Stand-off Control of Collaborative Robots

Fourth Year Group Project – Interim Statement

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1 Project Aims and Objectives

The main aim of this project is to develop a handheld device which allows users to wirelessly guide and control any ROS-enabled mobile robot system in close proximity. The human-robot interface (HRI) must be intuitive and accessible to non-professional users across various fields.

Hardware and software subsystems will be developed that will allow for pointing at locations and objects in order to send commands to the robot, which can be carried out semi-autonomously.

Table 1 presents a breakdown of the objectives with respect to their section of the aims. The project will be developed iteratively with the criteria for success set at two levels. To achieve the aims of the project and create a minimum viable product, all of the core objectives must be met, whilst the advanced objectives are the desired outcome of the aims.

Table 1: Breakdown of Objectives for the Project

Section of Aims	Core	Advanced
Hardware	Prototype device built with breadboards and mounted on arm straps to test basic design.	Final device manufactured with custom PCB and 3D printed chassis. It is field-tested and proven to be robust and lightweight enough to be worn over PPE for 8 hours in real environments
Laser Detection and localisation	The Robot can detect the laser and locate where in 2D space the laser is pointing and orient itself towards it for range finding	The Robot can identify where in 3D space the laser is pointing and navigate to it with reasonable accuracy and complete collision avoidance.
Communications	The Robot can receive a command from the device, with a computer as an intermediary	The Robot can execute a command directly from the device to reach the designated target and perform a relevant action
Robot Feedback	The Robot can inform the user if and what command it has received	The Robot can inform the user if a command cannot be executed and prompt alternative actions
Command Buffering	A single command can be buffered at a time	A “route” (multiple commands / waypoints) can be created, stored, and later executed
Integration	All systems function independently and can communicate between each other within a limited scope	All systems to be integrated to run concurrently, and with a greater range of flexibility

2 Project Motivation

The adoption of robots into all aspects of life continues to grow owing to the advances in developing more intelligent robotic systems. Task automation has been achieved in various fields, including manufacturing, warehouse organisation and agriculture. In this context, collaborative robots (cobots) are the most integral part of task automation [1][2] as they are designed to not only improve the efficiency of tasks and reduce labour costs but do so without posing any risks to human workers.

The collaborative robot market is expected to reach a market value of 7.5 billion USD by the end of 2027 and hold 29% of the total robot market [1]. State-of-the art robotic arms include "KUKA LBR models" and the "Fanuc CRs" [3], which carry out tasks accurately but are limited to completing a specific task within a limited range. Such solutions also require a very controlled environment.

Mobile solutions, such as the "VersaTrax", a mobile robot crawler able to reach small spaces under hostile conditions and transport cargo [4], carry out dangerous tasks but are usually operated by a highly-specific remote control system and require the operators to be technically trained and skilled.

The primary motivation for the project is thus to develop a handheld device to provide the human-robot interface (HRI) to bridge the gap between direct teleoperation and autonomous operation and allow the adoption of any ROS-enabled mobile robot system to create semi-autonomous solutions for various challenges. The developed product will allow humans with non-robotic backgrounds to control mobile robots by simply pointing a laser to designate a target location and/or object and have the robot carry out a set of relevant actions without further input. Example applications would include aiding humans in exploring dangerous environments such as mine shafts, assisting patients with mobility impairments or delivering items to custom locations nearby. In fact, the global market for semi-autonomous delivery robots is forecast to reach 826.47 million USD by 2029 [5] due to rising demands which the product aims to meet.

Potential clients include the project sponsors, ICE9 robotics, who design mobile robotic solutions for bespoke applications in harsh environments [6], to hospitals for patient care and emergency services for rescue operations. During a meeting with Matthew Nancekievill, the CEO of ICE9, on 11th October 2022, it was presented that mobile robotic systems could be made more flexible and adaptable to constantly changing environments in real time if operators were able to easily direct it according to their own perceptions of the environment, which is likely far more nuanced and detailed than the robot's. Solutions to this problem have been researched, but none are currently commercialised.

One important barrier to uptake is the public perception of robots, particularly in social applications. As highlighted by this review of social robots in healthcare [7], people are generally wary of adopting robotic solutions, with fears of job loss, privacy infringement and lack of emotional connection being the most prevalent concerns. As such, the team would need to also consider demonstrating that the project intends to improve the human workforce, not replace it, and continuously reflect on the social and ethical impact of the product. Time and resources would also have to be dedicated to training and supporting users, though the costs incurred are believed to be greatly outweighed by the benefits provided.

3 Systems Architecture Drawing & Software Flow Chart

The system architecture is shown in Fig. 1, with the shared sensors shown in the green area and the dedicated subteams for the required tasks shown in the blue sections.The lines represent the flow of data through the system, and the top-most level representation of signals sent between individual subsystem blocks. The subsystem teams are divided in a way such that there is a three-way support system in each block, and the sensor functionality is divided between both teams.

