Heriot-Watt University

ROBOTICS PROJECT B31XP

Robotic Furniture - Fetch with Temi

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Introduction

The United Nations reports that the elderly population, aged 60 or above, is increasing at a quicker pace compared to all the younger age groups across the world. The World Social Report 2023 indicates that by 2050, the population of people over the age of 65 will reach 1.6 billion, which is more than double the current figure of 760 million [1]. This demographic shift has significant implications for healthcare systems, social services, and the economy as a whole, and will require new approaches and policies to address the unique needs and challenges of an aging population. This report also indicates that also indicates that the population of people over the age of 80 is growing at an even faster rate, with the number projected to reach 459 million by 2050, up from the current figure of 155 million. This demands for more care workers to support the elderly people. These statistics are shown in Fig. 1. Shortage of care workers will result in elderly people not receiving continuous support from the health carers and consequently it will start affecting the quality of life and the health of the elderly people. Hence some innovative technologies, such as using smart devices that can monitor health and other daily activities, smart furniture that can provide support for the elderly or personal robots that can provide essential services to the elderly people and providing continuous long term care, are required to handle this problem and making elderly people more independent and enhance their quality of life. This project aims at developing a smart cupboard, that can communicate with a telepresence robot, Temi, and these two together facilitate delivering the food or medicine at the proper time,to the users, who have limited mobility.

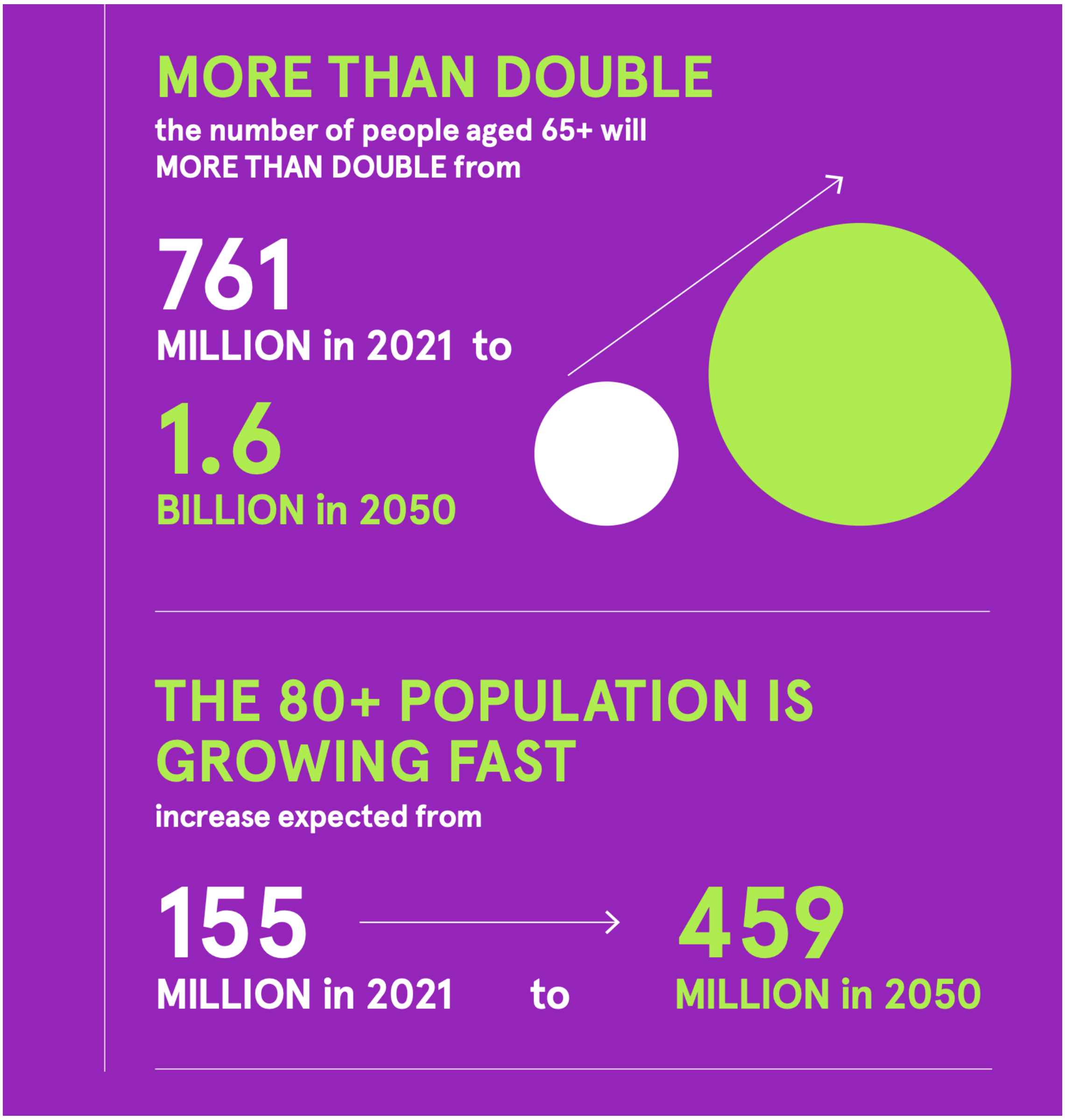

Fig. 1: Statistics of elderly [1]

