 2020. Sit-to-stand exercise programs improve sit-to-stand performance in people with physical impairments due to health conditions: a systematic review and meta-analysis. *Disability and Rehabilitation* 42(9), pp. 1202–1211. Available at: https://doi.org/10.1080/09638288.2018.1524518. PMID: 30668164.

Chen, Y., Tian, Y. and He, M. 2020. Monocular human pose estimation: A survey of deep learning-based methods. *CoRR* abs/2006.01423. Available at: https://arxiv.org/abs/2006.01423.

Fujita, E., Taaffe, D. R., Yoshitake, Y. and Kanehisa, H. 2019. Repeated sit-to-stand exercise enhances muscle strength and reduces lower body muscular demands in physically frail elders. *Experimental Gerontology* 116, pp. 86–92. Available at: https://www.sciencedirect.com/science/article/pii/S0531556518307058.

Ganesan, S. and Anthony, L. 2012. Using the kinect to encourage older adults to exercise: A prototype. In: *CHI '12 Extended Abstracts on Human Factors in Computing Systems*. New York, NY, USA: Association for Computing Machinery, p. 2297–2302, Available at: https://doi.org/10.1145/2212776.2223792.

Google. 2021. *Deploy machine learning models on mobile and iot devices*, [Online]. Available at: https://www.tensorflow.org/lite.

Lotfi, A., Langensiepen, C. and Yahaya, S. W. 2018. Socially assistive robotics: Robot exercise trainer for older adults. *Technologies* 6(1). Available at: https://www.mdpi.com/2227-7080/6/1/32.

Microsoft. 2021. *Azure kinect dk*, [Online]. Available at: https://www.microsoft.com/en-gb/p/azure-kinect-dk/8pp5vxmd9nhq.

Nied RJ, F. B. 2002. Promoting and prescribing exercise for the elderly. *American family physician* .

Papandreou, G., Zhu, T., Chen, L.-C., Gidaris, S., Tompson, J. and Murphy, K. 2018. *Personlab: Person pose estimation and instance segmentation with a bottom-up, part-based, geometric embedding model*, [Online].

Parkinson, S., Eatough, V., Holmes, J., Stapley, E. and Midgley, N. 2016. Framework analysis: a worked example of a study exploring young people's experiences of depression. *Qualitative Research in Psychology* 13(2), pp. 109–129. Available at: https://doi.org/10.1080/14780887.2015.1119228.

RaspberryPiFoundation. 2021a. *Camera module*, [Online]. Available at: https://www.raspberrypi.org/documentation/hardware/camera/.

RaspberryPiFoundation. 2021b. *Raspberry pi 4b*, [Online]. Available at: https://www.raspberrypi.org/products/raspberry-pi-4-model-b/.

Shrift, D. 2018. *The best way to improve senior mobility: the sit to stand exercise*, [Online]. Available at: https://dailycaring.com/the-best-way-to-improve-senior-mobility-the-sit-to-stand-exercise/.

Stickdorn, M., Hormess, M. E., Lawrence, A. and Schneider, J. 2018. *This Is Service Design Doing*, O'Reilly Media, Incorporated, chap. 7. https://www.thisisservicedesigndoing.com/methods/cardboard-prototyping.