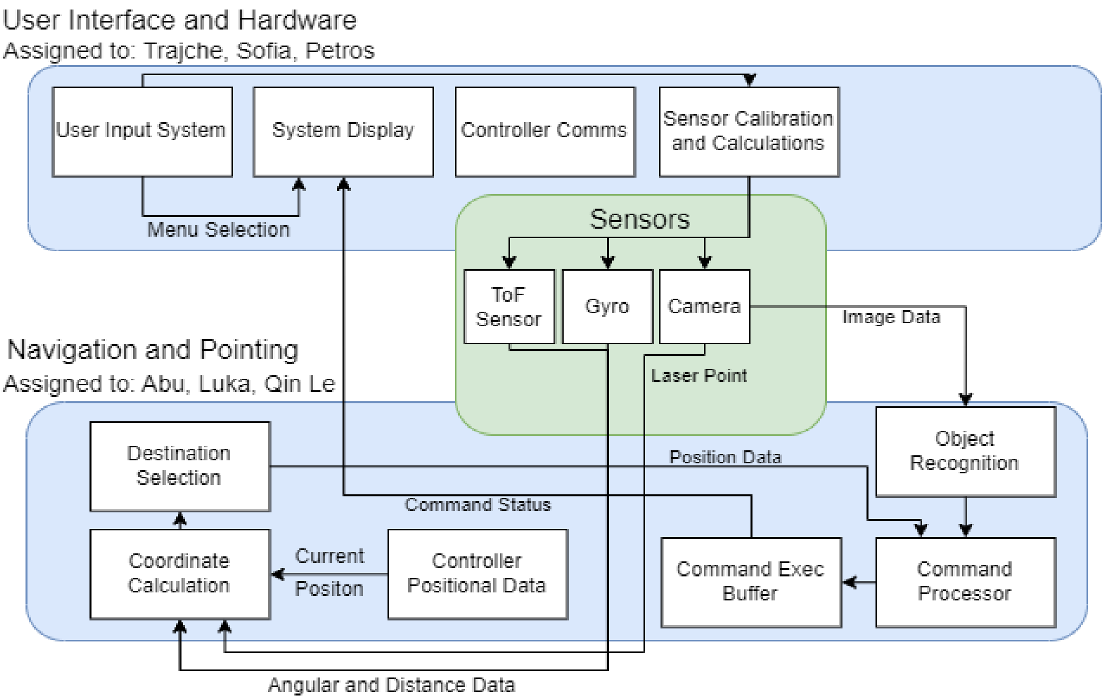

Figure 1: Project System Architecture Overview

The Software flow chart in Fig. 2 shows a condensed form of the team's intended software implementation, presenting a cursory overview of how the complete system handles interaction between its software segments. A more detailed view, with an example task such as picking up/placing down an item can be seen in Appendix IV.

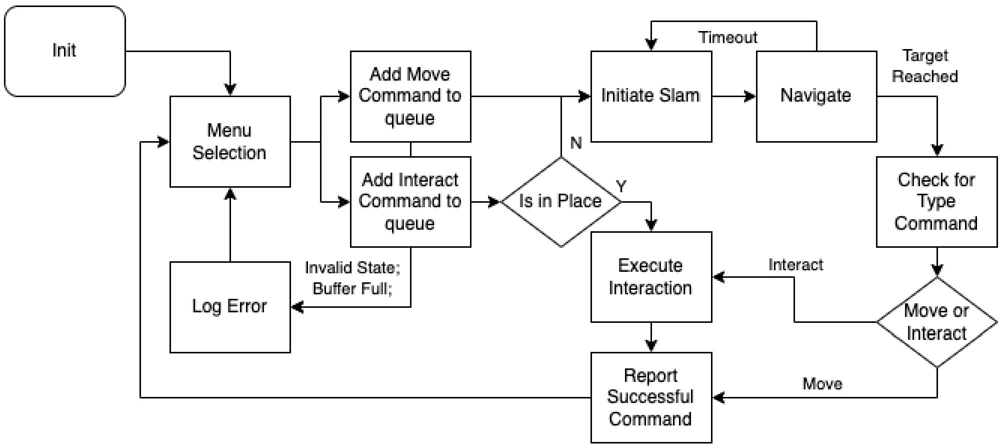

Figure 2: Project Software Flowchart

4 Literature Review

Historically, robot control has fallen under 2 major categories:

1. Direct Manual Control, joysticks, laptops or control substations are used to provide low-level instructions to a robot. Examples include remotely controlling a robot from a control station to explore a decommissioned nuclear facility or teleoperating a surgical robot [8]. This approach, however, results in expensive implementations with large infrastructures designed to achieve a limited range of (complicated) tasks.

