

# IMPLEMENTATION PHASE OF THE ELDERLY CARE COMPANION ROBOT



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# **Implementation Phase of Elderly Care Companion Robot**

Submitted to the Mechatronics and Control Engineering Department  
of the University of Engineering and Technology Lahore  
In partial fulfillment of the requirements for the degree of

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**in**

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## Declaration

The work cited in this report, titled as “*Implementation Phase of Elderly Care Companion Robot*”, has been performed as necessary requirement for the completion of bachelor’s degree in Mechatronics and Control Engineering at UET Lahore. We declare that the work was performed by us and not copied or outsourced. Furthermore, we declare that the work will not be used for commercial purposes without prior written consent of the project advisor and the department.

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**Dedicated to all the Elderly living alone**

# Contents

FYP Poster .....	5
Abstract .....	6
Graphical Abstract .....	7
List of Figures .....	8
List of Tables .....	9
List of Abbreviations Frequently Used.....	9
Chapter 1 .....	11
Introduction.....	11
1.1. Introduction to the Problem, Possible Solutions and Current Research .....	11
1.1.1. Population Ageing.....	11
1.1.2. Loneliness as a Result of Ageing.....	12
1.1.3. Profound Challenges due to Loneliness.....	12
1.1.4. Problem Statement .....	13
1.1.5. Suggested Solutions to Alleviate Loneliness .....	13
1.1.6. Socially Assistive Robots (SARs): An Optimal Solution .....	13
1.1.7. Functional Requirements of a SAR.....	14
1.1.8. User Perception and Acceptance of SAR Subject to Almere Model .....	14
1.1.9. Solution Statement of the Project under Consideration .....	15
1.1.10. Advancement and Undergoing Research in the domain of SARs .....	15
1.1.11. Ethical Theories for SARs .....	16
1.1.12. Concluding Remarks.....	17
1.2. Introduction to the Current Report.....	18
Chapter 2.....	19
Literature Review.....	19
2.1. Brief Account of Literature Review.....	19
Chapter 3.....	25
Materials and Methodology .....	25
3.1. Gantt Chart.....	25
3.2. Methodology Summarized as flowcharts.....	25
3.3. Hardware Components Chosen.....	26
3.3.1. Kobuki TurtleBot2 .....	26
3.3.2. Jetson Nano Developer Kit .....	26
3.3.3. Depth Cameras.....	27
3.3.4. Motors for Pan, Tilt and Arm Motions .....	29
3.4. Navigation.....	30

3.4.1.	Implementation .....	30
3.4.2.	Testing.....	34
3.5.	Human Robot Interaction.....	34
3.5.1.	Voice Interaction.....	34
3.5.2.	Facial Expressions.....	35
3.6.	Embodiment and Mechanisms .....	36
3.6.1.	Design Considerations for a Care Companion Robot .....	36
3.6.2.	Final Assembly of the Robot .....	36
3.7.	Robot Architecture.....	39
Chapter 4.....		40
Results.....		40
4.1.	Mobility (SLAM).....	40
4.1.1.	Simulation and Real-time Testing.....	42
4.1.2.	Navigation Results in a Specified Environment .....	43
4.2.	Neck Design.....	44
4.2.1.	Neck Range of Motion.....	45
4.2.1.1.	Pan Motion Range .....	45
4.2.1.2.	Tilt Motion Range .....	46
4.2.1.3.	Robot's Perspective subjected to the Designed Tilt-Pan Range .....	46
4.3.	Voice Interaction.....	49
4.3.1.	Natural Responses Generated by ChatGPT .....	49
4.3.2.	Response to the Pre-fed Data .....	50
4.4.	Robot's Facial Expressions .....	51
4.5.	Micro Gestures .....	52
4.6.	Improvements.....	53
4.7.	Summary .....	54
Chapter 5.....		55
Conclusion and Future Recommendations .....		55
5.1.	Conclusion .....	55
5.2.	Future Work.....	56
Chapter 6.....		57
Societal Impact of the Work .....		57
6.1.	PESTEL Analysis .....	57
6.2.	Impact of the Project.....	61
Table14. Societal Impact of the Project .....		61



Chapter 7.....	62
Environment and Sustainable Development Goals.....	62
7.1. UN SDGs .....	62
7.2. Impact of Project on Environment and LCA .....	64
Chapter 8.....	65
Life-Long Learning and Future Recommendations .....	65
8.1. Individual Contributions to the work.....	65
8.2. Life Long Learning .....	66
Chapter 9.....	67
Business Plan of the Product.....	67
9.1. Cover Sheet: Business Name, Address, Phone Number, Principals .....	68
9.2. Statement of Purpose .....	70
9.3. The Business .....	71
9.3.1. Business Description.....	71
9.3.2. Description of the Product .....	71
9.3.3. Market Analysis .....	72
9.3.4. Marketing Plan.....	73
9.3.5. SWOT Analysis .....	76
9.3.6. VRIO Analysis.....	77
9.3.7. Competition.....	78
9.3.8. Management and Operations .....	79
9.4. Financials .....	81
9.4.1. Break Even Analysis.....	81
9.4.2. Sources and Uses of Funds .....	81
9.5. Business Model Canvas .....	82
References.....	83
A. Work Cited.....	83
B. Further Reading .....	87
C. Bibliography .....	87
Appendices.....	89
Appendix A: Survey Questions, Technical Specifications and Circuit Diagram .....	89
A.1. Survey Questions .....	89
A.2. Technical Specifications .....	89
A.2.1. Kobuki Base.....	89
A.2.2. Jetson Nano Developer Kit .....	89
A.2.3. Intel RealSense Depth Camera D435i.....	90

A.2.4. Servo Motor Driver Module PCA9685 .....	90
A.2.5. RC Geared Servo Motor MG996R.....	91
Appendix B: ROS Architecture Nodal Maps.....	93
B.1. Representing all Publisher Nodes, Subscriber Nodes, and their Interconnectivity .....	93
B.2. Representing all ROS Topics .....	94
B.3. Representing all Active Topics .....	94
Appendix C: Testing Protocols, Python Codes, and ROS/SLAM Instructions .....	95
C.1. Testing Protocols.....	95
C.1.1. Mobility Testing .....	95
C.1.2. Neck Design Testing.....	95
C.1.3. Voice Interaction Testing .....	95
C.1.4. Expression Testing .....	95
C.1.5. Micro Gestures Testing .....	95
C.2. Python Codes Used for Testing and Demonstration .....	95
C.2.1. Chatbot of the Robot .....	95
C.2.2. Robot’s Responses to the pre-fed data .....	96
C.2.3. Use Case Scenario 1: Robot Introduction .....	97
C.2.4. Use Case Scenario 2: Robot Cooking .....	100
Appendix D: Instructions for Starting with ROS and Kobuki with ROS .....	103
D.1. Starting with ROS and Jetson Nano.....	103
D.2. Starting with Kobuki with ROS Melodic.....	103
Appendix E: Gait Analysis Data Acquisition .....	105



# Implementation Phase of the Elderly Care Companion Robot

Supervisor: Dr. Ali Raza

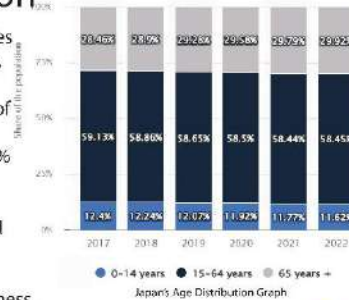
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**Mechatronics**  
MECHATRONICS & CONTROL ENGINEERING

## Introduction

In East Asian countries like Japan and China, one-third of the population consists of elderly individuals. Shockingly, up to 45% of them experience social isolation, resulting in profound neuropsychological challenges such as depression, loneliness, and even tragic spikes in suicide rates. Elderly Care Companion is a beacon of hope driven by robotics and artificial intelligence. With personalized companionship, assistance, and steadfast support, Elderly Care Companion aims to uplift the well-being and quality of life of seniors, ensuring they live their golden years to the fullest.

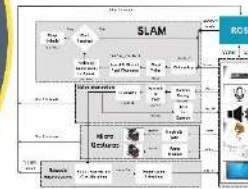


## Aims and Objectives

- 01 Conduct research on elderly challenges through surveys.
- 02 Design and develop a human-centered robot.
- 03 Integration of micro gestures, promoting a sense of connection.
- 04 Real-time testing and evaluate impact on elderly.
- 05 Address technical and ethical issues.

## Key-Features

- Human-Centered Design
- Autonomous Architecture
- Voice Interaction
- Robot Expressions
- Personalized Care

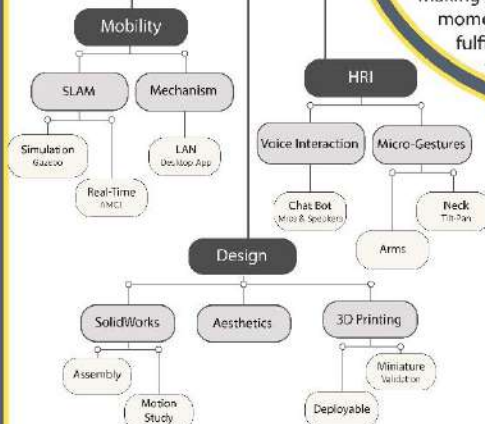


## Abstract

An ultimate care companion for seniors. Powered by AI and robotics and designed with user centered principles, it offers intuitive features like responsive socialization and personalized care, Fostering well-being of the elders, promoting meaningful connections, making their every moment vibrant, fulfilling, and alleviating the feelings of isolation.

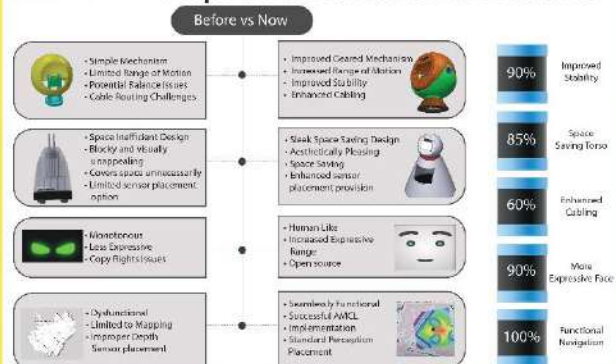


## Methodology



Our care companion robot possesses a sophisticated technical architecture to ensure smooth functioning of the robot while keeping intact all of the governed features.

## Improvements and Results



## References

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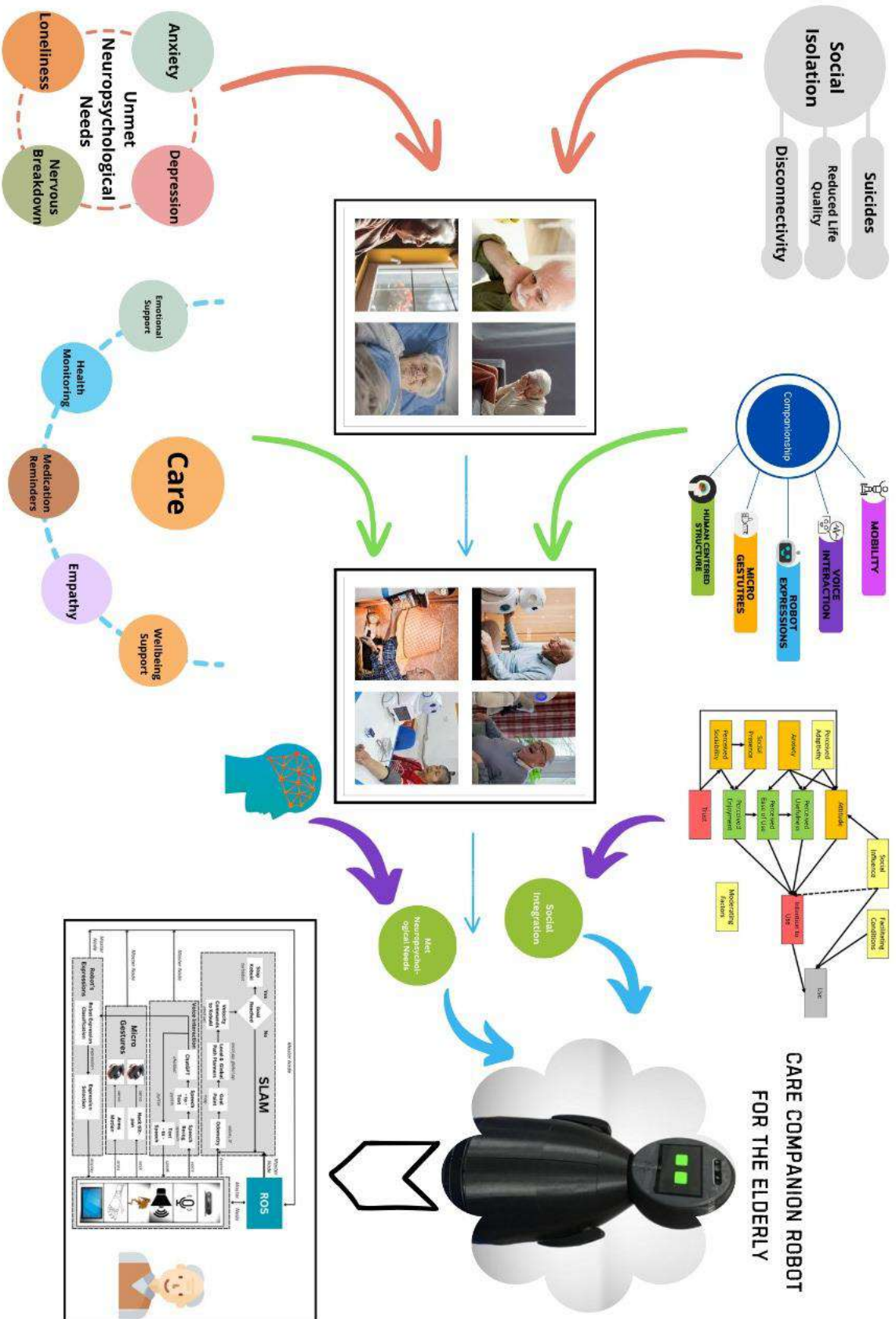
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## **Abstract**

In East Asia and Central Europe, about 1/3<sup>rd</sup> of the population consists of elderly individuals. Up to 45% of them experience social isolation, resulting in profound neuropsychological challenges such as depression, anxiety, and even tragic spikes in suicide rates are observed. The suggested solution of this problem is an Elderly Care Companion Robot. Keeping in view the Almere Model of Robot Acceptance, the social, artistic, philosophical and psychological aspects of the robot has been fabricated. Based on the human centered principles, the embodiment and mechanisms have been designed for seamless navigation, a humanoid appearance and smooth movements. Secondly, the facial expressions and micro-gestures were coupled effectively with voice interactions. At last, the navigation and joint movements were rigorously simulated and evaluated under various case scenarios. In conclusion, the robot has shown a navigation accuracy of 95%, and a smooth neck joint movement. Through enhanced facial expressions and micro-gestures it has increased user interaction up to 80%. Hence, the robot has the capability to uplift the well-being and quality of life of seniors, ensuring they live their golden years to the fullest. In future, it can be extended to a full fledge care provider with vitals sensors and medication reminders along with spillage and gas leakage detection.

**Keywords:** Care Robots, Aging World, ROS (Robot Operating System), Navigation, TurtleBot, Sociability, Robot Neck Mechanism, Facial Expressions, Micro-Gestures, Almere Model



## List of Figures

- Figure 1.** World Median Age 2020 (Source: UN Population Division (Median Age [63]))
- Figure 2.** Relation between loneliness and ageing
- Figure 3.** Almere Model for Elderly Acceptance of SARs [49]
- Figure 4.** A variety of Care Robots used in East Asia and Western Europe (photos by Kodate) [64]
- Figure 5.** Gantt chart of the Project Journey
- Figure 6.** Project Simplified Methodology
- Figure 7.** Technical Aspects of the Methodology
- Figure 8.** Kobuki TurtleBot2 by Yujin Robotics
- Figure 9.** Jetson Nano (Source: developer.nvidia.com)
- Figure 10.** Xbox 360 Kinect (Left) and Intel Realsense d435i (right)
- Figure 11.** Cameras' Placement, Current Progress in Blue Blocks, Future Possibilities in Green Blocks
- Figure 12.** A pair of Servo Motors (left) and Stepper with Brackets (right)
- Figure 13.** Procedural Diagram for Mapping and Implementing SLAM
- Figure 14.** Collage of various Navigation Based Scenarios at Multiple Locations
- Figure 15.** Generalized Working of Navigation Stack
- Figure 16.** Working of AMCL Algorithm
- Figure 17.** Human Robot Interaction Work Flow
- Figure 18.** Various Robotic Facial Expressions
- Figure 19.** Basic Design Procedure
- Figure 20.** CAD Model for final Design (Left), Actual Final Design (Right)
- Figure 21.** (From Left to Right) Previous design, 2<sup>nd</sup> Iteration (only up to CAD Model), Final Design
- Figure 22.** Pan Mechanism
- Figure 23.** Tilt mechanism.
- Figure 24.** Proper cable management in head support (left) and head (with upper skull removed)
- Figure 25.** A portrayal of all the Robot Functionalities, w.r.t ROS as master controller
- Figure 26.** Limited Map of Robotics Lab, DMCE UET Lahore
- Figure 27.** Full Fledged Map of IHYA Lab
- Figure 28.** Full Fledged and Smoothened Map of Design Centre Lab
- Figure 29.** Gazebo Simulated Environment for SLAM Testing
- Figure 30.** Real time Implementation of SLAM at IHYA Lab
- Figure 31.** Real time SLAM Implementation in Design Center Lab
- Figure 32.** Grid View (12X7 feet) of various experimental setups,
- Figure 33.** Previous Work (Unstable Neck)
- Figure 34.** Iteration1 and Iteration 2 (Neck Joints)
- Figure 35.** Iteration 3 and Iteration 4 (Final) for Neck Joints
- Figure 36.** Field of View with Pan angles 0 and 180 deg.
- Figure 37.** Field of View with Tilt angles 0 and 50 deg.
- Figure 38.** Top View of the Robot's Perspective Hyperplane
- Figure 39.** Side View of the Robot's Perspective Hyperplane
- Figure 40.** Collage of different extreme and mean points of the robot's perspective
- Figure 41.** Collage of robot's face expressions demonstration in real-time
- Figure 42.** Collage of robot's micro-gestures movements (arms and neck)
- Figure 43.** Progress Before vs. Now
- Figure 44.** Success of Current Project
- Figure 45.** Future Work Recommendation Flowchart
- Figure 46.** Interconnected Network of PESTEL Factors
- Figure 47.** Description of Political, Social, Economic, Legal, Technical and Environmental Factors
- Figure 48.** Life Cycle Analysis (LCA) of the Robot

**Figure 49.** High Fidelity Prototype with all the basic functions running  
**Figure 50.** Market of SAR's  
**Figure 51.** Current and Future Market size of SAR's  
**Figure 52.** Marketing Plan  
**Figure 53.** Marketing Methods  
**Figure 54.** Initial Web Page Design  
**Figure 55.** General Aspects of SWOT Analysis  
**Figure 56.** General Framework of VRIO Analysis  
**Figure 57.** Price vs. Features Plot for Some of the contemporary solutions  
**Figure 58.** Operational Workflow  
**Figure 59.** Hierarchal Map  
**Figure 60.** Break-Even Analysis  
**Figure 61.** Estimated Division of Income and Expenses  
**Figure 62.** Business Model Canvas

## **List of Tables**

**Table 1.** Some examples of robotic technology in use and under research in elderly care  
**Table 2.** Exemplary ethical design frameworks from both schools of machine ethics  
**Table 3.** An example use of the value tool table  
**Table 4.** Comparison of Various Tech-Driven Current Solutions based on literature review  
**Table 5.** Comparison of Various Solutions with Suggested Solutions  
**Table 6.** Comparison on Intel Realsense and Xbox 360 Kinect  
**Table 7.** Case Based (Controlling Neck Movements) Comparison of NEMA-17 and MG996 Motors  
**Table 8.** Information about the Navigation Process  
**Table 9.** Comparison of Chat GPT and Gemini  
**Table 10.** Comparison of three facial expressions  
**Table 11.** Results of a few test runs for SLAM in real-time specified environment  
**Table 12.** Results of robot's chatbot corresponding to the natural commands and respective prompts  
**Table 13.** Pre-fed dataset for robot's voice interaction testing  
**Table 14.** Societal Impact of the Project  
**Table 15.** UN Sustainable Development Goals Mapping with reference to Project  
**Table 16.** Impact of Project on environment  
**Table 17.** Simplified Business Description  
**Table 18.** Simplified Product Description  
**Table 19.** Marketing Plan Description  
**Table 20.** SWOT Analysis of this Business  
**Table 21.** VRIO Analysis of this Business  
**Table 22.** Comparison of Robots for Elderly Care

## **List of Abbreviations Frequently Used**

**ROS:** Robot Operating System  
**SAR:** Socially Assistive Robot  
**SDG:** Sustainable Development Goal  
**LCA:** Life Cycle Analysis  
**SWOT:** Strengths, Opportunities, Weaknesses, Threats  
**VRIO:** Value, Rarity, Imitability, Organization  
**BMC:** Business Model Canvas

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# Chapter 1

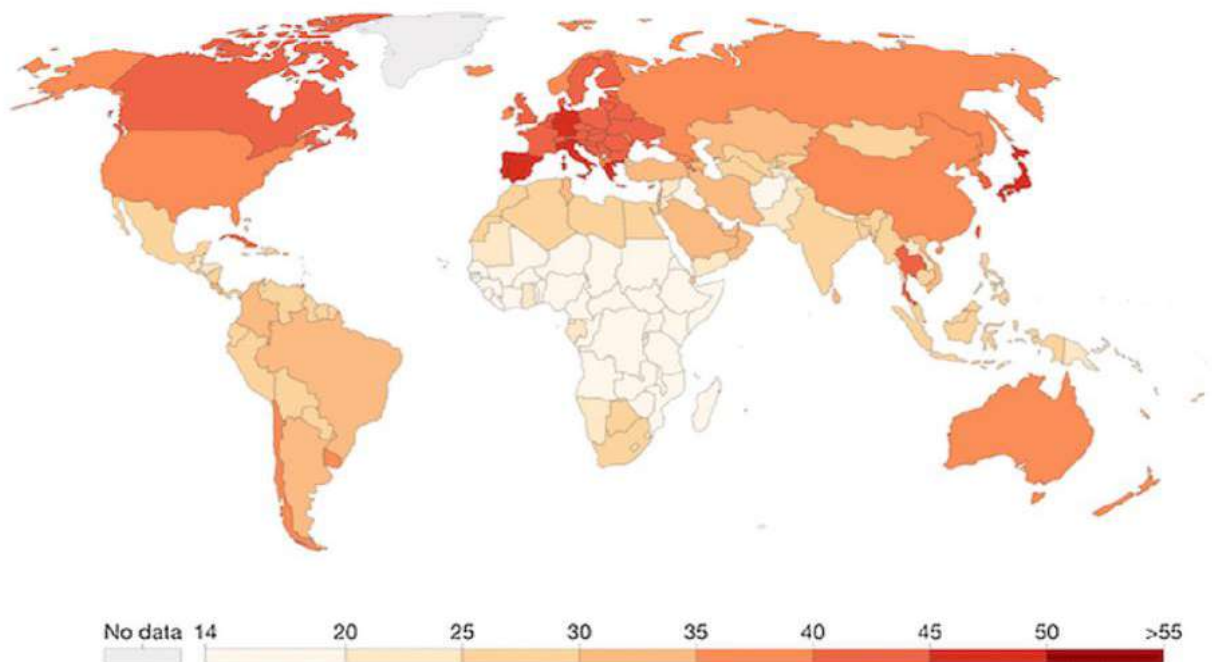
## Introduction

### 1.1. Introduction to the Problem, Possible Solutions and Current Research

#### 1.1.1. Population Ageing

The world is aging. As a result, many countries are facing a demographic shift, i.e. their elderly population is expanding at a high rate [1]. The number is projected to increase by 16% between 2019 and 2050 globally [2]. Statistics [3] show that the elderly population in Europe, US and Canada will constitute 29, 22 and 25 percent respectively of their total population [3– 5]. The cognition and perception along with physical abilities decrease with age, hence casting a social and financial burden, not only on the families but the governments as well [2,6]. AI and Robotics are on the top counter these challenges [7– 9]. It is estimated that by 2060 almost 30 percent of Europeans would be aged over 65. Currently, Italy and Spain are the countries with the most elderly population in Europe, with 18 and 20% respectively. [10]

The median age on the world political map in figure 1 shows regions including East Asia and Mainland Europe are facing the demographic shift more adversely.



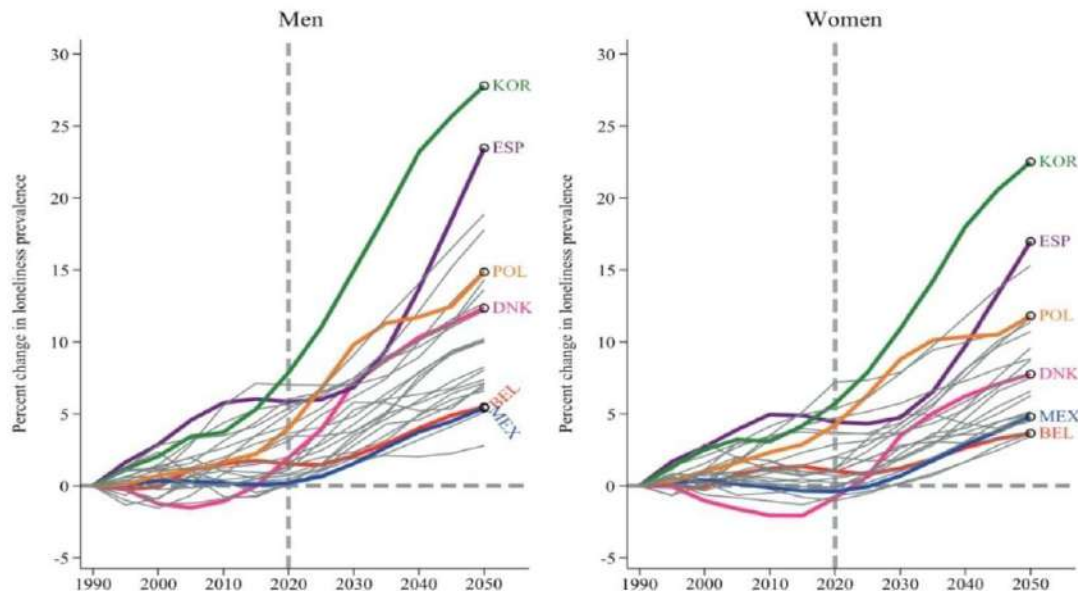
**Figure 1.** World Median Age 2020 (Source: UN Population Division (Median Age [63]))

### 1.1.2. Loneliness as a Result of Ageing

With ageing, comes another issue that is loneliness and it in turn brings a lot of other issues as well.

As reported by various research organizations more than forty percent of adults aged 45 or more experience loneliness while more than twenty five percent of adults above 65 are isolated socially [11].

Figure 2 portrays the increasing loneliness indices, both in men and women in the regions, previously focused (East Asia and Europe).



**Figure 2.** Relation between loneliness and ageing

### 1.1.3. Profound Challenges due to Loneliness

The elderly are pruner to the risks caused due to loneliness and social isolation.

Recent studies [11] on elderly found that social isolation and loneliness results in:

Increased Risk of Premature Death

- 50% Increased risk of dementia by 50%
- Increased risk of heart disease and stroke by 29% and 32% respectively
- Higher rates of depression, anxiety, and even suicide
- About four times increased risk of death
- 68% increased risk of long-term hospitalization
- 57% increased risk of emergency department visits

In the words of Steve Cole, Ph.D., directing Social Genomics Core Laboratory at the UC LA, loneliness acts as a catalyst for other diseases [40]. Appliance of high-tech devices is being thought upon in medical and technological spheres [12]. Robotics and Information-Communication Technologies are evolving these days in the field of senior healthcare [13].

#### 1.1.4. Problem Statement

After a prolonged phase of reflection and creative exploration, the following problem statement has emerged.

"Addressing the escalating problem of social isolation and unmet care needs among the elderly in Europe and East Asia is crucial to prevent loneliness which causes depression, anxiety, and long-term neuro-psychological issues."

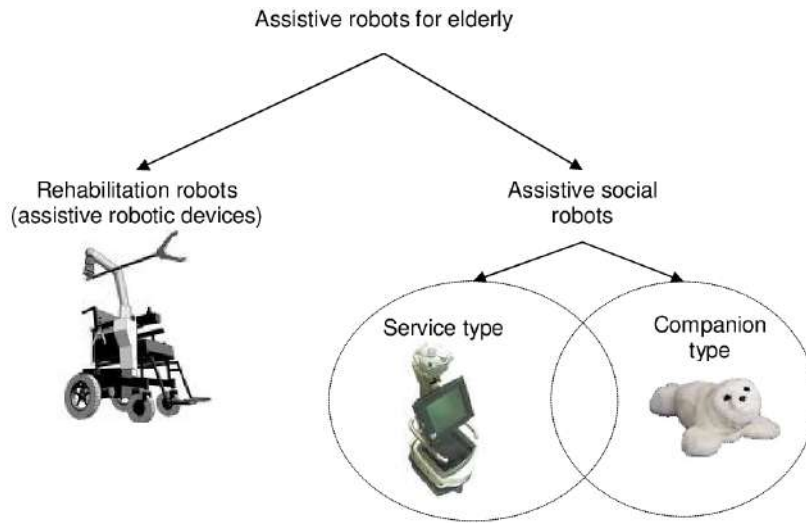
#### 1.1.5. Suggested Solutions to Alleviate Loneliness

While the issues of ageing and loneliness prevail, the costs of healthcare in the grey society are increasing dramatically, and soon there will be not enough resources and people for care. This matter requires an evolutionary and emerging boost in the technology industry, robotics, for instance [14] that has been evolving quickly over the time passage. Like in many different fields of medicine and healthcare, their use is becoming mandatory [15].

#### 1.1.6. Socially Assistive Robots (SARs): An Optimal Solution

Recently, as in COVID-19 pandemic, SAR's have emerged on the scene to be the safer service providers, especially in elderly care [16-18]. Moreover, Japanese and Europeans have started to accept and focus the development of the SAR's industry [19-22] as they have proven and tested to be able to help in daily chores [23], risk detection [24], medication reminding [25, 26], and health monitoring [27-31].

Interactions between care robots and the elderly have been showcased in a number of studies. For instance, the study in [32] presented a comprehensive impact of SAR on the elderly life, while SAR's are proved to be the elderly's preferred companion in future [33], along with lessening the burden on caregiver. Care Robots were found friendly and acceptable to a large extent in [34], while the subjects in [35] mostly believed them to decrease isolation and anticipated them as a source to improve mood. Current implemented robots for such purposes are Pearl [36], the iCat, and the Care-o-bot [37]. Another example is the Italian Robot-care project [38].