Related Works

Service robots are a type of highly sophisticated robots, which are designed to provide assistance to individuals who live independently by helping them with mobility, household chores, and keeping track of their health and safety, and they require the ability to adjust to the user's environment in order to operate safely in human-centered surroundings, interact with people, and provide assistance with everyday activities. Research on using service robots to make the life of elderly people started around 1994 with the Movaid robot, which was a robot arm, designed for performing household activities, such as removing bed sheets [5]. The SERROGA research project in Germany, aimed to develop robot-based health assistance services for older people so that they can live independently in their homes for longer time. The robots were designed to adapt to the user's needs and preferences, and various skills and behaviors were developed, such as person detection, pulse rate monitoring, and navigation and the result indicate that older people found the personal robot assistant as a meaningful social companion[6]. Another service robot developed for elderly care, called Pearl robot, assisted elderly people in mainly two things, navigating through the rooms and providing reminders at correct time for medicine and food [7]. Fraunhofer IPA developed another service robot, Care-o-bot, which has 4 generations, assisted people as a guide in early generation in the form of an arm robot, to a tray mounted robot, which can carry medicines to the elderly people[8]. The GiraffPlus project, of EU FP7, developed a telepresence robot that allows remote visits for elderly individuals at home. Along with that, it utilizes a network of sensors to monitor activities within and around the home, as well as on the elderly person's body to extract valuable information [9]. Another research project, Mobiserv, developed a robot that can provide assistance to elderly in health, mobility and social interaction, by integrating with various sensors, smart devices and smart clothes, and thereby making their life independent [10]. Another research developed a prototype called KATE for aged care center environments, used Temi robots as mediators between elderly people, family members, and carers and thereby enabling seniors to contact family members and carers as needed.In this project, multiple IoT devices, such as smart phones, sensors, are integrated with Temi robot. In addition,family members can instruct Temi robots to track their seniors, while staff members can use their app to store and retrieve health data [11].

Methodology

Design Considerations

The core problem statement can be considered ”deliver items on request, via a telepresence robot configured without manipulators”.

The user interface was centered around the témi interface, robot control, with furniture side electronics designed to receive requests, orchestrate the furniture and confirm.

Fig. 2: Cabinet:(left top) Rack design; (left lower) Charger positioning bracket; (center) Témi parked at furniture.; (right) Frame design.

Mechanical loading was based on the rear shelf size of témi. A key design decision was to standardise the item(s) via the use of trays, to simplify furniture interfaces, while retaining flexibility to convey a broad range of items. This allowed more generalised evaluation of:

- **Item caching**: Number and method for storing trays.
- **Ease of loading**: Reduce risk of jolt or tip to varying weight distributions including liquids.
- **Stability in transit**: Allowing of varying weight distributions and possible liquid cargo.
- **Item restrictions**: Allowing of varying weight distributions and possible liquid cargo.
- **Return retrieval**: Allowing of varying weight distributions and possible liquid cargo.

The resulting implementation is based on:

- Vertical loading to enable a simplified locking mechanism, reconciling the *ease of load* and *stability in transit* requirements.
- Vertical caching - reduced staging complexity at the cost of constraining maximum capacity.

Cabinet

Material selection: As the load bearing extremity of the prototype, strength and capacity for future modification were priorities over controlling weight. The use of 25mm mild steel, permits drilling to accept fittings without adversely compromising integrity. Similarly, SBR rails provide strength and smooth vertical motion. While the the weight contribution is significant, the is engineered to support them. 3D printed PLA was used for the mounting bracket to iterative prototype the design. A lead screw and bearing, provide sufficient vertical travel, and remains in position without active power.

Design features:

- Charger positioning bracket, simplifies accurate and reproducible positioning of the charge. Correct distance and orientation to the frame is required as the charger in turn dictates the parking position of the témi robot. Parking stance is critical to correct loading and minimising collision risk between robot and furniture.
- Lead screw, bearing and stepper motor are positioned to the rear of cabinet, allowing vertical control without interference to the central rack, and keeping pinch hazards away from the user side of the cabinet.

- scissor arm (not installed), provide sufficient lateral movement of the trays in a format that can also be confined to the narrow recess at the cabinet rear.
- SBR rails control rack motion exclusively to vertical travel. Extending the length of installed rail, would allow additional carrying capacity, however distance between the top shelf and ground is considered a limiting factor before mandating additional design changes.
- Dimensions expansion capacity built in on the expectation that additional requirements may arise during prototyping. Additional detail can be found in Appendix 3, Fig. 13.

Ergonomics: To provide aesthetic compatibility with a broad range of settings, the sides, floor and top of the cabinet can accept bespoke dressing the coordinate colour and texture with target locations. A rendering with pine panels can be seen in Fig. 2 (right).

Rack

Material selection: Standardising on 25mm mild steel for consistency with the frame meets the requirements for strength and modification, however adversely increases weight. Alternate materials for future iterations would reduce torque required to drive the lead screw.

Design features:

- SBR Linear Shaft Bearings provide a rigid connection to the cabinet mounted rails, with smooth low Resistance travel.
- Three pairs of *Shelves* for storing and delivering trays. Current inter-shelf clearance of 100mm could be reduced in future to increase density.
- Soft close Steel Drawer Runners to rated to 45 Kg were used to enable lateral shelf tray movement, exceeding the requirement for a maximum témi shelf carrying capacity of 3Kg [12]. In practice, it was important to ensure sufficient and even outward pressure was maintained on the sliders to maintain bearing integrity.
- Dimensions expansion capacity built in on the expectation that additional requirements may arise during prototyping. If this is not used in future iteration, the total width should be reduced and spacers removed to optimise materials and reduce loading. Additional detail can be found in Appendix 3, Fig. 14.