2. Autonomous Control, the robot is either pre-programmed to carry out specific tasks automatically (such as picking and placing robots in warehouses) or is given some high-level instructions to carry out without supervision. Any robust implementation of a fully autonomous mobile robot system either requires a well mapped environment or a limited instruction set to prevent ambiguity.

This project aims to expand outside this overwhelming duality of the nature of robot controllers, by developing a Human-robot interface for semi-autonomous applications, which are currently less common in the market. The device developed must be lightweight to allow the operator to be mobile as well as compatible with protective gear (PPE) worn in dangerous environments. As such, touchscreen devices such as tablets, discussed in [9], are deemed unsuitable for instruction input. However, device limitations such as lack of computational resources to handle the large amounts of data sent from the robot to the device are applicable to this project as well, and may have to be mitigated by also 'throttling packages sent to the device'.

Various methods of stand-off control for collaborative robots have been investigated over the years, with commands sent by audio (voice control), gesture control, or point and click laser control. As discussed in [10], voice control and gesture control suffer from errors due to ambiguity. It highlights the effective use of a simple laser pointer to guide a mobile robot to carry objects to assist people with mobility impairments, which inspired the team's decision to use a laser-pointer for target designation. Additionally, investigations that build on the same working principle ([11] [12]) have demonstrated that a laser point can be accurately identified using standard cameras with a narrow band-pass filter tuned to the laser's wavelength. Image processing can be used to eliminate reflections by setting threshold limits.

The solutions discussed used only the laser pointer as part of the interface with the rest of the processing implemented by bespoke robot designs. To implement a more general solution, the team proposes a handheld device that houses a microcontroller, orientation sensor, a set of ToF sensors and a screen to not only designate a target location but also provide instructions to carry out a range of tasks.

5 Budget Forecast

The budget of the team is going to be broken down into components that are needed for the prototypes.The team has had a successful application for the Sony University Programme. Hence the budget for the team is £2500.

Table 2: Bill of Materials (BOM) of the First Prototype [13]-[21]

Functional Purpose	Device	Price (GBP)	Number
Microcontroller	Sony Spresense	0	1
Battery	Rechargeable Battery 56456 702 099	47.06	1
Screen	LCD Screen MDT0500D6IH-RGB	28.66	1
Accelerometer	Sensor Addon Boards Spresense	48.73	1
Time of Flight sensor	Daughter Board VL53L0X	15.49	1
Camera	Spresense Camera	30.80	1
Buttons	Tactile Switch, RA3ETH9-08-0	1.05	4
Routing	Tp-link Router	31.69	1
Laser Emitter	2008361 Laser Diode	3.50	1
Total		210.13	

In Table 2 the budget that has already been spent for the first prototype of this project has been detailed. An additional budget is allocated of £700 for the second prototype, as improvements, such as upgrading to an RGBD camera, will be made to meet all objectives. It is crucial to bear in mind that certain components will break during testing, thus, ordering extras and setting a contingency budget of £1000 is essential. Furthermore, the university has provided the robot that the project is going to use with the wrist-mount device that is made. However, in the event that access to the robot is lost, funds must be set aside so that a replacement robot may be purchased. The university is also going to provide a 3D print of the chassis that will be used for the project at no additional cost.

6 Risk Register

Category	What is the risk?	Likelihood (L) 1=Unlikely 5=Very likely	Severity (S) 1=Little impact 5=Major impact	Risk factor (LxS=) Low Risk 1-7 Medium Risk 8-14 High Risk 15-25	Mitigation Strategy	Priority
	Team members unable to work due to illness or other extenuating circumstance	4	2	8	Distribute workload evenly and have members working in groups to cover for each other if needed	Medium
	Scheduling issues due to other commitments	3	1	3	Discuss when members need time off and schedule with flexibility	Low
	Loss of access to test robots provided by university	3	5	15	Reach out to sponsors and stakeholders for supply and include budget contingency	High
	Long shipping times/ delays to ordered components	4	3	12	Include alternate suppliers, use available components from university where possible	High
	Damaging/Losing components	3	2	6	Maintain a detailed inventory of components and have replacements for easily damaged components	Low
	Extenuating circumstances preventing field testing	2	4	8	Simulate testing and verify by setting up in-house testing	Medium

Figure 3: Risk Register

As can be seen in Fig. 3 the largest risks to the project are related to the hardware side, namely the loss of access to expensive test robots and the potential shipping delays on vital components. Contingencies have been made in either case to minimise the effective project time lost.
The former is mitigated with an Agreement with ICE9, the team's industrial sponsor, to obtain access to robots in ICE9's possession as a replacement to the Supplied Turtlebot 2, and for further system robustness testing if time allows.

7 Work to Date

Team management: Team roles were assigned after discussions of the interests and proficiencies of each team member in managerial and secretarial positions. A network for accountability and work sharing was established using collaboration tools such as GitHub, Trello and google drive.