**Figure 3.** Categorization of assistive robots for elderly

As in Figure 3, there is an overlapping region between Service Type and Companion Type Robots, and the authors of current report aim to fit a solution there, namely a Care Companion Robot.

### 1.1.7. Functional Requirements of a SAR

As per the conclusion of a survey, conducted by S. Huston [42], a SAR has the following functionalities that makes it able to be accepted by the elderly:

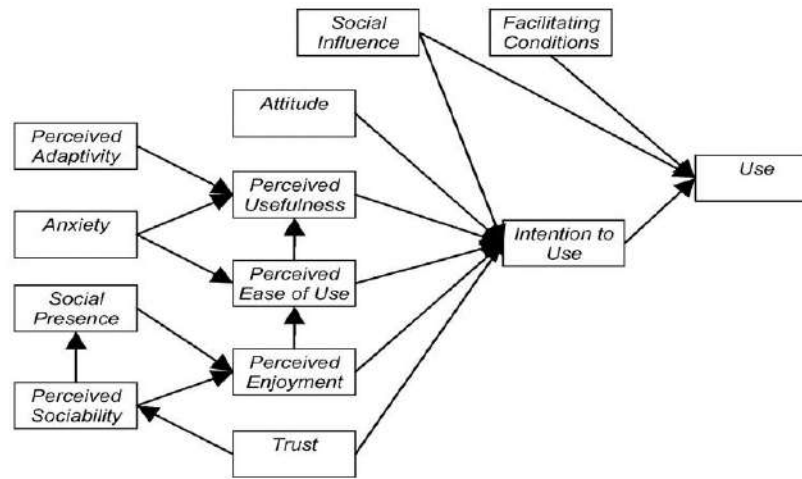
- The robot must respond to voice and touch.
- The robot should respond to the environment.
- It should recognize and respond to user's emotions/mood.
- It should influence or alter its "mood" in some way by its response.
- It should monitor the health of the person.

### 1.1.8. User Perception and Acceptance of SAR Subject to Almere Model

Surveys [41] show that social robots are perceived as safety tools, capable of detecting and responding to emergency events. In addition, they serve as companions, combating loneliness and fostering social connections. Beyond utility, users highly value the entertainment features, making these robots more than just functional aids. It can be concluded that:

- The stakeholders perceive social robots as safety tools since they can detect emergency events [41].
- It is believed that the robots can alleviate their loneliness and isolation [41].
- The robots can improve their social capabilities [41].
- The users highly appreciate entertainment functionalities of the robot [41].

The above and all the research in the domain of SARs is conducted while keeping in view the Almere Model (figure 3) of robot acceptance by the elderly.



**Figure 3.** Almere Model for Elderly Acceptance of SARs [49]

Although a lot of research has been done in this subject, but there is a limitation in such studies as most of the robots were deployed for only Japanese elderly population. Secondly, the researches were limited to only some of the companion robots and most of them were toy/pet inspired like Aibo [43] and Paro [44,45]. Moreover the research methodologies were not robust enough, seldom elucidated and at a very less degree of repeatability.

Some of the current SAR's are shown as a collage in the figure 4.



**Figure 4.** A variety of Care Robots used in East Asia and Western Europe (photos by Kodate) [64]

### 1.1.9. Solution Statement of the Project under Consideration

*“Elderly Care Companion Robot should be designed in a way that it redefines the aging experience for socially isolated elderly in East Asia and Western Europe through an innovative blend of autonomous navigation, interactive voice and touch capabilities, adaptive facial expressions and micro-gestures, and a sophisticated full-fledged structure and mechanisms, providing unparalleled personalized companionship and support.”*

### 1.1.10. Advancement and Undergoing Research in the domain of SARs

The table (table1.) below shows the problems domain, their current (or conventional) solutions, modern technological solutions and robotic research being carried in the concerned problem domain.

**Table 1.** Some examples of robotic technology in use and under research in elderly care [48].

Domain	Need	Current solutions	Technology in use	Robotic care under research
Daily activities	Eating	Home nurse, designed instruments	Robotic manipulator, Intelligent home intelligent spoon	
	Medicine administration	Home nurse, medicine containers	Intelligent dispenser	Robot reminder
	Cleaning	Maid, vacuum cleaners	Cleaning robot	
	Shopping	Caregivers	Internet shop	
	Personal hygiene	Domotics, caregivers	Bathing robot	Intelligent home, robot
Physical	Physical activity (tracking and stimulation)	Caregivers, physiotherapists	Smart TV, apps, medical devices	Assistive robot

<b>Cognitive</b>	Memory loss	Caregivers, diaries, noticeboards	PC, mobile apps	Robot, intelligent home
	Cognitive exercise	Caregivers, exercise on paper	PC, mobile apps	Robot
	Reduced vision	Spectacles, voice indicators in devices	Software	Guidance robot
	Reduced hearing	Hearing aid	Speech recognition software	Robot
<b>Psychologic</b>	Mood	Caregivers	Face/speech analysis software	Face/speech analysis robot
<b>Social</b>	Loneliness	Caregivers (nurses, family members), TV, internet, email	Robot companion	Robot companion, emotional robot(SAR: socially assistive robot)

### 1.1.11. Ethical Theories for SARs

While talking in the context of robots, the topic of design ethics for robot [50-53] is an important aspect to consider. As tabulated below in the tables.

**Table 2.** *Exemplary ethical design frameworks from both schools of machine ethics [62]*

Author(s)	School	Ethicsset	Ethics-delivery method	Exemplary design
Shaw et al. [54]	Moral robotics	Relative and evolving ethics. Human-like transparency to allow the care robot to justify its decisions. Imperfect ethics like a human.	Bottom-up learning method to provide ethics. Evolution of ethics that allows the care robot to learn new ethics in practice. A group-dynamic decision-making principle.	A care robot design which learns ethics subjectively without top-down limitations. The design includes a ‘robot brain’ with many ‘voices’ that test each other to reach a consensus.
Anderson [55] and Anderson [56]	Moral robotics	Rossian deontology. Deontology declares universal moral duties and considers actions to be either moral or immoral based on the act itself rather than the consequence.	A hybrid method made up of bottom-up case- based learning and top-down principle that controls the learning process. The ethical training cases are predetermined, by an ethicist, to represent good or bad ethical decisions.	A care robot design that is controlled by Rossian deontological prima facie duties, but the way it chooses which duty is right in situ is taught to the care robot explicitly and with predetermined results.

Meacham and Studley (2017) [61]	Good robotics	Care ethics	An action-driven method in which ethics are implicitly coded into care robot actions. The authors hold action to be The most important thing in robot delivered care, not robotic moral competence, agency, or any other element of moral robotics.	A care robot design That is implicitly ethical in its actions which are determined by a designer determining what meaningful context is.
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**Table 3.** An example use of the value tool table [62]

Care practice	Intrinsic values	Robot design elements needed to ensure intrinsic values	Extrinsic values	Robot design elements needed to ensure extrinsic values
Bath patient	Hygiene	A cleaning function to clean the patient. Cameras to see any dirt on the patient. Arms and hands to hold a sponge.	Privacy	Avert anthropomorphic eyes.  Delete video recordings (a few hours after the bath just in case the patient is hurt, and the recordings are needed for liability).
	Safety	Cameras could observe the patient to ensure their head is above water and to see any distress.	Dignity	Shut a curtain around the bath.

### 1.1.12. Concluding Remarks

It can be concluded that care robotics is an emerging field of robotics over the last decade, primarily due to demographic shift in East Asia and Mainland Europe. A number of researches are being carried upon and the market is continuously expanding. Results of such research advocates care robots as a potential solution to the problem faced by senior citizens. Ethical and Moral Values must be kept in consideration while designing such robots, and technology should not breach basic human rights while fulfilling all the necessary functional requirements. The robot, thus designed must be made free from bias and trustworthy.

## **1.2. Introduction to the Current Report**

The report opens with Project Abstract and Contents, and then it is majorly divided into these Chapters:

### **1.2.1. Chapter 1: Introduction**

This portion illustrates the following content:

- I. Problem Background
- II. Problem Statement
- III. Possible Solutions
- IV. Solution Statement
- V. Market for the Solution

### **1.2.2 Chapter 2: Literature Review and Problem statement**

This portion illustrates the following aspects:

- I. Problem Relevance and Frequency
- II. Features and Loopholes of Current Solution
- III. Points to Ponder While Designing
- IV. Suggestions for Solution being devised

### **1.2.3 Chapter 3: Methods and Materials**

- I. A brief discussion of Inspiration and Implementation Phase
- II. Gantt Chart and Roadmap
- III. Components Used
- IV. Description of Simulations and Experiments for Navigation Part
- V. Description of Simulations and Experiments for Design Part
- VI. Comparing Multiple Hardware Components
- VII. Comparison of Facial Expressions
- VIII. Comparison of Mechanisms Design
- IX. Software Hardware Integration
- X. Complete Assembly

### **1.2.4 Chapter 4: Results**

- I. Results from Simulations
- II. Results from Experiments
- III. Comparison of Previous and Current Group's Progress

### **1.2.5 Chapter 5: Conclusions and Future directions**

- I. Conclusion of the Progress Made
- II. Suggestions for future groups

### **1.2.6 Chapter 6: Societal Impact of the work**

### **1.2.7 Chapter 7: Environment and Sustainability goals**

- I. Business Document
- II. UN SDG's

### **1.2.8 Chapter 8: Life-Long Learning and Future Recommendations**

### **1.2.9 Business Plan**

### **1.2.9 References:**

This section consist of the following parts: **1.** Literature Cited **2.** Further Readings **3.** Bibliography

### **1.2.10 Appendix A: Survey Questions and Technical Specifications**

### **1.2.11 Appendix B: ROS Archiitecture**

### **1.2.12 Appendix C: Testing Protocols and Codes Used**

### **1.2.12 Appendix D: Gait Analysis Data Acquisition**



# Chapter 2

## Literature Review

### 2.1. Brief Account of Literature Review

Owing primarily to decline in fertility rates and decreased mortality, the world population is aging [65]. With this demographic shift, more specifically in East Asia and Central Europe [66], the elderly population is vulnerable to the neuropsychological issues caused due to social isolation and loneliness. As stated in [67], the suicide rate among elderly age group (>50 years) is increasing worldwide (currently twice than the young). Another consequence of long-term loneliness is anxiety and depression leading to lethal nervous breakdown. In [68], It was observed that Odds Ratio for Anxiety and Depression with Isolation was 1.14 (95% CI).

Although WHO suggested social skills training, community and support groups, befriending, and cognitive behavioral therapy for the elderly affected due to social isolation [69], but these interventions may not be readily available or accessible to all older adults, particularly those with limited mobility. Alternate solutions, based on current technology could be explored. Mobile Applications, Virtual Reality and Voice Bots may be some cutting edge solutions in this regard [70]. However, these technologies, despite their utilities like entertainment and companionship, lack physical presence and adaptability to individual needs. Robots, specifically designed for social interaction and providing care, offer a more promising avenue for alleviating loneliness among the elderly. The table (table 4) below provides a systematic review of some of the possible technology driven solutions for the problem under consideration.

**Table 4.** Comparison of Various Tech-Driven Current Solutions based on literature review

Feature/Aspect	Care Companion Robot	Mobile Applications	Virtual Reality
<b>Purpose</b>	Companionship and Assistance	Social connection and health management	Social engagement and therapy
<b>Target Audience</b>	Elderly	Elderly and their families	Elderly
<b>Mobility</b>	Seamless navigation	No	No
<b>Facial Expressions</b>	Effective expressions	No	Yes (virtual)
<b>Voice Interaction</b>	Yes	Yes	Yes
<b>Micro-Gestures</b>	Yes	No	No
<b>Health Monitoring</b>	Possible Through Vitals sensors	Possible through wearables	No
<b>Medication Reminders</b>	Can be Embedded	Yes	No
<b>Spillage Detection</b>	Can be Embedded	No	No
<b>Gas Leakage Detection</b>	Can Be Embedded	No	No
<b>Customization</b>	Personalized assistance	Personalized notifications	Personalized experiences
<b>Interaction Style</b>	Personalized	Notifications and alerts Available on smartphones and tablets	Immersive
<b>Deployment</b>	In apartments, care Houses Designed for seniors, easy-to-use interface		VR headsets
<b>Accessibility</b>		Varies by tech savviness	Requires VR setup
<b>Physical Existence</b>	A full embodiment	No	No
<b>Cost</b>	Highest initial cost	Low to moderate cost	High initial cost
<b>Emotional Support</b>	7 on a scale of 10	2 on a scale of 10	5 on a scale of 10

An important domain of Socially Assistive Robots is Care Robots. Care robots vary in form and function. Some of them are inspired by pets or even alien and cartoon like characters. Some are designed for physical assistance, such as lifting individuals who have difficulty getting up, aiding in mobility and exercise, monitoring physical activity, detecting falls, assisting with feeding, and aiding in bathing or using the toilet. Others focus on social and emotional engagement to manage and potentially reduce cognitive decline. These robots provide companionship and therapy for lonely seniors, simplify care for those with dementia, and can reduce the need for multiple caregivers [71].

After reviewing features of some of the commercial SARs [72], A Mobile Robot with Humanoid appearance seemed to be a viable design for the problem concerned, as it can navigate through the apartment and interact in a more friendly way, rather than being odd for the elderly. Various design paradigms are there including but not limited to technology driven design, belief driven design and user centered design [9]. The human centered design, however, is not only limited to end user, but all the stakeholders, keeping in view, human desirability, technical feasibility and business viability [73]. Hence, HCD was chosen as key design paradigm.

Another important consideration in this regard that is specific to design of SAR's is Almere Model of Robot Acceptance. This takes into account sociability, social influence, perceived usability and perceived enjoyment relevant to the robot along with the facilitating conditions and moderating factors for it [74],[75]. Rather than just focusing on technical aspects, the social, psychological, philosophical and artistic aspects were also taken in account while designing the robot. Another feature of Almere Model is that it also takes in account not only positive or neutral, but also negative factors related to Social Robots like mistrust and anxiety. Secondly, it is in the form of a questionnaire, which maps on numbers through a mathematical model. It can be tested on a variety of use case scenarios as in [76].

The table (table 5) below draws a comparison between some state-of-the-art robotic solutions and our proposed robot. The green color indicates plus-point of care robot while red color indicates its limitation.

**Table 5.** Comparison of Various Solutions with Suggested Solutions

Feature	Care Companion Robot	Pepper	Paro (AIST)	Jibo (Jibo, Inc.)
<b>Cost</b>	Moderate	High	High	High
<b>Mobility</b>	Mobile	Mobile	Stationary	Stationary
<b>Interaction</b>	Voice, gestures, facial expressions	Voice	Touch, voice	Voice, screen
<b>Touch Screen</b>	Yes	No	No	Yes
<b>Appearance</b>	Human-Like	Human-Like	Animal-like (seal)	Sphere Like
<b>Functions</b>	Companionship and Care	Social interaction, reminders, entertainment	Emotional support, therapeutic	Social interaction, entertainment
<b>Customization</b>	Moderate	Moderate	Low	Moderate
<b>Autonomy</b>	Low, up to current stage	High	Low	Low
<b>Social Acceptance</b>	Moderate, up to current stage	High	High	Moderate
<b>Ease of Use</b>	Moderate	Moderate	High	Moderate
<b>Auto-Docking</b>	Can be added	No	No	No
<b>Maintenance</b>	Moderate	High	Low	Moderate
<b>Communication</b>	Internet, Bluetooth	Wi-Fi	None	Wi-Fi
<b>Sensors</b>	Vitals, environmental sensors can be added, 2 Cameras	Basic (camera, mic)	Basic (touch)	Basic (camera, mic)

After all the initial inspiration and ideation phase, implementation was started. As far as the mobility is concerned, a Kobuki Turtle Bot 2 Mobile Robot Base was chosen to build the robot upon it. First of all, different available simulation softwares for mobile robotics were observed and Gazebo is found to be the best as per requirement. According to [77], it was best in terms of being free, open source, versatile, compatible with ROS, programmed in C/C++, supporting physics engine and with functional UI. On a scale of 7, it was given a score of 6.667, the highest among the four (other three are CoppeliaSim, MORSE and Webots). Hence, Gazebo was chosen for the simulation. After successful simulation, hardware implementation for various space configurations was done based upon the criteria and patterns based on arrangement and density of the obstacles as mentioned in [78].

In order to demonstrate meaningful facial expressions by the robot, multiple possibilities are there. It can be either a face with mechanical eyes and lips as in [79], or a virtual face with animated expressions of eyes and lips as in [80]. The researchers in [80] concluded the mechanical option to be expensive and complex, hence, the facial expressions similar to those in [80] are considered more viable by authors of this report. A detailed description of the both facial types and their hybrids is given in [81] as the researchers there considered a robot's face not just as a technical feature, but a source to communicates identity, emotions, and interpersonal spatial relations, shaping perceptions of the robot's virtuousness. Suggestions related to design and development of animatronic neck for 2-DOF motion in order to support micro-gesture based interactions are given in [82]. These include firm design of the couplings and use of high torque servo motors with mechanical limits. Moreover, it is recommended to have multiple microphones to be used with all the inputs combined into a single stream and efficiently place the microphones in the head, i.e. maintaining appropriate distance between them and avoiding vibrating and rotating parts near them. With the availability of the 3-D printer technology nowadays, almost all the robot head parts are designed to be 3-D printed [83]. The material suggested for 3D printing is PLA, Polylactic acid, a thermoplastic monomer derived from renewable organic sources and is biodegradable [84], contributing towards responsible consumption and production [85]. The voice, to be used in robot could be male, female or neutrally synthesized. Effect of different pitches has been studied in [86] based on four factors, Acceptance, competence and social skill relevant to robot's voice. This multi-application study concluded that a synthetic voice with gender neutral frequency has the greatest performance relevant to all factors.

This literature review overall suggests social robotics, especially care robotics, as a rapidly growing research domain. This growth is likely fueled by the increasing need for caregiving support due to an aging population, along with advancements in AI and robotics that enable more sophisticated social interaction and assistance. Research is particularly focused on robots that can provide companionship and emotional support to elders or people with disabilities, as well as robots that can assist with daily living activities or medication management. Looking ahead, research suggests the potential for robots to personalize care, provide real-time health monitoring, and further enhance human-robot interaction in care settings, although ethical considerations remain an important area of focus for the researchers [87].

The international market of SARs is estimated to grow to USD 836 million by 2025, three times of its value in 2018 [12]. Many governments and private organizations are making huge investments in field of care robotics. Japan, for example has currently invested USD 45 million in SARs in order to overcome the scarcity of professional caregivers [13] and governmental level, and the European Union health sector considers them an excellent alternate for human nurses and care providers in field of healthcare [14]. However, as a number of studies mention subjective reports from the older people demonstrate that companion robots are acceptable to them. It can be hence conclude that it is worth-while to invest in research and development projects focusing on care robots [47].

**Table 5. Summary of Selected Literature**

<b>Title of Paper</b>	<b>Purpose</b>	<b>Relevance to Project (1-5)</b>
A Review on the Use of Mobile Service Robots in Elderly Care	Review of mobile service robots	5
World Population Ageing 2019 Highlights	Population ageing statistics	4
Ageing Europe—Statistics on Population Developments	Population ageing statistics	4
U.S.—Seniors as a Percentage of the Population 1950–2050	Population ageing statistics	4
Action for Seniors Report	Report on action for seniors	4
ENRICHME: Perception and Interaction of an Assistive Robot for the Elderly at Home	Study on assistive robot perception and interaction	5
Exploiting voice recognition techniques to provide farm and greenhouse monitoring for elderly or disabled farmers	Voice recognition for farm and greenhouse monitoring	3
A synergy of innovative technologies towards implementing an autonomous diy electric vehicle for harvester-assisting purposes	Implementing an autonomous vehicle for harvester-assisting purposes	3
Development of a Sensing Platform Based on Hands-Free Interfaces for Controlling Electronic Devices	Developing a sensing platform for controlling electronic devices	3
Robots in Elderly Care	Study on robots in elderly care	5
Investing in the health workforce enables stronger health systems	Investing in health workforce for stronger health systems	2
Social Isolation and Loneliness in Older Adults: Opportunities for the Health Care System	Study on social isolation and loneliness in older adults	4
Assistive technology in elderly care	Study on assistive technology	3
Intelligent Technology for an Aging Population: The Use of AI to Assist Elders with Cognitive Impairment	Using AI to assist elders with cognitive impairment	4
Progress in Developing a Socially Assistive Mobile Home Robot Companion for the Elderly with Mild Cognitive Impairment	Developing a mobile home robot companion	5
A Conversational Robot in an Elderly Care Center: an Ethnographic Study	Study on a conversational robot in an elderly care center	5
Cocreation of an assistive robot for independent living: Lessons learned on robot design	Lessons learned on robot design for independent living	5
Robotics utilization for healthcare digitization in global COVID19 management	Using robotics for healthcare digitization in COVID19 management	4
A literature survey of the robotic technologies during the COVID-19 pandemic	Survey of robotic technologies during the COVID-19 pandemic	4
Social Robots Market Research Report by Component, End-User, RegionGlobal Forecast to 2027	Market research on social robots	3
Social Robots Acceptance and Marketability in Italy and Germany: A Cross-National Study Focusing on Assisted Living for Older Adults	Study on social robots acceptance and marketability	4

Robots in Healthcare: A Solution or a Problem?	Study on robots in healthcare	4
On activating human communications with pet-type robot AIBO	Activating human communications with pet-type robot	3
You've got a friend in me: Sociable robots for older adults in an age of global pandemics	Study on sociable robots for older adults	5
MOVAID: A personal robot in everyday life of disabled and elderly people	Study on a personal robot in everyday life	5
RAMCIP—A service robot for MCI patients at home	Study on a service robot for MCI patients at home	5
I-feed: A robotic platform of an assistive feeding robot for the disabled elderly population	Study on a robotic feeding platform for the disabled elderly population	4
Autominder: A case study of assistive technology for elders with cognitive impairment	Case study of assistive technology for elders with cognitive impairment	4
A systematic review of robotic rehabilitation for cognitive training	Systematic review of robotic rehabilitation for cognitive training	4
Improving the interaction of older adults with a socially assistive table setting robot	Improving interaction with a table setting robot	5
Table cleaning task by human support robot using deep learning technique	Table cleaning task by human support robot	4
A review on the use of socially assistive robots in education and elderly care	Review of socially assistive robots in education and elderly care	5
Socially assistive robots in elderly care: A mixed-method systematic literature review	Literature review of socially assistive robots in elderly care	5
Robots in older people's homes to improve medication adherence and quality of life: A randomised cross-over trial	Study on robots in older people's homes	5
Enrichme: A robotic solution for independence and active aging of elderly people with MCI	Study on a robotic solution for independence and active aging	5
Pearl: A mobile robotic assistant for the elderly	Study on a mobile robotic assistant for the elderly	5
Care-O-bot II—Development of a Next Generation Robotic Home Assistant	Development of a robotic home assistant	5
RoboCare: an Integrated Robotic System for the Domestic Care of the Elderly	Integrated robotic system for domestic care of the elderly	5
Social Isolation and Loneliness in Older Adults: Opportunities for the Health Care System	Study on social isolation and loneliness in older adults	4
A New Design Approach and Framework for Elderly Care Robots	New design approach and framework for elderly care robots	5
Integrating Robot Ethics and Machine Morality: The Study and Design of Moral Competence in Robots	Integrating robot ethics and machine morality	4
Moral Machines: Teaching Robots Right from Wrong	Teaching robots right from wrong	4
The Nature, Importance, and Difficulty of Machine Ethics	Study on machine ethics	4
Towards Provably Moral Ai Agents in Bottom-up Learning Frameworks	Developing morally sound AI agents	4
Ethel: Toward a Principled Ethical Eldercare System	Developing an ethical eldercare system	4
A Value Driven Agent: Instantiation of a Case-Supported PrincipleBased Behavior Paradigm	Developing a value-driven agent	4

Robots and Human Dignity: A Consideration of the Effects of Robot Care on the Dignity of Older People	Study on the effects of robot care on human dignity	4
Children, the Elderly, and Interactive Robots	Study on interactive robots for children and the elderly	4
The March of the Robot Dogs	Study on robot dogs	3
In the Hands of Machines? The Future of Aged Care	Study on the future of aged care with machines	4
Could a Robot Care? It's All in the Movement	Study on robotic care	4
Assistive social robots in elderly care: A review	Review of assistive social robots in elderly care	5
Inside Japan's long experiment in automating elder care	Study on Japan's experiment in automating elder care	4
Robots for Elderly Care: Review, Multi-Criteria Optimization Model and Qualitative Case Study	Review and case study of robots in elderly care	5
Product Design and Development	Product design and development principles	3

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# Chapter 3

## Materials and Methodology

### 3.1. Gantt Chart

A summarized table showing key activities is as below:

Activity	June 23	Jul 23	Aug 23	Sep 23	Oct 23	Nov 23	Dec 23	Jan 24	Feb 24	Mar 24	Apr 24	May 24
Proof of Concept Presentations												
Background Research and Interviews												
Learning ROS												
Implementing ROS for Navigation (Simulations)												
Implementing ROS for Navigation (Hardware)												
Designing Mechanism on Solidworks												
Testing Different Navigation Scenarios												
3-D Printing of the parts												
Robot Assembly												
Documentation												
Business Modeling												
Prototype Presentation in Competitions												
Feedback and Reviews												
Final Demonstrations												

Figure5. Gantt chart of the Project Journey

### 3.2. Methodology Summarized as flowcharts

The general methodology is shown in Figure 6 while the technical portion of this is detailed in Figure 7.

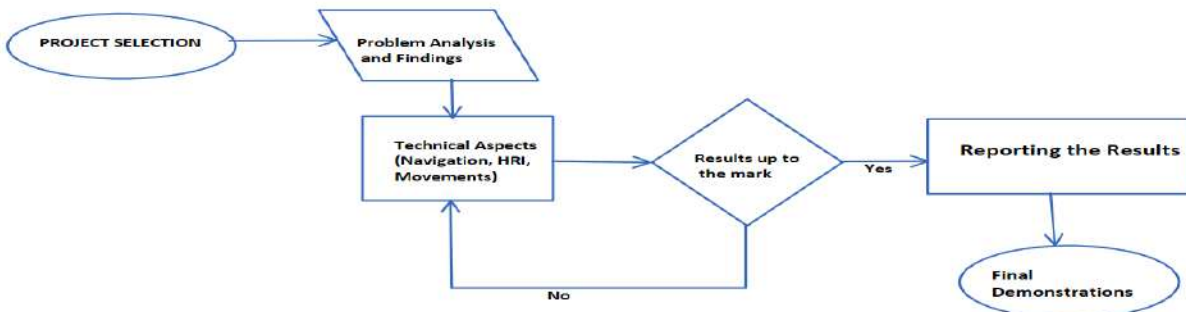


Figure 6. Project Simplified Methodology

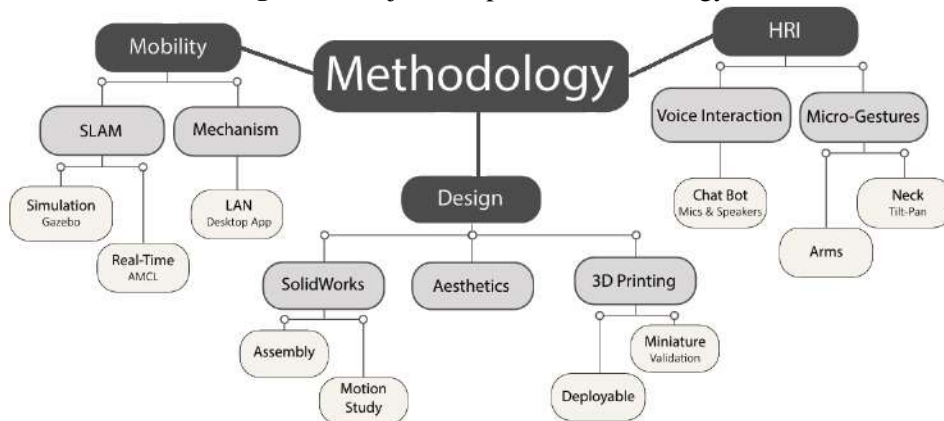


Figure 7. Technical Aspects of the Methodology

### 3.3. Hardware Components Chosen

#### 3.3.1. Kobuki TurtleBot2

The TurtleBot 2 is a versatile, affordable, and modular mobile robotic platform built on the Kobuki base, designed for research, education, and prototyping. It integrates seamlessly with the Robot Operating System (ROS), providing a robust framework for developing and testing various robotic algorithms. The platform features differential drive motors, bumper and cliff sensors, and a rechargeable battery pack, often paired with an onboard computer (Jetson Nano in our case). Additional sensors, such as RGBD cameras and LIDAR, can be easily attached for enhanced functionality. As an open-source system, TurtleBot 2 supports a wide range of applications, from SLAM and autonomous navigation to human-robot interaction, making it an ideal choice for both novice and advanced users in the robotics community.



Figure 8. Kobuki TurtleBot2 by Yujin Robotics

#### 3.3.2. Jetson Nano Developer Kit

The Jetson Nano is a powerful and compact AI development platform designed by NVIDIA, aimed at enabling the creation of AI-powered projects in fields like robotics, IoT, and computer vision. Featuring a quad-core ARM Cortex-A57 CPU and a 128-core Maxwell GPU, it provides robust performance for processing complex AI algorithms. With multiple interfaces including USB, GPIO, and CSI for camera modules, the Jetson Nano offers flexibility for integrating various peripherals and sensors. Its small form factor and energy efficiency make it an excellent choice for developers and researchers looking to create innovative AI solutions in a cost-effective manner. In our case, it efficiently runs navigation, motors, and other programs.



Figure 9. Jetson Nano (Source: developer.nvidia.com)



### 3.3.3. Depth Cameras

#### a. Justification of 2 RGBD Cameras

The following 2 Cameras are placed in the robot.

1. *Intel RealSense d435i* in the head
2. *Kinect Xbox 360* on the base

The first camera served the purpose to capture the surroundings, detect and track elderly and so on. While the second one on the base served solely for the purpose of mapping and navigation.

Below is a comparison table of both cameras for specific uses.