Trays

CAD software is used to model the tray for the témi robot designing a tray that can serve breakfast, medicine, and other items to older people using the témi robot. The tray is 278 mm long and can be placed on furniture and then slid down onto the témi robot.

Material selection: A tray that will serve older people food, beverages, and medicines. Easy to clean and resistant to stains, odours, and bacteria, it is also affordable and recyclable. The material used for the tray is an important consideration, so we used Plastic material to develop the tray, which is light weighted to carry.

Design features: The tray has dual purpose handles or grips that act as the cabinet interface and also making it easier for older people to carry and manoeuvre. Handles are ergonomically created to provide a stable and comfortable grip. The tray also has raised edges or compartments to prevent items from sliding off. The raised edges did not have too high to avoid making it difficult for older people to access the items on the tray. Moreover, we made a témi holder and témi tray; the holder is screwed to the témi to avoid falling, and the tray sits on the holder and has a perfect like lock system. Moreover, we made a few trays that categorised breakfast, coffee, bowls and medicines and designed a hole for RFID Tag to fit so the témi robot could recognise which tray belonged to which.

Fig. 3: Trays: (left) témi tray mount; (center) Medicine tray.; (right) Drinks tray.

Ergonomics: It is essential to consider the ergonomics of the tray design. The tray is designed with a slight tilt to make it more comfortable for older people, reducing strain on their wrists and arms. The height of the tray is also optimised. It goes near the furniture cabinet, slides down, and drops on the robot to make it easy for the robot to take the tray.

Safety: Safety is an important consideration when designing any product; we designed it to remove sharp edges and make it non-slip surfaces or edges that prevent items from sliding off the tray. Moreover, we made a round surface tray that matches the témi robot. While it is navigating, it avoids collision with people.

Software

The Software part of this project involves three sections,

- The Android app and UI
- IoT Service
- Furniture Controller

The Android App and UI

The témi android app interacts with the témi SDK to create personalised tasks with the témi robot. The SDK enabled customization of the témi robot, from navigation control to NLP for voice assistance. This project makes use of the most recent version of the témi SDK, v1.130.4 [13].

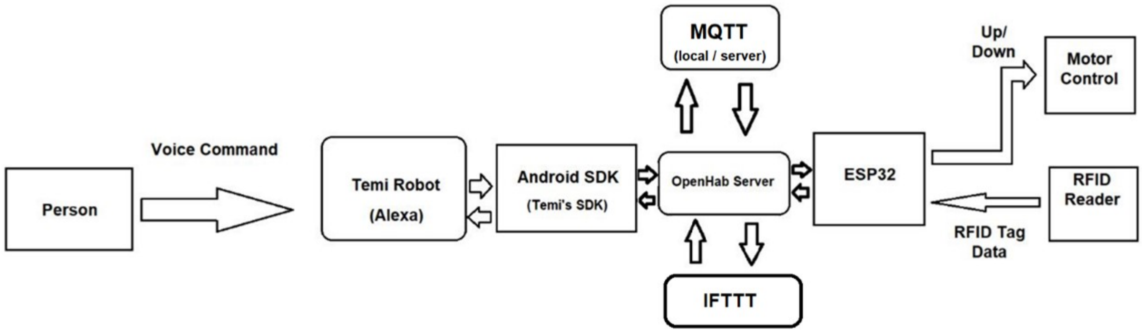

Fig. 4: Communication Flow Chart.

Receive Commands

One of the most important aspects of this project is customising voice commands to allow the témi robot to interface with the furniture. The témi robot includes built-in voice help - "Alexa" - in several languages [13] [2]. The asrResult method from the SDK is used to accept voice instructions after waking up témi to cover the voice flow in Launcher OS [13]. The asrResult is processed by NLP to train in voice commands, and related tasks for those instructions are done. And the robot.speak() is used to have témi respond to commands by speaking or to say messages using the TTS function from the témi SDK [13]. The example voice commands and replies used for testing are shown in Table 1.

When témi gets a command, it records the position where the command was received as the destination or obtains data from the destination to serve the tray in voice command and navigates to the destination after collecting it from the furniture.

Table 1: Témi Custom Voice Commands.

	Voice Commands	Response
1	"Bring me my Breakfast"	"Sure, please wait!"
2	"Bring me my medicine"	"Sure, I will get you in a minute"
3	"Bring me a coffee"	"Okay, Coffee is on its way!"
4	Default – when receives unknown commands	"Sorry I can't understand you, could you please ask something else?"

UI

The software designed to control témi has a simple and user-friendly layout. The UI is meant to allow direct interaction with the furniture via the button interface, which is represented by an image of the goods to be retrieved from the furniture. This project's prototype version has three trays that hold breakfast, medicines, snacks, and other items. Fig. 5 shows a user interface with buttons for interacting with the furniture. The app's number of trays as well as additional features can be adjusted.

