Tidy Up My Room, Robot!
An Investigation into Human-Robot Teamwork with a Living Room Setting

ENG4702: Final Year Project - Final Report

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Executive Summary

The aim of this report is to explore the interaction between humans and robots while collaboratively are tasked to tidy up a living environment. The human choice of how tasks are negotiated and distributed will be analyzed after observing the robots capabilities. In order to test this behaviour, a framework was programmed to allow a mobile manipulator, Fetch, the functionalities to communicate, navigate, detect and manipulate to tidy objects in a living room environment.

In order to test the negotiation and distribution of tasks, a framework for two way speech based communication was programmed. This allows participants to interact using speech with Fetch to assign which coloured blocks the participant and robot would collect. As this project is the second instalment of "An Investigation into Human-Robot Teamwork with a Living Room Setting", previous FYP student, Jake Santini's code was as a reference point for navigation, detection and manipulation with optimization of these functions done to accommodate for the changes in the scope task allocation.

This report details the proposal of a user study that uses programmed behaviour to supplement the investigation of human - robot interaction and the approach it took to program the platform that allows Fetch to tidy up in a living room setting.

Acknowledgement of Country

I first wish to acknowledge the people of the Kulin Nations, on whose land Monash University operates on. I would like to further acknowledge and pay respects to the Traditional Owners of the land wherever you may be viewing this from. I pay my respects to their Elders, past, present and emerging. Sovereignty has never been ceded. It always was and always will be, Aboringal Land.

Contents

1 Introduction

In 2020, the global cleaning service industry market was valued at $55 million and is projected to grow to an industry worth of $111 million by 2030 [1] . And thanks to advancement in technology, society has seen a big push for advancement in appliances that are used for domestic household chores such as the Roomba, an autonomous vacuum cleaner and Automower, an autonomous grass mower.

Development in these technologies not only benefits the economy but also consumers on an individual level. Oftentimes, cleaning can be inaccessible and hard to maintain for the eldery and those living with disability. With a need for services and technology able to perform higher level tasks and the spread of robots from an industrial setting into more domesticated and health care settings, trust (in robots) plays an important factor in human interactions and therefore could help increase the robot's acceptance in its role as a collaborative partner[2]".

Companies such as Preferred Networks [3] and service robotic challenges hosted by the World Robot Summit [4] push the boundaries of service robots by programming humanoid mobile manipulators to perform more advanced tasks such as tidying up a living room setting by detecting and placing objects away (Figure 1). These service robots are designed to work alongside humans so the human robot interaction is observed in these settings.

Figure 1. Preferred Networks' mobile manipulator autonomous tidying-up robot system a) picking & placing objects b) able to comprehend voice and finger-point commands

In this project, the human robot interaction of how humans delegate tidying up task loads to a robot is explored. This aims to show insight into the much larger focus of how the trust in robots has an influence on integration into society *[5].* This will be achieved by programming a Fetch robot that is able to navigate through a stage living room environment, detect objects, manipulate its end effector to grip and place objects in its correct storage location while simultaneously being safe and helpful to the person.

Work has been started by Jake Santini, who has worked on programming functions that will possibly act as the base code in this project. He has programmed functions that allow Fetch to navigate to tables in a stage living room, detect 50x50mm wooden cubes with ArUco markers, path planning Fetch's end effector to grip and pick up wooden cubes and deposit them into correct containers.

The aim of this project is to have a robust navigation and manipulation base taking inspiration from Jake's work or other resources that allows for collaborative tidying up between robot and user. This presents the opportunity for this project to expand the investigation on how humans delegate tasks to robots that require human robot interaction and collaboration to complete the task. Thus, this project will be focusing on functions that allow for task delegation such as two-way speech-based communication and the ability for humans to delegate tidying up tasks to the robot using speech.

This document details requirements and proposes approaches to these requirements and also sets a timeline which will be used to see this feature come into fruition.

2 Aims and Objectives

○ 2.1 Problem Opportunity Statement

■ 2.1.1 Current State

Currently there is no standardised framework to evaluate the collaboration of humans and service robots when they are tasked to share a common goal. Many works on service robots primarily focus on having the robots act autonomously without any collaboration or user collaboration in task distribution.

Previous work done on this project, by Jake Santini, created the framework of a pick and place mobile manipulator robot in a living room setting. Human-robot interaction is mediated through a touch screen GUI which is unrealistic when compared to human-human interaction.

■ 2.1.2 Impact

As a result, without a proper framework for human-robot collaboration existing service robots when unable to perform desired tasks will rely on humans taking over. Robots that are not able to collaborate with humans face the consequence of not being able to dynamically change tasks and thus may be deemed useless which is not ideal especially when helping out in domestic environments.

■ 2.1.3 Desired State

A two-way speech based communication system is implemented to enhance the interaction between human and robot. The human would feel more comfortable interacting with the robot and would put more trust in it to perform more complex tasks when asked to negotiate and distribute tasks.

By creating an open source framework that explores the interactions between humans and robots in task distribution, this should create a platform to test and better understand these interactions and thus contribute to the greater pool of research on how robots will be deployed and integrated more into society.

○ 2.2 Aims

To explore the interaction between humans and a domestic service robot while collaboratively tidying up a living room environment. The human choice of how tasks are negotiated and distributed to the robot after observing the robots full capabilities will also be analysed.

○ 2.3 Objectives

This project is split up into two sections which will have sub-objectives that fall underneath them:

1) Program a Fetch Robot to navigate a staged living room environment to assist a person to tidy up and have it safely work with humans.
    a) Create and optimize base code that allows Fetch to robustly navigate and manipulate objects in a living room in order to collaborate in tidying-up tasks with humans, using previous project works and other available resources.

   b) Increase the complexity of two-way user interaction from base code by using speech-based communication to share task-related information and progress.
   c) Program functionality that allows humans to delegate and negotiate variable task load to Fetch.
2) Explore the human-robot team performance by running a user study with participants working with the robot on tidying up measuring performance metrics such as mission success, level of errors, time taken to complete task and team cohesion.
   a) Examine the pattern in complexity of task load that participants initially delegate to Fetch after being able to observe Fetch's capabilities.
   b) Explore the reasons why participants change Fetch's task allocation during study.

3 State of the Field

3.1 Domestic robots

Service robots in a domestic environment 'often simplify and automate tedious tasks that need to be performed by humans' (e.g. vacuum cleaning, grass mowing and window cleaning).[6]

3.1.1 Single Function Autonomous Service Robots

The most notable domestic robots in the market today are vacuum cleaner robots, where the global market is estimated to be US $3.5B in 2021[7]. The popularisation of the Roomba produced by iRobot was pivotal in the development of other service robots that would conduct other household cleaning tasks. However with the shift in robots being able to perform higher level tasks in a domestic environment, robots need to have the ability to collaborate and work safely alongside humans.

3.1.2 Existing Tidying Up Robots Works

For those living with disability, especially those with limited mobility, a social assistive robot could be helpful for everyday maintenance of the household. Daily assistive robots in the application of tidying and cleaning rooms need the ability to recognise and localise itself in their environment, recognize different household items, generate motion of the arm, and navigate across the room [8].

Works from Jouhou System Kougaku (JSK) Laboratory, looks at the life-sized humanoid robot HPR2 performing kitchen helping behaviours. It consists of high level reasoning modules including '3D visual processor, force manipulation controller and walking controller'[9]. The JSK project, and many others[10][11],have a primary focus on the autonomous manipulation and navigation of the robot. What aspect that is not commonly covered is the interaction between humans and robots and so oftentimes robots perform independently to humans. However with daily assistive and service robots working in domestic environments it is important to highlight the importance of this interaction.

For many studies and developments, such as Preferred Networks (PFN) their Autonomous Tidying-Up Robot System has used voice and gesture commands to order the robot to complete the task, with the human then sitting back to let the robot complete the tasks [3]. This project challenges this and focuses on the collaboration between human and robot. The robot must have the ability to work with able bodied humans but also the disabled, elderly and children as they are the demographic that would benefit from service robots in a domestic environment the most.

3.2 Task Planning Algorithms

The human robot interaction of humans and robots collaboratively completing tasks has been studied over decades.[12] Studies find that 'humans would rather work with robotic teammates that accounts for their preferences'. [13]

The study into explicit and implicit task allocation techniques shows that implicit techniques produced a higher rate of task completion based on measurements such as completion time and robot errors. Implicit decision making by continuously evaluating which object to select based on changing factors while explicit decision making are decisions made by the user. This study reflects what has been done in this project so far, with explicit decision making through voice being the only way Fetch starts its action.

The need for robots to task plan is vital to ensure there is a sequence of actions that is followed to accomplish the desired task. The challenge in Artificial Intelligence (AI) is to ensure robots can plan when faced in uncertain environments with incomplete information [14]. There has been research into many algorithms that exist, each with their own set of strengths and weaknesses. As well as task planning, task allocation is an important aspect in this project, task allocation decomposes the problem into a series of subproblems and distributes them.

3.2.1 Genetic Algorithm (GA)

Often used in path navigation scenarios, the genetic algorithm is a widely used algorithm based on the 'survival of the fittest' principle [15] where a search technique is utilized to compute solutions to optimize a problem using independent computations based on a probabilistic strategy [16]. Applications of this algorithm are varied, including Job Shop Scheduling, where the genetic algorithm was successful in changing dynamic environments [17]. The implementation of this algorithm would be particularly useful for this project as the environment and variables will be constantly changing. For example, if the person still wants help or the number of blocks remaining.

3.2.2 Planning Domain Description Language (PDDL)

The monotonic PDDL-based planners are designed to be used for solving task planning problems. PDDL can be described as two basic building blocks, the first being Planning Domains and the second Planning Problems[18]. Planning Domain consists of using variables and encoding them as boolean or numeric state variables into actions that specify the task path given domain variables. Then the Planning Problem takes what is learnt in the Domain phase and a set of Actions is obtained using a set of variables and actions with a goal condition. It is found that PDDL performs better on problems that have longer solutions.

3.2.3 Answer Set Programming (ASP)

Originally developed for knowledge-intensive reasoning, situations where there is a general domain of knowledge, but can be used for tasking planning. ASP uses logic programming and, differently from PDDL, nonmonotonic reasoning [19] to allow for defining solutions to complex problems in a declarative manner. Similar to PDDL, ASP occurs in two steps, the first being Grounding where it learns which tasks have big impacts on the system . With the next step being Solving, which is the search for the most optimal answer using Boolean constraints [19]. ASP are better geared towards tasks with a large number of objects or situations that require complex reasoning. [20]

The concept of PDDL and ASP introduces the concept of task planning in two stages, where the robot learns information about its environment beforehand and then uses that information via Boolean functions to decide the most appropriate task; this framework could be implemented in this project.

○ 3.3 Dialog in task negotiation

In task negotiation and collaboration between humans and robots, communication through dialog is a useful mechanism to aid in the frequent negotiation, modification of joint goals and task division.