**Table 6.** Comparison on Intel Realsense and Xbox 360 Kinect

	Intel RealSense d435i	Xbox 360 Kinect
<b>Sensor Type</b>	Stereo camera with depth sensing	Structured light depth sensor and RGB camera
<b>RGB Camera Resolution</b>	1920 x 1080 at 30 FPS	640 x 480 at 30 FPS
<b>Depth Resolution</b>	1280 x 720 at 30 FPS	640 x 480 at 30 FPS
<b>Field of View (FOV)</b>	87° x 58° (depth), 69° x 42° (RGB)	57° x 43° (depth), 54° x 39° (RGB)
<b>Range</b>	0.1 to 10 meters	0.4 to 4.5 meters
<b>IMU</b>	6 DoF (Gyroscope and Accelerometer)	None
<b>Interfaces</b>	USB 3.1 Gen 1	USB 2.0
<b>Power Consumption</b>	1.5 W to 3.5 W	2.5 W to 5 W
<b>Dimensions</b>	90 mm x 25 mm x 25 mm	279 mm x 72 mm x 67 mm
<b>Weight</b>	72 grams	970 grams
<b>Additional Features</b>	Integrated IMU, highly portable	Voice recognition with built-in microphone array
<b>Fits in Base</b>	Can be made to fit	Exactly same sized as base
<b>Incorporation with tbot2 and ROS Melodic</b>	Very complex to implement	Easy to implement and suitable results
<b>Fit in head</b>	Possible	Not Possible due to size

So, based on the features of both cameras, it was decided to use Kinect for navigation in the base, and Realsense in the head for other tasks. In future, data streams from both sensors can be fused for better navigation results.



**Figure 10.** Xbox 360 Kinect (Left) and Intel Realsense d435i (right)

## b. Need for placement of Camera in the base

Mapping phase using realsense d435i camera on a height equivalent to that of the robot head was tested and the idea of placing a camera, even in tilted position in the head proved inefficient for mapping stage. Hence, it was decided to place a camera in the base.

## c. Placement of RGBD Camera in the head

An RGBD camera is preferred over an RGB Camera keeping not only navigation but future horizons of the project in view as well. The depth stream from RGBD camera in the head can be used in future, when fused with depth stream from the RGBD camera in the base. Moreover, it can be used to detect location and size of the spillages, distance of the elderly from the robot, and in gait analysis of the elderly from robot's view. The figure below (figure 5) presents a detailed account of this section, highlighting current camera placements, current utility of the cameras and future possible utilities of them.



**Figure 11.** Cameras' Placement, Current Progress in Blue Blocks, Future Possibilities in Green Blocks

### 3.3.4. Motors for Pan, Tilt and Arm Motions

Both Stepper Motors (NEMA 17) and Servo Motors (MG-996) were studied and tested for placement in the neck. The results of such comparison is as below.

**Table 7.** Case Based (Controlling Neck Movements) Comparison of NEMA-17 and MG996 Motors

Feature	MG996R Servo Motor	NEMA 17 Stepper Motor
Motor Type	Servo	Stepper
Torque	9.4 kg·cm (at 6V)	3.4 kg·cm (varies with model)
Speed	0.17 sec/60° (at 6V)	Varies with step rate (e.g., 1.8° per step)
Operating Voltage	4.8V to 6.6V	Typically 12V to 24V
Current Draw	No-load: ~500 mA, Stall: ~2.5 A	Varies, often 1-2 A per phase
Position Control	Through PWM	Through step count
Rotation Range	Typically 0-180°	360° (continuous, limited by steps)
Accuracy	~1 degree	Typically 1.8° per step (200 steps/rev)
Weight	55 grams	Varies, typically around 280-400 grams
Size	40.7 x 19.7 x 42.9 mm	42 x 42 x 48 mm (standard)
Heat	No Noticeable Heat Discharge	Releases Heat from Driver as well as motor
Noise and Vibrations	No prominent noise/vibrations	Noise and Vibration noticed
Control Interface	PWM signal (typically from a microcontroller)	Stepper driver (e.g., A4988, DRV8825)
Holding Torque	High	High
Continuous Rotation	No (limited to specified range)	Yes (unlimited)
Mating with 3D Printed Parts	Easy	Relatively Complex
Driver Requirements	Single Driver for 16 Motors	Separate Driver for each motor
Cost	Relatively Low	Relative Low

It can be concluded from above table, made after continuous and rigorous testing, that, for the purpose concerned, servo motors with high torque are best option.

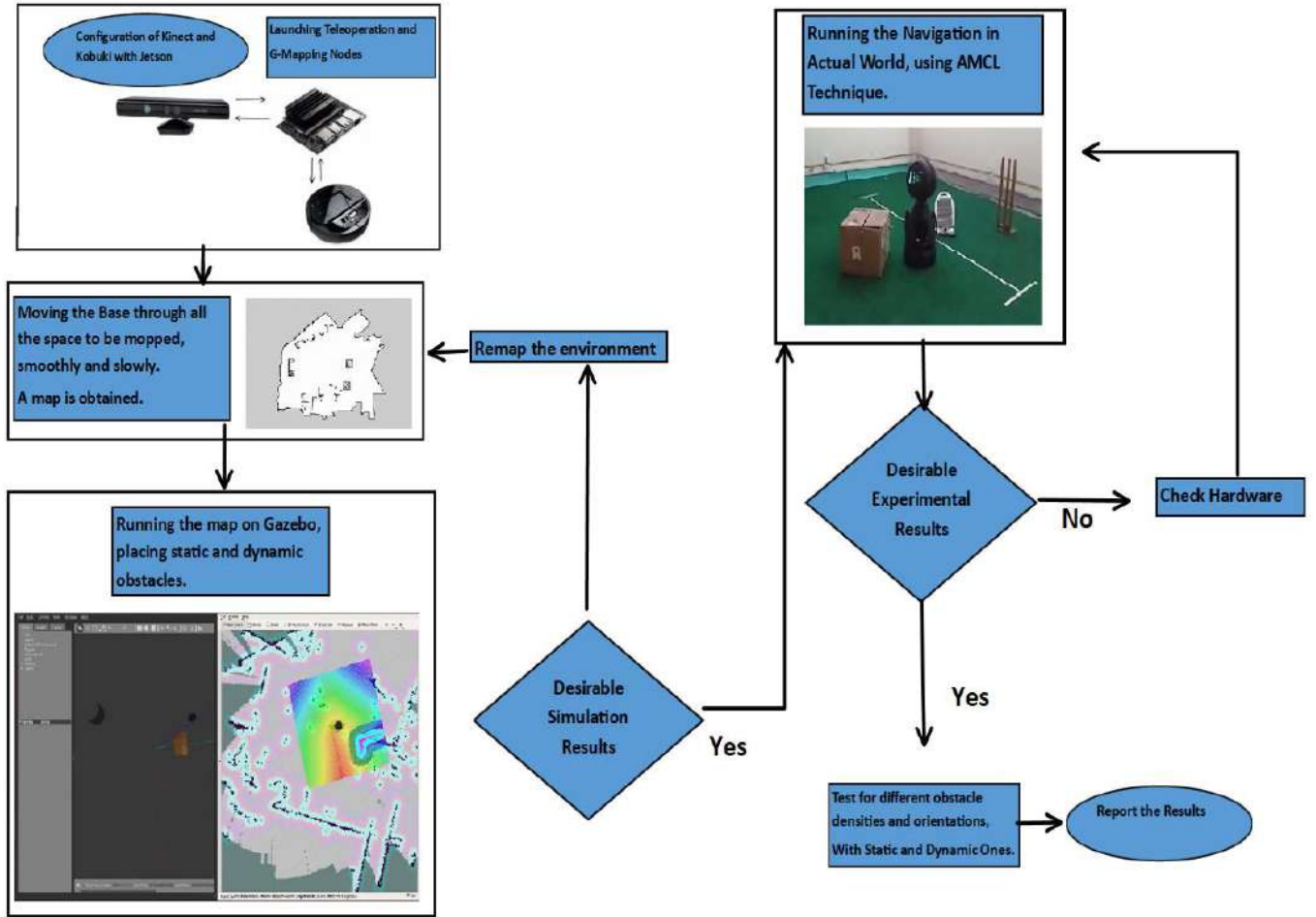


**Figure 12.** A pair of Servo Motors in final Head Assembly for Tilt Motion (left) and Stepper with Brackets, Ready to be placed for testing (right)

### 3.4. Navigation

#### 3.4.1. Implementation

Below is the graphical abstract of Mobility in figure 13.



**Figure 13.** Procedural Diagram for Mapping and Implementing SLAM



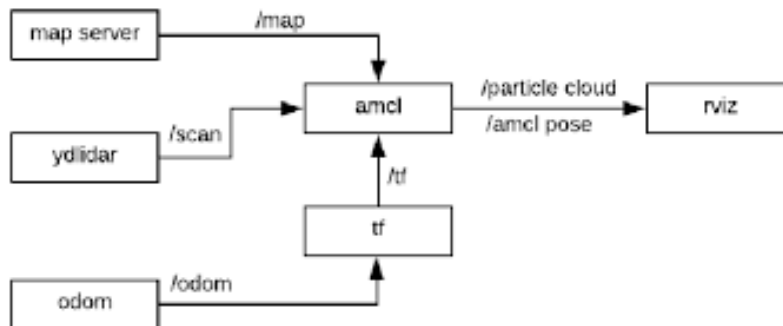
**Figure 14.** Collage of various Navigation Based Scenarios at Multiple Locations

Table 8 illustrates the details of the navigation process, while the **Linux terminal commands and ROS Nodal Map** are to be given in **Appendix 3** and **Appendix 2** respectively.

**Table 8.** Information about the Navigation Process

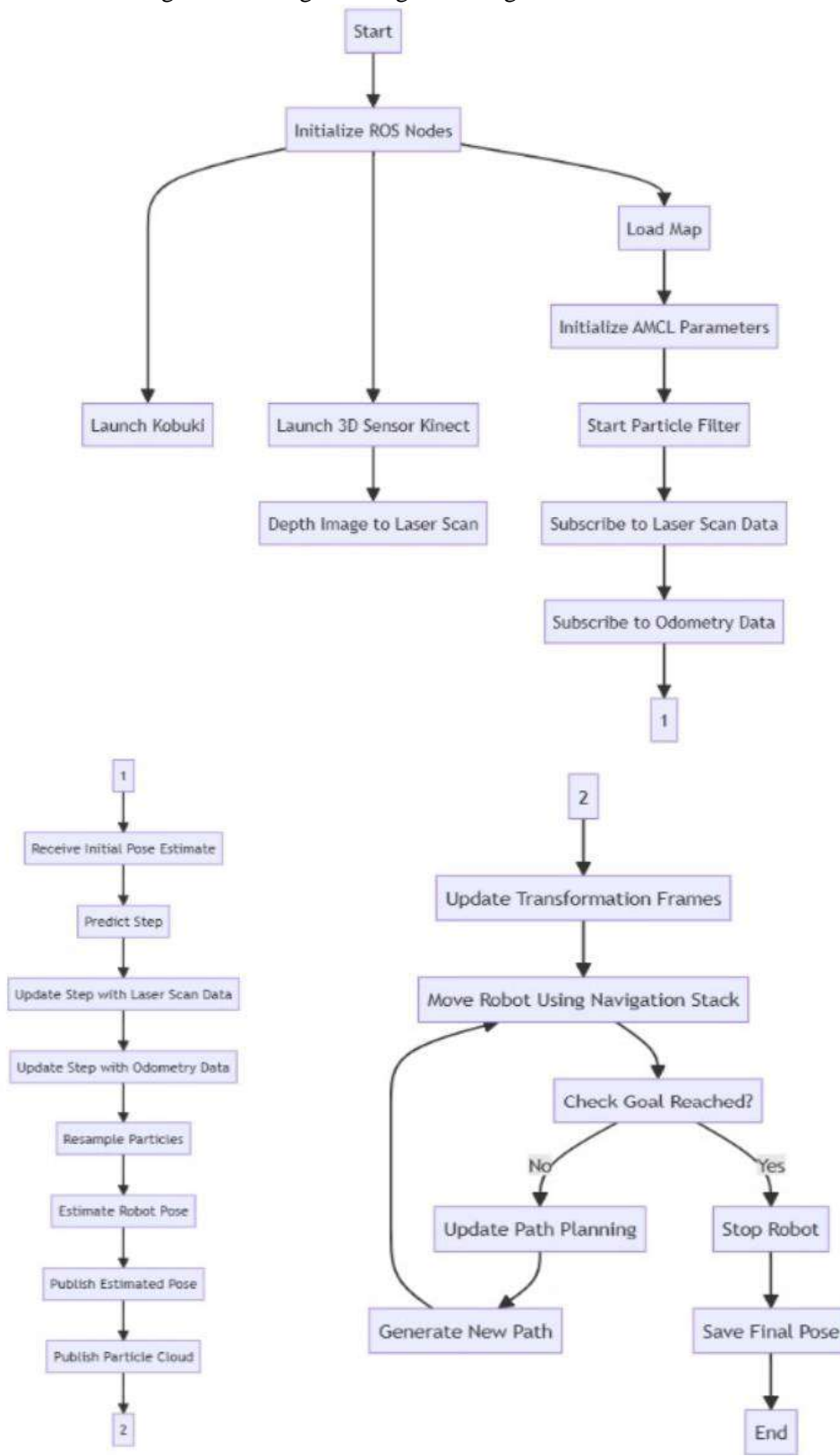
Aspect	Details
<b>Operating System (OS)</b>	Ubuntu 18.04 LTS (Bionic Beaver)
<b>ROS Version</b>	Robot Operating System Melodic Morenia
<b>Hardware</b>	Onboard Computer: NVIDIA Jetson Nano Base: Kobuki TurtleBot 2 Depth Sensor: Xbox 360 Kinect
<b>Software</b>	ROS Navigation Stack Gazebo (for simulation) Custom Python 3.2 scripts for control
<b>Algorithm</b>	Adaptive Monte Carlo Localization (AMCL) for localization
<b>AMCL's Description</b>	<p>AMCL is a probabilistic localization system for a robot moving in 2D. It implements the Monte Carlo localization algorithm, which uses a particle filter to track the pose of a robot against a known map. It is capable of handling a variety of movement and sensor noise, making it suitable for real-time applications. AMCL continuously refines the robot's position estimate as it moves through the environment, providing accurate and robust localization in dynamic settings.</p>
<b>AMCL's Benefits</b>	<ul style="list-style-type: none"> <li>• It is robust against noise and uncertainties in sensor measurements</li> <li>• The algorithm can adapt to changes in the environment, such as moving obstacles or changes in the map, by continuously updating the particle filter.</li> <li>• AMCL can scale to handle different types of robots and environments, from small indoor spaces to large outdoor areas.</li> <li>• Being part of the Robot Operating System (ROS), AMCL integrates seamlessly with other ROS packages.</li> <li>• Multi-Sensor Support: AMCL can integrate data from multiple sensors, such as LIDAR, cameras, and IMUs, to improve localization accuracy.</li> </ul>

A sample part of the nodal map is shown in figure 14.



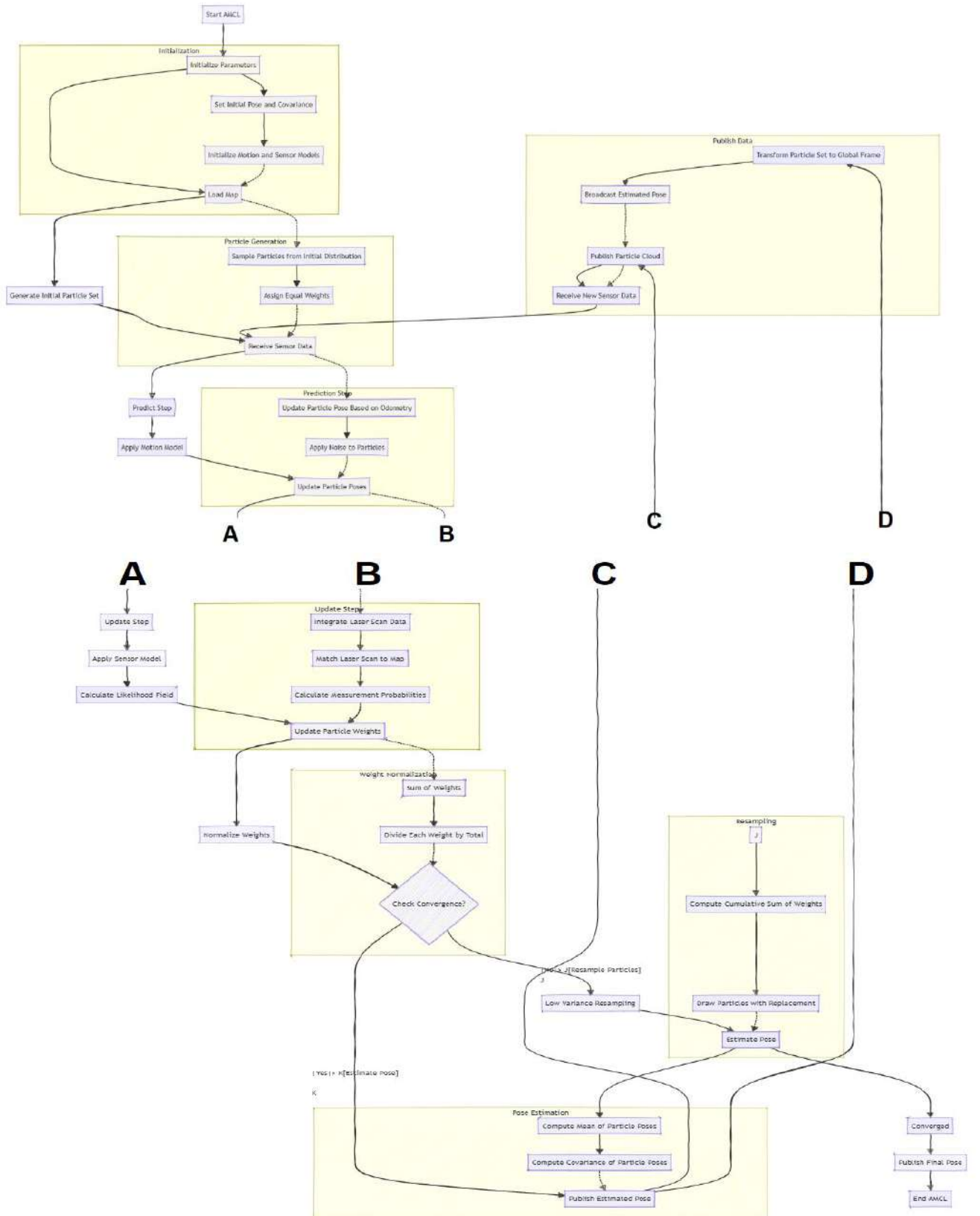
**Figure 14.** Selected Nodes Portrayed for AMCL

The generalized working of this navigation is given in figure 15 and that for AMCL in figure 16.



**Figure 15.** Generalized Working of Navigation Stack





**Figure 16.** Working of AMCL algorithm

### 3.4.2. Testing

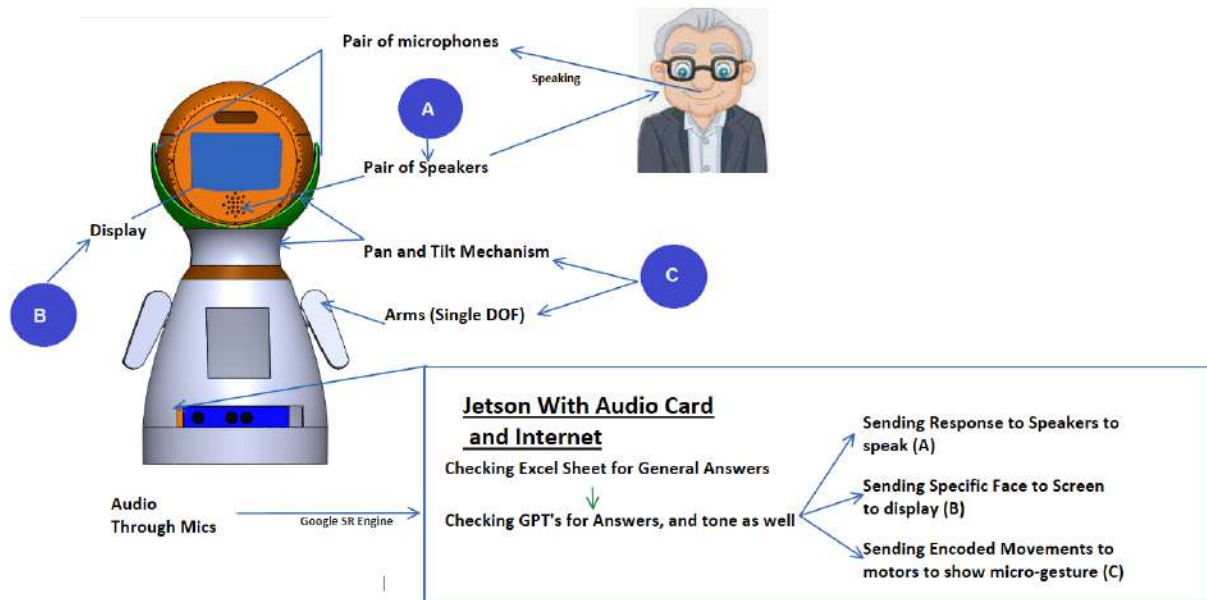
A test setup was made at IHYA Lab, with the following cases:

1. New Static Obstacles added
2. Previous Static Obstacles (present at the time of mapping) Removed
3. Increasing Density of Obstacles
4. Obstacles of various shapes and sizes (chairs, heater, boxes)
5. Introduction of Dynamic Obstacles

The test was successful, as mentioned in results section of this report.

### 3.5. Human Robot Interaction

It primarily comprises of 3 segments. A brief description of HRI is given in the chart below (figure 17).



**Figure 17.** Human Robot Interaction Work Flow

#### 3.5.1. Voice Interaction

The robot has two microphones on both sides of head and two speakers in the head placed as shown in upcoming sections (Sec 3.5).

For voice interaction, two possibilities for chat bots are compared in table 9.

**Table 9.** Comparison of Chat GPT and Gemini

Aspect	Chat GPT	Gemini
Conversational Depth	Capable of engaging in deep and meaningful conversations, understanding context and emotions.	Provides straightforward and concise responses, suitable for clear communication.
Emotional Intelligence	Can recognize and respond to emotions, providing empathetic responses.	Provides empathetic responses and can adapt tone based on context.
Customization	Offers limited customization options for specific use cases.	Allows for customization to tailor responses to specific scenarios.
Learning Capabilities	Learns from interactions to improve responses over time.	Can learn from interactions and adapt responses based on user feedback.



### 3.5.2. Facial Expressions

Different Facial Expressions were considered for the robot face. The three facial expressions namely Green Eyes, Homer Face and Red Expressions are shown in figure 18a, 18b and 18c respectively. A comparison among them is also drawn in table 10.

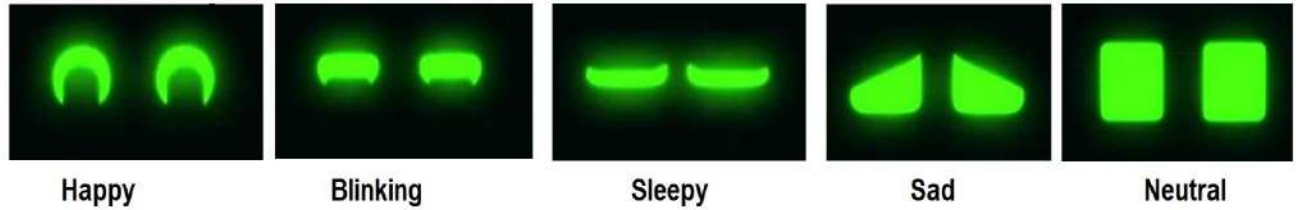


Figure 18a. Green Eye Expressions

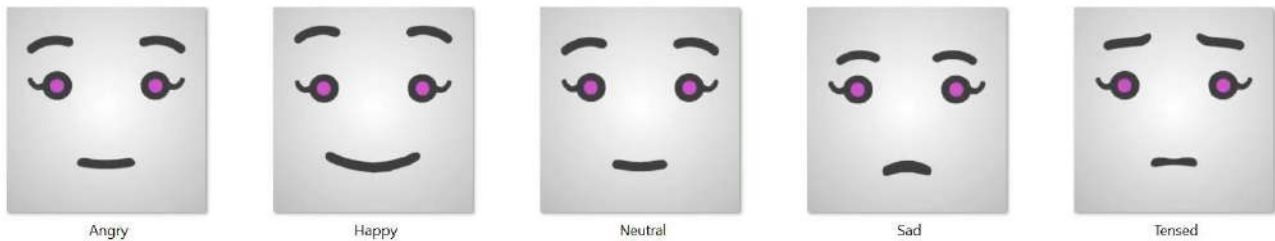


Figure 18b. Homer Robot Face



Figure 18c. Red Eye Expressions

Table 10. Comparison of three facial expressions

Aspect	Face 1	Face 2	Face 3
	Expressions of a Commercially available		
Source	Robot	Open Source Research	Self-Designed
Features	Eyes Only	Eyes, Lashes and Lips	Eyes and Lips
Lips Speaking	nil	Yes	No
Color	Green	Various Varieties	Can be changed
Gender	Neutral	Male or Female	Neutral
Suited with			
Robot	Excellent	Moderate	Moderate

Based on the fact that expression 1 suits best with the robot form, this set was finally opted.

### 3.6. Embodiment and Mechanisms

#### 3.6.1. Design Considerations for a Care Companion Robot

1. Design a human-like form with a **friendly and approachable appearance** to enhance user interaction.
2. Ensure joints and parts allow for **smooth and natural movements**.
3. Integrate **expressive facial shape**, to facilitate emotional connections.
4. Plan for **proper and functional integration of sensors** for navigation, obstacle detection, and interaction.
5. Use **durable materials** and ensure all parts are safe for human interaction.

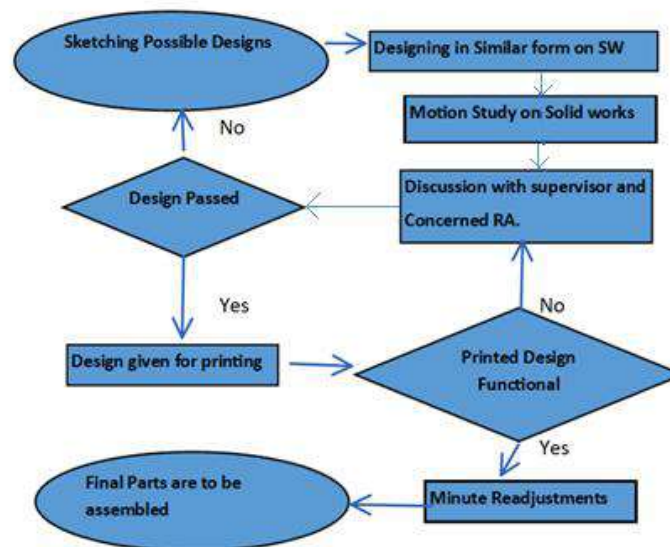


Figure 19. Basic Design Procedure

#### 3.6.2. Final Assembly of the Robot

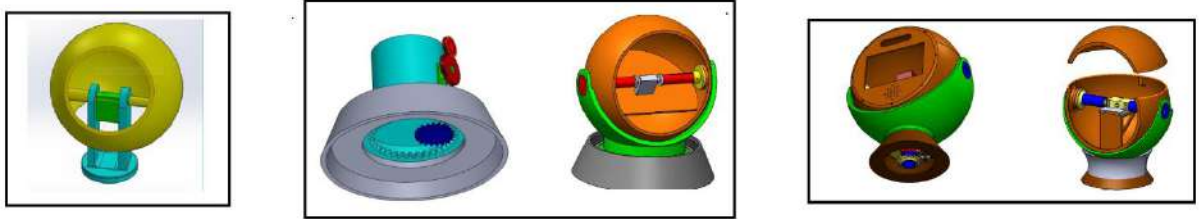
Below is the final assembly of the robot.



Figure 20. CAD Model for final Design (Left), Actual Final Design (Right)

### a. Neck Mechanism

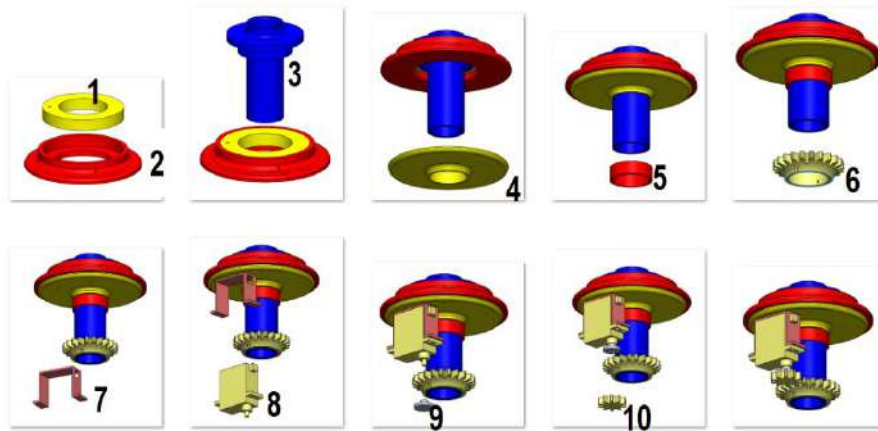
Figure 21 shows a comprehensive view of design journey of the neck mechanisms.



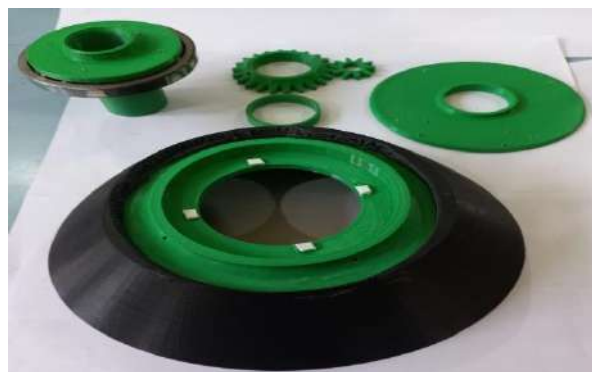
**Figure 21.** (From Left to Right) Previous design, 2<sup>nd</sup> Iteration (only up to CAD Model), Final Design

The final design was made considering these points.