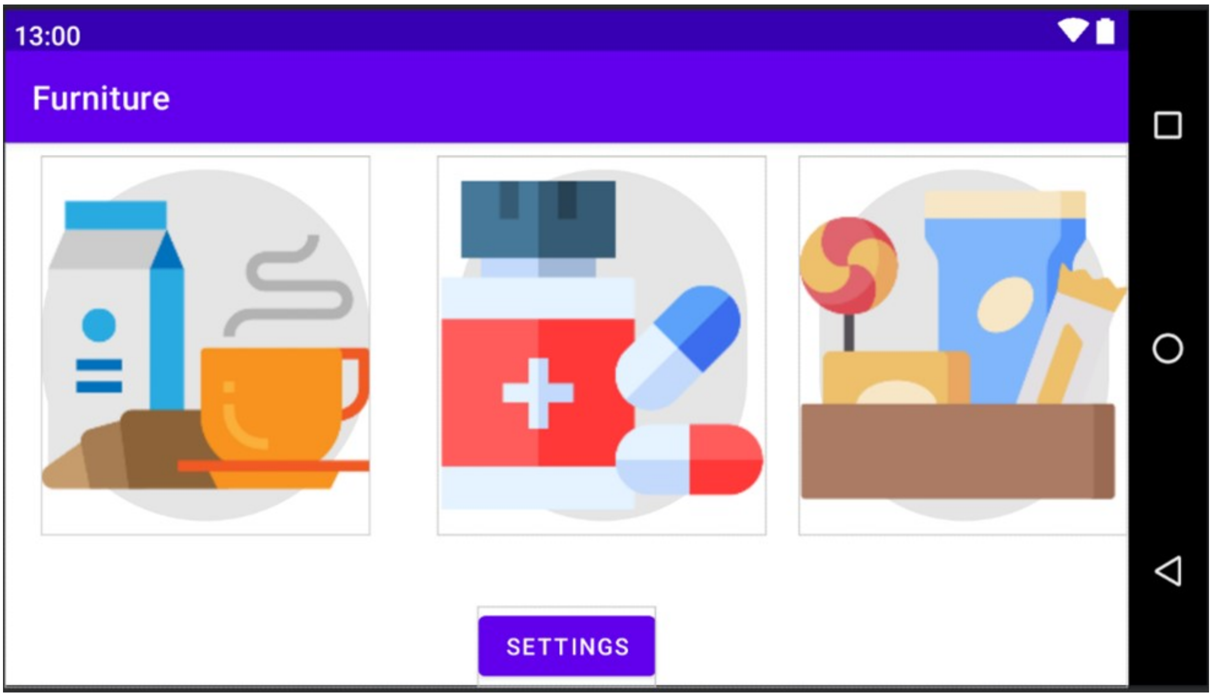

Fig. 5: Témi application UI.

IoT communication

To interact with the furniture, the Android app communicates with the openHAB IoT server through REST API. The REST API [14] may be used to quickly access the majority of openHAB products. OkHttp3 is used by the Android app to make REST API queries. OkHttp3 is an HTTP client that supports HTTP and curl commands and is the best option for posting or receiving REST API in an Android app [15]. This configuration is initially tested on a LAN network since openHAB REST API works properly in LAN networks as well, making it a backup network if the internet goes down. The openHAB REST API connects to the host server's local IP address using the curl command for REST API, which can be found on the openHAB dashboard [14].

Table 2: REST API communication in the app.

REST API	**Data shared**	**Example**
http://<localhost_ip>:8080/rest/items/post_furniture	Tray selected, arrival of témi	"T1","T2"; "arrived"
http://<localhost_ip>:8080/rest/items/get_furniture/state	State of furniture, task completed indication	"T1:ready"; "done"

IoT Service

MQTT broker provides the IoT service via openHAB IoT server. MQTT is a popular IoT messaging protocol due to its highly lightweight messaging (publish/subscribe) and low coding and network capacity requirements [16].

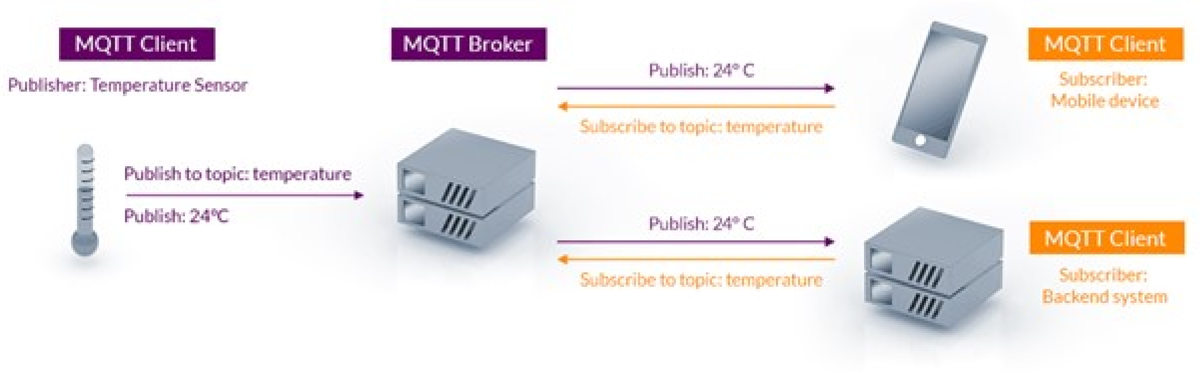

Fig. 6: Example of MQTT messaging [2].

A MQTT broker is used by the MQTT client to publish or subscribe messages to and from other subscriber clients. Fig. 6 shows an example of how the MQTT protocol works. The MQTT broker connects the two-subscriber client to the publisher client. The openHAB server is utilised as a MQTT Broker in this project to interact with témi and furniture. The openHAB server may also be linked to the openHAB cloud server for wide-area connectivity, allowing other users to operate and monitor the system from any location. To enhance the system's capabilities, the openHAB cloud may be linked to IFTT.