Research: The team has researched and reviewed relevant papers and projects to generate ideas for the working principle and overall product design. A laser pointer was selected for target designation and the Spresense camera for detection along with appropriate sensors for range-finding and orientation. The development was then carried out in parallel for the 2 main subsystems as follows:

Software: A skeleton code for the prototype GUI was developed, such that integration will not be bottlenecked further down the line. The team has also begun to design a laser tracking system in Python and OpenCV using a desktop camera before moving on to the Microcontroller Camera. To ensure that the laser can be identified the system applies 3 filters based on Hue saturation, Size, and Brightness, the details of which can be seen in Appendix X. Furthermore, the team has made significant progress on the specifics of ROS and the Turtlebot. After several debugging sessions the team is now able to perform autonomous navigation using the Turtlebot and map out a control map environment. With the arrival of the Spresense camera, integrating the laser tracking system on the Turtlebot is now a priority of the team.

Hardware: The team decided a wrist-mounted device would be most compatible with PPE in hazardous environments and development began along that route. The electronic components to develop the first prototype were selected (to optimize specs, costs, size, weight and delivery times) and ordered. Some of the sensors, such as the TOF and Accelerometer were tested and quantized on arrival. A chassis prototype was designed on Fusion 360 that will house the electronic components, with a test model that was 3D printed to make sure the component layout was accessible physically. As for design on the PCB, using the BOM detailed in table 1 and the respective constraints for the screen and other components, the minimum optimal size of the PCB has been determined and would be the foundation for further work of electronics CAD.

The above work has resulted in the team being on track towards a minimum viable product for the end of semester 1, such that even with major issues, if the team focuses solely on integration, the delivery of our aims would be successful.

8 Plan for Semester 2

As the team's intention is to build a Minimum Viable Product by the end of block 2, the next step would be to integrate both hardware and software components to establish a functioning prototype of the system by the start of block 3 so that additional development and refining may occur.

Project Block 3. The prototype that will be going into block 3 will be revised at the start of February in preparation for the interim presentation and any scheduled outreach demonstrations. The team will then move forward to fully integrate all subsystems and maintain autonomous operation without the aid of a computer, using a mountable prototype. The commands at this point should allow the robot to define itself in a 3D space and move to the target point while avoiding obstacles. Further robustness work will also be in progress such as utilizing pulse modulation for further filtering of the detection.

Project Block 4. The work's focus would now shift towards the interactions the robot should be able to perform. Initial development would focus on orientation and preset instructions and then move towards machine learning to teach the robot to recognise specific objects and automatically map them to relevant prompts in the user interface. Furthermore, the bulk of quantisation and testing would be performed during this block, in preparation for the drafting of the Final Report. After the controlled testing is concluded, specific environments such as a mine shaft, or other unknown and uncontrolled environments would be used for further testing.

Project Block 5. Work after this point is aimed towards further work considerations and any demonstration finalisations. Creating a demonstration suitable for non-professionals is a priority. Especially one showcasing live programming and learning, to map a previously unused command to a specific object, and changes between robot platforms.

Contingency. The team has a robust system of three-way accountability and support within the subsystems outlined in section 3. Furthermore, the team's individual logging of tasks and work done should result in minimum work lost in the case of any personal setbacks. So far, the risks outlined in section 7, have been mitigated by the early focus on researching the components and ordering them, as well as the agreement for robot replacements in place. The period between the 1st and 2nd semesters is dedicated to the revision of plans, and adjustments to any time sensitive tasks to account for any unforeseen issues in need of mitigation. Project block 3 and 4 have purposefully segmented sections such that there is a buffer between the two main deliverables, and that there is a cascading priority of the deliverables.

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10 Appendices

10.1 Appendix I - Norms Review

The team agrees with the majority of the Norms outlined. There are certain subsections that the team agrees with completely, whereas others have been altered and adjusted to better conflate the team's vision and the project's intention.

Task Delivery: The team accepts all subsections of the task delivery norm, the tasks are referenced distinctly as well as the integration between them is specifically outlined. Further elaborations are made for the specific metrics of success which is also a good and transparent guideline that the team can use for the purposes.

Researching / Literature Review: The team accepts the Researching/Literature Review norm in its entirety. The norm outlined is a standard professional overview of a successful literature review and research process that an industrial or academic project should have.

Design: The team accepts the Design norm completely. It is more brief and succinct than other norms, however, it covers the majority of what a well organised design process should entail.

Implementation: The team accepts the Implementation norm. It is fully clear to the team that the project is intended as a physical system and it is well within the team's vision. The segmented delivery of prototype and final designed product is also a good reflection of the team's planned design process.

Novelty: The team accepts the Novelty norm. It is completely understandable that the more novel the final idea is and the less it reuses old concepts without trying new ones is better for the overall delivery of the project.