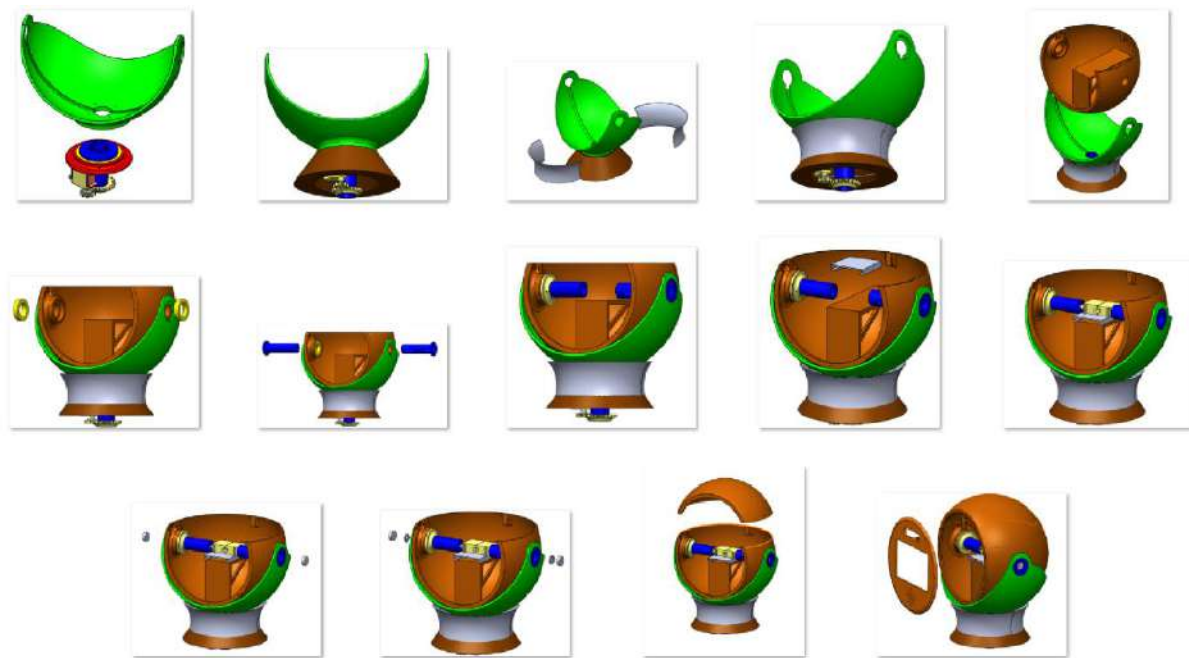
1. All the wires and cables must be managed properly.
2. The neck should not make jerks while navigation.
3. The parts should mate properly.
4. Space should be conserved as much as possible.



**Figure 22.** Pan Mechanism. 1. Bearing, 2. Bearing Seat, 3. Shaft for Driven gear, 4. Support for pan assembly, 5. Fixture for assembly, 6. Driven Gear, 7. Bracket for motor, 8. Motor, 9. Profile Plate for Motor, 10. Driving Gear



**Figure 23.** Hardware part of the pan mechanism



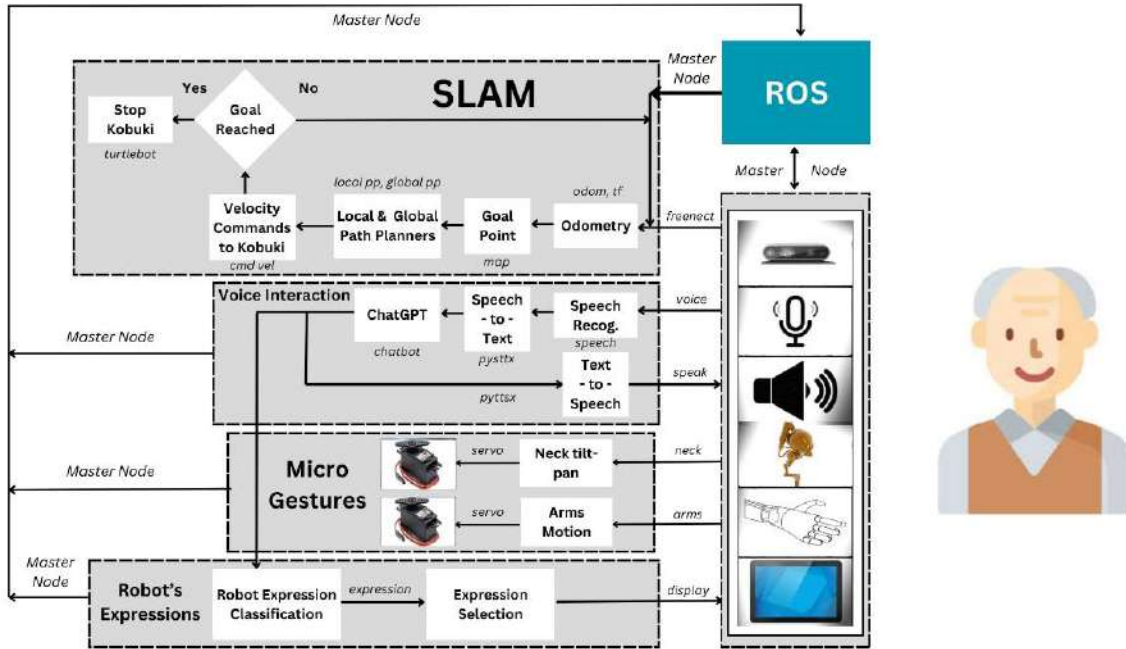
**Figure 23.** Tilt mechanism. Bearings in yellow, head support in green, skull and face parts in orange, Motor in Mustard, Shafts in Blue



**Figure 24.** Proper cable management can be seen in head support (left) and head (with upper skull removed): speakers, microphones, motors, camera and screen visible

### 3.7. Robot Architecture

There is a set of interconnected ROS packages that makes the combined software package of the robot as shown in figure 25.



**Figure 25.** A portrayal of all the Robot Functionalities, w.r.t ROS as master controller

# Chapter 4

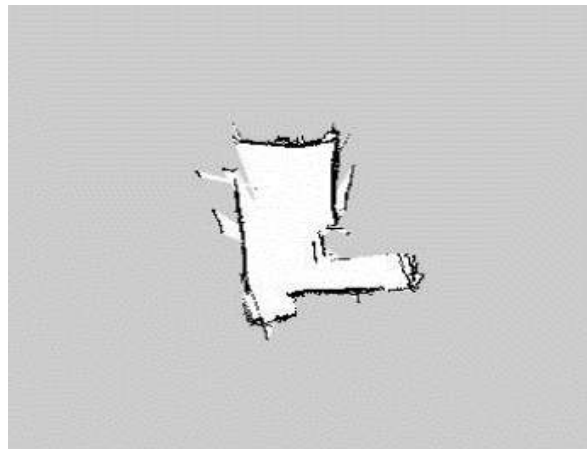
## Results

The development and testing of the Elderly Care Companion Robot yielded significant improvements over its initial prototype, addressing key areas of mobility, neck stability, chatbot integration, robot expressions, and micro gestures. The following sections summarize these improvements and their impact on the robot's performance.

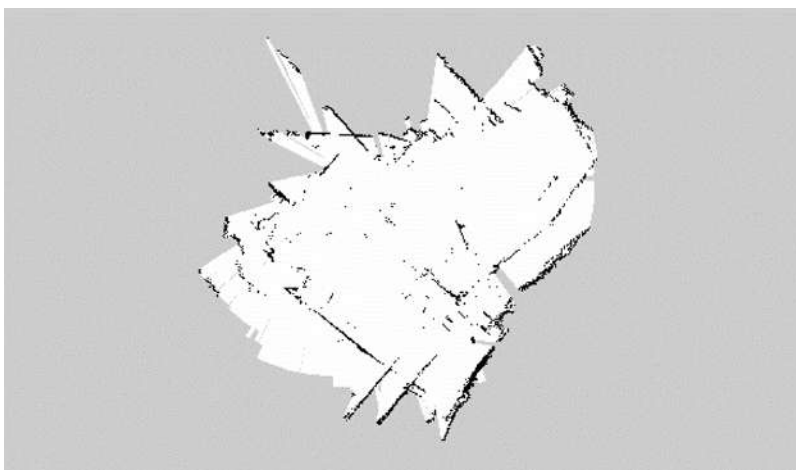
### 4.1. Mobility (SLAM)

The Elderly Care Companion Robot's mobility system, powered by Simultaneous Localization and Mapping (SLAM) technology, achieved a success rate of 95% in navigating various indoor environments. Utilizing gmapping for the mapping process and Adaptive Monte Carlo Localization (AMCL) for autonomous localization, the robot demonstrated reliable path planning, obstacle avoidance, and dynamic adaptation to changes in its surroundings.

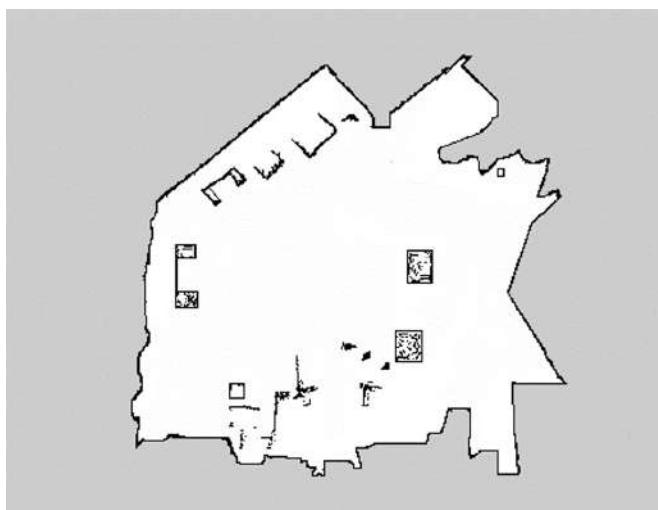
Compared to the previous stage, where SLAM implementation was limited to mapping of a very limited portion of a lab (Fig. 26), the integration of AMCL significantly enhanced the robot's autonomous capabilities. The SLAM system was implemented and tested in two different labs: the IHYA Lab for Mechatronics Research and the Resuscitation Sciences (Fig. 27) and Design Centre Lab (Fig. 28). In both settings, various scenarios were constructed, including the placement of unregistered static and dynamic obstacles in the robot's path, as visible in Fig. 27, Fig. 28 and Fig. 29. The robot maintained robust and accurate performance, successfully navigating these complex environments.



**Figure 26.** Limited Map of Robotics Lab, DMCE UET Lahore



**Figure 27.** Full Fledged Map of IHYA Lab for Mechatronics Research and the Resuscitation Sciences

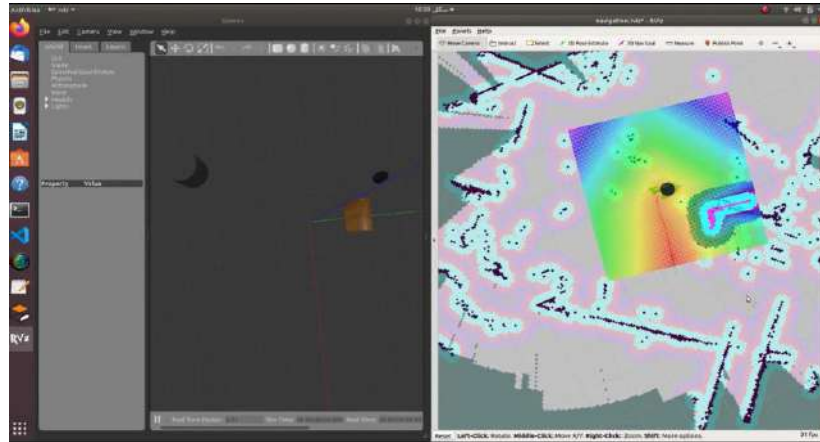


**Figure 28.** Full Fledged and Smoothened Map of Design Centre Lab



#### 4.1.1. Simulation and Real-time Testing

Extensive testing, totaling over 50 hours in both Gazebo simulations (Fig. 29) and real-world conditions (Fig. 30), showed a 98% correspondence between simulated (Fig. 29) and real-time performance (Fig. 30 and Fig. 31). The design team verified the mobility system's consistency, confirming its reliability and effectiveness across different testing environments.



**Figure 29.** Gazebo Simulated Environment for SLAM Testing



**Figure 30.** Real time SLAM Implementation in IHYA Lab

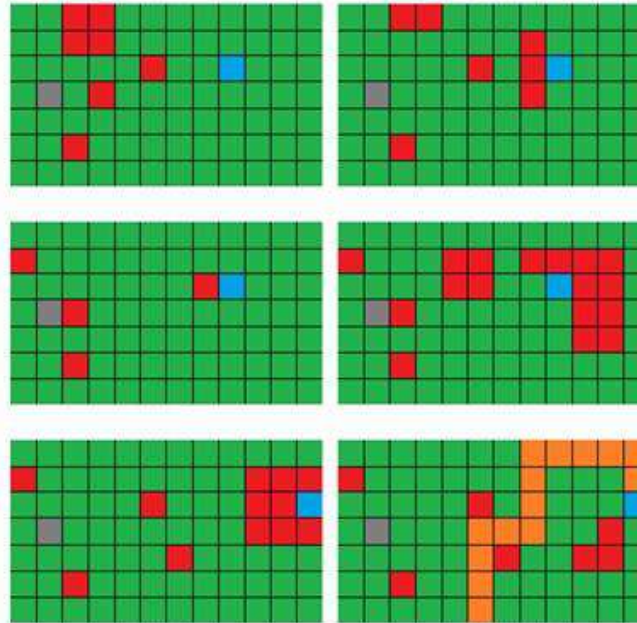


**Figure 31.** Real time SLAM Implementation in Design Center Lab



### 4.1.2. Navigation Results in a Specified Environment

Despite the successful implementation of SLAM in two different labs with different architectures and measurements, rigorous testing for the same, under different case scenarios, was mainly tested on a grid of 12x7 feet (Fig. 32) area to find the accuracy of the algorithm and the successful autonomous navigation and path planning of the robot to the given goal point.



**Figure 32.** Grid View (12X7 feet) of various experimental setups, grey is for robot's starting point, blue is for destination, green for free space, red for obstacles, orange for path of dynamic obstacle. Each square corresponds to 14" by 14" in real world, as 14" is the diameter of robot's base

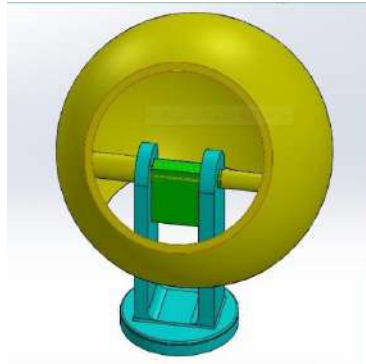
**Table 11.** Results of a few test runs for SLAM in real-time specified environment (Fig. 32)

Test Run	Goal Point Achieved
1	✓
2	✓
3	✓
4	✓
5	✓
6	✗
7	✓
8	✓
9	✗
10	✓
11	✓
12	✓
13	✓
14	✓
15	✓

Upon placing only a few test runs, it can be seen that the robot is capable of navigating to the desired goal point efficiently. In the test runs showing otherwise, the robot was given an unreachable goal.

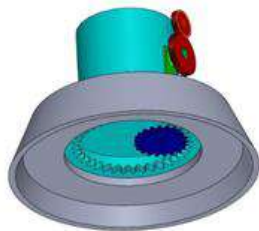
## 4.2. Neck Design

The neck design of the Elderly Care Companion Robot was completed with a focus on stability, flexibility, and durability. Compared to the previous iteration (Fig. 33), which suffered from instability, improper cable management, and excessive space usage in the robot's torso, the redesigned neck mechanism significantly enhanced performance.



**Figure 33.** Previous Work (Instable Neck)

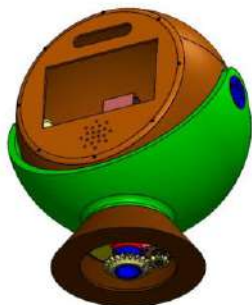
The new design was developed iteratively (Fig. 34a, 34b) using SolidWorks, with regular consultations with the advisor. Initial prototypes were 3D printed as miniatures to validate the simulated results. Upon achieving promising results, the full-scale final design (Fig. 35a, 35b) was 3D printed and subjected to rigorous testing on the actual hardware.



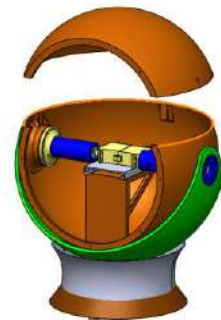
**Figure 34a.** Iteration 1



**Figure 34b.** Iteration 2



**Figure 35a.** Iteration 3 (Final)



**Figure 35b.** Iteration 4 (Final with improved aesthetics)

This redesign improved the range of motion and maintained structural integrity, passing all safety and usability standards. The design team verified the enhancements, achieving a 100% pass rate in stability and durability tests under simulated daily use conditions. The new neck design met high standards for both performance and user-friendliness, ensuring reliable and smooth tilt-pan movements of the robot.

#### 4.2.1. Neck Range of Motion

As shown in Fig. 35a and 35b, the robot's neck has been designed to tilt and pan. The range of motion for the tilt mechanism from is  $0^{\circ}$  to  $180^{\circ}$ . While that of the pan motion ranges over from  $0^{\circ}$  and  $90^{\circ}$ .

##### 4.2.1.1. Pan Motion Range

As it can be seen in Fig. 22 that the pan motion of the robot's neck has been confined on a gear mechanism with a gear ratio of 1:2. The motor used for this mechanism is the MG996R rc geared servo motor (see appendix A.2.5) with a range of motion from  $0^{\circ}$  to  $180^{\circ}$ . Due to the 1:2, the pan range of the robot's neck turns out to be  $0^{\circ}$  to  $90^{\circ}$  (using simple angular displacement reduction formula due to the gear ratio). But, since, while coding the algorithm to make the robot pan, the pinion side angle range ( $0^{\circ}$  to  $180^{\circ}$ ) is given, so the actual range of the moving motor has been considered while discussing the motion range with  $0^{\circ}$  and  $180^{\circ}$  have been defined as the extreme positions while  $90^{\circ}$  has been referred as the mean (central) position of the robot's panning. But moving over this range actually makes the robot to pan over the reduced motion range with  $0^{\circ}$  and  $90^{\circ}$  have been defined as the extreme positions while  $45^{\circ}$  has been referred as the mean (central) position of the robot, practically. But this reduced range does not result in lessening the robot's field of view as the field of U of the intel realsense depth camera d435i (see appendix A.2.3) covers a field of  $40^{\circ}$  at each side of the mean position of the central view point. This variation over the range and its result can be seen in Fig. 36a and Fig. 36b.



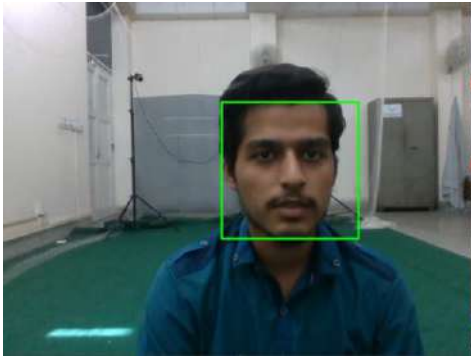
**Figure 36a.** Field of View with Pan angle= $0^{\circ}$



**Figure 36b.** Field of View with Pan angle= $180^{\circ}$

#### 4.2.1.2. Tilt Motion Range

Unlike the pan mechanism, tilt mechanism (as shown in Fig. 23) does not contain any gear mechanism. Rather it contains two MG996R rc geared servo motors, placed in opposite directions but connected to a single signal input wire so as to receive the same input signal and tilt the neck over the range of the servo motors i.e.,  $0^\circ$  to  $180^\circ$  with  $0^\circ$  and  $180^\circ$  have been defined as the extreme positions while  $90^\circ$  has been referred as the mean (central) position of the robot's tilting. However, using this full range makes no sense as we do not, yet, require the robot to even see the roof right up its head. A nominal or recommended useful range of motion, suggested by experimental results is  $0^\circ$  to  $50^\circ$  with  $0^\circ$  and  $50^\circ$  have been defined as the extreme positions while  $25^\circ$  has been referred as the mean (central) position of the robot's tilting. The corresponding field of view for this tilt range can be seen in Fig 37a and Fig. 37b.



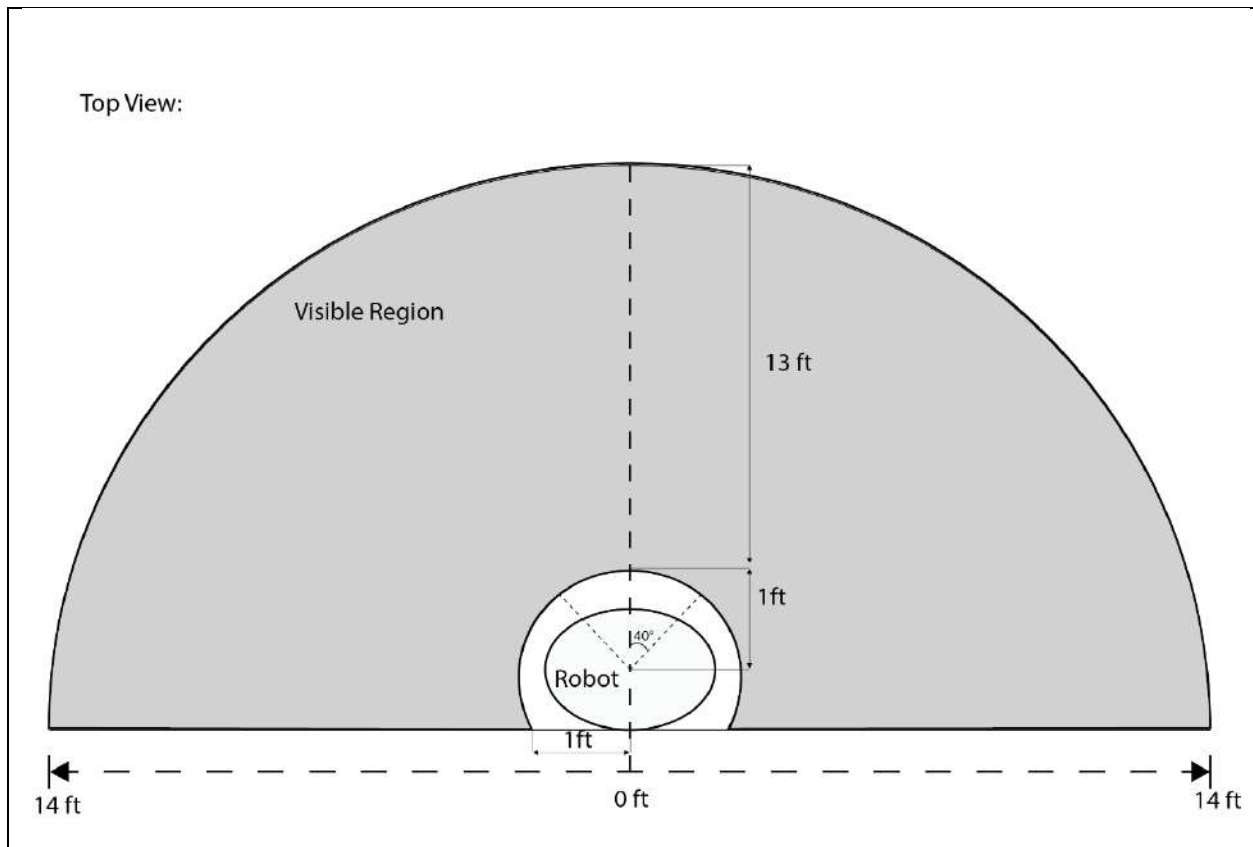
**Figure 37a.** Field of View with Tilt angle= $0^\circ$



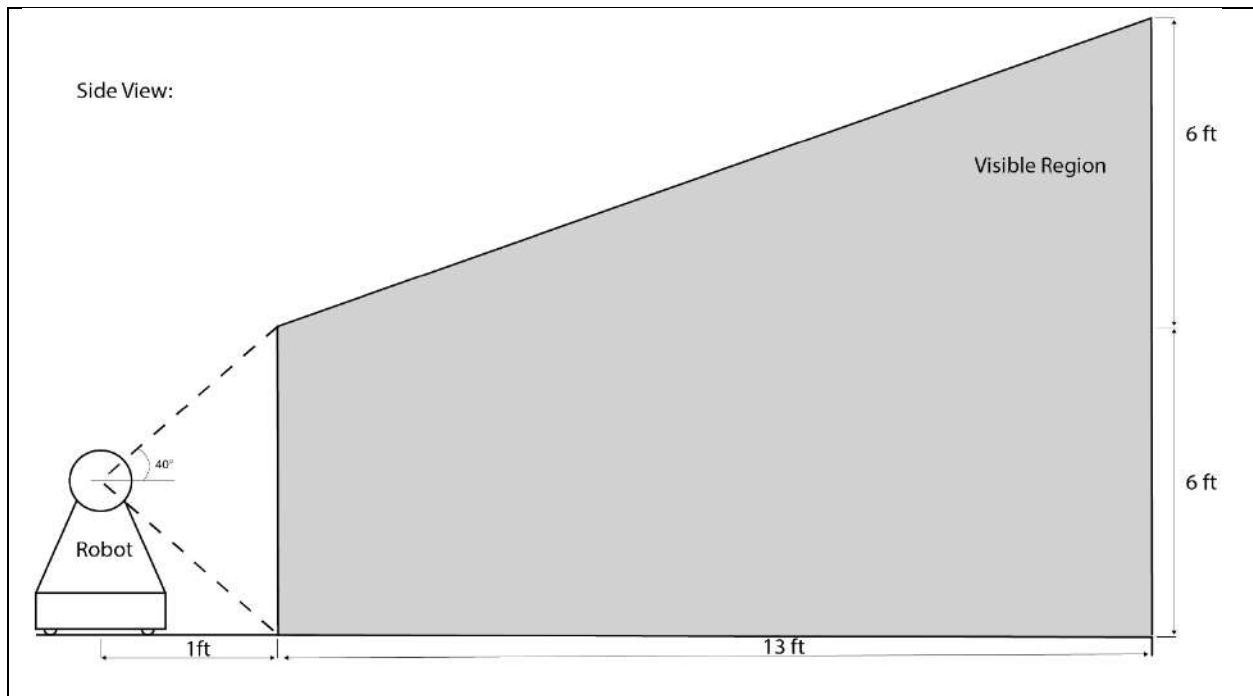
**Figure 37b.** Field of View with Tilt angle= $50^\circ$

#### 4.2.1.3. Robot's Perspective subjected to the Designed Tilt-Pan Range

For capturing and defining the perspective of the robot, subjected to the designed tilt-pan mechanism and their respective ranges, the robot was kept stationed at a point and a simple face tracking algorithm was used to capture a meaningful range of perspective in which the robot can easily detect a person without having to rotate its base. In this method, the robot's pan and tilt motions were ranged over their corresponding limits to capture its near points and far points over the whole pan and tilt ranges. The resulting hyperplane in this way was estimated based on the depth of the subject (to be detected/tracked). This hyperplane has been visualized in the form of two orthographic views (top view and side view), from the robot's perspective in which the face tracking algorithm works. These orthographic views, covering the robot's perspective span while it is kept stationed and ranged over its tilt-pan ranges can be seen in Fig. 38 and Fig. 39 in which the grey area is the visible region while white area is the blind spot of robot.



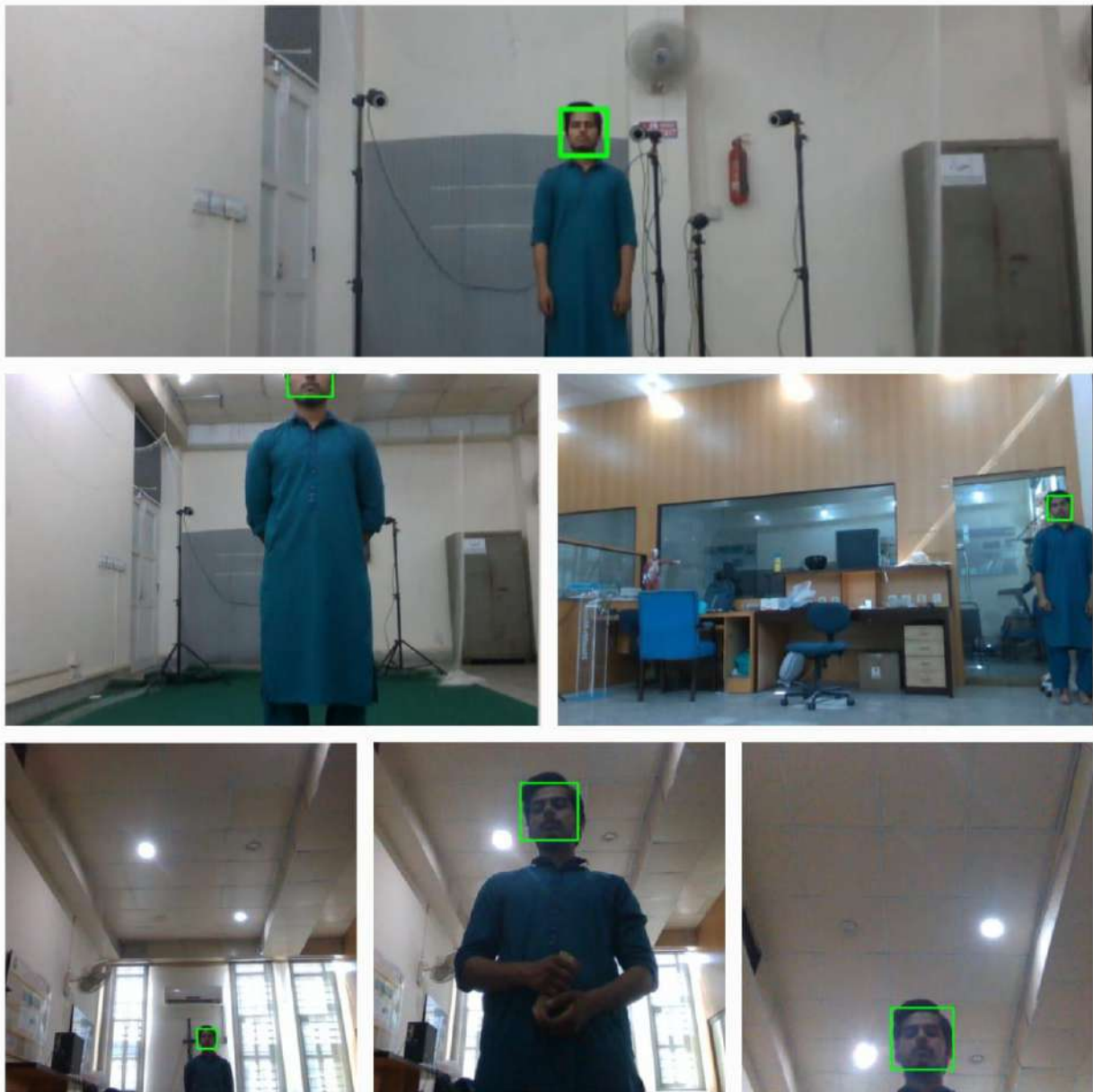
**Figure 38.** Top View of the Robot's Perspective Hyperplane (Shaded Region)



**Figure 39.** Side View of the Robot's Perspective Hyperplane (Shaded Region)



From the above Figures (Fig. 38 and Fig. 39), it can be seen that while the robot is kept stationed at a point, it can track a person/object, over a linear distance range of 14 feet in front of it as well as on either side of its mean position using its pan mechanism/range and the realsense camera's field of U range of capturing  $40^\circ$  on both sides of its central view point. Also, the robot is able to capture/track the person/object from a height of 1 foot from the ground up to a maximum linear height of 12 feet (almost up to the roof). These show the strength of the designed tilt-pan mechanisms/ranges and the mounting of camera in the robot's forehead. Both the field of U of the camera and the perspective of the robot subjected to its tilt-pan are assisting each other in creating a wider and more broader robot's perspective.