Furniture Controller

For IoT connectivity, the furniture is fitted with a node MCU esp32 microcontroller. The esp32 is linked to openHAB through the MQTT protocol. For communication, the MQTT network in this project employs "hw/robotarium/temi/input" as the subscriber topic and "hw/robotarium/temi/output" as the publisher subject. Table 3 data is utilised in the connection between témi and Furniture.

Table 3: MQTT communication in Node MCU esp32.

Action	Topic	Sender	Data
To get Tray 1	"hw/robotarium/temi/input"	Témi robot	"T1"
To get Tray 2	"hw/robotarium/temi/input"	Témi robot	"T2"
To get Tray 3	"hw/robotarium/temi/input"	Témi robot	"T3"
Arrival notification	"hw/robotarium/temi/input"	Temi robot	"arrived"
Furniture state	"hw/robotarium/temi/output"	Furniture	"ready"/"not ready"
Task completed	"hw/robotarium/temi/output"	Furniture	"Done"

"T1", "T2", and "T3" are obtained from the témi robot to signal the necessary tray, and the furniture processes it to feed it to the robot. The "arrived" data indicates that the furniture is ready to receive the tray. The "Furniture state" command is used to determine the condition of furniture. This returns "ready" when the furniture has received the data for the needed tray and the tray is ready to be served, and "not ready" when the furniture encounters a difficulty or errors while doing the operation. The action "Task complete" is used to inform the témi robot that the tray has been carefully put over the robot and that it is okay to move out of the furniture.

Electronics

Prior to the integration of our prototype, each component had to be tested separately to check whether they are working with the ESP32. This project consists of a RFID reader to detect the tags on every shelf of the cabinet, a stepper motor which is connected to the ESP32 via the DRV8825, and a servo motor for the sliding mechanism. The software used for the electronics section is Arduino IDE.

RFID Reader

The RFID Reader consists of seven various connections from the reader to the ESP32. The wiring diagram of the RFID Reader is shown below in Fig. 7.

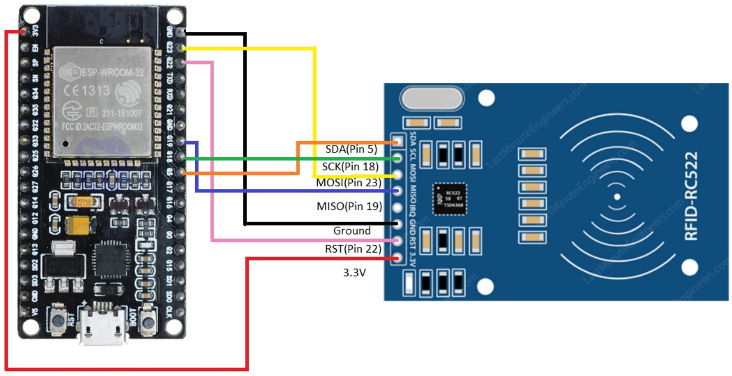

Fig. 7: RFID Reader Wiring Diagram

There are two critical components involved for the RFID, one component is referred to as the reader and the other component is referred to as the tags.The reader consists of an antenna that continuously emits radio frequency waves [3]. The tags consists of an antenna and a chip for the transmission of a signal and to also receive them [3]. Once the tag is close to the reader, the electrons are received by the antenna inside the tag and the chip inside the tag gets powered up [3]. The chip then sends back radio waves to the reader as an acknowledgement that it received the signal from the reader, and this mechanism is known as backscatter [3]. The technical specifications of the RFID Reader is provided below in Table 4.

Table 4: RFID Technical Specifications [3].

Item	**Value**
Frequency Range	13.56 MHz ISM Band
Host Interface	SPI / I2C / UART
Operating Supply Voltage	2.5 V to 3.3 V
Max. Operating Current	13-26mA
Min. Current (Power down)	10µA
Logic Inputs	5V Tolerant
Read Range	5 cm

Before making the connections of the RFID, it is important to understand the pinout module of the RC522 RFID Reader. The pinout module of the RFID Reader is shown below in Fig. 8.

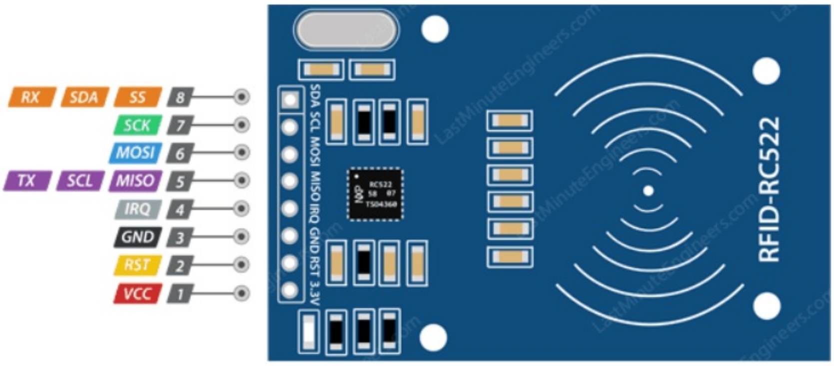

Fig. 8: RFID Pinout [3]

As observed from Fig. 8, there are eight various pinout for the RFID Reader. The purpose of each pinout is shown below in Table 5.

Table 5: RFID Pinout Purpose [3].