■ 3.3.1 Template-based output generation

Natural Language Generation is a sub-area of linguistics that looks at the 'automated production of spoken or written content in human language'[21]. Slot filling templates are used by slotting the content into pre-built linguistic structures. This can provide high quality output however may take a significant amount of time to develop the template. Further, due to the template structure, the system is not flexible to output it is not programmed to accept.

■ 3.3.2 Joint Intention Theory & Collaboration

Agent communication languages defined using joint intention theory, a method used to describe the mental states of team participants. In communication there are conversation policies, where Joint Intention Theory is used through the mental states of the agents and using state information to communicate [22].

For agents to share a common goal there should be 'commitment to the joint activity and commitment to mutual support', meaning that both agents need to be sincere about completing the shared goal. Information needs to be shared through communication especially if one agent only knows partial information about the task.

○ 3.3 Challenges around working with robots

■ 3.3.1 Trust

As the development of humanoid robots increases it is important the robot is able to exhibit socially inline behaviours in order to work alongside humans. Service robots that provide services like tidying-up and catering benefit consumers as well as service providers, however there is a lack of trust between human and robot that makes their integration into society more of a theoretical concept. One way to build trust is to have the robot exhibit human-like behaviour [23]. Behaviours include displaying gaze cues show the 'increase anthropomorphism drives trust when user comfort is low'[24]. A limitation in this study is the small spread of participants who were generally tech savvy which does not represent the average demographic found in households.

Another way to build trust is through voice. Again mimicking human interaction, factors like voice naturalness [25], gender [26] and accent impact how the user trusts the robot [27][28]. In this project the default Fetch voice, a male robotic voice, will be used in the trials and the increase of interaction of two-way speech-based communication between robot and user will be explored.

4 Requirements, Specifications and Approach

4.1 Requirements

Taking into account the objectives of this project Fetch should be able to fulfil these high level requirements. These requirements were not changed from the original proposal.

Table 1 Requirements for High Level Feature Requirements

Requirement ID	Requirement Description
R.01	Speech-based two way communication between Fetch and User.
R.02	Users are able to distribute tasks to Fetch.
R.03	Producing a functional navigation and manipulation base code.
R.04	User study should be carried out using programmed functions as a test case.

4.2 Specification and Approach

The following section shows the work done to complete the project

4.2.1 Speech-based two way communication between Fetch and User.

At the moment, Santini's base code requires humans to communicate using a GUI, with options being 'Yes', 'Continue', 'Stop Assistance' and 'Emergency Stop'. From all the functionalities that have already been implemented, the interaction between Fetch and the User is the least developed and is the most unrealistic when compared to real life human- human interactions. This feature feels like the next step in this project as it is a large factor into users building trust with Fetch.

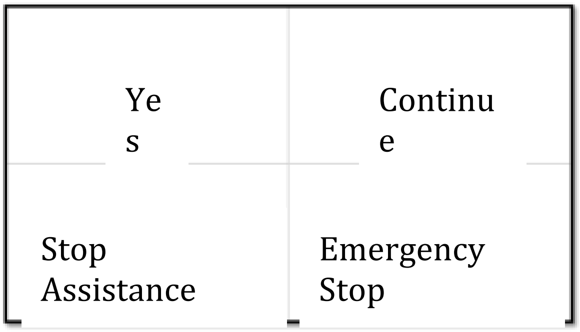


Figure 2. J.Santini's GUI for communication.

To complete this requirement two separate functions need to be implemented. The first being Fetch's ability to synthesise speech from text and the second being the ability to recognise speech from humans.

Originated from Santini's code `sound_play`, a ROS package used to play sound files and synthesize speech [29] was used to allow for text to speech functionalities. This allowed blocks of text in the form of scripts to be passed through the function and to be projected verbally by Fetch.

In order to recognise humans' spoken response ROS package `deepspeech`, provides speech-to-text transcriptions using pretrained neural networks available from Mozilla [30]. With a further integration of Deepspeech's example, Microphone VAD Streaming by R.Morais and N.Stoker [31], allows for the continuous streaming from a microphone using voice activity detection (VAD) and is useful for 'quick, real-time testing'.

Table 2. Test of raw transcriptions and recognize text using DeepSpeech

Raw Transcription: The quick brown fox jumped over the lazy dog
Recognized: to quit found fox jumps over the lazy dog Recognized: the quick brown fox dumped over the lazy dog
Raw Transcription: Hi, my name is Jenny and I study mechatronics engineering at Monash University.
Recognized: i name is jennie and i said he mechanics engineering easier ity Recognized: i my name is jenny and ice study mahicanni engineering at monastery Recognized: i name is jennie and i study matacani engineering at monash universi ty
Raw Transcription: Red
Recognized: i Recognized: read Recognized: and Recognized: and
Raw Transcription: Fetch could you pick up the red blocks
Recognized: eh can you please to cope the red blocks Recognized: french could you please pick up the red blocks Recognized: french could you please be up the red books

From some testing of the program, it was found that it was much more efficient at recognising words correctly when in longer statements. This allows for Fetch to recognize full sentences instead of a set dictionary of programmed words like in FYP Coffee Baristas 2021 [32], where raw transcriptions are simplified down to a string containing dictionary words .

Antlion Audio's wired USB microphone [33] was used to pick up the user response, which when initially proposed was to be connected into the USB 3.0 ports on the access panel of Fetch. However after some testing when the user is standing any distance away from the microphone then Fetch is unable to recognize any speech.

So instead the program was modified to use ROS multiple devices, where the main script running from Fetch published to the conversation topic where the subscriber on a secondary laptop prompted for the conversation function to run and information of the assigned colours was published back on the colour topic to the main script once the conversation script was finished. This also proves to be beneficial as the participant and Fetch are able to stand a comfortable and safe distance away from each other.

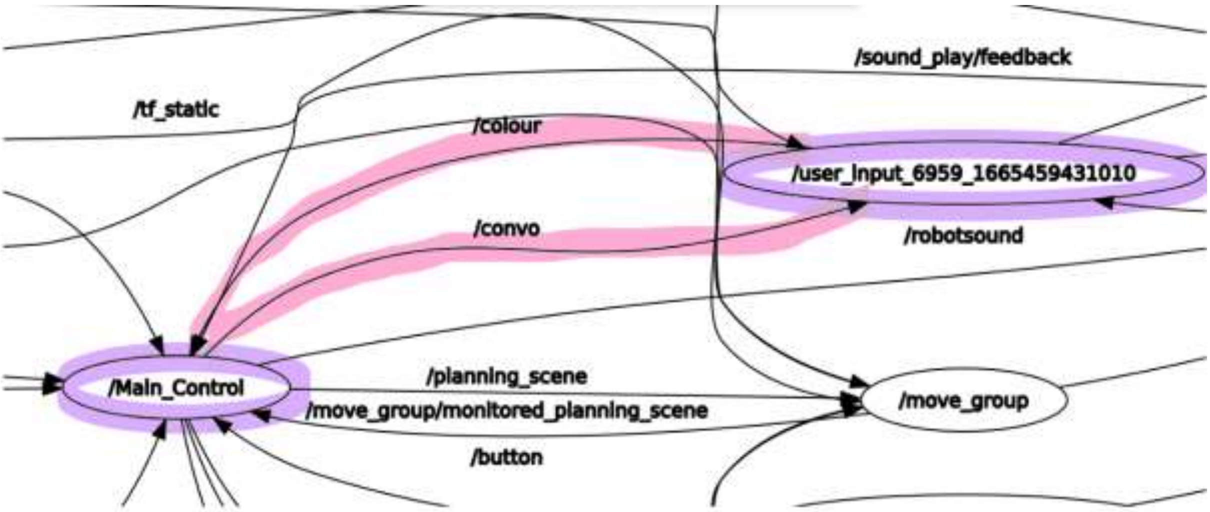


Figure 3. Node and topic interaction for communication sequence.

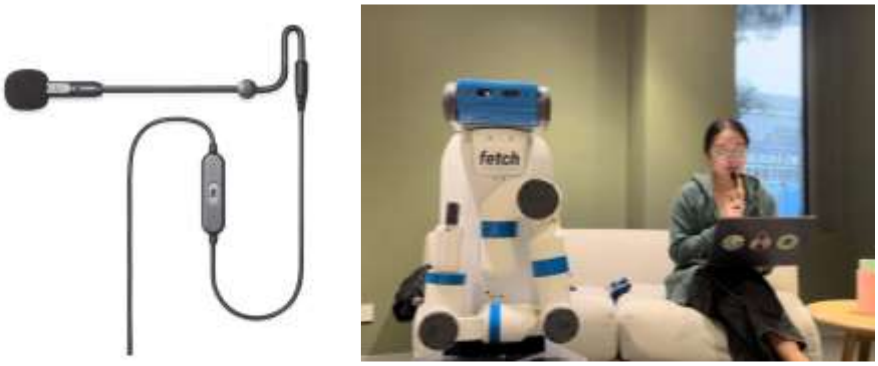


Figure 4. a) Antlion Audio's USB microphone. b) Participant and human standing a safe distance while performing task allocation conversation.

- 4.2.2 *Users are able to delegate tasks to Fetch.*

Using the functionalities of requirement R.01, the user should be able to delegate tasks to Fetch. The main focus of this task will be seeing how much the user will delegate to Fetch after observing the full capabilities of the robot.

Speech-based communication would be used between human and robot, where the robot would ask the human what coloured block the robot should put away, a verbal exchange of task confirmation should be done as well to reduce error. The study would also examine how much load the human places on themselves, which means that the robot would have knowledge of what task the human is completing, again by asking the participant questions such as "What colour will you be putting away?", "How about you pick up the blue block?".

In order to approach this, a function was programmed that iterated through the questions, referred to as stages, to determine what colour the user and Fetch would be assigned with stages for confirmation to reduce error.