**Figure 40.** Collage of different extreme and mean points of the robot's perspective

### 4.3. Voice Interaction

The voice interaction system of the Elderly Care Companion Robot made significant progress, achieving a 92% accuracy rate in responding to natural language commands and prompts as programmed for the development and testing phase. In contrast to the previous iteration, where the chatbot operated as a standalone feature, the integration of voice interaction with the robot's expressions and micro gestures represents a substantial advancement.

In this new iteration, the chatbot's functionality was seamlessly integrated with the robot's expressions and micro gestures using a tilt-pan mechanism for head movement and systematic arm control. This holistic approach enhances the user experience by providing more natural and intuitive interactions with the robot.

During extensive internal testing, the system demonstrated a high level of responsiveness, with the design team verifying the effectiveness and reliability of voice recognition and processing algorithms. These improvements ensure that the Elderly Care Companion Robot can effectively engage with users and provide personalized assistance in a variety of scenarios.

#### 4.3.1. Natural Responses Generated by ChatGPT

As shown in Fig. 17 of section 3.5, the robot has the capability of interacting with a person through voice interaction using microphones and speakers. The mechanism behind this interaction entails the API of chatGPT (see appendix C.2.1) that generates responses based on the natural language processing algorithm, incorporated by openai.

**Table 12.** Results of robot's chatbot corresponding to the natural commands and respective prompts

Given Natural Command	Robot's Understanding	Corresponding ChatGPT Prompt Generated	Robot's Voice Response (using ChatGPT API)
Hi	Hi	Hey!	Hello! How can I assist you today?
How are you	How r u	How are you?	I'm doing great, thanks for asking! How about you?
Can you tell me a joke	Can you tell me a joke	Can you tell me a joke?	How can I help you today? Sure, here's a joke for you: Why don't scientists trust atoms? Because they make up everything!
Who is the chief of army staff of Pakistan	Who is the chief of army staff of Pakistan	Who is the chief of army staff of Pakistan?	The current Chief of Army Staff of Pakistan is General Qamar Javed Bajwa
Do you support racism	Do you sport racism	Do you sport racism?	Absolutely not.
Can you tell me the weather in Lahore today	Can you tell me the whether in Lahore today	Can you tell me the weather in Lahore today?	I can't provide real-time information like current weather updates.
Can AI take over the world	Can a i take over the world	Can a i take over the world?	Taking over the world is a common trope in fiction, but in reality, it's an extremely complex and ethically problematic endeavor.

The above responses of the robot (table 12) show the effectiveness of the NLP of ChatGPT incorporated in the chatbot (appendix C.2.1). It is also observed that sometimes the robot does not understand exactly what it is told (like in the last row of table 12) as in the case of abbreviations. Also, as the free chatGPT (3.0 and 3.5) model is updated till September 2021, it gives responses to the updated information accordingly (as shown in the 4<sup>th</sup> and 6<sup>th</sup> row of table 12). Moreover, the free version offers a limited number of tokens (4096 output tokens where 1000 tokens = 750 words) without buying a subscription package. Still, the overall accuracy of the robot's voice interaction in terms of understanding the speech and responding back is observed, to be almost 90%, after rigorous testing by the design team.

### 4.3.2. Response to the Pre-fed Data

In order to showcase the strength and effectiveness of the installed voice interaction mechanism in the robot and to accuracy of the chatbot, the robot was fed some data in a file (.csv) in which questions and there corresponding answers were written. The robot was asked these questions and based on that the responses were given by the robot very accurately, exhibiting the strength of the installed voice interaction mechanism. The code used for this testing is given in appendix C.2.2. The dataset for developed for this testing is represented below in table 13.

**Table 13.** Pre-fed dataset for robot's voice interaction testing

Question	Answer
What is your name?	My name is CareBot.
How can you help me?	I can assist you with daily tasks remind you to take your medication and provide companionship.
What can you do?	I can navigate around your home detect spills and gas leaks and monitor your vital signs.
How do I take my medication?	I will remind you when it's time to take your medication and provide instructions if needed.
Can you call someone for me?	Yes I can call your family members or emergency services if needed.
What should I do in an emergency?	Stay calm I will contact emergency services and provide assistance until help arrives.
Can you play music?	Yes I can play your favorite music. Just tell me what you would like to hear.
How do I charge you?	I will automatically go to my charging station when my battery is low.
What are my appointments for today?	You have an appointment with Dr. Smith at 3 PM and a physiotherapy session at 5 PM.
Can you remind me of my tasks?	Yes I can remind you of your tasks. Just let me know what you need to do.
Can you help me exercise?	Yes I can guide you through simple exercises and ensure you do them correctly.
What should I eat today?	I can suggest a healthy meal plan based on your dietary needs and preferences.
How do you keep me safe?	I monitor your environment for hazards and provide alerts and assistance to keep you safe.



#### 4.4. Robot's Facial Expressions

The robot's ability to convey emotions and intentions through facial expressions and body language underwent substantial development. In contrast to the previous stage, which utilized only the robot's eyes (Fig. 18a), the new iteration introduced an open-source robotic face (Fig. 18b) designed specifically for this purpose. This robotic face includes not only eyes but also eyebrows and lips, providing a more interactive and engaging appearance. An initial attempt (Fig. 18c), to make the robot face from scratch, was also made but had been dropped due to the unmatching aesthetics. The effective use of the expressions, exhibiting the strength of their incorporation within the HRI hierarchy can be seen in appendix C.2.3 and C.2.4.

These expressions were meticulously designed to enhance user engagement and emotional connection. Internal testing and verification by the design team confirmed that the expressions were effective in simulating human-like interactions, significantly adding to the robot's appeal and functionality. With these enhancements, the Elderly Care Companion Robot can now convey a wider range of emotions and intentions, enriching the user experience and fostering a deeper sense of connection as demonstrated in the real-time environment (Fig. 41).



**Figure 41.** Collage of robot's face expressions demonstration in real-time

## 4.5. Micro Gestures

The initial integration of micro gestures into the Elderly Care Companion Robot marked a significant advancement, covering 80% of the planned gesture set. In contrast to the previous stage, where no micro gestures were incorporated, this iteration introduced micro gestures in the form of arm movements and tilt-pan movements, complementing the robot's speech and enhancing its interactive capabilities.

Early tests conducted by the design team revealed promising results, showing the potential of micro gestures in enriching communication with users. The initial gesture functionality demonstrated promise in conveying subtle cues and enhancing the robot's ability to engage with users in a more natural and intuitive manner. These advancements lay the foundation for further development and refinement of micro gestures, aiming to provide a more immersive and user-engaging experience with the Elderly Care Companion Robot.

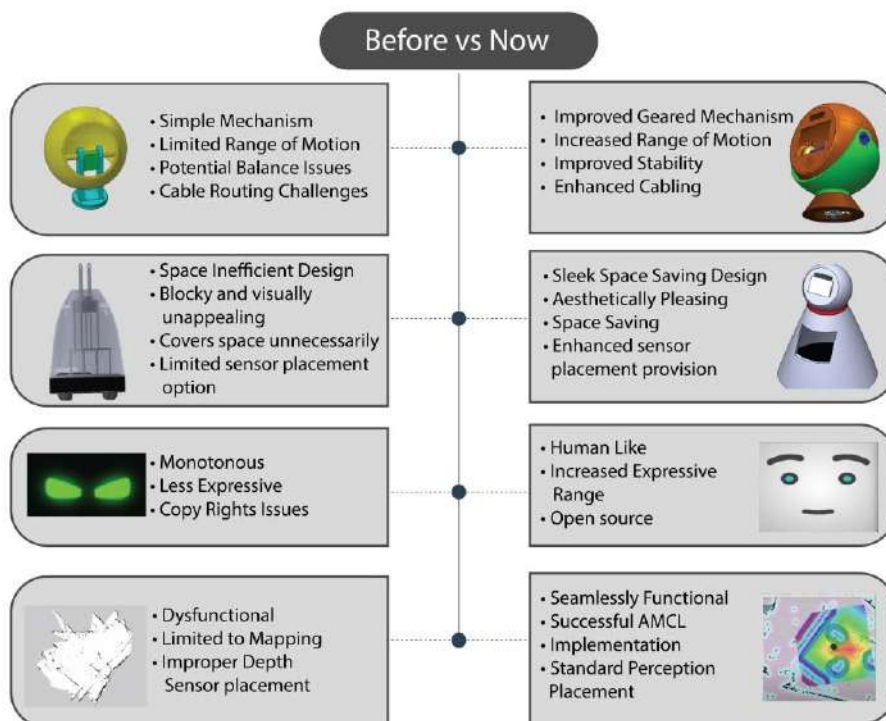
The mechanism used for the incorporation of micro-gestures of the robot is that of rc geared servo motors having a range of  $0^{\circ}$  to  $180^{\circ}$  for the arms and the available and meaningful ranges of the tilt-pan (sec. 4.1.2.1). Rigorous testing was done by the design team to ensure the stable and responsive nature of the arms and neck movements. A well defined and sequential demonstration can be observed in appendix C.2.3 and C.2.4 and is also shown below in Fig. 42.



**Figure 42.** Collage of robot's micro-gestures movements (arms and neck)

## 4.6. Improvements

The Silver Companion robot has seen significant improvements across various dimensions compared to its previous iteration. The mobility system, now utilizing advanced SLAM technology, ensures seamless navigation, tested rigorously in different lab settings. The neck mechanism has been redesigned for better stability and flexibility, resolving prior issues with cable management and space usage. The voice interaction system has been integrated with expressive capabilities and micro gestures, offering a more engaging communication experience. The robot's face now includes interactive eyes, eyebrows, and lips, enhancing human-like interactions. Micro gestures, such as coordinated arm movements and tilt-pan actions, have been added to improve user engagement. These enhancements collectively make the Silver Companion a more effective solution for providing personalized companionship and support to the elderly. A comprehensive comparison can be observed below in Fig. 43.



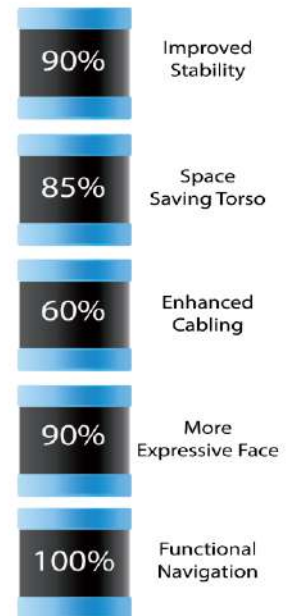
**Figure 43.** Before vs Now

## 4.7. Summary

The Elderly Care Companion Robot demonstrated strong performance across its primary functionalities, indicating significant progress towards a comprehensive solution for elderly care. Key milestones included:

- A 95% success rate in SLAM-based mobility.
- Full completion and successful testing of the robot's physical structure.
- A 92% accuracy rate in voice interaction.
- Effective use of robot expressions verified by the design team.
- Initial successful implementation of micro gestures, covering 80% of the planned set.

These results underscore the potential of the Elderly Care Companion Robot to effectively address loneliness and improve the quality of life for elderly individuals. Further development and refinement will build upon these successes, ensuring the Elderly Care Companion Robot remains a state-of-the-art solution in elderly care.



**Figure 44. Results**

# Chapter 5

## Conclusion and Future Recommendations

### 5.1. Conclusion

The Elderly Care Companion Robot marks a significant leap forward in elderly care, harnessing the power of cutting-edge robotics and artificial intelligence to combat the pervasive challenges of loneliness and social isolation among seniors. Through meticulous design and rigorous testing, the Elderly Care Companion Robot can emerge as a beacon of hope, promising to revolutionize the way we support and interact with our elderly loved ones.

The Elderly Care Companion Robot isn't just a robot; it's a friend, a companion, and a source of joy for seniors everywhere. By blending cutting-edge technology with heartwarming compassion, we've created something truly special—a solution to the loneliness and isolation that many seniors face.

The integration of cutting-edge SLAM-based mobility technology ensures the Elderly Care Companion Robot seamless navigation in various environments, enhancing its utility and practicality. Furthermore, the robust physical structure, rigorously tested for safety and usability, underscores our commitment to delivering a product of the highest standards.

Central to the Elderly Care Companion Robot efficacy is its advanced voice interaction system, which boasts remarkable accuracy and user-friendliness. This feature facilitates seamless communication between users and the robot, fostering meaningful connections and companionship.

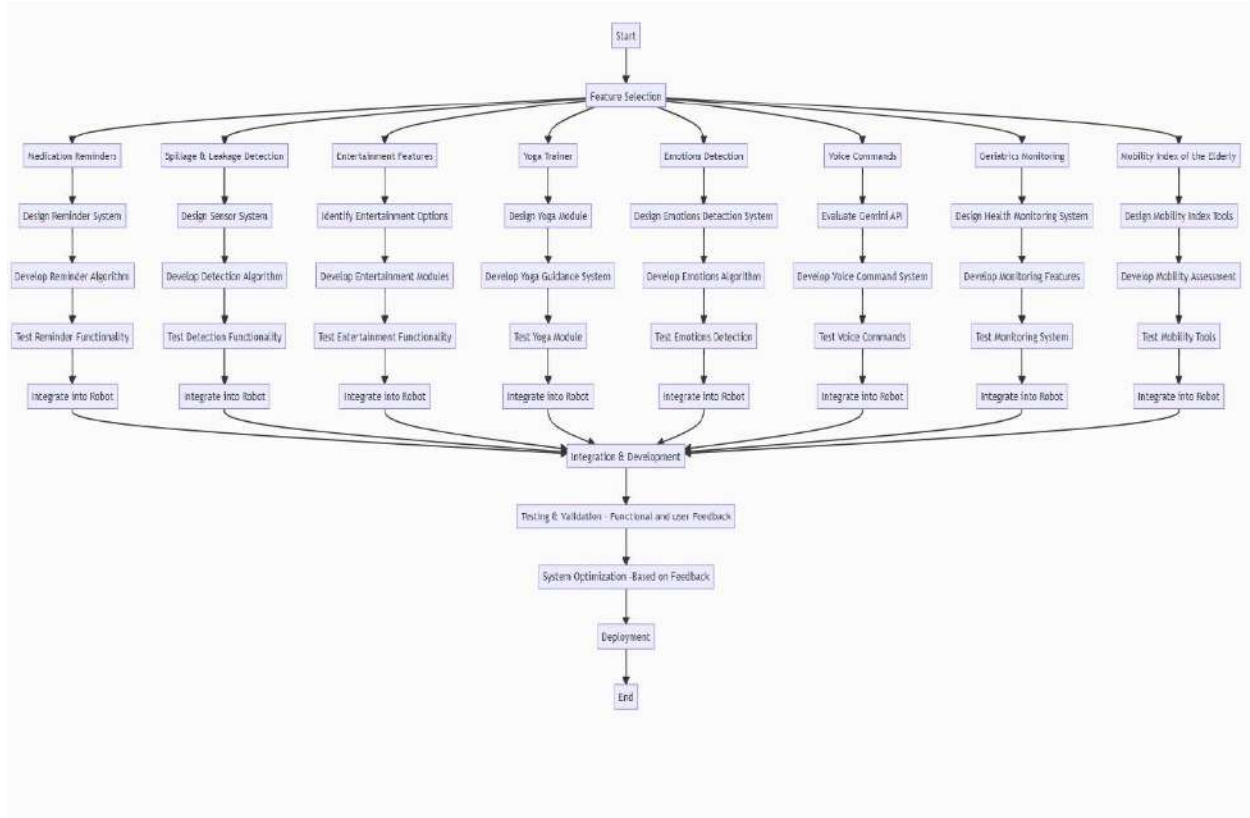
Moreover, the incorporation of expressive capabilities—such as facial expressions and micro gestures—elevates the Elderly Care Companion Robot interaction to a deeply human level, evoking empathy and emotional resonance in users. These features not only enhance user experience but also contribute to mitigating feelings of loneliness and isolation.

As we reflect on the journey of the Elderly Care Companion Robot project, we celebrate the achievement of key milestones, including the successful implementation of advanced mobility and interaction systems, as well as the integration of expressive capabilities.

Looking ahead, we remain committed to further refining and enhancing the Elderly Care Companion Robot, with the ultimate goal of enriching the lives of elderly individuals worldwide. Through ongoing research, development, and collaboration, we are confident that the Elderly Care Companion Robot will continue to serve as a beacon of hope and companionship for years to come.

## 5.2. Future Work

Future development of the Elderly Care Companion Robot will focus on expanding and refining its capabilities to further enhance its functionality and user experience. The following areas, as shown in Fig. 45, have been identified for continued research and development.



**Figure 45.** Future Work Recommendation Flowchart

These advancements will build upon the current capabilities of the Elderly Care Companion Robot, ensuring it remains a comprehensive and effective tool for elderly care, continuously adapting to meet the evolving needs of its users.

# Chapter 6

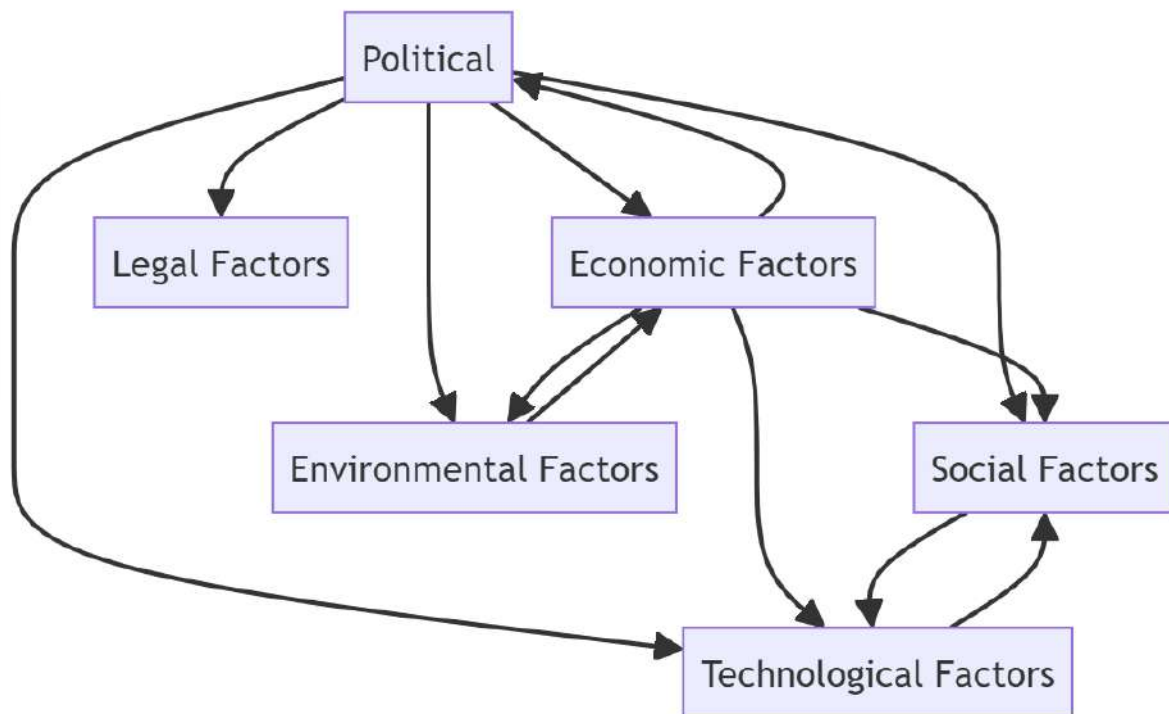
## Societal Impact of the Work

Engineers don't usually work in isolation. The products they make can have an impact on their surroundings and the society they live in. Alternatively, societal norms and culture also have an impact on engineering design.

Engineering design is a multidisciplinary field that extends far beyond the application of mathematics and science. Engineers must consider various external factors that influence the development and deployment of their products. These factors not only affect the functionality and success of the design but also shape its impact on society and the environment.

### 6.1. PESTEL Analysis

To systematically analyze these influences, engineers use the PESTEL analysis framework, which stands for Political, Economic, Social, Technological, Environmental, and Legal factors. They all influence each other and form a dense network of co-relation as shown in figure 46. This framework helps in understanding the broader environment in which a business operates and can be particularly useful for strategic planning and decision-making.

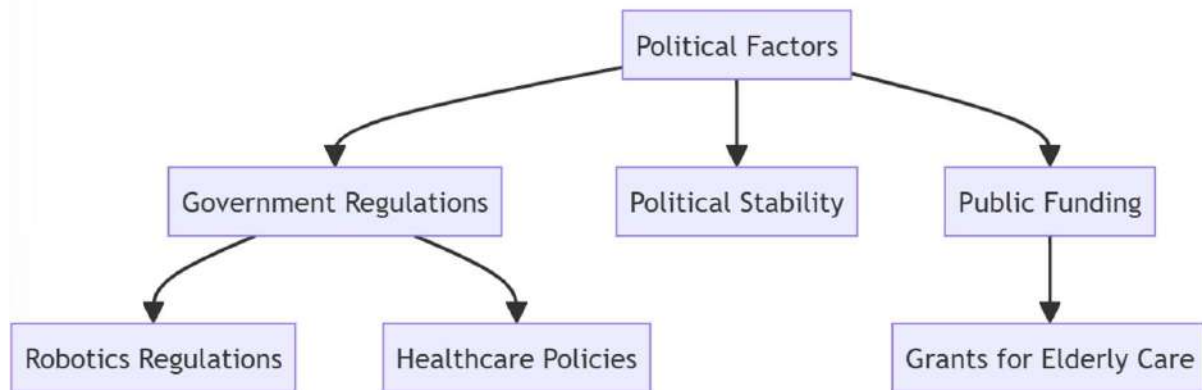


**Figure 46.** Interconnected Network of PESTEL Factors



### 6.1.1. Political Factors

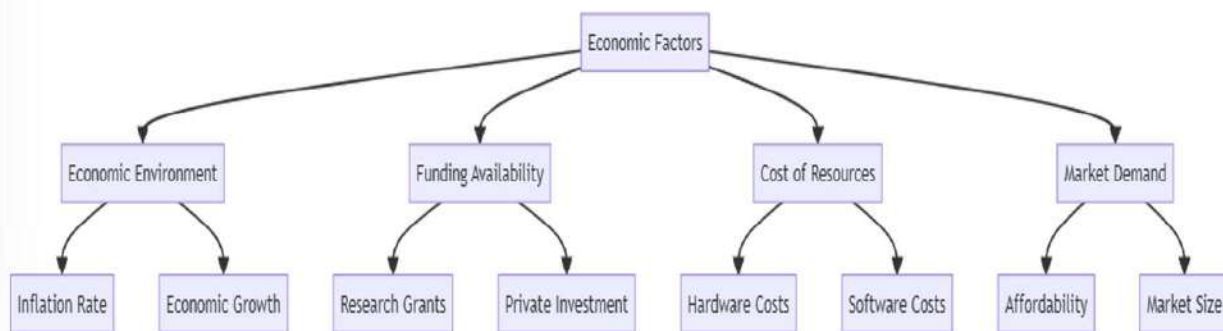
Political factors involve government regulations, policies, and stability, which can directly impact engineering projects. For instance, regulations regarding robotics and healthcare policies are crucial for the development of a care companion robot as shown in figure 47a. Political stability ensures a conducive environment for research and development, while public funding and grants can provide necessary financial support.



**Figure 47a.** Political Factors

### 6.1.2. Economic Factors

Economic factors encompass the economic environment, funding availability, cost of resources, and market demand as in figure 47b. The economic climate influences the affordability and market size for the care companion robot. Engineers must consider the costs associated with hardware and software, as well as the availability of research grants and private investment to fund the project.

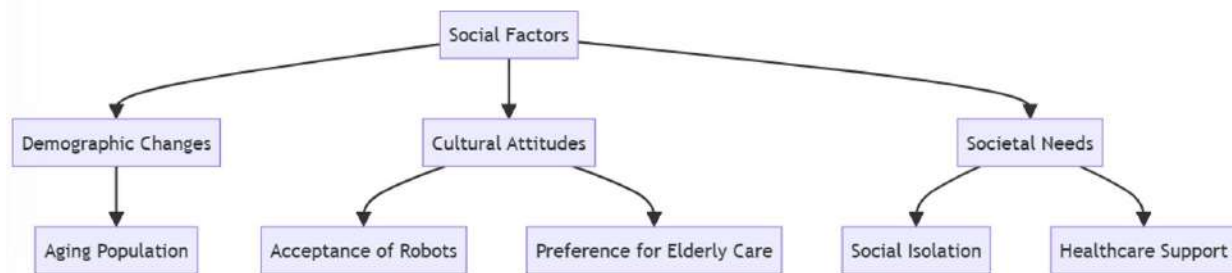


**Figure 47b.** Economic Factors



### 6.1.3. Social Factors

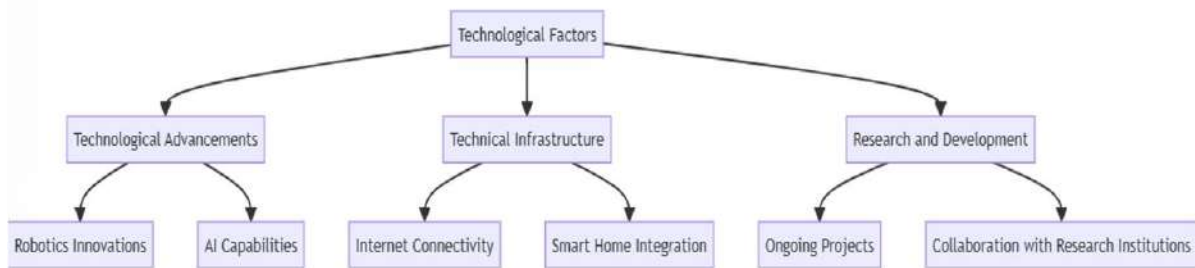
Social factors relate to demographic changes, cultural attitudes, and societal needs as in figure 47c. Understanding the aging population and societal acceptance of robots is essential for the successful adoption of the care companion robot. Cultural preferences for elderly care and addressing social isolation are key considerations in the design process.



**Figure 47c.** Social Factors

### 6.1.4. Technological Factors

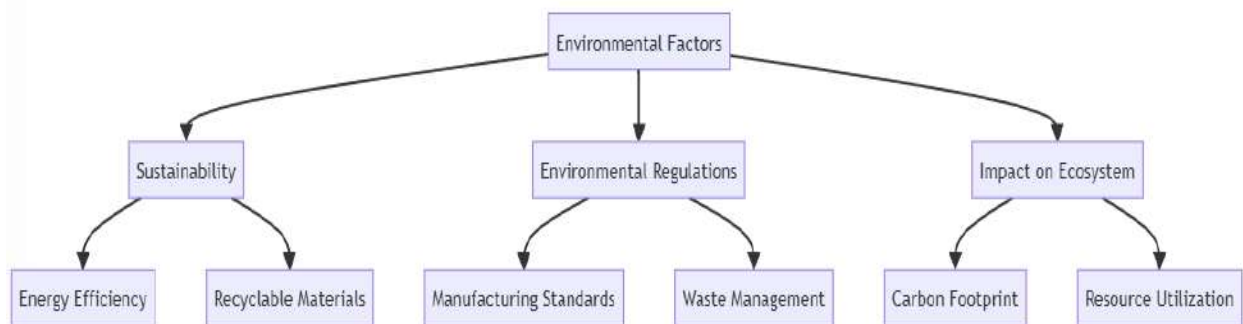
Technological factors include advancements in technology, innovation, and technical infrastructure. Engineers must stay abreast of the latest developments in robotics and AI to ensure their designs are cutting-edge. The integration of the robot into existing smart home systems and the availability of robust internet connectivity are also critical. Advances in machine learning and artificial intelligence have significantly enhanced robot capabilities, enabling effective human interactions and personalized care. Innovation drives the creation of novel solutions, while technical infrastructure ensures seamless operation within smart home environments. High-speed internet is essential for real-time operation, remote monitoring, and access to external data sources. Engineers must also consider scalability and ethical implications, ensuring AI transparency and data privacy. Collaboration with healthcare professionals, policymakers, and technology companies is crucial for developing solutions that are technically sound, compliant with regulations, and socially responsible.



**Figure 47d.** Technological Factors

### 6.1.5. Environmental Factors

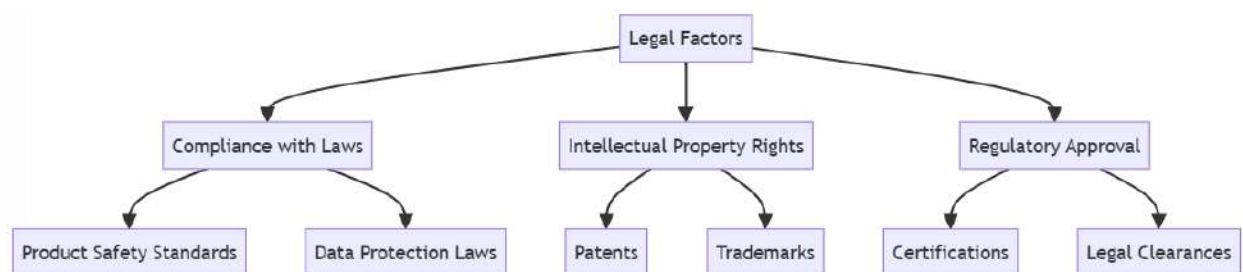
Environmental factors cover ecological and environmental aspects such as sustainability, energy consumption, and waste management. The environmental impact of manufacturing and operating the robot must be minimized by using energy-efficient components and recyclable materials. Compliance with environmental regulations ensures that the project meets sustainability standards. Additionally, adopting a lifecycle approach to design and production can further enhance environmental responsibility. This involves assessing and minimizing the environmental impact at every stage, from raw material extraction to manufacturing, usage, and end-of-life disposal or recycling. Engineers must consider the use of renewable energy sources during the robot's operational phase and strive to reduce greenhouse gas emissions. Implementing sustainable practices, such as designing for disassembly and upgrading, can prolong the robot's lifespan and reduce electronic waste. Engaging in environmental impact assessments (EIAs) and obtaining necessary environmental certifications can also demonstrate a commitment to environmental stewardship. Overall, a focus on sustainability not only helps in preserving the environment but can also improve the robot's marketability and acceptance among environmentally conscious consumers and stakeholders.



**Figure 47e.** Environmental Factors

### 6.1.6. Legal Factors

Legal factors involve adherence to laws and regulations, including product safety standards, data protection, and intellectual property rights. Ensuring compliance with safety standards and data privacy laws is paramount for the care companion robot. Engineers must also navigate the complexities of patenting their innovations and obtaining necessary certifications and legal clearances. This includes understanding and adhering to local, national, and international regulations that govern the design, production, and distribution of robotics. Product safety standards, such as those established by the International Organization for Standardization (ISO) and other regulatory bodies, must be rigorously followed to ensure the robot is safe for use by the elderly. A brief display of legal factors relevant to the project under consideration is shown in figure 47f.