Pinout	Purpose
VCC	Supplies power to the module. This can be anywhere from 2.5 to 3.3 volts
RST	Input for reset and power-down. When this pin goes low the module enters power-down mode. Module is reset on the rising edge of the signal.
GND	Ground pin and needs to be connected to the GND
IRQ	Interrupt pin that alerts the microcontroller when an RFID tag is in the vicinity.
MISO/SCL/TX	Pin acts as master-in-slave-out when SPI interface is enabled, as serial clock when I2C interface is enabled and as serial data output when the UART interface is enabled.
SCK(Serial Clock)	Accepts the clock pulses provided by the SPI bus master, ESP32.
MOSI(Master Out Slave In)	SPI input to the RC522 module.
SS/SDA/Rx	Pin acts as a signal input when the SPI interface is enabled, as serial data when the I2C interface is enabled and as a serial data input when the UART interface is enabled.

While referring to the RFID Pinout Purpose in Table 5, it is also important to refer to the pinout of the ESP32, to make sure the wires are connected to the right pins [4]. The ESP32 pinout which has been linked to the RFID Reader is shown below in Fig. 9.

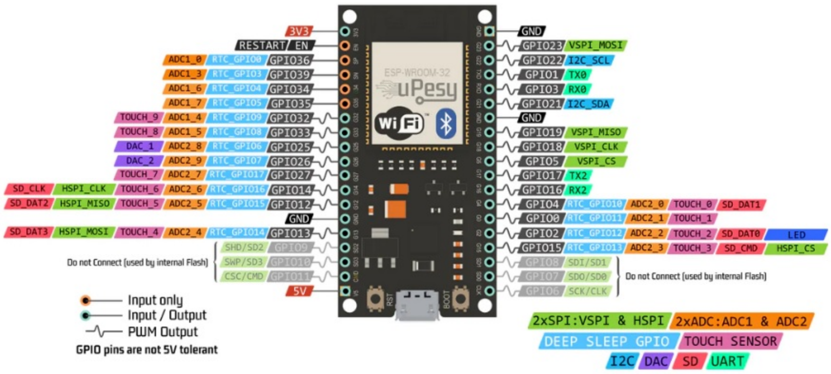

Fig. 9: ESP32 Pinout [4]

Stepper Motor

The Stepper Motor is connected to the ESP32 via the DRV8825 Stepper driver. The wiring diagram of the Stepper Motor via the DRV8825 Stepper driver is shown below in Fig. 10.

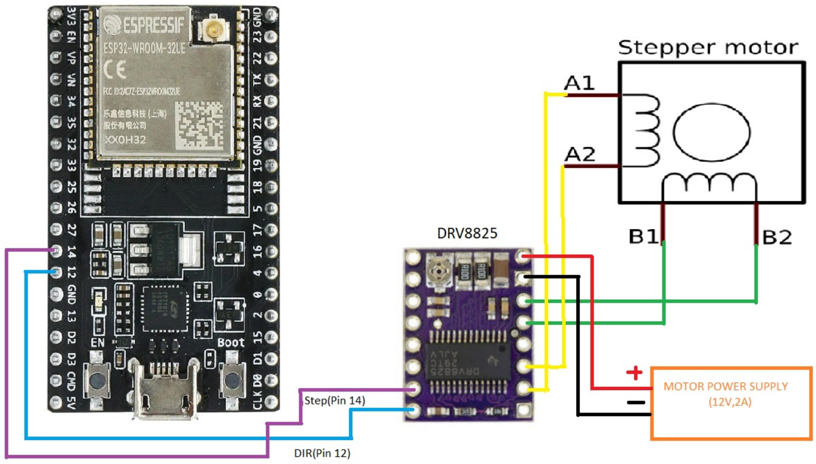

Fig. 10: Steppermotor Circuit Diagram

As observed from Fig. 10, the stepper motor consists of coils that needs to be energized and to receive pulses at a certain frequency [17]. The primary purpose of the DRV8825 stepper driver is to satisfy the high current requirements of the Stepper motor. The ratings of the stepper motor are 12V and 2A, which is provided by the power supply to the DRV8825 as shown in Fig. 10. There are two digital pins that are needed from the stepper driver to the ESP32, one is referred to as the STEP Pin and the other is referred to as the Direction Pin. The purpose of the Direction Pin is to control the direction the stepper motor should rotate, while the Step Pin is to control the number of Steps in a 360 degrees revolution.

Servo Motor

The wiring diagram of the Servo Motor to the ESP32 is shown below in Fig. 11.