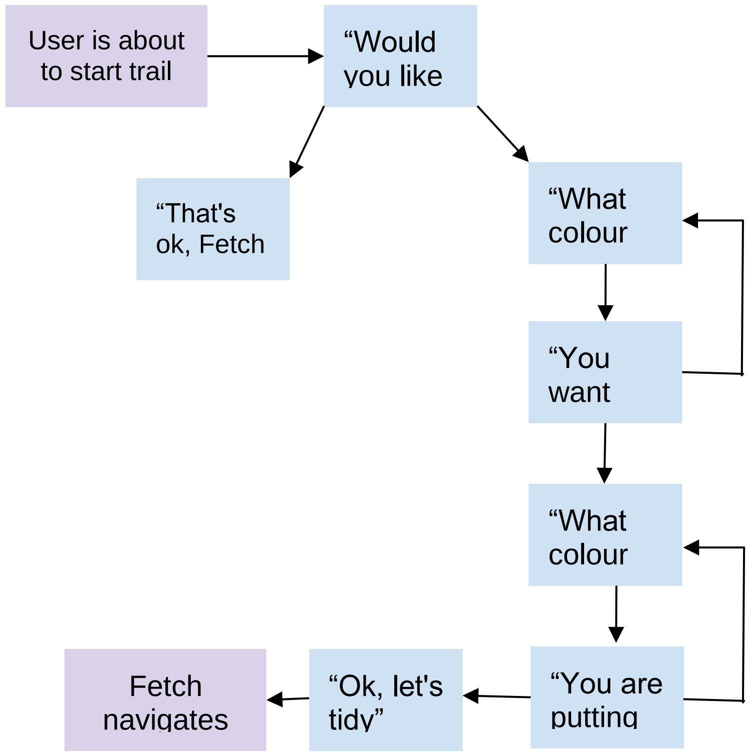


Figure 5. Proposed flow of human-robot interaction

The first step to complete this function was building a conversation path having the user input be binary Yes (Y) or No (N) keyboard strokes. Where Yes responses will move the function to the next stage and No responses will bring the user back to the previous question, which is representative of the conversation path in Figure 2. Further only a small section of the full conversation was used for the initial function. This created a foundation to add additional questions and functionality.

```
question = ['Hi, I''m Fetch. Would you like me to clean?',
            'Which colour would you like me to collect?',
            'You would like me to pick up the red blocks?',
            'OK, picking up red blocks']

while current_stage < num_stages:

    if (current_stage == 0):
        talk(question[current_stage])
        input1 = raw_input('Y/N:')

        if input1 == 'Y':
            current_stage = current_stage + 1

    elif (current_stage == 1):
        talk(question[current_stage])


        input2 = raw_input('R/B:')
        current_stage = current_stage + 1


    elif (current_stage == 2):
        talk(question[current_stage])
        input2 = raw_input('Y/N:')

        if input2 == 'Y':
            current_stage = current_stage + 1
        elif input2 == 'N':
            current_stage = current_stage - 1

    elif (current_stage == 3):
        talk(question[current_stage])
        current_stage = current_stage + 1
```

Figure 6. V0 of conversation flow using keyboard input

The next stage was to replace the input of keys to speech. Using a modified function of Microphone VAD Streaming, discussed in the section above, users have the ability to speak into the microphone and have their speech recognized when the function is called. Although good, Fetch is unable to determine what the words mean, so by giving Fetch keywords for each stage it can recognise which words are important. The function that allows Fetch to listen is called until a keyword is detected.

Table 3. Keywords for a given stage

Question (Stage)	Keywords
Would you like to clean together?	yes, ok, good, no
OK. Which colour would you like me to collect?	red, blue, green, yellow
You would like me to pick up the **%colour_fetch** coloured blocks?	yes, ok, good, no
OK, I'll pick up the **%colour_fetch** blocks.'	
I think you should pick up the **%colour_human** blocks. What do you think?'	yes, ok, good, no
What coloured blocks did you want to pick up?	red, blue, green, yellow
OK, you can pick up **%colour_human** blocks. Ready to clean?	yes, ok, good, no

Figure 7. Transcript of Fetch colour allocation. Listening function being recalled until a keyword is detected

With stage progression and speech input completed, the next stage was to finalise the conversation flow. Consideration was placed into three pathways; Who would lead the negotiation? And conversation paths were mocked up.

Table 4. Proposed conversations for differing lead negotiator

1. Robot leading negotiation
F: Hi Im Fetch, Would you like to clean with me? H: Yes F: I think you should pick up the green blocks. H: OK F: In that case, I’ll pick up yellow blocks. What do you think? H: Sounds good F: Ok, I'll pick up yellow blocks and you pick up green blocks.
2. Human leading negotiation
F: Hi Im Fetch, Would you like me to help clean? H: Yes F: What colour should I pick up? H: Yellow F: Ok I will pick up yellow blocks ? H: Yes F: Ok, What colour do you want to pick up ? H: I'll pick up green F: Ok lets start, Im picking up yellow blocks and you pick green blocks
3. Shared negotiation
F: Hi I’m Fetch, Would you like to clean? H: Yes F: What colour should I pick up? H: I think you should pick up blue blocks F: Ok I will pick up blue blocks ? H: Yes F: I think you should pick up yellow.What do you think ? H: Ok F: Ok, you can pick up yellow.

Shared negotiation was selected as the pathway for conversation as it allowed for both parties to suggest task allocation and made use of speech recognition full capabilities to recognise full sentences; unlike in the Robot Lead Negation where users only response was Yes or No. Where full conversation flow is detailed in Figure 8.

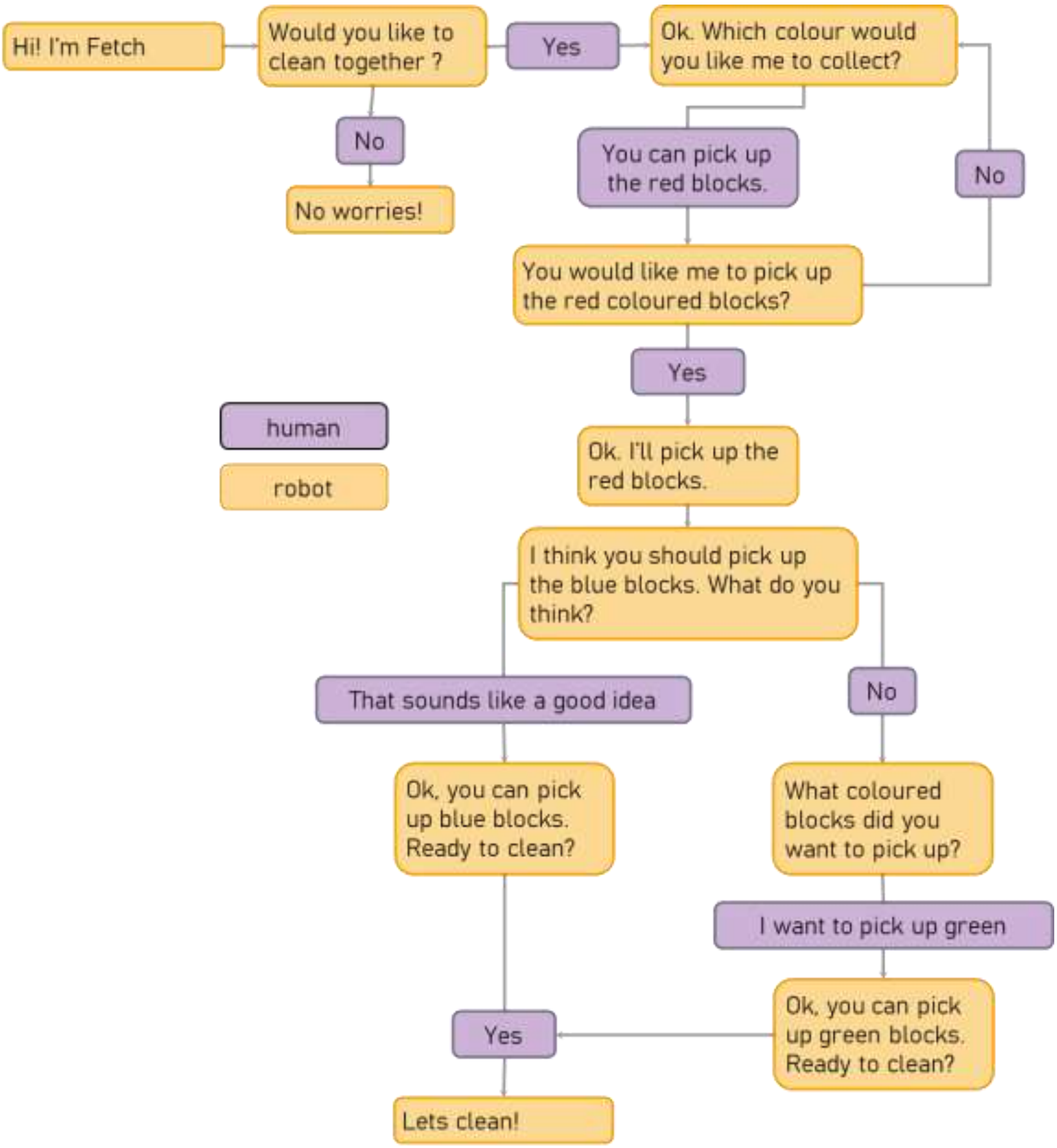


Figure 8. Final conversation flow for task allocation between human and robot

It was also important to test this function informally on test participants in order to gather any improvements needed to make this function more robust.

The first being that users did not know when to speak. Due to the nature of conversation we respond to questions as soon as they are asked, in this code however there is a slight delay from the end of the question to when Fetch is ready to listen for a response which causes the user to respond quickly. To combat this a short sound was added, similar to the ones found in Alexa's or Google Homes to prompt the user for a response.

Furthermore, the detection of speech is not always accurate and keywords might not be recognized, if no keywords were recognized in a certain frame then it will continue to call the function. Similar to the first bug, users were unable to tell when to resay their response. As a work around, a GUI (terminal commands) is used to show the question that was asked, when Fetch is listening and what Fetch recognised.

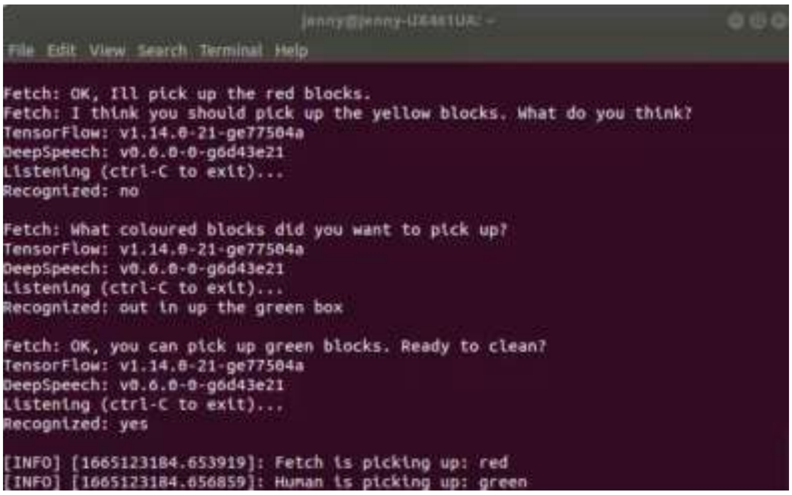


Figure 9. Terminal GUI that display the transcript of the conversation

■ 4.2.3 Producing a functional navigation and manipulation base code.

Requirement R.03, resourcing and producing a functional navigation and manipulation base code, requires programming Fetch so that it can robustly navigate around a staged living room environment and also safely manipulate its end effector to grip objects.

Santini's previous tidying up sequence and function for navigation, detection and manipulation was used, where Fetch follows the sequence in decision making shown in Figure 10 to tidy up.