Software: The team accepts the Software norm as outlined by the supervisors. The use of ROS is an industry standard and having the project developed in ROS will ensure the team maximises compatibility with a wide range of commercial grade robots which is beneficial for the success of the project.

Experimentation skill: The team accepts the Experimentation Skill norm in its entirety. Proper characterisation of the finished system and outline of its limitations is a necessary task the team must complete to best emphasise the overall viability of the system.

Outreach: The team has a suggestion for a change in the wording of this norm and the overall to better quantify the extent of the delivery of the project along this metric:

- 2.ii) No outreach attempted.
- 2.i) Limited demonstrations of the project to the project sponsors.

- 1st) Successful demonstrations of the final or near-final project and its capacities to project stakeholders. Demonstration at commercial or public engagement activities, such as entering the ideas into entrepreneurial competitions, such as the Venture Further Award or engagement with possible end-users.

Planning & Project management: The Team agrees with the Planning & Project Management norm and its guidance. The metrics outlined are specific and reflective of a good planning process spanning the entire duration of the project, which would benefit the quality of work and replicability of the project.

Organisation & Team working: The team agrees with the Organisation & Team working norms. The norms detailed are very thorough and cover all aspects of organisation and workload balancing and are a good indicator of the efficiency in human resources planning of the project.

Video presentation of project: The team agrees with the guidance outlined Video presentation of project norms. The information detailed is an acceptable guideline for the production of the final video presentation as well as a good outline of the timeline needed for that production.

10.2 Appendix II - Team 10 equality, diversity and inclusion policy and statement

Team 10 is committed to encouraging equality, diversity and inclusion among our members, and eliminating unlawful discrimination to any and all vulnerable groups among us.

We recognise the systemic imbalances and unconscious biases people have and we aim to mitigate those to the fullest extent possible to foster a truly equal and unbiased setting.

10.2.1 Our policy's purpose

This policy's purpose is to:

1. Provide equality, fairness and respect for all in our interactions within the team and with persons outside it.

2. Ensure equal opportunity to all members for decision making power and critical input relating to the project and its deliverables.

3. Ensure all conflicts stemming from breaches of equality, diversity and inclusion are dealt with swiftly and tactfully

10.2.2 Our commitments

The Team commits to:

1. Encourage equality, diversity and inclusion in the team as they are good practice and foster a productive environment.

2. Create a working environment free of bullying, harassment, victimisation and unlawful discrimination, promoting dignity and respect for all, and where individual differences and the contributions of all members are recognised and valued.

3. Take seriously complaints of bullying, harassment, victimisation and unlawful discrimination by both fellow members and any people outside the team over the course of the project's work activities.

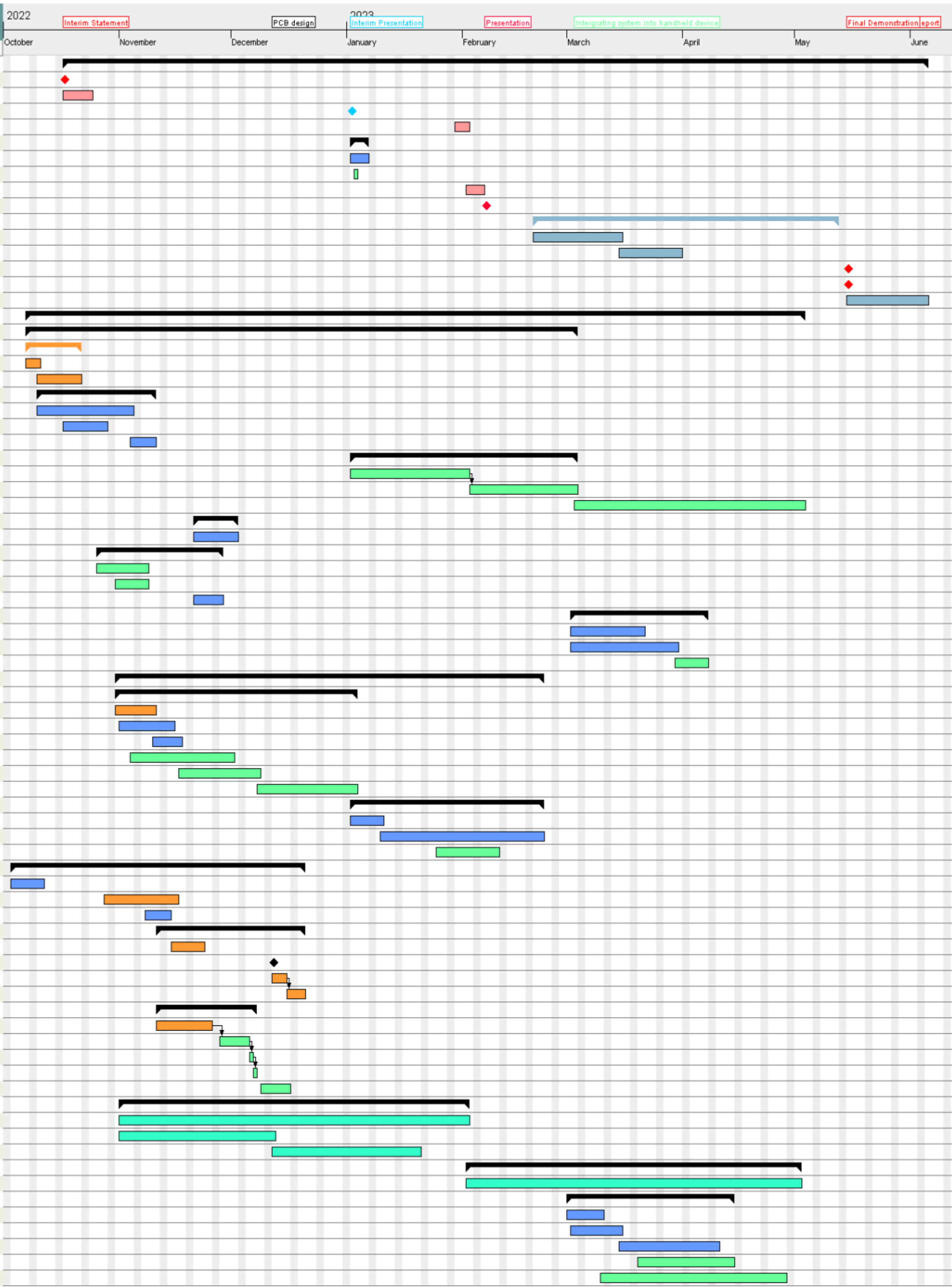
4. Make opportunities for proposal, development and execution of work on the project available to all members, who will be helped and encouraged to develop their full potential, so their talents and resources can be fully utilised to maximise the efficiency of the organisation.