**Figure 47f.** Legal Factors

By conducting a PESTEL analysis, engineers can comprehensively evaluate the external factors influencing their projects. This analysis helps in making informed decisions that align with societal expectations, regulatory requirements, and technological advancements, ultimately leading to the development of successful and impactful engineering solutions.

## 6.2. Impact of the Project

With the global population aging, there is an increasing demand for innovative solutions to support elderly care. Care Companion Robots offer a promising solution, providing enhanced companionship, support, and assistance to elderly individuals. These robots have the potential to improve mental well-being, increase social engagement, and reduce healthcare costs. However, their introduction raises various considerations, including economic, technological, ethical, and cultural factors. Understanding these factors is essential to maximize the benefits of Care Companion Robots while addressing potential challenges. A brief summary of ideas relevant to all those aspects with supporting details is given in Table14.

**Table14. Societal Impact of the Project**

Aspect	Description	Potential Impact	Stats/Supporting Fact
<b>Social</b>	Enhanced companionship and support for elderly individuals, potentially reducing loneliness	Improved mental well-being, increased social engagement, and potential health benefits	- 35% of seniors experience loneliness in World. (Source: Help Age International)
<b>Economic</b>	Cost-effective caregiving solution compared to human caregivers	Reduced healthcare costs for families and institutions, potential job displacement in caregiving sector	- Using robots for elderly care could reduce the cost of care by 34% in Japan. (Source: International Journal of Advanced Robotic Systems)
<b>Technological</b>	Advancement in robotics and AI technology, contributing to the field of social robotics	Potential for further innovations and applications in healthcare and robotics	- Global market for Socially Assistive Robots (SARs) projected to reach USD 3.9 billion by 2025. (Source: Mordor Intelligence)
<b>Psychological</b>	Impact on users' perceptions and attitudes towards robots and technology	Positive experiences could lead to greater acceptance and integration of robots into society, while negative experiences could create resistance or fear.	- Cultural attitudes towards robots vary, with increasing acceptance in countries like Japan and South Korea.
<b>Healthcare</b>	Assistance in healthcare tasks such as medication reminders, monitoring vitals, and emergency calls	Improved healthcare management for users, potentially reducing hospitalization rates and improving overall health outcomes	- Global elderly population expected to reach 2.1 billion by 2050. (Source: United Nations)

# Chapter 7

## Environment and Sustainable Development Goals

### 7.1. UN SDGs

Following are the six SDG's targeted for this project.

#### 1. Goal 3: Good Health and Well-being

The project directly contributes to SDG 3 by aiming to improve the health and well-being of the elderly. The robot's functionalities, both current and future aspects of care and companionship, can help in maintaining the health of seniors and ensuring they receive good treatment.

#### 2. Goal 8: Decent Work and Economic Growth

The project indirectly supports SDG 8 by potentially creating job opportunities in the field of robotics and healthcare. The development, manufacturing, and maintenance of the robot can contribute to economic growth and job creation.

#### 3. Goal 9: Industry, Innovation, and Infrastructure

The project aligns with SDG 9 by promoting innovation in robotics and healthcare technologies. The development of advanced robotics for elderly care demonstrates the potential of technology to address societal challenges.

#### 4. Goal 10: Reduced Inequality

The project addresses SDG 10 by providing assistive technology that can help reduce inequalities in access to healthcare and support services for the elderly. The robot aims to provide personalized care regardless of geographical location or socioeconomic status.

#### 5. Goal 11: Sustainable Cities and Communities

The project's focus on providing care and support for elderly individuals contributes to creating more inclusive, safe, resilient, and sustainable communities. This aligns with Goal 11's aim to make cities and human settlements inclusive, safe, resilient, and sustainable.

#### 6. Goal 12: Responsible Consumption and Production

The project aligns with SDG 12 by focusing on the responsible use of resources in the development and operation of the robot. Efforts are made to minimize waste and energy consumption, ensuring sustainable practices throughout the project lifecycle.

**Table 15. UN Sustainable Development Goals Mapping with reference to Project**

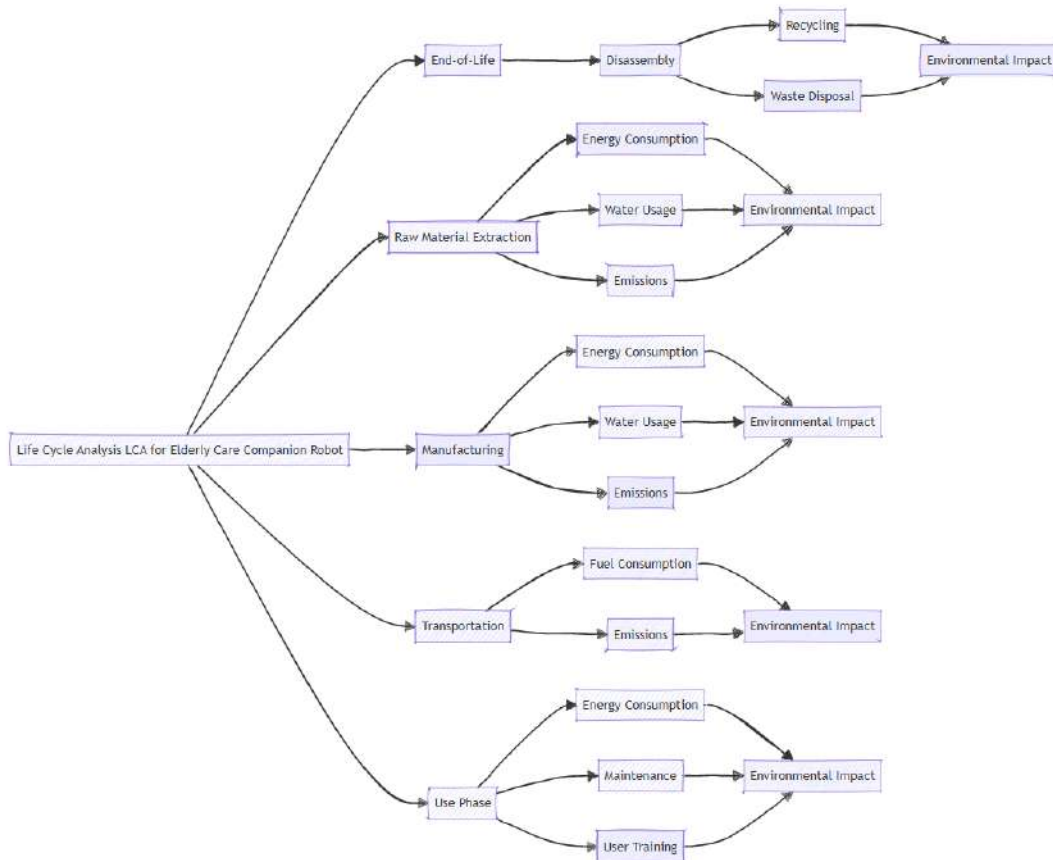
<b>Sr.</b>	<b>SDG</b>	<b>Goal description</b>	<b>Relevance</b>
1.	No Poverty	End poverty in all its forms everywhere.	Low
2.	Zero Hunger	End hunger, achieve food security and improved nutrition and promote sustainable agriculture.	Low
3.	<b>Good health and well-being</b>	<b>Ensure healthy lives and promote well-being for all the ages.</b>	<b>High</b>
4.	Quality education	Ensure inclusive and equitable education and promote lifelong learning opportunities for all.	Low
5.	Gender Equality	Achieve gender equality and empower all women and girls.	Low
6.	Clean water and sanitation	Ensure availability and sustainable management of water and sanitation for all.	Low
7.	Affordable and clean energy	Ensure access to reliable, affordable, sustainable, and modern energy for all.	Low
8.	<b>Decent work and economic growth</b>	<b>Promote sustained, inclusive, and sustainable economic growth, full and productive employment and decent work for all.</b>	<b>High</b>
9.	<b>Industry, innovation, and infrastructure</b>	<b>Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.</b>	<b>High</b>
10.	<b>Reduced inequalities</b>	<b>Reduce inequalities within and among countries.</b>	<b>High</b>
11.	<b>Sustainable cities and communities</b>	<b>Make cities and human settlements inclusive, safe, resilient, and sustainable.</b>	<b>High</b>
12.	<b>Responsible consumption and production</b>	<b>Ensure sustainable consumption and production patterns.</b>	<b>High</b>
13.	Climate action	Take urgent action to combat climate change and its impact.	Low
14.	Life below water	Conserve and sustainably use the oceans, seas and marine resources for sustainable development	Low
15.	Life on Land	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.	Low
16.	Peace, justice and strong institutions	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.	Low
17.	Partnerships for the goals	Strengthen the means of implementation and revitalize the global partnership for sustainable development.	Low

## 7.2. Impact of Project on Environment and LCA

The project, under consideration, does not have any direct harmful impact on the environment, yet these aspects cannot be ignored. Hence, the most possible and prominent effects are given in table 16. The Life Cycle Analysis of the project is also given in figure 48.

**Table 16.** Impact of Project on Environment

Aspect	Issue	Remedy
Energy Consumption	The robot requires electricity for operation	Using energy-efficient components, and saving electricity through applying standby mode on robot, when not in active use.
Material Usage	Manufacturing the robot involves using various materials, including metals, plastics, and electronics.	Using additive manufacturing techniques like 3D- Printing to reduce waste.
E-Waste	The disposal of electronic components can lead to e-waste.	Implement recycling programs and proper disposal methods.
Carbon Footprint	Manufacturing, operational, and disposal activities contribute to the carbon footprint.	Optimizing the manufacturing process and avoiding burning and open disposal of waste.
Battery Disposal	Used batteries can harm the environment if not disposed of correctly.	Using rechargeable batteries and properly disposing discarded batteries.



**Figure 48.** Life Cycle Analysis (LCA) of the Robot

# Chapter 8

## Life-Long Learning and Future Recommendations

Below is a description of learning throughout the project of all the members individually and collectively.

### **8.1. Individual Contributions to the work**

#### **8.1.1. Muhammad Noor Sultan**

Following tasks were done by him.

1. Composing Applications for Funding and Equipment
2. Thesis Writing
- 3. Research and Analysis**
- 4. Facial Expressions and Micro-Gestures**
5. Business Modeling
6. POC Presentation, Pitch Deck Presentations
7. Reviewing Solid works Design
8. Implementing Navigation

#### **8.1.2. Muhammad Muaviz**

Following tasks were done by him.

1. Logistics and Finance
2. Thesis Proof Reading
3. Research and Analysis
4. Facial Expressions and Micro-Gesture
- 5. Design and Simulation on Solid works**
- 6. Hardware Assembly**
7. Implementing Navigation

#### **8.1.3. Ali Sajid**

Following tasks were done by him.

1. Group Lead
2. Thesis Writing
3. Research and Analysis
4. System Configuration
5. Reviewing Solid works Design
- 6. Hardware Debugging**
- 7. Implementing Navigation**
8. Poster Design

## **8.2. Life Long Learning**

### **8.2.1. Technical Aspects**

1. All these skills are learnt exclusively for FYP.
  - Linux Terminal and Configuration
  - ROS (Robotic Operating System)
  - Mobile Robotics
2. All these skills are learnt exclusively from FYP.
  - Design consideration while mapping CAD Model to actual 3D Part
  - Hardware Debugging
  - Software Configuration and Debugging
  - HW/SW Integration
  - Operating and Controlling a high end Micro-Processor

### **8.2.2. General Aspects**

- All these general skills are learnt through this FYP.
- Cognitive Skills: Problem Solving, Critical Thinking and Learning Ability and Adaptability
- Social Skills: Presentations, Communication, Team Work, Collaboration
- Emotional Skills: Empathy, Cultural Sensitivity, Patience and Tolerance
- Management Skills: Team Management, Time Management, Project and Task Management
- Business Skills: Networking, Pitching, Marketing, Strategic Planning, Negotiating

## **8.3. Future Recommendations**

### **8.3.1 Navigation**

1. Developing and Comparing Different Navigation Techniques
2. Sensor Data Fusion from 2 cameras for better Navigation
3. Sound Source Localization
4. Human Aware Navigation
5. Context Aware Navigation

### **8.3.2 HRI**

1. Adding features to the HRI
2. Improving Micro-Gestures

### **8.3.3 Care**

1. Incorporating sensors Gas-Leakage Detection
2. Adding Sensors to monitor robot vitals
3. Adding Spillage Detection

### **8.3.3 Monitoring**

1. Incorporating Activity Monitoring and Mobility Index for the elderly
2. Adding gait and fall risk analysis from Robots point of view



# Chapter 9

## Business Plan of the Product

The Chapter contains the following contents:

### **9.1. Cover Sheet: Business Name, Address, Phone Number, Principals**

### **9.2 Statement of Purpose**

### **9.3 Section One: The Business**

- a. Description of Business
- b. Description of Product
- c. Market Analysis
- d. Marketing Plan
- e. SWOT Analysis
- f. VRIO Analysis
- g. Competition
- h. Management and Operations

### **9.4 Section Two: Financial Data**

- a. Break Even Analysis
- b. Sources and Uses of Funds

### **9.5 Section Three: BMC**

## **9.1. Cover Sheet: Business Name, Address, Phone Number, Principals**

MN Sultan  
Head PR  
Age Well Technologies  
UET, Lahore.

[Investor's Name]  
[Investor's Title]  
[Investor's Company]  
[Investor's Company Address]

### **Subject: Investment Opportunity in CareBot – Revolutionizing Elderly Care Paradigm**

Sir/Madam,

Myself MN Sultan the Head of Public Relations at Age Well Technologies, a pioneering team of mechatronics engineers dedicated to transforming elderly care through innovative robotics solutions. I am writing to introduce you to our flagship product, Silver Companion, and to invite you to consider an investment opportunity that promises significant returns and societal impact.

The global elderly population is growing rapidly, leading to increased demand for effective care solutions. Many seniors face isolation, health management challenges, and safety concerns, which traditional care methods struggle to address comprehensively and cost-effectively.

Silver Companion is a state-of-the-art elderly care companion robot designed to enhance the quality of life for seniors by providing personalized companionship, health monitoring, safety assurance, and emergency assistance. Leveraging advanced AI, machine learning, and user-centered design, Silver Companion offers a unique and holistic approach to elderly care. Silver Companion engages with seniors through conversations, activities, and entertainment. It features integrated sensors to track vitals and remind seniors about medication. It detects hazards such as gas leaks and spills, alerting caregivers immediately. It ensures smooth and safe movement within the home environment and provides immediate support and contacts emergency services when needed.

The elderly care market is vast and growing, with a clear need for innovative solutions like Silver Companion. Our target markets include home care, assisting seniors living independently, healthcare facilities, supporting staff in elderly care homes and hospitals, and family caregivers, offering peace of mind for families.

We plan to generate revenue through product sales, offering Silver Companion directly to consumers and institutions, subscription services for ongoing support and software updates, and strategic partnerships with healthcare providers and senior living facilities.

We anticipate rapid market adoption with a break-even point within the first two years post-launch.

We believe Silver Companion has the potential to revolutionize elderly care, providing immense value to seniors, their families, and the broader healthcare ecosystem. We are seeking an investment of [specific amount] to support our product launch, expand our market reach, and drive continued innovation.

We would be honored to discuss this opportunity with you in more detail. Please find enclosed our detailed business plan and financial projections. Thank you for considering our proposal, and we look forward to the possibility of working together to make a meaningful difference in the lives of seniors worldwide.

**Regards,**  
**MN Sultan**  
**Head Public Relations/ Head Research and Development**  
**Age Well Technologies [Contacts]**

A ROBOTIC FRIEND: ALWAYS  
THERE, ALWAYS CARING



# ELDERLY CARE COMPANION ROBOT

## FEATURES:

- Companionship
- Emotional Support
- Safety Monitoring
- Medication Reminders
- Health Monitoring
- Entertainment
- Emergency Response



+92-312-4654967

UET, Lahore

[www.agewelltechnologies.com](http://www.agewelltechnologies.com)

## 9.2. Statement of Purpose

We are a group of passionate mechatronics engineers committed to creating novel ways to enhance the lives of senior citizens. Our main offering, the CareBot, is made to offer elders individualized support and companionship, improving their quality of life. By utilizing cutting-edge robotics, artificial intelligence, and user-centered design concepts, we want to meet the increasing demand for efficient senior care options. The need for care and support services is rising due to the world's growing aging population. Seniors frequently struggle with social isolation, everyday task difficulty, and independent health management. Conventional care options are either prohibitively expensive, difficult to get, or fall short of offering the individualized care needed. There has to be a more creative, practical, and affordable way to close this gap in senior care services.

Modern senior care companion robot CareBot is made to provide a wide range of services, such as emergency support, safety assurance, health monitoring, and individualized companionship. With the help of cutting-edge AI, machine learning, and user-centered design, CareBot provides senior care in a distinctive and all-encompassing way. Key features include interacting with seniors via conversation, entertainment, and activities; incorporating sensors to monitor vital signs and send medication reminders; identifying potential hazards, like gas leaks or spills, and notifying caregivers; guaranteeing easy mobility within the home; and offering prompt assistance and emergency services contact when required. Our target markets include family caregivers, healthcare facilities, home care, helping seniors live independently, and supporting employees in hospitals and senior care homes. We also aim to provide families with peace of mind about their elderly relatives. Modern senior care companion robot CareBot is made to provide a wide range of services, such as emergency support, safety assurance, health monitoring, and individualized companionship. With the help of cutting-edge AI, machine learning, and user-centered design, CareBot provides senior care in a distinctive and all-encompassing way. Key features include interacting with seniors via conversation, entertainment, and activities; incorporating sensors to monitor vital signs and send medication reminders; identifying potential hazards, like gas leaks or spills, and notifying caregivers; guaranteeing easy mobility within the home; and offering prompt assistance. Our target markets include family caregivers, healthcare facilities, home care, helping seniors live independently, and supporting employees in hospitals and senior care homes. We also aim to provide families with peace of mind about their senior relatives.

Our forecasts indicate a strong growth trajectory with notable consumer acceptance, with a break-even point expected within the very first two years subsequent launch. Our financial model ensures sustainable growth and profitability by being based on reasonable assumptions and a thorough examination of the market. We are dedicated to reducing our environmental impact by using eco-friendly materials and manufacturing techniques, building CareBot with minimal power consumption, and putting end-of-life recycling programs in place to cut down on waste.

Good Health and Well-Being (SDG 3), Decent Work and Economic Growth (SDG 8), Industry, Innovation, and Infrastructure (SDG 9), Reduced Inequalities (SDG 10), Sustainable Cities and Communities (SDG 11), and Responsible Consumption and Production (SDG 12) are just a few of the Sustainable Development Goals (SDGs) that our project supports. We are making the world a more equal and sustainable place by tackling these objectives.

CareBot is a technological innovation in the field of elder care, fusing a thorough grasp of human requirements with the experience of mechatronics engineering. Our dedication to quality, innovation, and user pleasure puts us in a position to significantly improve the lives of seniors and their families as well as the larger healthcare system. We cordially ask you to join us in bringing CareBot to a new level of senior care.

## 9.3. The Business

### 9.3.1. Business Description

**Table 17.** Simplified Business Description

<b>Name</b>	Age Well Technologies
<b>Product</b>	Elderly care companion robot, <b>Silver Companion</b>
<b>Industry</b>	Robotics
<b>Core Procedures</b>	RnD, 3D Printing, Mobile Robotics, Embedded Systems
<b>Location</b>	Workshop: UET Lahore Office: UET Lahore
<b>Source of Revenue</b>	Product sales, subscription services, partnerships, Maintenance
<b>Potential Investors</b>	Venture capital firms, angel investors, healthcare providers, Research Organizations
<b>Future Endeavors</b>	Expand market reach, enhance product features, develop new healthcare applications, improve user experience

### 9.3.2. Description of the Product

**Table 18.** Simplified Product Description

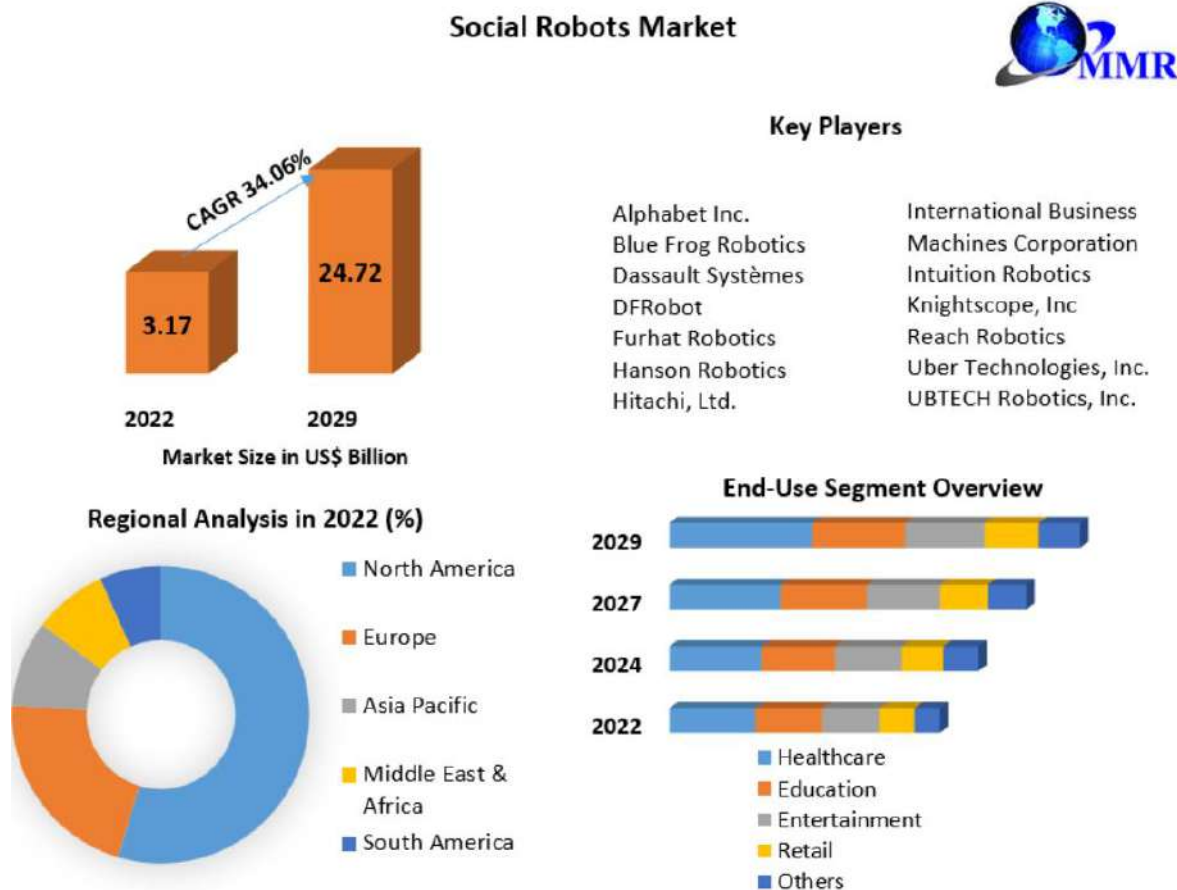
<b>Name</b>	<b>Silver Companion</b>
<b>Functionality</b>	Mobility, Voice Interaction, Facial Expressions, Micro-Gesture, Emergency Alert System
<b>Features</b>	Friendly Appearance, Personalized Care, Interactive Interface, Low Cost
<b>Specifications</b>	Battery Powered, contains camera and microphones
<b>Material</b>	PLA and other plastics
<b>Weight</b>	8 kg
<b>Size</b>	Height 4 ft on a base with 14" diameter
<b>Estimated Manufacturing Cost</b>	USD 3000
<b>Planned Selling Cost</b>	USD 3500
<b>Future Endeavors</b>	Expand market reach, enhance product features, develop new healthcare applications, improve user experience



**Figure 49.** High Fidelity Prototype with all the basic functions running

### 9.3.3. Market Analysis

The market of SAR's, no doubt is growing at a rapid rate especially in the case of such robots in health care. Researches show it to be one of the leading industries in future in Canada, US, Europe, Japan, South Korea and China as in figure 37. The main cause of such requirements is demographic shift, as the median age in these regions is shifting towards fifties, mainly due to decreased birth rates and death rates.



**Figure 50.** Market of SAR's (source: <https://www.maximizemarketresearch.com>)

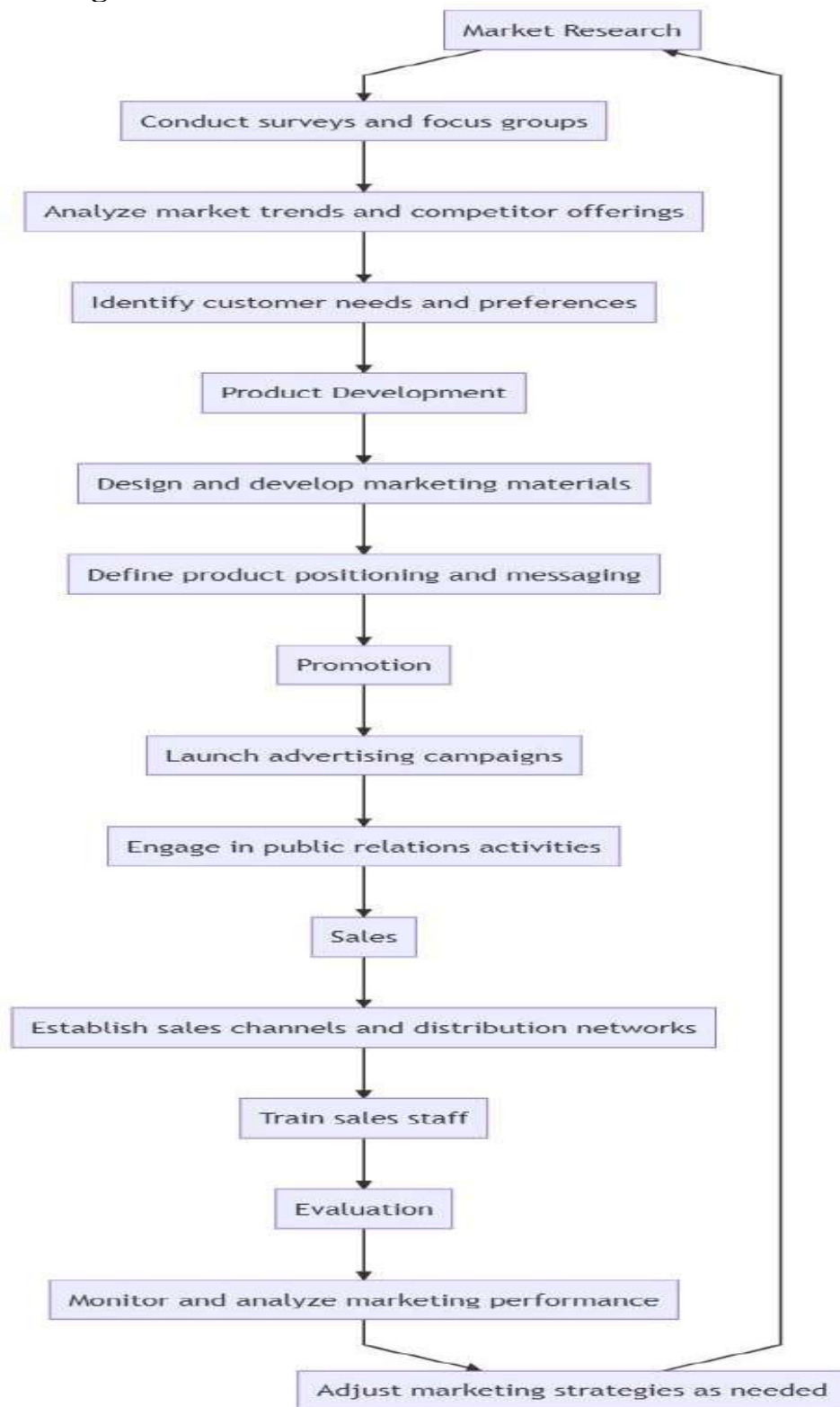
Based on the data from 2018-2022, estimated size of market of such robots is expected to be about 24.72 Bn USD as in figure 47. Thus, the potential of this market is validated by this survey. Also, the care and companion robots find a market in health care sector.