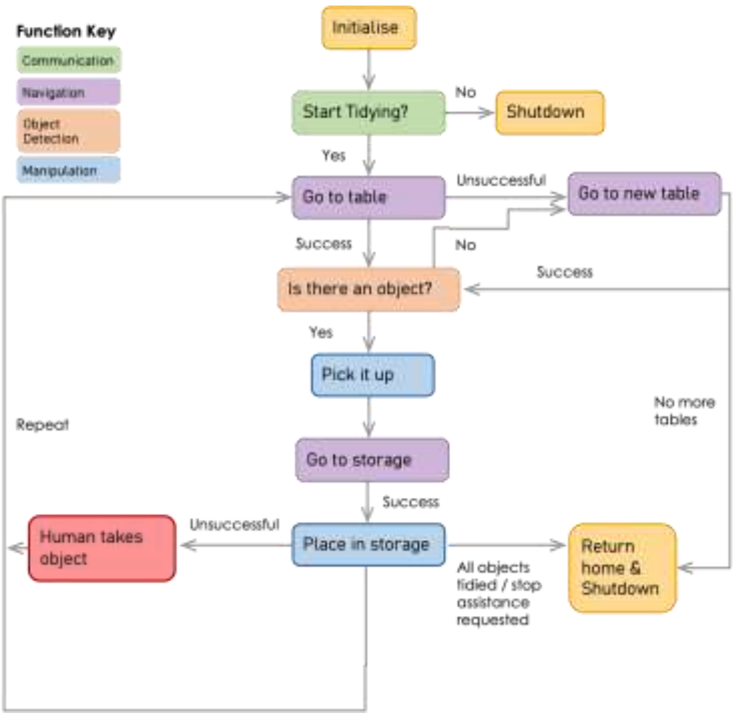


Figure 10. Santini's Flow Diagram of Fetch's decision states during tidying process

An objective of this project is to conduct a user study and to test Fetch's behaviour on humans. Further will be discussed in the next section, however, the base code needed to be split into two stages. Which means some functions need to be modified for the different requirements of each stage.

Table 5. Proposed description and function sequence that Fetch performs for each Stage of user study.

Stage 1	**Stage 2**
Participants watch Fetch autonomously pick and place objects until all objects are tidied.	Participants and Fetch use speech to collaboratively assign tasks then tidy objects together until all Fetch's objects are tidied.
● Localisation in a home position ● Navigation to a table ● Scanning for objects ● Picking up first object detected ● Navigation to correct storage location ● Placement of object ● Repeat until all objects are tidied	● Localisation in a home position ● *Task delegation and allocation with human* ● Navigation to a table ● *Scanning for assigned object* ● Picking up detected object ● Navigation to correct storage location ● Placement of object ● Repeat until all assigned objects are tidied

4.1.1.1 4.2.3.1 Navigation

Fetch should be able to travel around the living room without colliding into fixed objects.

Table 6. Requirements for Navigation

Requirement ID	Requirement Description
R.03.01	Building a map of the living room for localisation.
R.03.02	Navigation of Fetch to certain waypoints.
R.03.03	Avoid fixed objects in the living room (Eg. tables, walls, furniture)

Saniti's code for the navigation portion was quite robust, with all three of the requirements below being met so there were not many changes made. Any changes during this project was to optimise the location of each table and storage locations using trial and error. And a new map of the room was produced due to the change in table location. And where both Stage 1 and 2 have no differing requirements.

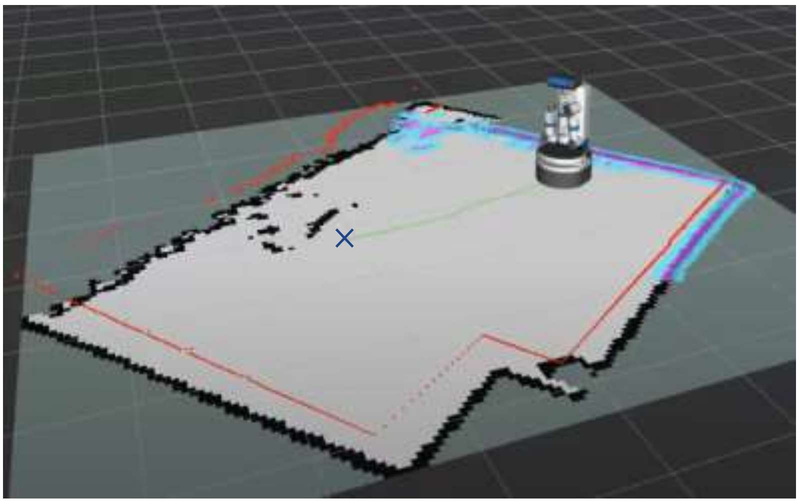


Figure 10. Fetch path planning (green) to table waypoint (dark blue)

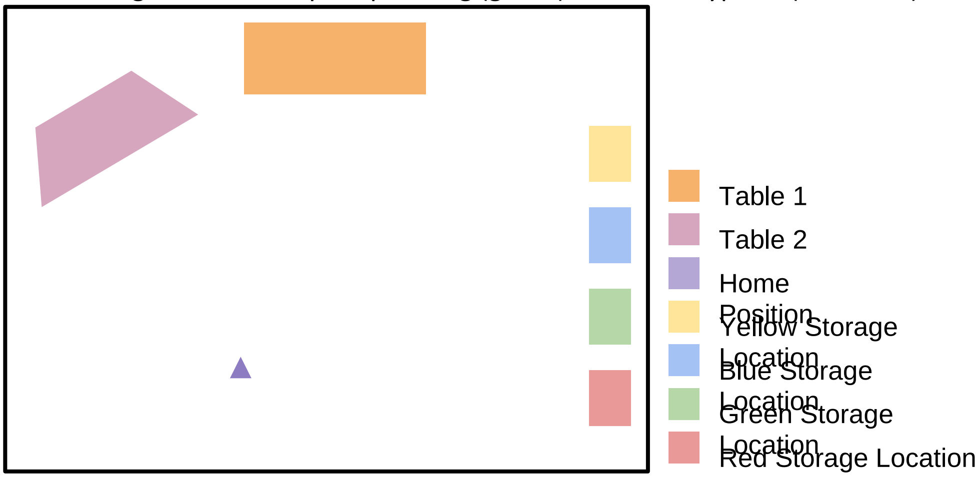


Figure 11. Layout of room

4.1.1.2 4.2.3.2 Object Detection

Fetch should be able recognize objects that require manipulation.

Table 7. Requirements for Objection Detection

Requirement ID	Requirement Description
R.03.04	Able to detect blocks with ArUco markers

Santini uses `Aruco_detect`, a ROS package that finds ArUco makers in images stream and publishes corner points and estimates 3D transform from the camera to the fiducials [34]. The process for Stage 1 remains unchanged, where fetch scans for aruco markers moving the angle of its head if necessary to increase the range of view. Then stores and passes the information of ID value and location of the first marker regardless of the colour it detects to the next stage.

Aruco markers were modified slightly to increase the marker's visibility with a white margin framing the marker which increases the contrast between the marker edge and the white background. The old marker's exclusion of the white border meant that the marker corners had to be detected amongst the table environment. [35]

Figure 12. Comparison of blocks from current marker (left) to previous marker (right)

In Stage 2, since Fetch is now assigned it should only pass information for blocks of that colour. To do this the script is modified to check for the detected blocks if the ID value matches with the colour, if not keep scanning until an object with matching ID is found.

```
Fetch is searching for an object
Fetch is looking at: 1, 0, 0.45
Detected 3 objects
Fetch is looking at: 1, 0.22, 0.45
Detected 2 objects
Fetch is looking at: 1, 0, 0.45
```

Fetch: "I could not find any objects here, I am moving to the second table"

```
sound_play action: Succeeded
Fetch is moving to The Second Table
Fetch reached The Second Table
```

```
Fetch is searching for an object
Fetch is looking at: 1, 0, 0.45
Detected 1 objects
Broadcasting transforms for ID 1
Fetch has found a red object
Waiting for get_planning_scene
```

Figure 12. Fetch detecting blocks in Fetch's assigned colour (red) in Stage 2.

4.1.1.3 4.2.3.3 *End Effector Manipulation*

Fetch should be able to grasp objects using its end effector

Table 4 Requirements for End Effector Manipulation

Requirement ID	Requirement Description
R.03.05	Fetch should determine transformations needed to reach an object.
R.03.06	Grippers should not break objects when picking them up.
R.03.07	Deposit objects into correct baskets.

Once the object is detected, Fetch needs to pick up the object off the table and place it into storage locations. Unchanged from Santini's function, Fetch uses the ROS package MoveIt! a motion planning framework. The same movement occurs in both stages, where the gripper poses in quaterian coordinates are given to the arm in stages with the gripper picking the object up from above.

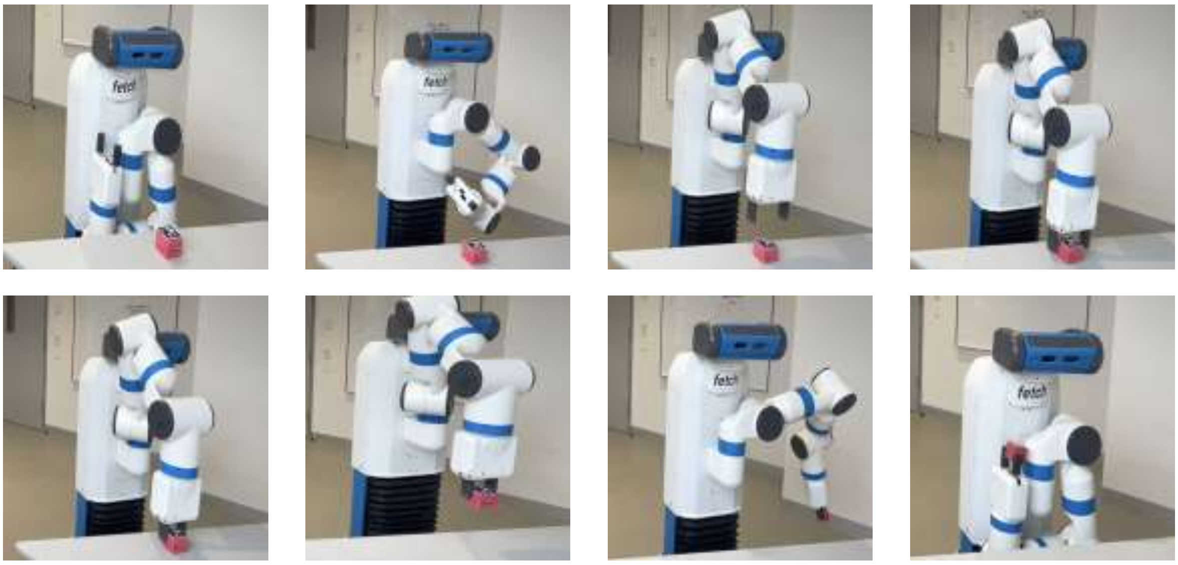


Figure 13. Fetch gripper poses to pick up an object from a top approach.

The placement sequence was changed from Santini code which originally had the same 90 degree rotation of the gripper in the y axis using quaternion coordinates as the picking sequence. This is an example of task space planning, where the position and the orientation of the end-effector is given. This proved to take a lot of time performing the action and oftentimes a valid path to the position could not be achieved which then bypasses the action completely.

This was changed to simpler movements that stayed consistent for each place sequence as joint space planning was used. Fetch was given angular displacement values for each joint of the robotic arm.