5. Make decisions concerning members being based exclusively on merit and have unbiased disciplinary procedures over any breaches of personal conduct.

10.2.3 Agreement to follow this policy

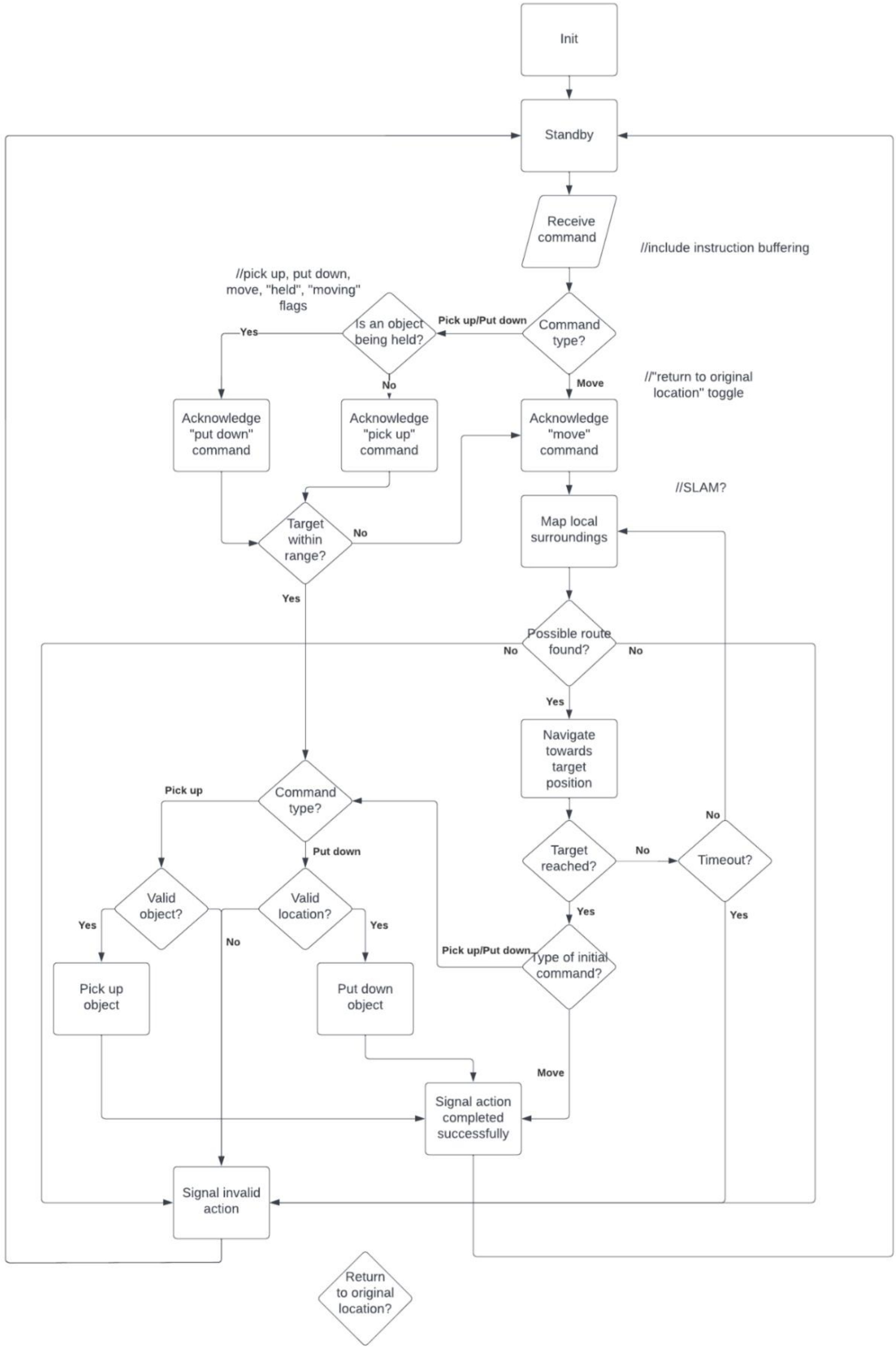
The equality, diversity and inclusion policy is fully supported by every member of the team, signed below: **Trajche Bojadjiev, Luka Durasinovic, Petros Filoxenidis, Qin Le Lee, Sofia Beniadis, Abu Sae**