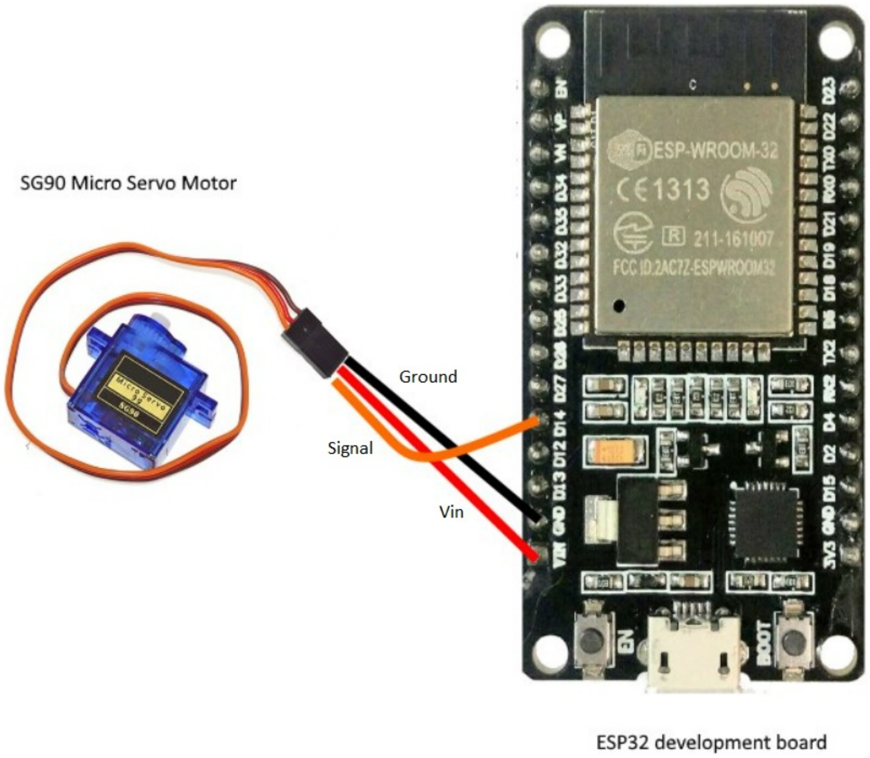

Fig. 11: Servo ESP32 Diagram

As observed from Fig. 11, the servo motor consists of three various pins. One pin is referred to as the VIN, the second pin is referred to as the Ground and the third pin is referred to as the signal. The ESP32 can power up the servo and the signal should be connected to a digital PWM (Pulse Width Modulation) Pin. Although, the ESP32 is enough to power up the Servo, but for safety reasons, a power supply of 5V and 1A can be used to power up the servo, with an additional wiring from the negative of the power supply, connected to the ground of the ESP32.

Experiments and Results

Témi Parking Test

To quantify the expected variation in témi loading stance, multiple leave and return journeys were conducted using four different waypoints. Variation in angle, and lateral position of the témi was used to mitigate collision risk by informing dimensions of the furniture travel, tray and tray mount. For example, the width of the rear mount stopper was reduced based on test data. Prior to the test, the témi charging station was positioned perpendicular to a reference point, and a template was marked to record centre, along with corresponding left and right edges of the témi tray. Testing conditions were reset after the first run, which indicated more precision was required in ensuring the charging station was perpendicular to the reference point. Measurements were taken relative to the leading edge of the témi tray to maximise offset resulting from both variation if angle and horizontal positioning.

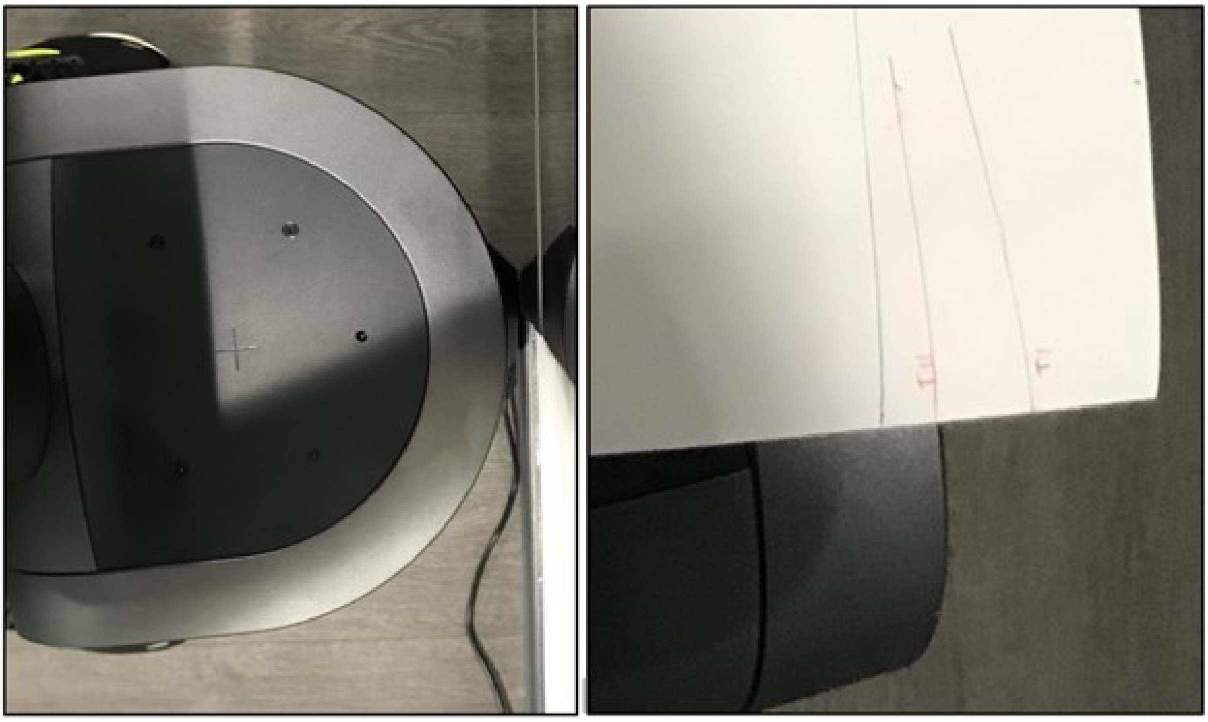

Fig. 12: Parked témi and Template marking test result.