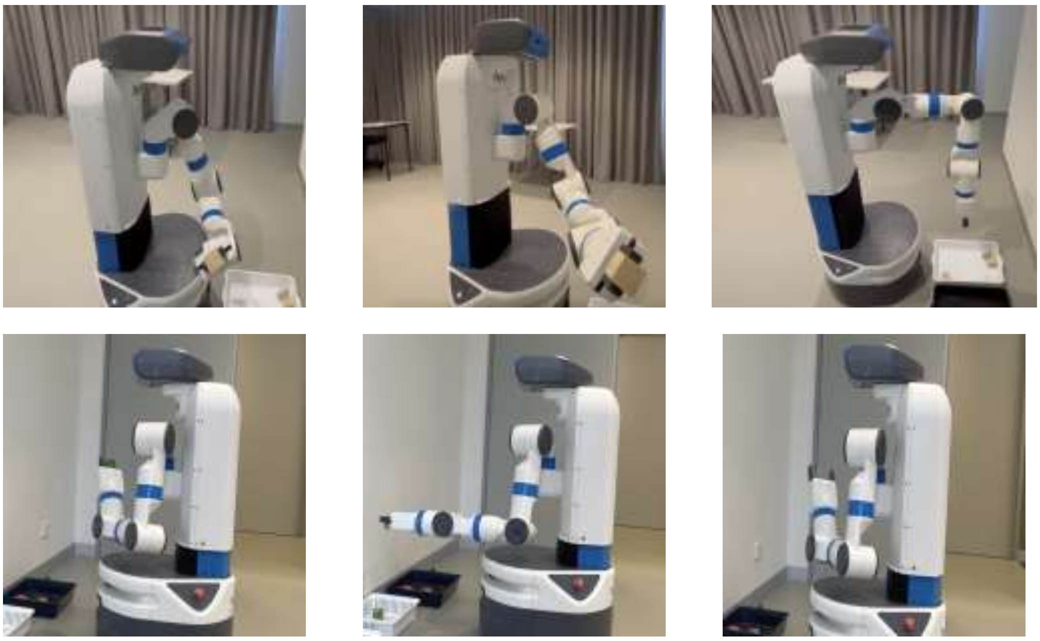


Figure 14. Top: Santini's placing sequence. Bottom: New placing sequence

In manipulation a common error in run time that occurred was Fetch's arm colliding into itself and other objects. Object avoidance in Fetch comes in two forms. The first is built into Fetch which is more used when navigating, LiDAR sensors is a laser able to detect objects at shin level heights [36]. This then causes a limitation that objects taller than this such as tables and Fetch's torso and base are not accounted for. MoveIt! using Planning Scene ROS API to add static objects into the world where Fetch would avoid these areas [37].

Santini's code had pre-existing boundaries for the floor, tables and walls. More emphasis was placed in this project refining the object boundaries for Fetch's toro and base which oftentimes were the targets of collision when Fetch needed to retuck its arm after picking up the object.

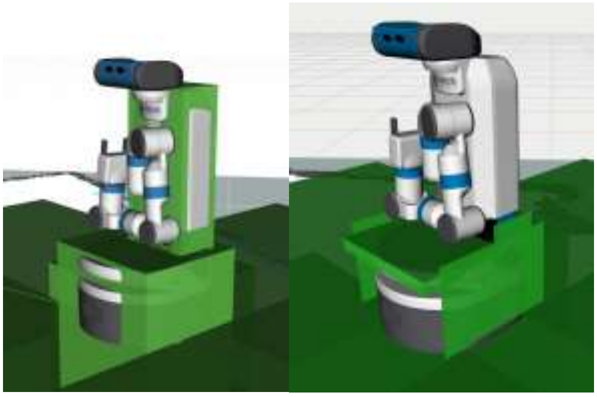


Figure 15. Previous (left) and current (right) object boundaries for Fetch's torso and base.

- 4.2.4 User study should be carried out using programmed functions as a test case

Table 5 Requirements for Non Functional Requirements

Requirement ID	Requirement Description
R.04	Fetch Robot should be used to perform functions.
R.05	User study should be carried out using programmed functions as a test case.

After all testing of Fetch functionalities are deemed to be robust and safe, then the user study can be conducted in order to investigate the human robot interaction while collaborating in tidying up tasks.

The main steps to be followed to conduct the user study are listed, however will be subjected to changes:

- Submit amendments for approval for the Human Ethics Form from Monash
- Recruit 25-50 participants by posting posters around campus and advertising on social media
- Have the participants observe Fetch tidy up on its own to display its full capabilities
- Then have the participants collaborate with Fetch in tidying up tasks
- During the study the following would be investigated
    - Why did / didn't the participant choose for the robot to assist in tidying tasks?
    - The decision process when the participant allocates the robots task load

However due to the unpredictable nature of a pandemic, all social distancing and quarantine guidelines will be followed according to Monash University's and the Victorian Government recommendation. Therefore if in person activities are restricted then the user study will not go ahead and instead the final deliverable for this project is robust tidying up robot.

5 Scope, Project Plan & Timeline

5.1 Project Scope

The scope of the project lies in the requirements, where the aim for this project is to produce a robust tidying up robot and to test this behaviour on participants in a user study. This will include ensuring foundational functionalities of navigation, detection and manipulation. Santini's work on this project was used as the base code for these functions due to the familiarity with the code through observing the testing stages of his project. And programming a functionality that allows for two-way speech based communication between human and robot and also programming a feature that allows the user to delegate task load to the robot.

There are many other functions that could be added on to this base code in order to optimize the performance of the Fetch, for example, improved object detection using machine learning algorithms to eliminate the use of ArUco markers or optimizing path planning of the end effector when picking up objects. These should not be features included in this scope and could be the focus of another Final Year Project in the future.

During the time of this project the scope was changed to accommodate for time constraints. All the programming requirements were fulfilled with a robust code that allows for task allocation and tidying up. Since the programming took a lot more time than expected this left an unreasonable amount of time to conduct a user study, with turn around periods for an ethics application to be amended and approved, recruitment of participants, conducting user studies and analysis of results. So, it was discussed that it was better to dedicate more time to produce a more robust program.

The initial proposed timeline looked at programming and completing functions in a Waterfall like Model, where only one feature is worked on and the next starts when it is completed. This proved to be not very realistic where requirements were changed and added during the duration of the project.

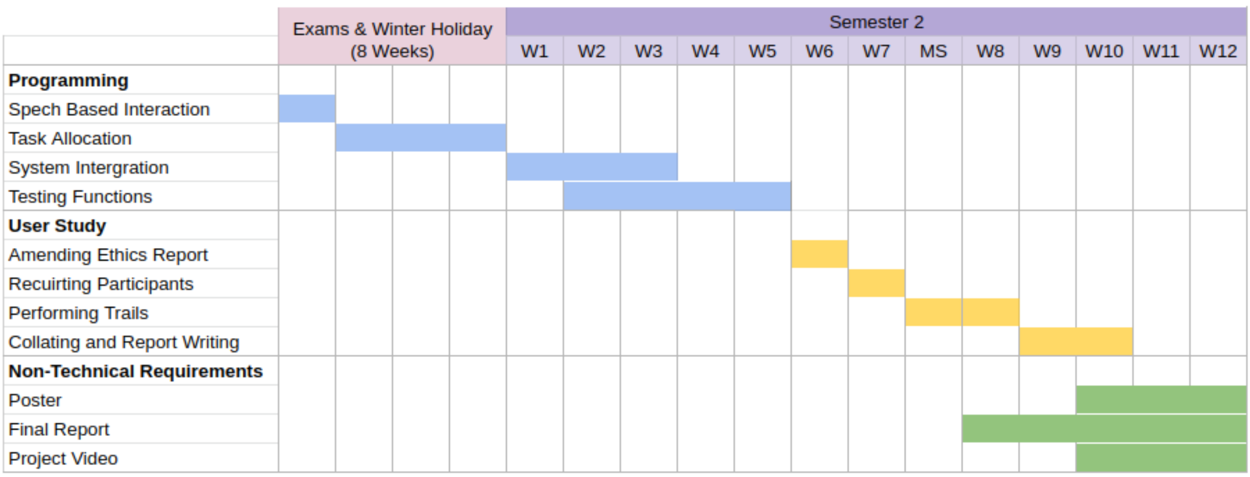
It was difficult to create a timeline for this project as it felt like features were viewed as gaps of time and having a programmers naivety of not understanding how long it would take to complete them. The timeline didn't account for random bugs that appeared during testing and additional features that weren't considered in the project proposal. For example, major bugs delayed the timeline included collision geometry suddenly deciding they would collide into itself and needing to adjust object boundaries or DeepSpeech interfering with the differing python environments on Fetch's freight so needing to implement a virtual python environment in order to run deepspeech on Fetch. Additional features that needed to be included were the implementation of multiple devices to use the laptop as sound input and modifying object detection to only detect Fetch's assigned blocks during Stage 2.

What realistically occurred were some functions being worked on simultaneously to each other but also was a natural result of increased time pressure. For example, in weeks 1-6 in Semester 2 all functions required for the modification of base code were worked on at the same time. On a more individual and productivity level, this allowed me to jump in and out of functions and concepts leaving me time to reflect on one while working on another. It was beneficial that this was an individual project as it allows me to jump so fluidly across the features and no extra work needed to be done to communicate these decisions.