10.3 Appendix III - Project Gantt Chart



Name	Begin date	End date
Deliverables	17/10/2022	05/06/2023
Interim Statement	17/10/2022	25/10/2022
Draft interim statement	17/10/2022	24/10/2022
Interim Presentation	02/01/2023	07/02/2023
Draft Slides	30/01/2023	02/02/2023
Independent Test	02/01/2023	06/01/2023
software	02/01/2023	06/01/2023
hardware	03/01/2023	03/01/2023
Final Slides	02/02/2023	06/02/2023
Presentation	07/02/2023	07/02/2023
Final Report	20/02/2023	12/05/2023
Draft Final Report	20/02/2023	15/03/2023
Rework Final Report	15/03/2023	31/03/2023
Submition of Final Report	15/05/2023	15/05/2023
Final Demonstration	15/05/2023	06/06/2023
Rework Stop motion presentation	15/05/2023	05/06/2023
Software	07/10/2022	03/05/2023
Guidance System	07/10/2022	03/03/2023
Research	07/10/2022	21/10/2022
Component selection	07/10/2022	10/10/2022
Filtering and Detecting	10/10/2022	21/10/2022
Detection Testing	10/10/2022	10/11/2022
Skeleton Code	10/10/2022	04/11/2022
Colect Data	17/10/2022	28/10/2022
Finalising Code	04/11/2022	10/11/2022
Implementing system into robot	02/01/2023	03/03/2023
2D space identification	02/01/2023	02/02/2023
3D space identification	03/02/2023	03/03/2023
Intergrating system into handheld de...	03/03/2023	03/05/2023
Mobile Platform Implementation	21/11/2022	02/12/2022
Integrating skeleton code to ROS	21/11/2022	02/12/2022
Create GUI	26/10/2022	28/11/2022
Outcome responses (LED)	26/10/2022	08/11/2022
Options menu screen	31/10/2022	08/11/2022
...	21/11/2022	28/11/2022
Object Detection / system output	02/03/2023	07/04/2023
Verify object	02/03/2023	21/03/2023
Specify simple task to be done to ...	02/03/2023	30/03/2023
Intergrate to robot and have it ou...	30/03/2023	07/04/2023
ROS	31/10/2022	22/02/2023
Phase 1	31/10/2022	03/01/2023
Teleoperation Setup	31/10/2022	10/11/2022
Enable commands (ROS)	01/11/2022	15/11/2022
Map a fixed Environment using t...	10/11/2022	17/11/2022
Implement Commands	04/11/2022	01/12/2022
Run autonomously	17/11/2022	08/12/2022
Intergrate Laser Tracking Softwar...	08/12/2022	03/01/2023
Phase 2	02/01/2023	22/02/2023
Accomplishing Assigned Task to ...	02/01/2023	10/01/2023
Feedback Message Received to th...	10/01/2023	22/02/2023
Robot executing said Task	25/01/2023	10/02/2023
Hardware	03/10/2022	20/12/2022
BOM	03/10/2022	11/10/2022
Source components	28/10/2022	16/11/2022
Layout	08/11/2022	14/11/2022
Prototype	11/11/2022	20/12/2022
Breadboard Design	15/11/2022	23/11/2022
PCB design	12/12/2022	21/12/2022
PCB printing	12/12/2022	15/12/2022
testing functionality	16/12/2022	20/12/2022
Chassis design	11/11/2022	07/12/2022
Chassis Design	11/11/2022	25/11/2022
3D print the Chassis	28/11/2022	05/12/2022
Assembling	06/12/2022	06/12/2022
Testing Mobility	07/12/2022	07/12/2022
Testing of the prototype	09/12/2022	16/12/2022
Viable Product Sem 1	01/11/2022	02/02/2023
Video record of independent subsyst...	01/11/2022	02/02/2023
Independent subsystem developed a...	01/11/2022	12/12/2022
Begin software and hardware intergra...	12/12/2022	20/01/2023
Viable Product Sem 2	02/02/2023	02/05/2023
Video record	02/02/2023	02/05/2023
Subsystems intergrated together	01/03/2023	14/04/2023
Communication of Device and R...	01/03/2023	10/03/2023
Respond of Device to the Laser	02/03/2023	15/03/2023
Output task to perform	15/03/2023	10/04/2023
Excute Task	20/03/2023	14/04/2023
Running simulation on final system	10/03/2023	28/04/2023