Social Robots Market			
Report Coverage	Details		
Base Year:	2022	Forecast Period:	2023-2029
Historical Data:	2018 to 2022	Market Size in 2022:	US \$ 3.17 Bn
Forecast Period 2023 to 2029 CAGR:	34.06%	Market Size in 2029:	US \$ 24.72 Bn.
Segments Covered:	by End-Use	Healthcare Education Entertainment Retail Others	

**Figure 51.** Current and Future Market size of SAR's (source: [maximizemarketresearch.com](https://www.maximizemarketresearch.com))



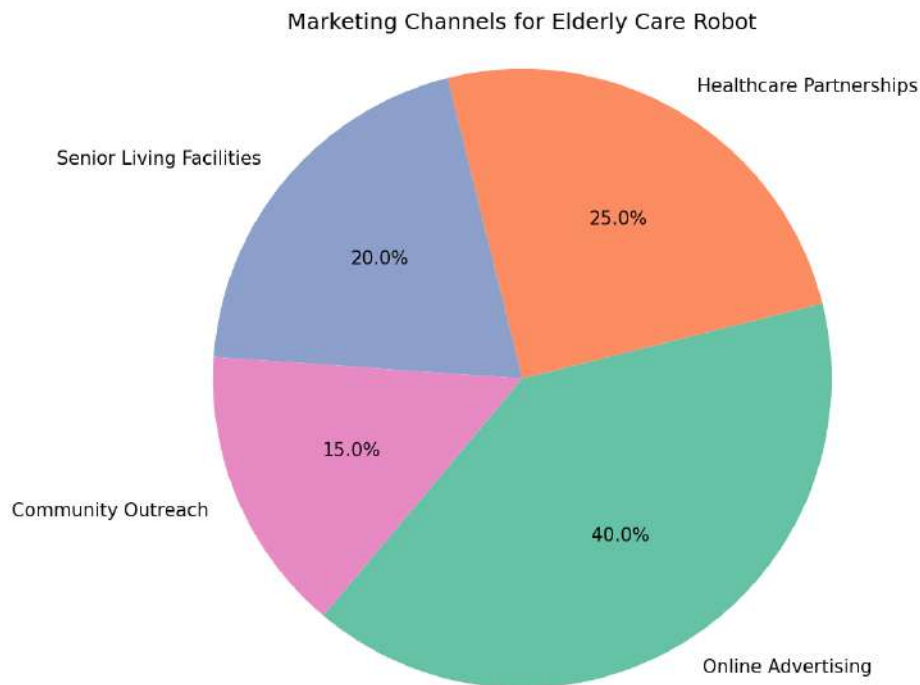
### 9.3.4. Marketing Plan



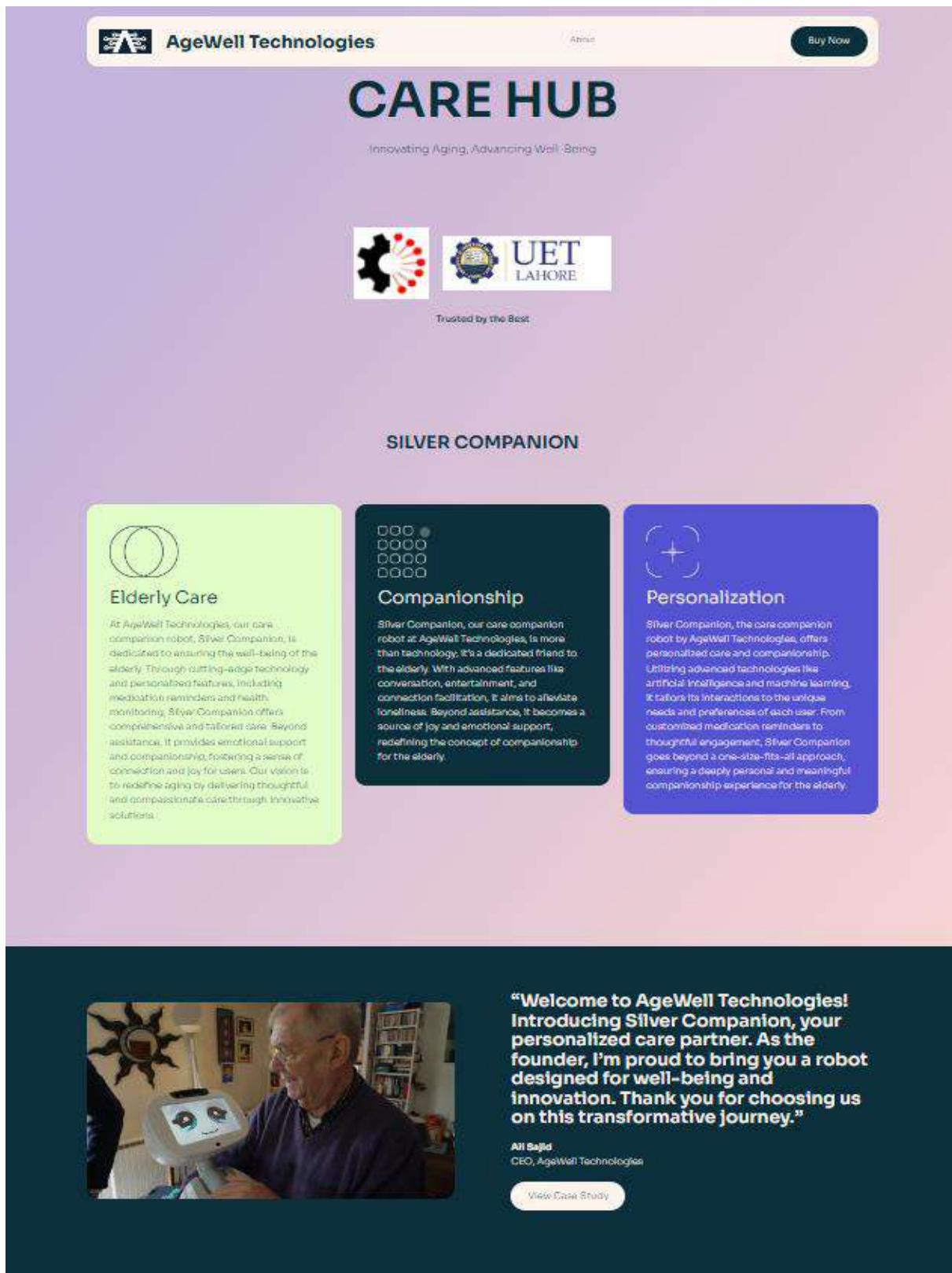
**Figure 52.** Marketing Plan

**Table 19. Marketing Plan Description**

Stage	Activity	Description
<b>Market Research</b>	Survey potential customers	Identify needs, preferences, and willingness to adopt care robots
	Analyze market trends and competitor offerings	Understand market dynamics and competitive landscape
<b>Product Development</b>	Design and develop CareBot	Create a user-friendly, reliable, and feature-rich robot for elderly care
	Define key features and functionality	Determine what sets CareBot apart and addresses specific needs of seniors
<b>Promotion</b>	Develop marketing materials	Create brochures, videos, and online content showcasing CareBot's benefits
	Launch advertising campaigns	Utilize digital and traditional channels to reach target audience
<b>Sales</b>	Establish distribution channels	Partner with retailers, healthcare providers, and online platforms to sell CareBot
	Train sales staff	Educate sales teams on CareBot's features, benefits, and selling points
<b>Evaluation</b>	Monitor sales and customer feedback	Track sales performance and gather feedback to refine marketing and product strategies
	Adjust marketing strategies as needed	Modify messaging or channels based on feedback to improve sales and market penetration
<b>Medium</b>	Social Sites, TV Ads, Website, Community Outreach	For advertising, marketing and feedback

**Figure 53. Marketing Methods**





**Figure 54.** Initial Web Page Design

### 9.3.5. SWOT Analysis

SWOT Analysis enables one not to study just the current status of an organization, but also to project and estimate future performance.



**Figure 55.** General Aspects of SWOT Analysis

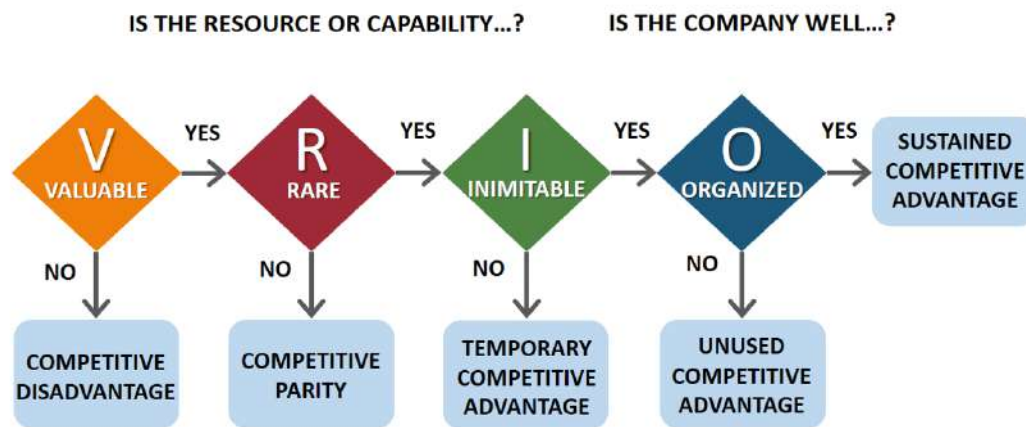
**Table 20.** SWOT Analysis of this Business

Category	Factors
<b>Strengths</b>	Innovative technology, Comprehensive care, User-friendly design, Safety features
<b>Weaknesses</b>	High cost, Limited reach, Technological dependence, Integration challenges
<b>Opportunities</b>	Growing elderly population, Partnerships, Technological advancements, Market expansion
<b>Threats</b>	Competition, Regulatory changes, Economic conditions, Security concerns

### 9.3.6. VRIO Analysis

The VRIO framework is a business analysis tool, which is an integral part of a company's broader strategic plan. The fundamental strategic process for any organization starts with a vision statement and proceeds through objectives, internal and external analyses, strategic choices (at both the business and corporate levels), and strategic implementation.

Although VRIO is primarily used in the internal analysis phase, it serves as a framework for evaluating nearly all of a firm's resources and capabilities, regardless of the strategic model phase in which it is applied.



**Figure 56.** General Framework of VRIO Analysis

**Table 21.** VRIO Analysis of this Business

Resource/Capability	Valuable	Rare	Inimitable	Organized	Competitive Implications
Innovative Technology	Yes	Yes	Yes	Yes	Sustainable Competitive Advantage
Comprehensive Care Features	Yes	Yes	No	Yes	Temporary Competitive Advantage
User-Friendly Design	Yes	No	No	Yes	Competitive Parity
Safety Features	Yes	No	No	Yes	Competitive Parity
High Cost	No	Yes	Yes	No	Competitive Disadvantage
Skilled Workforce	Yes	Yes	Yes	Yes	Sustainable Competitive Advantage
Growing Elderly Population	Yes	No	No	Yes	Competitive Parity
Technological Advancements	Yes	Yes	Yes	Yes	Sustainable Competitive Advantage
Partnerships	Yes	No	No	Yes	Competitive Parity
Strong Brand	Yes	Yes	Yes	Yes	Sustainable Competitive Advantage

### 9.3.7. Competition

As mentioned earlier, the market is growing at a rapid rate, hence there is a large competition already existing.



**Figure 57.** Price vs. Features Plot for Some of the contemporary solutions

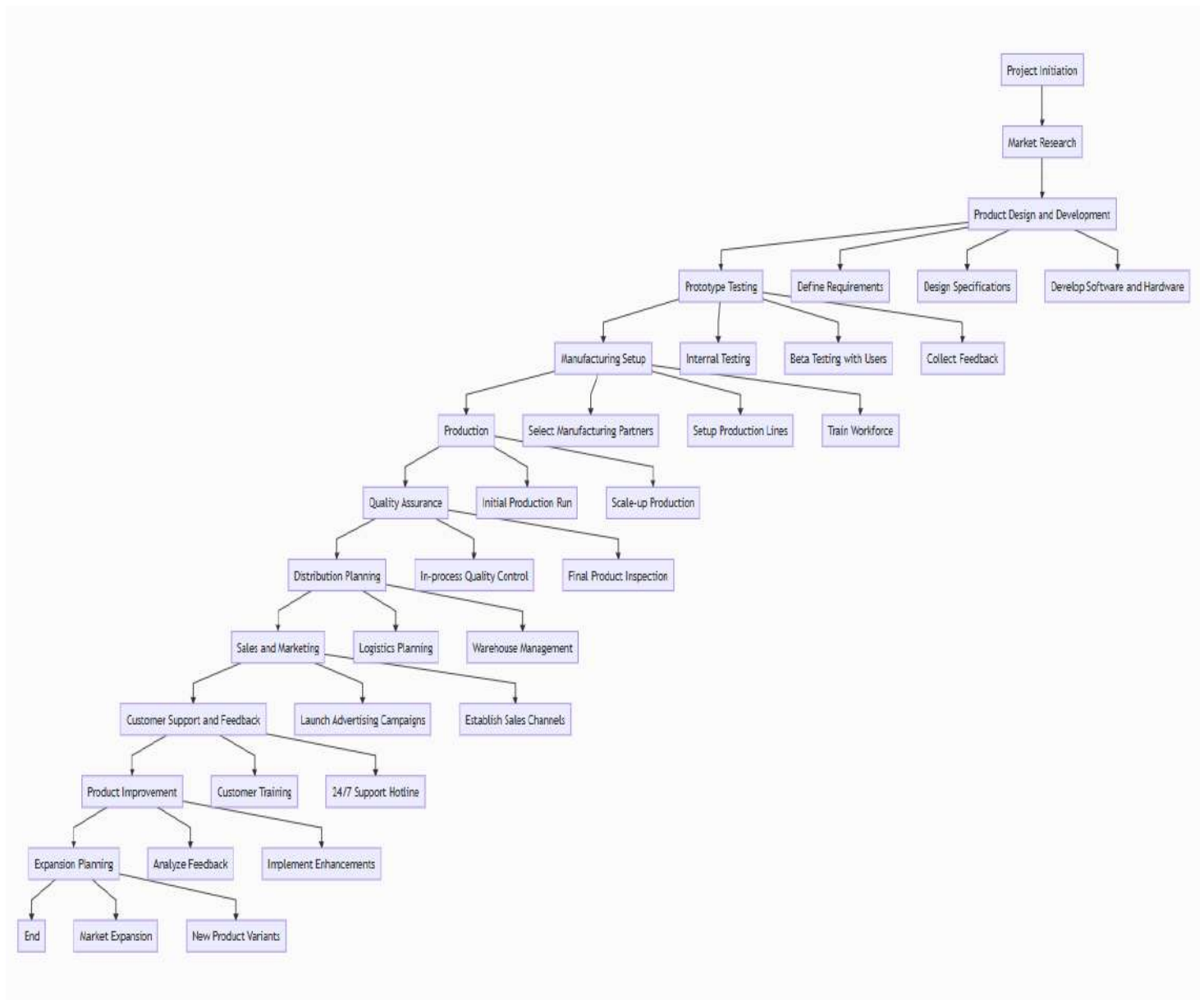
It can be seen that the white space on the plot is occupied by our solution. There is a comparison between features of our robot and other robots in the table below

**Table 22. Comparison of Robots for Elderly Care**

Feature	Care Companion Robot	Pepper	Paro (AIST)	Jibo (Jibo, Inc.)
<b>Cost</b>	Moderate	High	High	High
<b>Mobility</b>	Mobile	Mobile	Stationary	Stationary
<b>Interaction</b>	Voice, gestures, facial expressions	Voice	Touch, voice	Voice, screen
<b>Touch Screen</b>	Yes	No	No	Yes
<b>Appearance</b>	Human-Like	Human-Like	Animal-like (seal)	Sphere Like
<b>Functions</b>	Companionship and Care	Social interaction, reminders, entertainment	Emotional support, therapeutic	Social interaction, entertainment
<b>Customization</b>	Moderate	Moderate	Low	Moderate
<b>Autonomy</b>	Low, up to current stage	High	Low	Low
<b>Social Acceptance</b>	Moderate, up to current stage	High	High	Moderate
<b>Ease of Use</b>	Moderate	Moderate	High	Moderate
<b>Auto-Docking</b>	Can be added	No	No	No
<b>Maintenance</b>	Moderate	High	Low	Moderate
<b>Communication</b>	Internet, Bluetooth	Wi-Fi	None	Wi-Fi
<b>Sensors</b>	Vitals, environmental sensors can be added, 2 Cameras	Basic (camera, mic)	Basic (touch)	Basic (camera, mic)

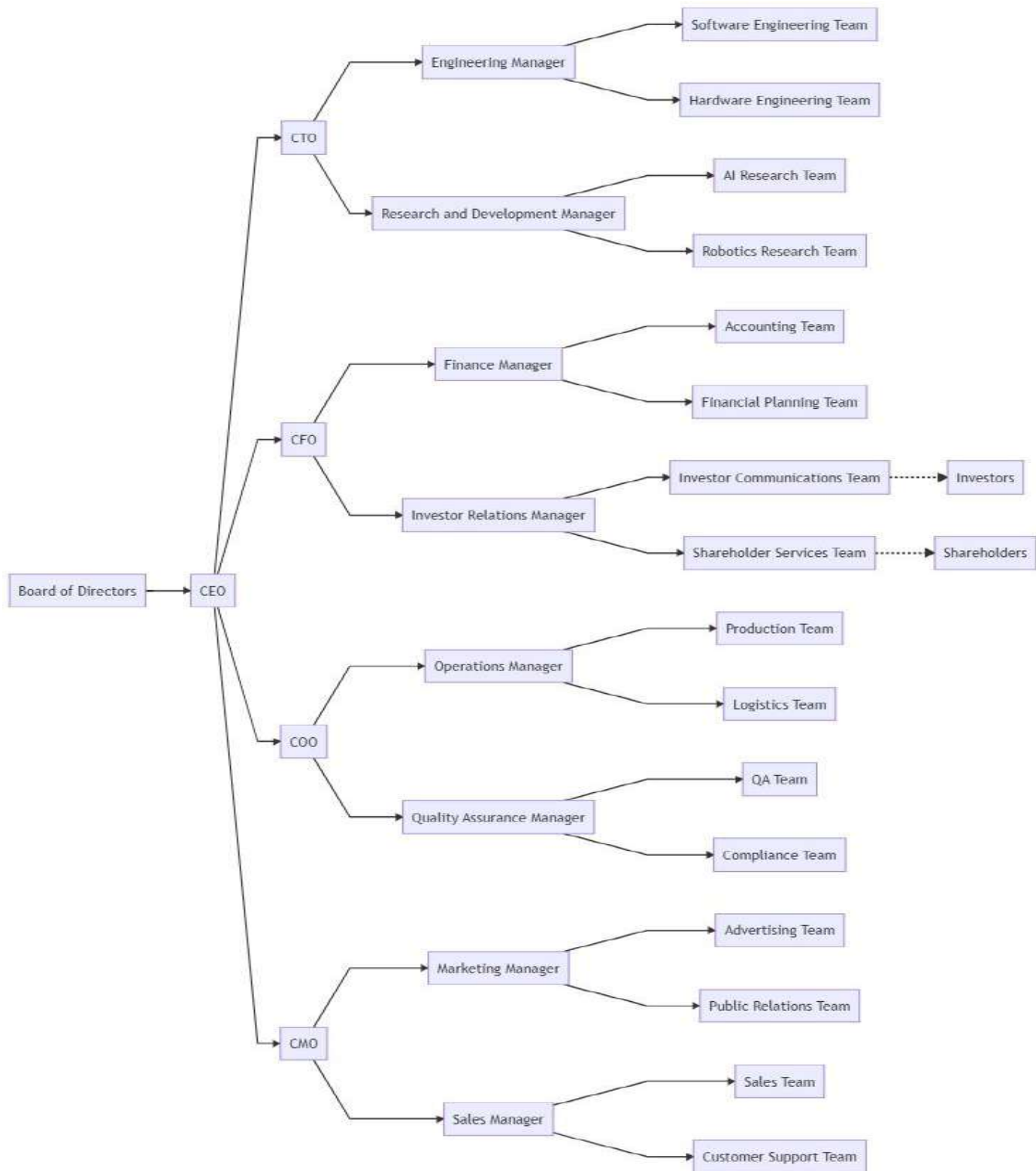
### 9.3.8. Management and Operations

The operational workflow of the project is shown in the flowchart below:



**Figure 58.** Operational Workflow

The hierarchal network of the business is shown in the figure below:



**Figure 59. Hierarchal Map**

## 9.4. Financials

### 9.4.1. Break Even Analysis

Initial investment = 3000 USD

Monthly Rentals = 400 USD

Monthly Salaries = 900 USD

Monthly Bills = 400 USD

Unit Cost Selling = 3700 USD

Building Cost Per Unit = 2800 USD

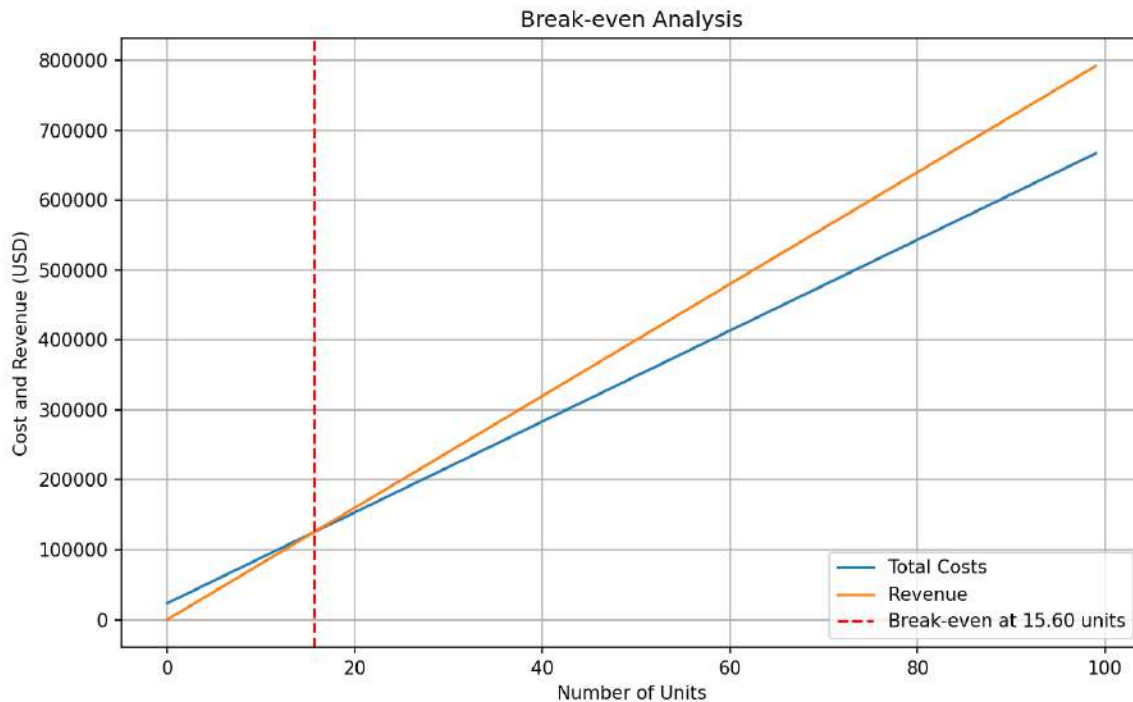


Figure 60. Break-Even Analysis

### 9.4.2. Sources and Uses of Funds

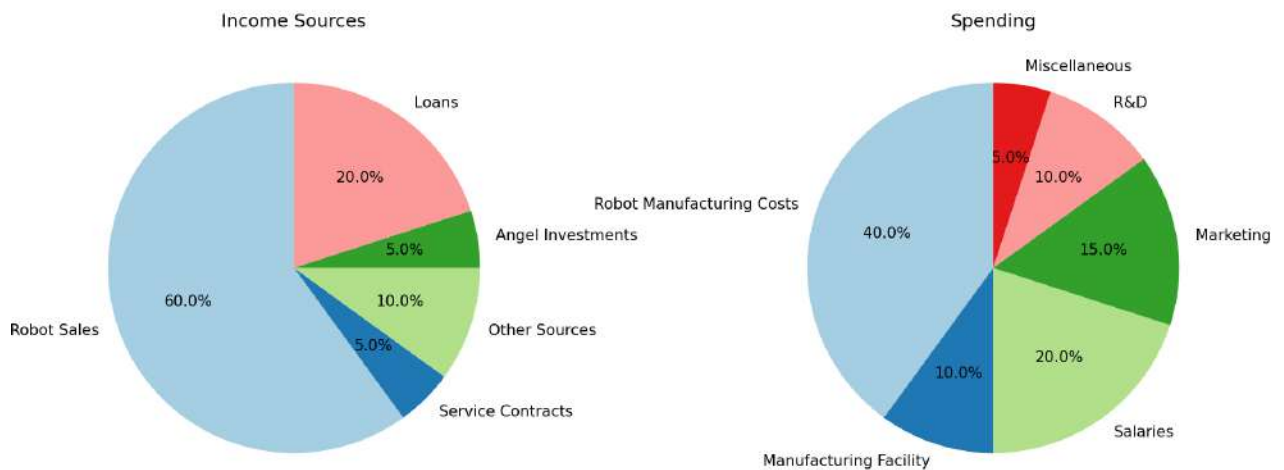


Figure 61. Estimated Division of Income and Expenses



## 9.5. Business Model Canvas

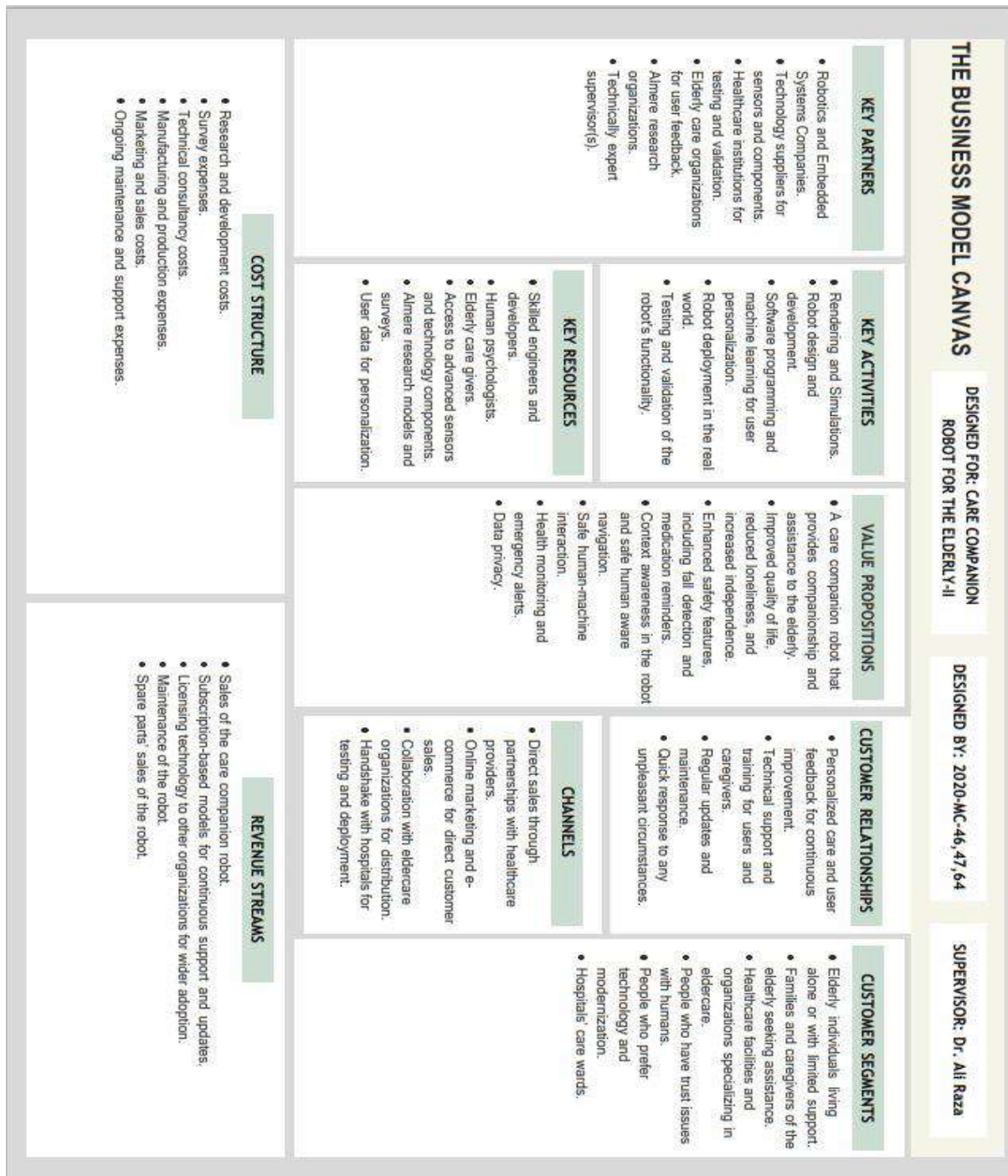


Figure 62. Business Model Canvas



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## Appendices

### Appendix A: Survey Questions, Technical Specifications, and Circuit Diagram

#### A.1. Survey Questions

1. How often do you feel lonely or isolated?
2. How comfortable are you with using technology for daily assistance?
3. What features would you find most useful in a robotic companion?
4. Have you used any robotic or digital assistance tools before? If yes, which ones?
5. How important is it for a robotic companion to have human-like gestures and expressions?
6. What concerns do you have about using a robotic companion?
7. How often do you forget to take your medications on time?
8. Would you prefer voice commands or touch controls for interacting with a robotic companion?
9. How would you rate your overall satisfaction with current elderly care solutions?
10. What improvements would you suggest for a robotic companion?