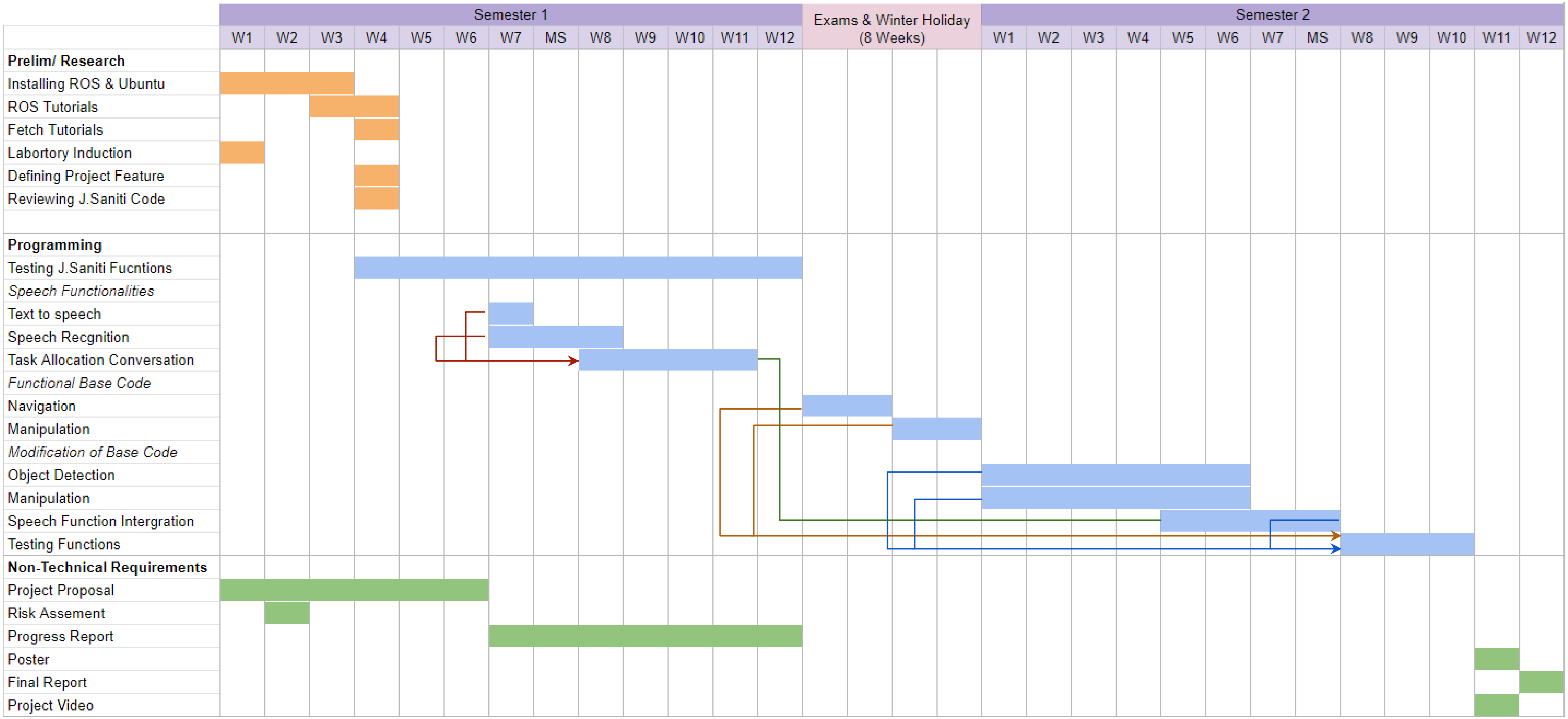
5.2 Project Plan & Timeline

Initial Proposed Timeline for Semester 1&2

Amended Timeline for Semester 2



Updated Gantt Chart with Critical Path



6 Discussion

6.1 Summary of work completed

The aim set out at the beginning of this project was to produce a system using a mobile manipulator, Fetch, that can allocate tidying tasks between human and robot in a living room setting. The system can be divided into functions that allow Fetch to perform this behaviour safely.

Previous works on this program by Santiti provide basic functionalities and my unique contributions to these functions will be summarized below.

6.1.1 Communication

The main focus of this project was to investigate how humans assign tasks to robots where they are tasked to complete an activity together. Where the complexity of communication between human and robot was increased so that the participant and Fetch could use two way speech communication to assign tasks.

This needed two specific functions. Text to speech was already existent in the base code, using sound_play ROS package that allows Fetch to respond and ask questions using speech. And speech recognition integrated using DeepSpeech allows Fetch to listen and recognise real time voice activity detection using a microphone.

Both these two functions were then used to create a conversation flow that will run at the beginning of Stage 2 (Table 5) in the user study, which is a shared negotiation interaction between human and robot that will decide which coloured blocks each party will collect while tidying. The conversation includes confirmation stages where Fetch checks with the user on their decision and the participants confirmation of the task progresses the conversation to the next stage or disapproval will repeat colour allocation questions.

6.1.2 Navigation

Santini's navigation functions were pretty robust. So the changes to this function were relatively minor. A new map was created of the room and location coordinates were adjusted to better represent the new layout, which included relocation of the two tables and having four storage locations instead of only two.

6.1.3 Detection

In object detection Fetch can detect multiple objects if it's in Fetch's field of vision but will only send one marker's information to the next stage. When Fetch is assigned a colour in Stage 2, object detection is modified to pass marker's information if the block is the assigned colour.

6.1.3 Manipulation

Once an object is detected, manipulation of the arm needs to occur to reach the object from off the table and then place the object into the storage container. The picking up sequence proved to be quite robust and the only changes were on the collision boundaries to decrease the risk of Fetch's arm colliding into its torso and base.

The main changes to manipulation was for the placing sequence. Instead of a top approach like what the picking sequence follows, a more simpler movement was implemented which was more time efficient and safer when collaborating with humans.

■ 6.1.4 Code Integration

This project was not about building these functions from scratch but instead implementing and integrating already existing ROS packages together into one robust and safe system. The biggest integration was how communication fit amongst the rest of the code and how the variables returned from communication for assigned colours can be used in object detection and manipulation sequence.

■ 6.1.4 Physical Testing on Robot

Many robotic studies often don't pass simulation testing. Fortunately, this project had a large emphasis on testing on a physical mobile manipulator. Once features are tested using simulation and are deemed to be robust then the behaviour was tested on Fetch. More often than not the physical test did not mirror what was represented in the simulation.

For example when testing DeepSpeech on Fetch, an error occurred where Python3 environments interfered with DeepSpeech which is only compatible with python 2.7 environment. To combat this bug a virtual python environment was created which is a tool that keeps dependencies between projects separate [38]. Furthermore, when the microphone input was attached to Fetch it was not able to pick up any sound due to the distance. So instead, running ROS on multiple devices was needed so that the microphone input would come from the laptop which included creating a subscriber and publisher messages between scripts to call functions to run.

○ 6.2 Findings

With my knowledge and experience into programming a robotic system being only limited to this year combined with the time constraints of a years long project there were certain limitations that arised.

■ 6.2.1 Santini's Base Code

In order to investigate how tasks are allocated between robot and human it was important that functions for navigation, detection and manipulation for tidying up were already programmed and task allocation functions would be just integrated on top of this system. In the project proposal, the mention of using other sources for this base code could be used. But instead, due to familiarity through observation of testing alongside him, Santini's work was used as the base code and the feature of task allocation was integrated on top of it.

However, Santini's base code came with known limitations and bugs. A large portion of the project was spent optimizing the base code and making sure it was robust, which then delayed the project's timeline where that time could've been used to deepen the complexity of task allocation or be used to conduct a user study.

Reflecting on this decision after the completion of the project, using Santini's code feels as if it was the most effective choice for the situation. The effort that would've been put into research, implementing and testing other codes and having the possibility for that code not being adequate for application would have been more time consuming. And knowing that Santini's code worked and that it was made specific for tidying up in the same space would eliminate that time period.

■ 6.2.2 Limited Vocabulary

The choice of structuring the conversation flow as iterative if statements with a limited selection of key words had its limitations. Although it met the requirements of task allocation there could have been alternate and more robust ways in creating this feature.

Participants needed to be instructed before interacting with Fetch what the keywords were which creates restrictions on what responses the participant can provide. Which means different phrases that mean the same thing aren't registered as valid responses. For example, "no" is the only response that allows users to disagree with Fetch's questions so slang like "nope", "nah" won't be accepted. Similarly if a keyword is used in a response Fetch will assume a direction. So Fetch will register, "I have green hair" and assume that green blocks would be picked up. This works to an extent in this application where only the colours differentiate the tasks but once a larger range of objects are introduced this will be an issue.

Alternative algorithms could be used to replace the use of keywords. Natural Language Processing (NLP) software can identify 'grammatical structure within a sentence' and handle phonetic, lexical and grammatical tasks [39]. This would give participants responses more context and would be more applicable in other applications.

6.2.3 Nature of individual projects

As a University Honours Project, this had deliverables that needed to be completed and was not just solely focused on design and programming. This meant that time had to be allocated to complete these deliverables which reduced time to work on the program.

In addition, I found it was difficult during the year to stay accountable and motivated since there is no one to keep you accountable other than yourself. When viewing other Final Project teams having that external motivation and pressure was an envious trait.

Having team members working on this project may have propelled the project along at a faster rate. Not only that more hands would reduce the workload but also problem solving and debugging phases would be significantly faster as ideas could be bounced around.

6.3 Stakeholder feedback and future work

Although the program requirements of task allocation and tidying functionalities were met there are definitely improvements to the program that can be made.

Flow of the conversation at the moment is relatively simple so different variables can be added to make the task have more components. For now, colour is the only factor that distinguishes the task, the quantity of blocks can be added as a factor to be negotiated. More research can be put into replacing the use of keywords with something like a Natural Language Processing software, which will increase the application of this task allocation interaction.

If this project was to be continued as a Final Year Project I would suggest looking into the actual sequence of cleaning that combines all the functions of communication, navigation, detection and manipulation. The sequence at the moment does not handle errors very well so features that mitigate run time errors. This will allow fetch to have a more robust base to add more additional features onto it in more future works.

7 Conclusion

With the increasing spread of service robots in our domestic settings the trust in these robots plays an important factor in their full integration into society. The collaboration between humans and robots was investigated in this project through the means of task allocation where human and robot use two way speech based communication to negotiate and assign tidying up tasks to tidy in a living room setting.

A mobile manipulator, Fetch was programmed to: use voice and speech recognition in two way communication to assign coloured blocks to each party, navigate through a staged living room environment to object location and to avoid obstacles and to detect and manipulate objects from tables and place them in their corresponding storage locations.

With no prior knowledge into physically programming robotic behaviour before this year I have experienced the strenuous labours of software development and its implementation onto physical systems and this project has deepened my knowledge and interest in what factors have an influence on human robot interactions. The completion of this project provides an open source framework that can be used in user studies to explore the interaction between humans and robots of task distribution via speech. And therefore minutely contributes to the very large and revolutionary research into how robots will be deployed and integrated more into society.