Fig. 12 (left) shows the return stance of an outlying test result and the angle. The corresponding offset can be seen annotated as T11 on the paper template seen in Fig. 12 (right). Also shown is the annotation T1, which was discarded as a test setup artifact and provided critical insight to the sensitivity of initial test conditions.

Table 6: Summary of parking test results.

Waypoint	**Average Deviation**	**Mean offset(mm)**	**Comment**
kitchen	0.5	4.5	Short route
dining table	0.9	5.4	Medium route
sofa	2.5	7.6	Long route with multiple turns and unmapped obstacles.
sofa clear runs	1.5	5.7	Excludes sofa journeys that encountered unmapped obstacles.
entrance	2.3	3.4	Long Route

The test results summarised in Table 6, indicate that the témi robot is more precise and consistent that human positioning the charger. This highlighted the need for a reproducible charger position and resilience to accidental relocation in a home environment. Measurements showed highest variation on longer routes and where unmapped obstacles were encountered. Additionally, positioning bias towards the return direction was indicated.

Conclusion

Developing support systems that can help extend the duration independent living is critical for enhancing their quality of life and lowering the burden on healthcare systems and care services. The study detailed creation of a robotic furniture system that used a telepresence robot to acquire and distribute things from a smart closet. The system's user interface is user-friendly, allowing direct contact with the furniture via an image-based button interface. The smart furniture includes IoT connectivity and RFID technology, allowing users to grab objects without moving around their living areas. While the system appears to be promising, there are still limits that must be addressed in future design iterations to ensure its effective integration and operation. Overall, the development of smart furniture systems and service robots has the potential to address the demands of an ageing population while also improving their independence, convenience, and quality of life.

Limitations and Future Works

We see the next priority for future work as a safety evaluation, which should in turn be used to inform the next iteration of design. Two specific area for attention are the pinch hazard presented from the scissor mechanism used for lateral draw extension, and collusion hazard mitigation related to the racks vertical travel. Pending results from a safety evaluation, integration of components such as card reader, shelf extender and limit switches should be completed. Currently there are fixed tray references without user flexibility to redefine. Software enhancement could readily allow user defined tray names that link to RFID encoded cards. The app's number of trays as well as additional features can be adjusted. Additional work is proposed to enhance control over position and stance of the robot when returning with a loaded tray. This is seen as critical to increasing the utility to a broader range of users and levels of mobility. Performing a user evaluation is also seen a key next step to inform further development, and should be used to set feature priorities. As a minimum, both operators and carers should be considered as user groups. In addition to ensuring the furniture is fit for purpose, results might also be considered based on probability of influencing product adoption potential outlined in Rogers innovation theory [18].

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Appendix A - Source File Link

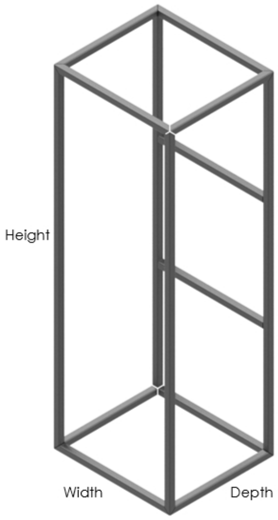
Source files can be found at:

https://www.notion.so/Source-Files-1da1591b836d4cac92d70754738981cb?pvs=4

Summary of archives:

- UI and témi source code.
- ESP32 source code.
- Tray and tray mount CAD files.
- Frame, rack and charger bracket CAD files.
- Frame and rack dimensions.
- Temi parking test results.

Appendix B - Criteria for Cabinet Measurements

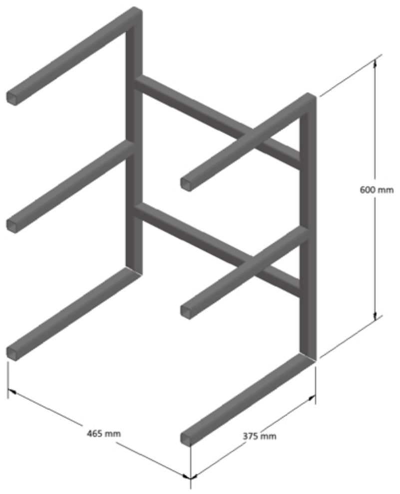


Height	(mm)
Space for items on top shelf	300
Shelf middle to upper	300
Shelf lower to middle	300
Temi Tray height	720
Spacing	30
Total Height	**1650**

Depth	(mm)
Frame Material thickness	30
Vertical mechanism	80
Clearance	10
Shelf frame thickness	20
Slide Length	350
Frame Material thickness	30
Total Depth	**520**

Width	(mm)
Left Frame Material thickness	30
Left Travel clearance	33
Left Shelf material	20
Left Rail width	13
Left Shelf arm	5
Left Temi positioning margin	50
Temi width	278
Right Temi positioning margin	50
Right Shelf arm	5
Right Rail width	13
Right Shelf material	20
Travel clearance	33
Right Frame Material thickness	30
Total Width	**580**

Fig. 13: Fundamental frame sub-dimensions.



Height	(mm)
Shelf middle to upper	300
Shelf lower to middle	300
Total Height	**600**

Depth	(mm)
Shelf frame thickness	20
Slide Length	350
Total Depth	**370**

Width	(mm)
Left Shelf material	20
Left Rail width	13
Left Shelf arm	5
Left Temi positioning margin	50
Temi width	278
Right Temi positioning margin	50
Right Shelf arm	5
Right Rail width	13
Right Shelf material	20
Total Width	**464**

Fig. 14: Fundamental rack sub-dimensions.