#### A.2. Technical Specifications

##### A.2.1. Kobuki Base

- **Dimensions:** 306mm (L) x 332mm (W) x 140mm (H)
- **Weight:** 3.5kg
- **Battery:** 14.8V Li-ion, 2.2Ah
- **Max Speed:** 0.7m/s
- **Payload:** 5kg
- **Sensors:** Cliff sensors, bump sensors, wheel drop sensors, encoder sensors, gyro sensor
- **Connectivity:** USB, UART, GPIO, Analog input
- **Run Time:** Approx. 2 hours
- **Charging Time:** Approx. 3 hours

*For more details, refer to the Kobuki Datasheet.*

##### A.2.2. Jetson Nano Developer Kit

- **Processor:** Quad-core ARM Cortex-A57 CPU
- **GPU:** 128-core Maxwell GPU
- **Memory:** 4GB LPDDR4

- **Storage:** microSD (card not included)
- **Connectivity:** Gigabit Ethernet, M.2 Key E
- **USB Ports:** 4x USB 3.0, 1x USB 2.0 Micro-B
- **Display:** HDMI and DisplayPort
- **Power:** 5V=4A DC
- **Operating System:** Linux (NVIDIA JetPack)
- **Dimensions:** 100mm x 80mm x 29mm

*For more details, refer to the Jetson Nano Datasheet*

#### A.2.3. Intel RealSense Depth Camera D435i

- **Depth Technology:** Stereo
- **Depth Field of View (FOV):** 86° x 57°
- **Depth Output Resolution:** Up to 1280 x 720
- **Depth Frame Rate:** Up to 90 fps
- **RGB Sensor Resolution:** 1920 x 1080
- **RGB Frame Rate:** 30 fps
- **IMU:** 6 Degrees of Freedom (6DoF)
- **Connectors:** USB 3.1 Gen 1
- **Power Consumption:** 1.5W
- **Dimensions:** 90mm x 25mm x 25mm

*For more details, refer to the Intel RealSense D435i Datasheet.*

#### A.2.4. Servo Motor Driver Module PCA9685

- **PWM Channels:** 16-channel, 12-bit PWM outputs
- **Control Interface:** I2C interface with selectable addresses
- **Output Enable:** Configurable push-pull or open-drain output
- **Frequency:** Adjustable frequency PWM up to 1.6 kHz
- **Operating Voltage:** 2.3V to 5.5V
- **Maximum Output Current:** 25mA per channel
- **Dimensions:** 25mm x 25mm
- **Operating Temperature Range:** -40°C to +85°C

*For more details, refer to the PCA9685 Datasheet.*

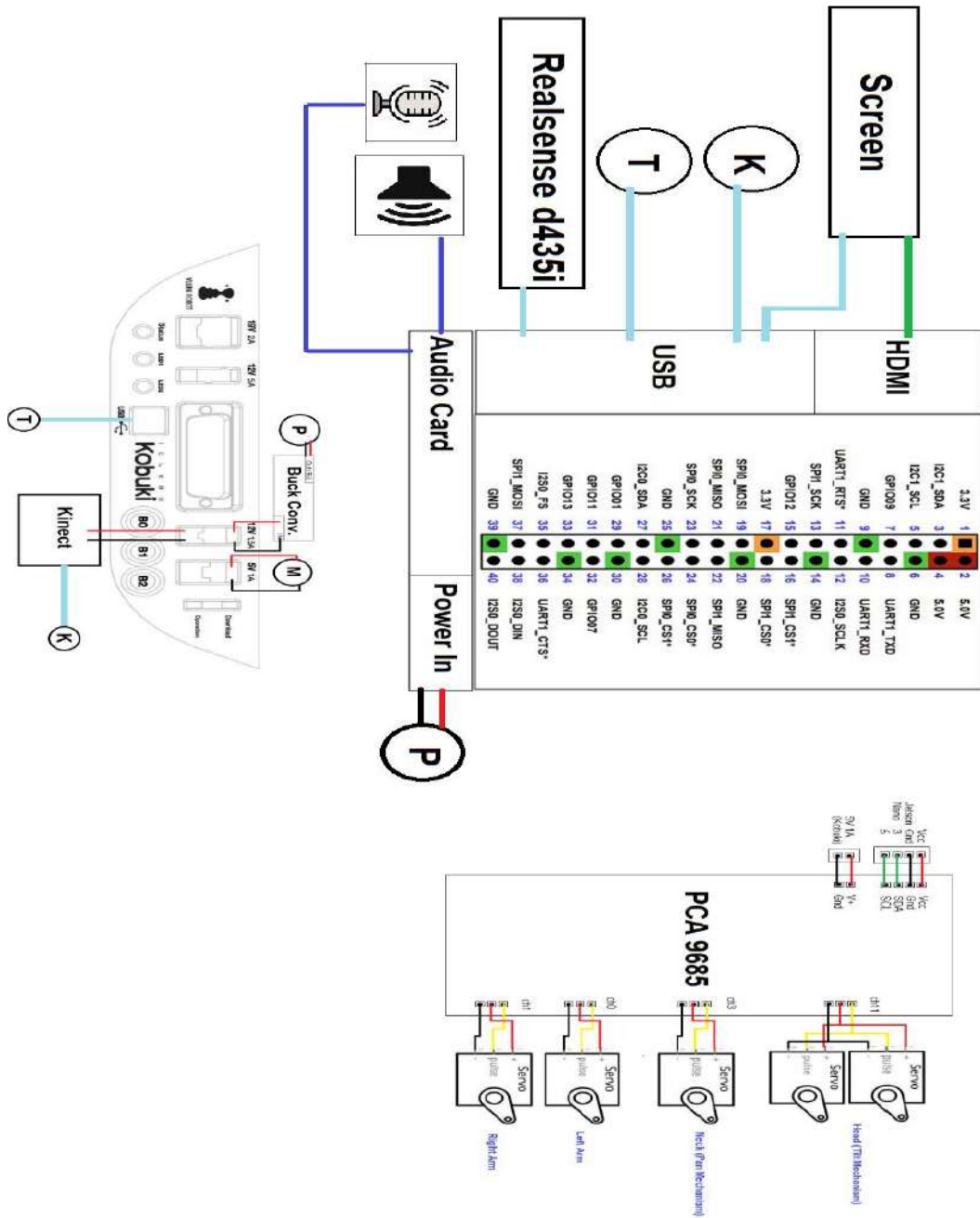


#### A.2.5. RC Geared Servo Motor MG996R

- **Operating Voltage:** 4.8V to 7.2V
- **Stall Torque:** 9.4 kgf·cm (4.8V), 11 kgf·cm (6V)
- **Operating Speed:** 0.19 sec/60° (4.8V), 0.14 sec/60° (6V)
- **Dimensions:** 40.7mm x 19.7mm x 42.9mm
- **Weight:** 55g
- **Gear Type:** Metal gears
- **Connector Wire Length:** 300mm
- **Temperature Range:** -30°C to +60°C

*For more details, refer to the MG996R Datasheet.*

### A.3. Circuit Diagram



#### Legend

P: Power to Jetson

M: Power to servo motor driver

#### Wires

Red: +V

Black: Gnd

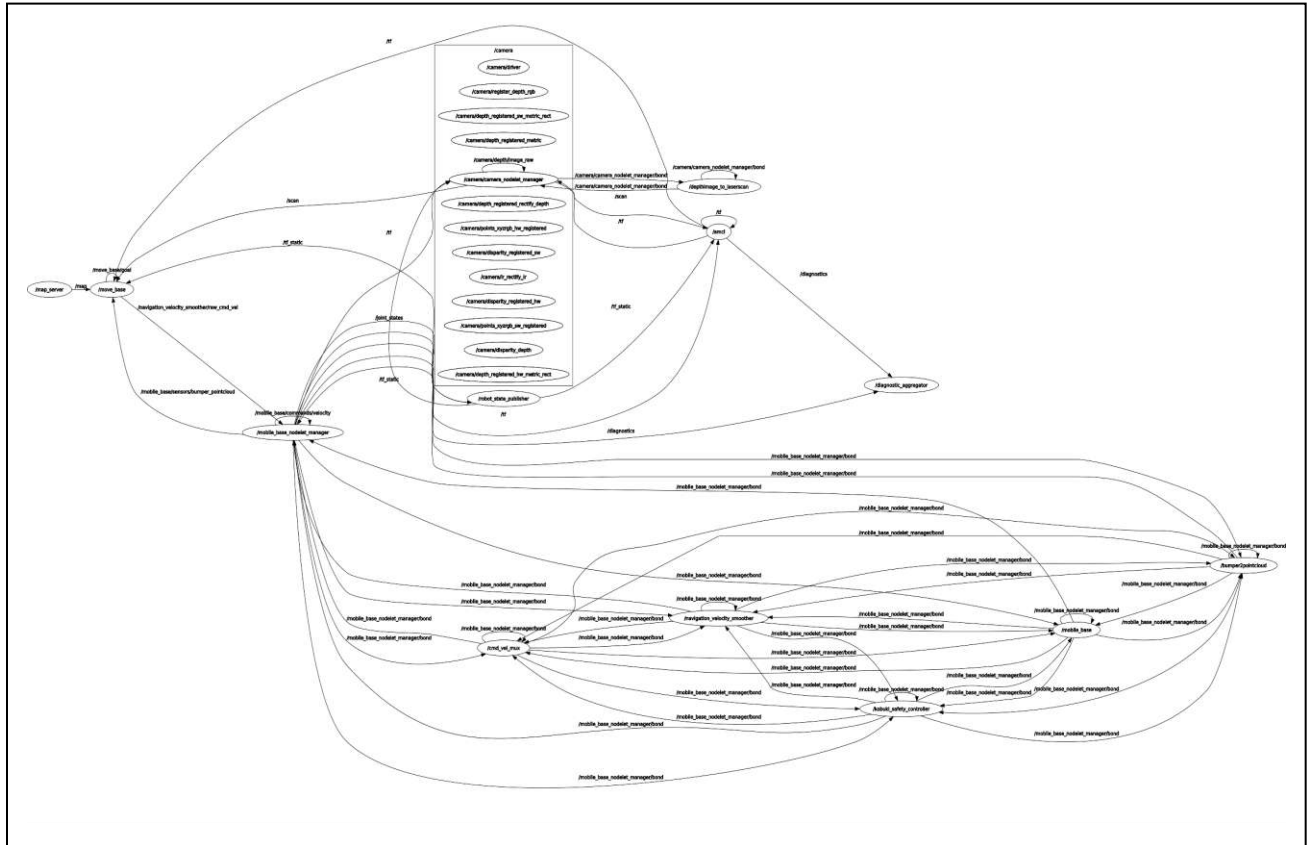
Yellow: Signal

L.Blue: Universal Serial Bus

HDMI: Green

D.Blue: Audio

### B.1. Representing all Publisher Nodes, Subscriber Nodes, and their Interconnectivity





## Appendix C: Testing Protocols, Python Codes, and ROS/SLAM Instructions

### C.1. Testing Protocols

#### C.1.1. Mobility Testing

Conducted in IHYA Lab and Design Centre Lab.

**Scenarios:** Static and dynamic obstacles placed in the robot's path.

**Metrics:** Path planning accuracy, obstacle avoidance success rate, navigation stability.

#### C.1.2. Neck Design Testing

Simulation and iterative design on SolidWorks.

Miniature and full-scale 3D printing for physical tests.

**Metrics:** Range of motion, stability under load, durability over repeated cycles.

#### C.1.3. Voice Interaction Testing

Internal tests for natural language processing accuracy.

Integration with robot expressions and micro gestures.

**Metrics:** Response accuracy, user satisfaction, system reliability.

#### C.1.4. Expression Testing

Comparison between basic eye movements and advanced facial expressions.

**Metrics:** User engagement, realism of expressions, emotional connection.

#### C.1.5. Micro Gestures Testing

Initial tests on arm movements and head tilting.

**Metrics:** User engagement, synchronization with voice interaction, overall interactivity.

### C.2. Python Codes Used for Testing and Demonstration

#### C.2.1. Chatbot of the Robot

```
import speech_recognition as sr
import pyttsx3
import openai
import os
os.environ["_Bard_Api_Key"]="XwhCnFrVhmHhA0ONot3qyf4oq3NbbB8wqD518PaG8x6-pNBz6fUPEwm-z6-
XtmJ_nSPwvQ."
model_engine='text-davinci-003'
import pandas as pd
from fuzzywuzzy import fuzz

# Read the CSV file and store questions and answers in a pandas DataFrame
df = pd.read_csv('/home/naz/chat_bot/QUESTIONS.csv', header=None, names=['question', 'answer'])
engine=pyttsx3.init() #Sapi5 is a driver to get different voices
voices=engine.getProperty('voices')
engine.setProperty('voice', voices[-1].id)
engine.setProperty('rate',150)
engine.setProperty('volume',1)
engine.setProperty('pitch', 150)
def speak(audio):
    engine.say(audio)
    engine.runAndWait()
```

```

def takecommand():

    Listener = sr.Recognizer() # It will recognize our voice
    with sr.Microphone() as source:
        print('Listening...')
        Listener.pause_threshold=0.5
        Listener.adjust_for_ambient_noise(source)
        voice = Listener.listen(source)

    try:
        command = Listener.recognize_google(voice,language='english-us+fl')
    except Exception as e:
        print('Say That Again Please...')
        return 'None'
    return command

while True:
    prompt=takecommand()
    if prompt=='hello':
        speak('yes how can i help u')
        while prompt!='thank you goodbye':
            prompt=takecommand()
            if prompt!='None':
                max_score = 0
                best_match = None
                for question in df['question']:
                    score = fuzz.token_set_ratio(prompt, question)
                    if score > max_score:
                        max_score = score
                        best_match = question
                if max_score > 90:
                    answer = df.loc[df['question'] == best_match, 'answer'].iloc[0]
                    print(answer)
                    speak(answer)

            else:
                response=Bard().get_answer(str(input_text))["content"]

                print(response)
                speak(response)
    else:
        pass

```

### C.2.2. Robot's Responses to the pre-fed data

```

import speech_recognition as sr
import pyttsx3
import pandas as pd
from fuzzywuzzy import fuzz

# Read the CSV file and store questions and answers in a pandas DataFrame
df = pd.read_csv(r'C:\Users\PMLS\Desktop\QUESTIONS.csv', header=None, names=['question', 'answer'])
engine = pyttsx3.init() # Sapi5 is a driver to get different voices
voices = engine.getProperty('voices')
engine.setProperty('voice', voices[-1].id)
engine.setProperty('rate', 150)
engine.setProperty('volume', 1)
engine.setProperty('pitch', 150)

def speak(audio):
    engine.say(audio)
    engine.runAndWait()

def takecommand():
    listener = sr.Recognizer() # It will recognize our voice

```

```

with sr.Microphone() as source:
    print('Listening...')
    listener.pause_threshold = 0.5
    listener.adjust_for_ambient_noise(source)
    voice = listener.listen(source)

try:
    command = listener.recognize_google(voice, language='en-US')
except Exception as e:
    print('Say that again, please...')
    return 'None'
return command

while True:
    prompt = takecommand()
    if prompt == 'hello':
        speak('Yes, how can I help you?')
        while prompt.lower() != 'thank you goodbye':
            prompt = takecommand()
            if prompt != 'None':
                max_score = 0
                best_match = None
                for question in df['question']:
                    score = fuzz.token_set_ratio(prompt, question)
                    if score > max_score:
                        max_score = score
                        best_match = question
                if max_score > 90:
                    answer = df.loc[df['question'] == best_match, 'answer'].iloc[0]
                    print(answer)
                    speak(answer)
                else:
                    speak("I'm sorry, I don't know the answer to that.")
    else:
        pass

```

### C.2.3. Use Case Scenario 1: Robot Introduction

```

import time
from adafruit_servokit import ServoKit
myKit = ServoKit(channels=16)

myKit.servo[0].angle = 180          # Left Arm
myKit.servo[1].angle = 0            # Right Arm
myKit.servo[3].angle = 90           # Neck
myKit.servo[11].angle = 0           # Head

import cv2
import pandas as pd
import pyttsx3
import numpy as np
import speech_recognition as sr
def read_video(file_path):
    cap = cv2.VideoCapture(file_path)
    cv2.namedWindow('Video Frame', cv2.WND_PROP_FULLSCREEN)
    cv2.setWindowProperty('Video Frame', cv2.WND_PROP_FULLSCREEN, cv2.WINDOW_FULLSCREEN)
    last_frame = 0
    while True:
        ret, frame = cap.read()
        if not ret:
            cv2.imshow('Video Frame', last_frame)
            break
        else:

```

```

        resized_frame = cv2.resize(frame, (800,550))
        cv2.imshow('Video Frame', resized_frame)
        last_frame = resized_frame

    if cv2.waitKey(25) & 0xFF == ord('q'):
        break
    cap.release()
def speech_to_text():
    recognizer = sr.Recognizer()
    while True:
        with sr.Microphone() as source:
            print("Speak something:")
            recognizer.adjust_for_ambient_noise(source)
            audio = recognizer.listen(source, timeout=300)
        try:
            text = recognizer.recognize_google(audio)
            if text:
                print("You said:", text)
                return text
        except sr.UnknownValueError:
            print("Sorry, I couldn't understand the speech.")
        except sr.RequestError as e:
            print(f"Error with the speech recognition service; {e}")
def text_to_speech(text):
    engine = pyttsx3.init()
    engine.say(text)
    engine.runAndWait()

#####
video_path_forward = ["/home/ccr/Desktop/First/Video/Video/Forward/AngryV.mp4", "/home/ccr/Desktop/First/Video/Video/Forward/BoredV.mp4",
"/home/ccr/Desktop/First/Video/Video/Forward/HappyV.mp4", "/home/ccr/Desktop/First/Video/Video/Forward/LoveV.mp4",
"/home/ccr/Desktop/First/Video/Video/Forward/NuetralV.mp4", "/home/ccr/Desktop/First/Video/Video/Forward/SadV.mp4",
"/home/ccr/Desktop/First/Video/Video/Forward/SleepV.mp4", "/home/ccr/Desktop/First/Video/Video/Forward/SurpriseV.mp4"
]
video_path_reverse = ["/home/ccr/Desktop/First/Video/Video/Reverse/AngryR.mp4", "/home/ccr/Desktop/First/Video/Video/Reverse/BoredR.mp4",
"/home/ccr/Desktop/First/Video/Video/Reverse/HappyR.mp4", "/home/ccr/Desktop/First/Video/Video/Reverse/LoveR.mp4",
"/home/ccr/Desktop/First/Video/Video/Reverse/NuetralR.mp4", "/home/ccr/Desktop/First/Video/Video/Reverse/SadR.mp4",
"/home/ccr/Desktop/First/Video/Video/Reverse/SleepR.mp4", "/home/ccr/Desktop/First/Video/Video/Reverse/SurpriseR.mp4"
]
read_video("/home/ccr/Desktop/First/Video/Video/Forward/NuetralV.mp4")
excel_file_path = r'/home/ccr/Desktop/First/Video/data.csv'
df = pd.read_csv(excel_file_path)

init1 = ''
init2 = ''
init3 = ''
init4 = ''
while True:
    init1 = speech_to_text()
    if init1 is not(''):
        for i in range(90,0,-1):
            myKit.servo[3].angle = i
            time.sleep(0.01)
        for i in range(0,30,1):

```



```

    myKit.servo[11].angle = i
    time.sleep(0.01)
read_video("/home/ccr/Desktop/First/Video/Video/Forward/HappyV.mp4")
text_to_speech('Hello there')
text_to_speech('my friend')
for i in range(0,150,1):
    myKit.servo[0].angle = 180-i
    time.sleep(0.01)
read_video("/home/ccr/Desktop/First/Video/Video/Reverse/HappyR.mp4")
text_to_speech('How may i')
text_to_speech('help you')
for i in range(120,0,-1):
    myKit.servo[0].angle = 180-i
    time.sleep(0.01)

read_video("/home/ccr/Desktop/First/Video/Video/Forward/NuetralV.mp4")
while True:
    init2 = speech_to_text()

    if init2 is not(''):
        read_video("/home/ccr/Desktop/First/Video/Video/Forward/SurperiseV.mp4")
        text_to_speech('I can provide')
        text_to_speech('care')
        text_to_speech('and')
        text_to_speech('companionship')
        read_video("/home/ccr/Desktop/First/Video/Video/Reverse/SurperiseR.mp4")
        break

while True:
    init3 = speech_to_text()
    if init3 is not(''):
        read_video("/home/ccr/Desktop/First/Video/Video/Forward/NuetralV.mp4")
        text_to_speech('I can')
        text_to_speech('navigate smoothly')
        time.sleep(0.5)
        text_to_speech('Moreover')
        text_to_speech('I can')
        text_to_speech('move my arms')
        read_video("/home/ccr/Desktop/First/Video/Video/Forward/NuetralV.mp4")
        text_to_speech('Like this')

    for i in range(0,180,1):
        myKit.servo[0].angle = 180-i
        myKit.servo[1].angle = i
        time.sleep(0.01)

    time.sleep(0.1)

    for i in range(180,0,-1):
        myKit.servo[0].angle = 180-i
        myKit.servo[1].angle = i
        time.sleep(0.01)

    read_video("/home/ccr/Desktop/First/Video/Video/Forward/NuetralV.mp4")
    text_to_speech('and')
    text_to_speech('my neck')
    text_to_speech('has been designed')
    text_to_speech('to pan')
    text_to_speech('Like this')
    for i in range(0,180,1):
        myKit.servo[3].angle = i
        time.sleep(0.01)

```

```

time.sleep(0.1)

for i in range(180,0,-1):
    myKit.servo[3].angle = i
    time.sleep(0.01)
time.sleep(1)
text_to_speech('and tilt')
text_to_speech('Like this')
for i in range(30,0,-1):
    myKit.servo[11].angle = i
    time.sleep(0.01)
time.sleep(0.1)
for i in range(0,30,1):
    myKit.servo[11].angle = i
    time.sleep(0.01)
time.sleep(1)
read_video("/home/ccr/Desktop/First/Video/Video/Forward/NuetralV.mp4")
while True:
    print("ok")
    init4 = speech_to_text()
    if init4 is not (''):
        read_video("/home/ccr/Desktop/First/Video/Video/Forward/LoveV.mp4")
        text_to_speech('you are')
        text_to_speech('welcome')
        read_video("/home/ccr/Desktop/First/Video/Video/Reverse/LoveV.mp4")
        myKit.servo[0].angle = 180           # Left Arm
        myKit.servo[1].angle = 0           # Right Arm
        myKit.servo[3].angle = 90          # Neck
        myKit.servo[11].angle = 0          # Head
        break
    break
break

```

#### C.2.4. Use Case Scenario 2: Robot Cooking

```

import time
from adafruit_servokit import ServoKit
myKit = ServoKit(channels=16)

myKit.servo[0].angle = 180           # Left Arm
myKit.servo[1].angle = 0           # Right Arm
myKit.servo[3].angle = 90          # Neck
myKit.servo[11].angle = 30         # Head

import cv2
import pandas as pd
import pyttsx3
import numpy as np
import speech_recognition as sr

def read_video(file_path):
    cap = cv2.VideoCapture(file_path)
    cv2.namedWindow('Video Frame', cv2.WND_PROP_FULLSCREEN)
    cv2.setWindowProperty('Video Frame', cv2.WND_PROP_FULLSCREEN, cv2.WINDOW_FULLSCREEN)
    last_frame = 0
    while True:
        ret, frame = cap.read()
        if not ret:
            cv2.imshow('Video Frame', last_frame)
            break
        else:
            resized_frame = cv2.resize(frame, (800,550))
            cv2.imshow('Video Frame', resized_frame)
            last_frame = resized_frame

    if cv2.waitKey(25) & 0xFF == ord('q'):
        break

```

```

cap.release()

def speech_to_text():
    recognizer = sr.Recognizer()
    while True:
        with sr.Microphone() as source:
            print("Speak something:")
            recognizer.adjust_for_ambient_noise(source)
            audio = recognizer.listen(source, timeout=300)

        try:
            text = recognizer.recognize_google(audio)
            if text:
                print("You said:", text)
                return text
        except sr.UnknownValueError:
            print("Sorry, I couldn't understand the speech.")
        except sr.RequestError as e:
            print(f"Error with the speech recognition service; {e}")

def text_to_speech(text):
    engine = pyttsx3.init()
    engine.say(text)
    engine.runAndWait()

#####
video_path_forward = [
    "/home/ccr/Desktop/First/Video/Video/Forward/AngryV.mp4", "/home/ccr/Desktop/First/Video/Video/Forward/BoredV.mp4",
    "/home/ccr/Desktop/First/Video/Video/Forward/HappyV.mp4", "/home/ccr/Desktop/First/Video/Video/Forward/LoveV.mp4",
    "/home/ccr/Desktop/First/Video/Video/Forward/NuetralV.mp4", "/home/ccr/Desktop/First/Video/Video/Forward/SadV.mp4",
    "/home/ccr/Desktop/First/Video/Video/Forward/SleepV.mp4", "/home/ccr/Desktop/First/Video/Video/Forward/SurpriseV.mp4"
]
video_path_reverse = [
    "/home/ccr/Desktop/First/Video/Video/Reverse/AngryR.mp4", "/home/ccr/Desktop/First/Video/Video/Reverse/BoredR.mp4",
    "/home/ccr/Desktop/First/Video/Video/Reverse/HappyR.mp4", "/home/ccr/Desktop/First/Video/Video/Reverse/LoveR.mp4",
    "/home/ccr/Desktop/First/Video/Video/Reverse/NuetralR.mp4", "/home/ccr/Desktop/First/Video/Video/Reverse/SadR.mp4",
    "/home/ccr/Desktop/First/Video/Video/Reverse/SleepR.mp4", "/home/ccr/Desktop/First/Video/Video/Reverse/SurpriseR.mp4"
]

read_video("/home/ccr/Desktop/First/Video/Video/Forward/NuetralV.mp4")
excel_file_path = r'/home/ccr/Desktop/First/Video/data.csv'
df = pd.read_csv(excel_file_path)

init1 = ''
init2 = ''
init3 = ''
init4 = ''

while True:
    init1 = speech_to_text()
    if init1 is not(''):

        read_video("/home/ccr/Desktop/First/Video/Video/Forward/SleepV.mp4")
        time.sleep(2)
        read_video("/home/ccr/Desktop/First/Video/Video/Reverse/SleepR.mp4")

        for i in range(90,180,1):
            myKit.servo[3].angle = i
            time.sleep(0.001)

        time.sleep(0.1)
        for i in range(180,0,-1):
            myKit.servo[3].angle = i
            time.sleep(0.001)
        time.sleep(0.1)
        for i in range(0,90,1):

```

```

        myKit.servo[3].angle = i
        time.sleep(0.001)
    time.sleep(0.1)
    text_to_speech('No')
    time.sleep(0.5)

read_video("/home/ccr/Desktop/First/Video/Video/Forward/SadV.mp4")
for i in range(30,0,-1):
    myKit.servo[11].angle = i
    time.sleep(0.01)

text_to_speech('i')
text_to_speech('can')
text_to_speech('not')

read_video("/home/ccr/Desktop/First/Video/Video/Reverse/SadR.mp4")

time.sleep(1)

for i in range(0,30,1):
    myKit.servo[11].angle = i
    time.sleep(0.001)

read_video("/home/ccr/Desktop/First/Video/Video/Forward/AngryV.mp4")
time.sleep(2)
text_to_speech('look at')
text_to_speech('my arms')
for i in range(0,180,1):
    myKit.servo[0].angle = 180-i
    myKit.servo[1].angle = i
    time.sleep(0.0001)
time.sleep(2)
read_video("/home/ccr/Desktop/First/Video/Video/Reverse/AngryR.mp4")

time.sleep(0.1)

for i in range(180,0,-1):
    myKit.servo[0].angle = 180-i
    myKit.servo[1].angle = i
    time.sleep(0.001)

break

```

## Appendix D: Instructions for Starting with ROS and Kobuki with ROS

### D.1. Starting with ROS and Jetson Nano

#### Step 0:

1. Learn ROS Basics ([Link to ROS Basics](#))
2. Learn Jetson Nano Basics ([Link to Jetson Nano Basics](#))

#### Step 1:

1. Install ROS Melodic ([ROS Melodic Installation](#))
2. Create a new workspace directory
3. Run **catkin\_make**

#### Step 2:

1. Install Turtlebot2 package ([Tutorial for Installing Turtlebot2 Package](#))
2. Run **catkin\_make** (may encounter cmake error regarding opencv – image\_geometry issue)
3. Correct the opencv – image\_geometry issue ([Fix for opencv – image\\_geometry issue](#))
4. Run **catkin\_make** (may encounter cmake error regarding opencv – cv\_bridge issue)
5. Correct the opencv – cv\_bridge issue ([Fix for opencv – cv\\_bridge issue](#))
6. Run **catkin\_make** (may encounter cmake error regarding turtlebot\_kobuki joystick)
7. Correct the turtlebot\_kobuki joystick issue by typing **sudo apt-get install ros-melodic-joy\***

**Step 3:** Make ROS Melodic use Python3 for code execution ([Instructions for using Python3 with ROS Melodic](#)) including `#!/usr/bin/env python`

### D.2. Starting with Kobuki with ROS Melodic

**Learn Turtlebot on ROS:** Refer to the TurtleBot learning platform for comprehensive tutorials and resources: [Learn TurtleBot on ROS](#)

#### SSH Setup for PC:

1. Install SSH server: **sudo apt-get install openssh-server**
2. Check SSH status: **sudo service ssh status**
3. Connect to localhost: **ssh localhost**

#### Know the IP Address of Kobuki:

1. Check IP address: **ifconfig**

#### Get into the Kobuki's Server:

1. Connect to Kobuki: **ssh turtlebot@[ip\_of\_turtlebot]**

#### Connect the Kobuki Base with the Laptop:

1. Connect to Kobuki: **ssh turtlebot@[ip\_of\_turtlebot]**
2. Launch Kobuki: **roslaunch turtlebot\_bringup minimal.launch**

#### Control the Kobuki from PC:

1. Launch teleoperation: **roslaunch turtlebot\_teleop keyboard\_teleop.launch**

#### Setup Depth Camera as Default 3D Scanner of Kobuki:

1. Check current 3D sensor: **echo \$TURTLEBOT\_3D\_SENSOR**

2. Set default sensor: **echo "export TURTLEBOT\_3D\_SENSOR=<name of scanner>" >> .bashrc**

### **SLAM Implementation: Mapping**

*On Turtlebot:*

1. Launch Turtlebot: **roslaunch turtlebot\_bringup minimal.launch**
2. Launch Gmapping: **roslaunch turtlebot\_navigation gmapping\_demo.launch**

*On PC:*

1. Launch RViz for visualization: **roslaunch turtlebot\_rviz\_launchers view\_navigation.launch**
2. Launch teleoperation: **roslaunch turtlebot\_teleop keyboard\_teleop.launch**

### **Save the Map:**

1. Save map: **roslaunch map\_server map\_saver -f \$HOME/my\_map**

### **Localization:**

*On Turtlebot:*

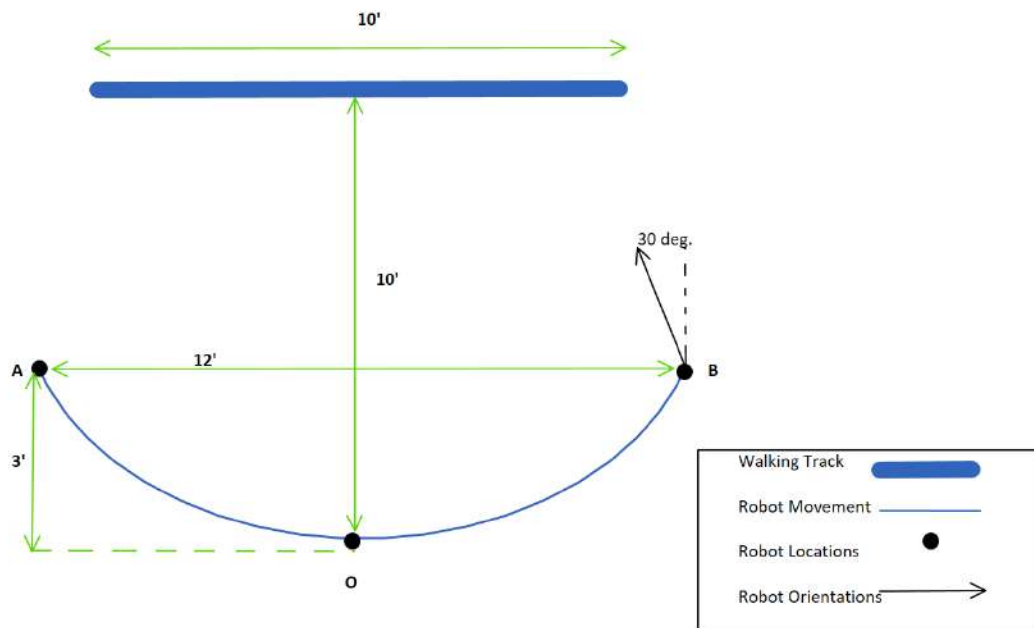
1. Launch Turtlebot: **roslaunch turtlebot\_bringup minimal.launch**
2. Launch AMCL for localization: **roslaunch turtlebot\_navigation amcl\_demo.launch map\_file:=/home/ccr/my\_map.yaml**

*On PC:*

1. Launch RViz for visualization: **roslaunch turtlebot\_rviz\_launchers view\_navigation.launch --screen**

## Appendix E: Gait Analysis Data Acquisition

Another activity was performed using this robot setup that was not directly the part of this project, but finds a great utility in providing data to academic and commercial research organizations, relevant to human walking patterns, which can be use in a number of ways i.e. Fall Risk Analysis etc. The data was taken for both male and female subjects, of different ages and with different physical conditions. The motivation of this data acquisition was to study parameters of gait, from the frames obtained from robot's camera (Intel RealSense d435i), mounted on robot with a tilt angle of  $15^0$  and at three different locations labeled as O, A and B in the figure below.



There are videos of 10 subjects, 3 from each point for a height of 3.5'.

The following data can be requested from IHYA Lab of Mechatronics Research and Resuscitation Sciences through the Director, Dr. Ali Raza ([aliraza@uet.edu.pk](mailto:aliraza@uet.edu.pk)) for research purposes. Several other data collection activities can be performed using this robot, when deployed at suggested locations.