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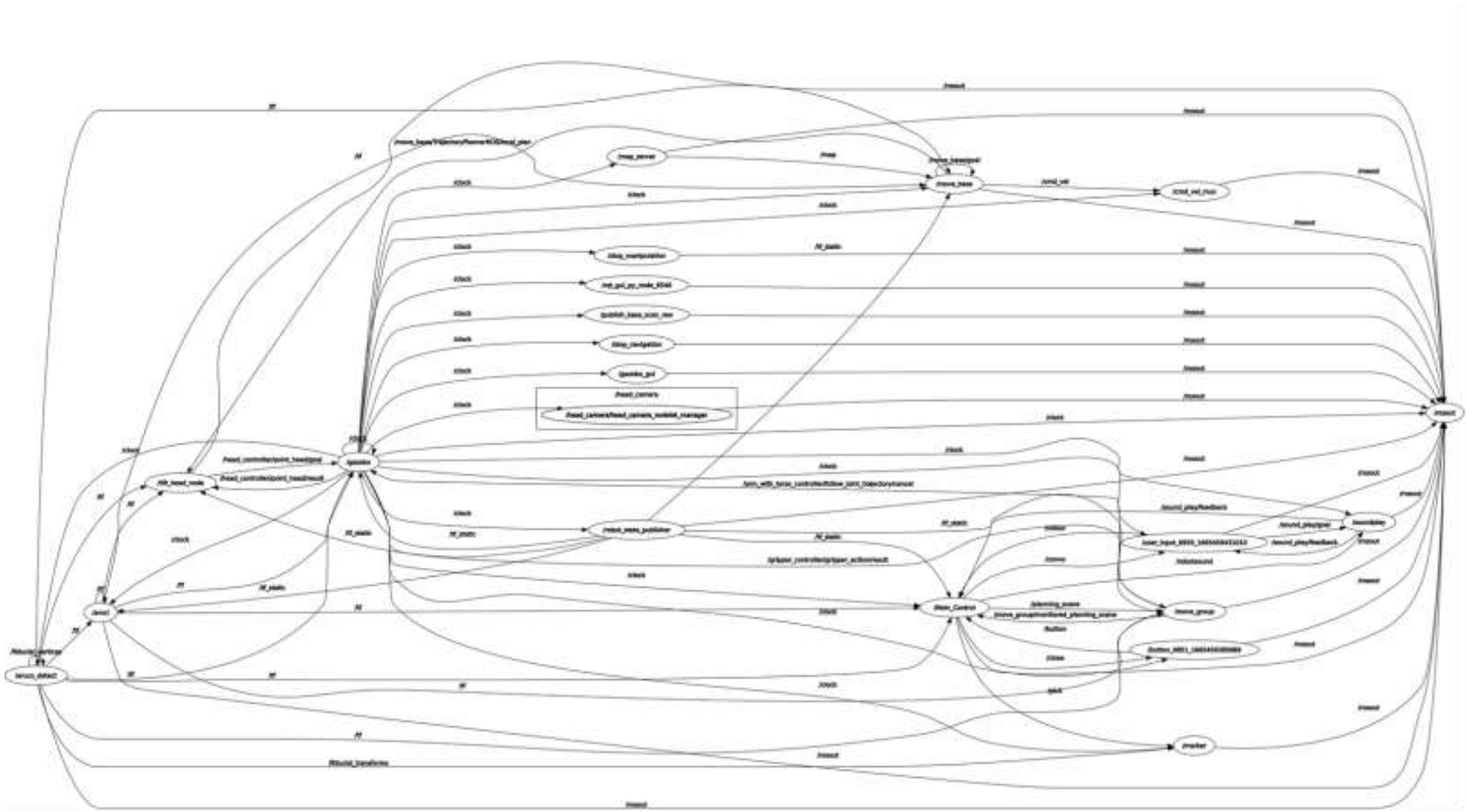
9 Appendices

9.1 Appendix A:Diagram of ROS Nodes Interaction



9.2 Appendix B: Project Risk Assessment

MONASH University

Risk Assessment [Ref Number: 35700]

Date Printed: Friday, 8 April 2022

Name	**ENG4071_CL_2022_S1_JennyLam_TidyUpMyRoomRobot!**	**Current Rating**	**Residual Rating**
Location	**Clayton - 18 Alliance Ln - Engineering 36 (36)**	Medium	Medium
Business Unit		**Last Review Date**	**Risk Owner**
Electrical & Computer Systems Eng		11/03/2022	JENNY LAM
Risk Assessment Team		**Risk Approver**	
Nicole Lee Robinson (Research Fellow) Wesley Patrick Chan (Research Fellow)		Nicole Lee Robinson	
Additional Notes			
Describe task / use			
Lab work that will be conducted in Monash's Robotics Lab, which will include operating the Fetch Robotic, human-robot interaction user study and prolonged exposure to computers.			

Risk Factors

Risk Factor	0.1 - Falls from any height (e.g. falling down stairs)

Description

Fetch Robot may fall down stairs.

- 1.0 - Fixed plant (e.g. cool rooms, fume cupboards, safety showers, boilers, lathes, lifts, gas mains, PET scanners) -- No
- 2.0 - Transport and mobile plant (e.g. motor vehicles, forklifts, walky stackers, trolleys and wheelbarrows) -- No
- 3.0 - Powered equipment, tools and appliances (e.g. computers, workshop equipment, kitchen equipment, gas cylinders) -- No
- 4.0 - Non-powered handtools and equipment (e.g. furniture and fittings, ladders, handtools, packing equipment, glassware) -- No
- 5.0 - Chemical materials (e.g. dangerous goods, hazardous substances, poisons and drugs) -- No
- 6.0 - Materials and substances (not otherwise selected from category 5.0) -- No
- 6.3 - Fire and smoke -- No
- 7.1 - Outdoor working environment (e.g. carparks, walkways, outdoor stairs) -- No
- 7.2 - Indoor working environment (e.g. internal rooms, floor surfaces, stairwells) -- No
- 8.5 - Biological materials (e.g. animals, non-living animal materials, microorganisms) -- No
- 8.4 - Personal impairment and/or interaction (e.g. pre-existing medical condition, assisting a patient) -- No
- 9.1 - Psychological (e.g. stressful situations) -- No

Risk Assessment [Ref Number: 35700]

Date Printed: Friday, 8 April 2022

Risk Factor	1.1 - Colliding with stationary objects

Description	
Robot may collide into objects.	• 1.0 - Fixed plant (e.g. cool rooms, fume cupboards, safety showers, boilers, lathes, lifts, gas mains, PET scanners) -- No • 2.0 - Transport and mobile plant (e.g. motor vehicles, forklifts, walky stackers, trolleys and wheelbarrows) -- No • 3.0 - Powered equipment, tools and appliances (e.g. computers, workshop equipment, kitchen equipment, gas cylinders) -- No • 4.0 - Non-powered handtools and equipment (e.g. furniture and fittings, ladders, handtools, packing equipment, glassware) -- No • 5.0 - Chemical materials (e.g. dangerous goods, hazardous substances, poisons and drugs) -- No • 6.0 - Materials and substances (not otherwise selected from category 5.0) -- No • 6.3 - Fire and smoke -- No • 7.1 - Outdoor working environment (e.g. carparks, walkways, outdoor stairs) -- No • 7.2 - Indoor working environment (e.g. internal rooms, floor surfaces, stairwells) -- No • 8.5 - Biological materials (e.g. animals, non-living animal materials, microorganisms) -- No • 8.4 - Personal impairment and/or interaction (e.g. pre-existing medical condition, assisting a patient) -- No • 9.1 - Psychological (e.g. stressful situations) -- No

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Risk Assessment [Ref Number: 35700]

Date Printed: Friday, 8 April 2022

Low	Low		
Existing Controls	**Proposed Controls**		
• 5 - Administrative control measures: Mandatory safety induction and training. Ensure users are aware of the risk. • 4 - Engineering control measure: A remote controller joystick is used to take over control of the robot and stop the robot. • 4 - Engineering control measure: Estop button on robot to cut off motor power and stop the robot.	Description	Responsibility	Target Date
	Clearing the work environment before operation.	JENNY LAM	11/03/2022

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Risk Assessment [Ref Number: 35700]

Date Printed: Friday, 8 April 2022

Risk Factor	2.5 - Crushed by or between objects

Description	
Pinch point on robot. Robot hitting people.	• 1.0 - Fixed plant (e.g. cool rooms, fume cupboards, safety showers, boilers, lathes, lifts, gas mains, PET scanners) -- No • 2.0 - Transport and mobile plant (e.g. motor vehicles, forklifts, walky stackers, trolleys and wheelbarrows) -- No • 3.0 - Powered equipment, tools and appliances (e.g. computers, workshop equipment, kitchen equipment, gas cylinders) -- No • 4.0 - Non-powered handtools and equipment (e.g. furniture and fittings, ladders, handtools, packing equipment, glassware) -- No • 5.0 - Chemical materials (e.g. dangerous goods, hazardous substances, poisons and drugs) -- No • 6.0 - Materials and substances (not otherwise selected from category 5.0) -- No • 6.3 - Fire and smoke -- No • 7.1 - Outdoor working environment (e.g. carparks, walkways, outdoor stairs) -- No • 7.2 - Indoor working environment (e.g. internal rooms, floor surfaces, stairwells) -- No • 8.5 - Biological materials (e.g. animals, non-living animal materials, microorganisms) -- No • 8.4 - Personal impairment and/or interaction (e.g. pre-existing medical condition, assisting a patient) -- No • 9.1 - Psychological (e.g. stressful situations) -- No

Low	Low
Existing Controls	**Proposed Controls**
• 5 - Administrative control measures: Mandatory safety induction and training. Ensure users are aware of the risk. • 4 - Engineering control measure: All pinch points are clearly indicated with warning labels. • 4 - Engineering control measure: Mandatory safety induction and training. Ensure users are aware of the risk. • 3 - Isolation of risk: User studies with untrained participants should be supervised by a trained user who can activate the E-stop	

Risk Assessment [Ref Number: 35700]

Date Printed: Friday, 8 April 2022

Risk Factor	5.7 - Electricity

Description	
Batteries in the robot and connection to wall socket when charging.	• 1.0 - Fixed plant (e.g. cool rooms, fume cupboards, safety showers, boilers, lathes, lifts, gas mains, PET scanners) -- No • 2.0 - Transport and mobile plant (e.g. motor vehicles, forklifts, walky stackers, trolleys and wheelbarrows) -- No • 3.0 - Powered equipment, tools and appliances (e.g. computers, workshop equipment, kitchen equipment, gas cylinders) -- No • 4.0 - Non-powered handtools and equipment (e.g. furniture and fittings, ladders, handtools, packing equipment, glassware) -- No • 5.0 - Chemical materials (e.g. dangerous goods, hazardous substances, poisons and drugs) -- No • 6.0 - Materials and substances (not otherwise selected from category 5.0) -- No • 6.3 - Fire and smoke -- No • 7.1 - Outdoor working environment (e.g. carparks, walkways, outdoor stairs) -- No • 7.2 - Indoor working environment (e.g. internal rooms, floor surfaces, stairwells) -- No • 8.5 - Biological materials (e.g. animals, non-living animal materials, microorganisms) -- No • 8.4 - Personal impairment and/or interaction (e.g. pre-existing medical condition, assisting a patient) -- No • 9.1 - Psychological (e.g. stressful situations) -- No

Low	Low
Existing Controls	**Proposed Controls**
• 5 - Administrative control measures: Mandatory safety orientation and training. Ensure all users are aware of the risk. • 3 - Isolation of risk: Charging the robot with chargers provided by the company.	

Risk Factor	8.1 - Experiencing or witnessing mental stress events (e.g. traumatic events)

Description

Participants who participate in the user study may experience stress if the robot acts unexpectedly.

- 1.0 - Fixed plant (e.g. cool rooms, fume cupboards, safety showers, boilers, lathes, lifts, gas mains, PET scanners) -- No
- 2.0 - Transport and mobile plant (e.g. motor vehicles, forklifts, walky stackers, trolleys and wheelbarrows) -- No
- 3.0 - Powered equipment, tools and appliances (e.g. computers, workshop equipment, kitchen equipment, gas cylinders) -- No
- 4.0 - Non-powered handtools and equipment (e.g. furniture and fittings, ladders, handtools, packing equipment, glassware) -- No
- 5.0 - Chemical materials (e.g. dangerous goods, hazardous substances, poisons and drugs) -- No
- 6.0 - Materials and substances (not otherwise selected from category 5.0) -- No
- 6.3 - Fire and smoke -- No
- 7.1 - Outdoor working environment (e.g. carparks, walkways, outdoor stairs) -- No
- 7.2 - Indoor working environment (e.g. internal rooms, floor surfaces, stairwells) -- No
- 8.5 - Biological materials (e.g. animals, non-living animal materials, microorganisms) -- No
- 8.4 - Personal impairment and/or interaction (e.g. pre-existing medical condition, assisting a patient) -- No
- 9.1 - Psychological (e.g. stressful situations) -- No

Low	
Existing Controls	**Proposed Controls**
• 5 - Administrative control measures: Mandatory safety orientation and training. Ensure they are aware of the risks. • 3 - Isolation of risk: Participants will be supervised when interacting with the robot. Supervisors will be there for emotional support and reassurance. • 4 - Engineering control measure: Estop button on robot to cut off motor power and stop the robot.	