10.4 Appendix IV - Example Command Flow



10.5 Appendix V - Laser Detection Code

```python
import cv2
import numpy as np

#initialise object
tracker = cv2.VideoCapture(0)

tracker.set(cv2.CAP_PROP_AUTO_EXPOSURE, 0.25) # disable auto exposure
tracker.set(cv2.CAP_PROP_EXPOSURE, -9.0)

#pts = []
laser_detector = cv2.createBackgroundSubtractorMOG2(history = 10000, varThreshold = 10000)

while (1):
    # Take each frame
    ret, frame = tracker.read()
    cv2.imshow('original', frame)

##############################################################################################
    #Detect laser motion
    mask_motion = laser_detector.apply(frame)
    contours, _ = cv2.findContours(mask_motion, cv2.RETR_TREE, cv2.CHAIN_APPROX_SIMPLE)

    for cnt in contours:
        #calculate area and remove big elements
        area = cv2.contourArea(cnt)
        if area > 100 and area < 500:#
            x, y, w, h = cv2.boundingRect(cnt)
            #cv2.drawContours(frame, [cnt], -1, (0,255,255), 2)
            cv2.rectangle(frame, (x,y), (x+w, y+h), (0,255,255), 3)

    cv2.imshow('mask_motion', mask_motion)

###############################################################################################
    # Detect laser colour

    # Convert BGR to HSV
    hsv_frame = cv2.cvtColor(frame, cv2.COLOR_BGR2HSV)

    #define range of red color in HSV

    #test for lower and upper bound of red hue
    lower_red = np.array([0, 0, 255])
    upper_red = np.array([255, 255, 255])

    #perfect red hue boundary
    lower_red_1 = np.array([30, 150, 50])
    upper_red_1 = np.array([255, 255, 180])

    # lower boundary RED color range values; Hue (0 - 10)
    lower_red_low = np.array([0, 100, 20])
    upper_red_low = np.array([10, 255, 255])

    # upper boundary RED color range values; Hue (160 - 180)
    lower_red_up = np.array([160,100,20])
    upper_red_up = np.array([179,255,255])

    lower_mask = cv2.inRange(hsv_frame, lower_red_low , upper_red_low)
    upper_mask = cv2.inRange(hsv_frame, lower_red_up, upper_red_up)

    full_mask = lower_mask + upper_mask

    result = cv2.bitwise_and(frame, frame, mask=full_mask)
    cv2.imshow('result',result)

    #blurring test
    kernel = np.ones((15,15), np.float32)/225

    smoothed = cv2.filter2D(result, -1, kernel)
    blur = cv2.GaussianBlur(result, (15,15), 0)
    median = cv2.medianBlur(result,15)
    bilateral = cv2.bilateralFilter(result, 15, 75, 75)
    #cv2.imshow('smoothed',smoothed)

    #Threshold the HSV image to get only red colors

    mask_colour = cv2.inRange(hsv_frame, lower_red_1, upper_red_1)
    cv2.imshow('mask_colour', mask_colour)

    red_filter = cv2.bitwise_and(frame, frame, mask = mask_colour)
    cv2.imshow('red_filter', red_filter)

    (minVal, maxVal, minLoc, maxLoc) = cv2.minMaxLoc(mask_colour)

#######################################################################################
    #the circle to prove tracking laser
    #cv2.circle(red_filter, maxLoc, 20, (10, 100, 20), 2, cv2.LINE_AA)
    #cv2.imshow('Track Laser', red_filter)
    cv2.circle(frame, maxLoc, 20, (0, 255, 255), 2, cv2.LINE_AA)
    cv2.imshow('Track Laser', frame)

    #print(maxLoc)
    #cv2.imshow('mask', full_mask)
    #cv2.imshow('result', tracker)

    if cv2.waitKey(1) & 0xFF == ord('q'):
        break

tracker.release()
cv2.destroyAllWindows()
```

10.6 Appendix VI - Version 4 of CAD Model for chassis