Risk Factor	4.3 - Musculoskeletal stress from awkward posture or repetitive movements

Description

Sitting at a workstation for a long periods of times.

- 1.0 - Fixed plant (e.g. cool rooms, fume cupboards, safety showers, boilers, lathes, lifts, gas mains, PET scanners) -- No
- 2.0 - Transport and mobile plant (e.g. motor vehicles, forklifts, walky stackers, trolleys and wheelbarrows) -- No
- 3.0 - Powered equipment, tools and appliances (e.g. computers, workshop equipment, kitchen equipment, gas cylinders) -- No
- 4.0 - Non-powered handtools and equipment (e.g. furniture and fittings, ladders, handtools, packing equipment, glassware) -- No
- 5.0 - Chemical materials (e.g. dangerous goods, hazardous substances, poisons and drugs) -- No
- 6.0 - Materials and substances (not otherwise selected from category 5.0) -- No
- 6.3 - Fire and smoke -- No
- 7.1 - Outdoor working environment (e.g. carparks, walkways, outdoor stairs) -- No
- 7.2 - Indoor working environment (e.g. internal rooms, floor surfaces, stairwells) -- No
- 8.5 - Biological materials (e.g. animals, non-living animal materials, microorganisms) -- No
- 8.4 - Personal impairment and/or interaction (e.g. pre-existing medical condition, assisting a patient) -- No
- 9.1 - Psychological (e.g. stressful situations) -- No

Low	Low		
Existing Controls	**Proposed Controls**		
• 3 - Isolation of risk: Ergonomic office equipment (height adjustable tables/ monitors, chairs, mice)	Description	Responsibility	Target Date
	Taking regular breaks.	JENNY LAM	16/03/2022

Risk Assessment [Ref Number: 35700]

Date Printed: Friday, 8 April 2022

Risk Factor	7.1 - Fungi, viruses & bacteria and parasites

Description	
COVID-19	• 1.0 - Fixed plant (e.g. cool rooms, fume cupboards, safety showers, boilers, lathes, lifts, gas mains, PET scanners) -- No • 2.0 - Transport and mobile plant (e.g. motor vehicles, forklifts, walky stackers, trolleys and wheelbarrows) -- No • 3.0 - Powered equipment, tools and appliances (e.g. computers, workshop equipment, kitchen equipment, gas cylinders) -- No • 4.0 - Non-powered handtools and equipment (e.g. furniture and fittings, ladders, handtools, packing equipment, glassware) -- No • 5.0 - Chemical materials (e.g. dangerous goods, hazardous substances, poisons and drugs) -- No • 6.0 - Materials and substances (not otherwise selected from category 5.0) -- No • 6.3 - Fire and smoke -- No • 7.1 - Outdoor working environment (e.g. carparks, walkways, outdoor stairs) -- No • 7.2 - Indoor working environment (e.g. internal rooms, floor surfaces, stairwells) -- No • 8.5 - Biological materials (e.g. animals, non-living animal materials, microorganisms) -- No • 8.4 - Personal impairment and/or interaction (e.g. pre-existing medical condition, assisting a patient) -- No • 9.1 - Psychological (e.g. stressful situations) -- No

MONASH University

Risk Assessment [Ref Number: 35700]

Date Printed: Friday, 8 April 2022

Medium	Medium
Existing Controls	**Proposed Controls**
• 6 - Personal Protective Equipment: Wearing a mask according to guidelines recommended by Monash University and the Victorian Government. • 5 - Administrative control measures: Following vaccine and social distancing guidelines recommended by the Victorian Government.	

Appendix

Documents Referenced

Fetch User Manual
RA#: 17574 Fetch Robots
RA#: 31165 J.Santini
RA#: 29369 G10 RA
RA#: 22536 COVID RA

Risk Matrix Level	
Negligible	No additional control measures required
Low	Manage by routine procedures at local management level
Medium	Management responsibility must be specified and response procedures monitored
High	Senior management attention needed and management responsibility specified
Extreme	Immediate action required and must be managed by senior management with a detailed plan

o

9.3 Appendix B: Risk Management Plan

Non-OHS details all major project risks and their dependencies associated with the project, which can include delays and deadlines. The Risk Levels are determined by a Risk Assessment Matrix, Figure XX, which takes into account likelihood and consequence. A risk assessment table, Table XX, describes the non-OHS risks that are associated with this project and the mitigation strategies and residual risk.

Consequence and Likelihood	Insignificant	Minor	Serious	Disastrous	Catastrophic
Rare	L	L	L	L	M
Unlikely	L	L	M	M	S
Possible	L	M	M	S	H
Likely	L	M	S	H	E
Almost Certain	M	S	H	E	E

Figure 16. Risk Assessment Matrix

Table 6. Risk Assessment Table

Project Risk	Risk	Likelihood	Consequence	Risk Level	Mitigation	Residual Risk
Needing to recode existing functions	Less time to program new features	Possible	Serious	M	Observe Jake's code while it is being tested and reorganize functionalities that would be useful and not need to be changed and take note on functions that need optimizing using Jake as a resource while he is still completing the project.	The new features would not be as polished as they need to be, creating a pattern of future FYP schedules having to recode features in this project.

Coding of a subfeature takes longer than expected.	Delayed integration and testing of the full system.	Possible	Serious	M	To create a detailed list of what needs to be completed in order to complete a subfeature. Ask for advice from supervisors when stuck.	As a consequence of the delayed completed system then user study will not be conducted.
Time taken away from feature programming due non technical requirements	Quality of technical and non-technical requirement s are lacking.	Possible	Serious	M	Working on both tasks concurrently. Keeping detailed documentation during programming to make preparing non technical requirements easier.	
Not finding appropriate ROS / Fetch packages to perform needed tasks.	Needing to code functions to perform tasks.	Unlikely	Minor	L	Ask the supervisor for advice on a better way to go about the particular task.	Supervisors are unavailable and advice is not helpful. This should not be very likely to happen.
In person activities restriction due to COVID	Limited access to Robotic Lab for testing.	Possible	Minor	M	Working permits during restriction to allow for work in the Labs.	Based on previous projects, working permits were permitted so risk would be unlikely to occur.
Very few participants volunteer for	Data is not accurate due to small	Unlikely	Serious	M	To advertise to as many groups as possible.	Data is not accurate due to small sample size.

user study.	sample size.				To persuade participants using money rewards for their time. To determine the minimum number of participants needed to produce a viable study.	

9.4 Appendix C: Sustainability Plan

- Seager, Selinger & Wiek (2012)

When compared to *Business-as-usual* and *System Engineering,* Sustainable Engineering Science has a very agreeable approach to how it deals with complexity, which I believe is an important factor to sustainability. Its view of 'Anticipation, Adaptation and Resilience' allows for designs and processes to be able to face new information and challenges, meaning that the process would be more robust and have an increased longevity. When compared to the Business as usual approach, the view towards complexity means that there is a narrow focus which introduces obstacles and delays. Especially in very stressful times, with the very real issues of climate change, this mindset will not be able to survive. Similarly, for Systems Engineering, cost benefit and optimization is the main focus, this means that tradeoffs need to be made.

Further, more disagreeable in the Business-as-usual is the lack of consideration in environmental, social and at some levels economic issues. I believe that this is extremely detrimental to the issue of sustainability since it disproportionately benefits the rich who are mainly responsible for the current processes in place and keeps the poor poorer. However in Sustainable Engineering Science views engineering in a more holistic manner, considering the technical aspect but also the social, economical and environmental aspect.

The ethics behind Sustainable Engineering is quite interesting, in this model, ethics of technology is not viewed as very individualistic, where traditional norms allow individuals to use technology without adhering to social norms. In Sustainable Engineering, macroeconomics looks at how responsibility is left with the larger social, institutionalized groups who are responsible for developing these technologies. I think that this is important, because it places the responsibility of those who are in power to provide and design sustainable processes and doesn't shift the responsibility to their consumers.

- Sustainable Project Plan

For this Final Year Project, the development of task negotiation on the Fetch uses software. Sustainable Engineering in a software lense has slightly different metrics compared to a process based design.

Based on the GREENSOFT Model, the sustainability of software engineering can be observed and can be split into levels inspired by life cycle. For this project, the development stage looks at mainly the environmental impact to energy consumption used when programming and developing the functionality, which spans the majority of the time allocated for this project, this would include the energy to power devices and the transportation to campus. However, I believe that the environmental impact during the development stage is quite insignificant as there is only one person working on this project.

For the usage phase of this project, it would be assumed that Fetch performed in the case study with other human participants. Again, energy consumption would be considered, Fetch needs to be charged quite regularly and takes 3.5 hours to change to 90% capacity [40]. The social implications for this stage would include factors such as developing participants' trust in services robots which then could lead to greater implications for greater and normalisation human-robot interaction in the future.

In a more broader sense, this project explores the integration of robots into society. In this context, the issues of sustainable engineering can be explored. Since Robotics and Artificial Intelligence is quite a new area of research it has the most potential to develop new applications that can improve sustainability and quality of life.

The social implications of this project allows for the interaction between humans and robots in a domestic setting. For a service robot to perform household tasks means that it can relieve users from tedious routines and free up time for the individual. An important consideration of this project was that Fetch would be able to perform its tasks safely and efficiently and would be able to interact with people of all abilities and other life factors (age) .

Robotics, normally in the industrial setting, is associated with the improvement of efficiency of processes but at the same time increasing the unemployment rate of human labourers. The loss of employment due to robotics directly affects the economic and social model of sustainable development [41]. This can be seen in different ways, the first a reduction in paid workforce is a social impact but then the cost of producing the deliverable would be cheaper, which of course is an economic impact. A possible outcome of this project would be the slow reduction of cleaning staff needed for cleaning services, which can be already seen by the advancements in single function autonomous robots such as the Roomba, a vacuum cleaner robot and Robotic Lawn Mowers.

Furthermore, there is a cost of manufacturing the robots and requires sustainable solutions where the economic and environmental cost of manufacturing, maintaining and disposing of the robots needs to be considered. A very easy solution would be to reuse robots and allow them to adopt new functionalities [42]. For example, on the small scale, the Fetch Robot is used to perform different functions across the multiple Final Year Projects, this reduces the need for a new robot to be used for each project. However, for service robots in real life settings, robots that are designed for multiple tasks would be seen as more highly sustainable.