H.A.R.P.E.R- Progress Report

Hull University's, **A**utomated, **R**eal-time, **P**alletising, **E**xperimental, **R**obot

Being a group project submitted in partial fulfilment of the requirements for the degree of Master's in Engineering

Mechatronics and Robotics
at the University of Hull
by

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Contents

Abbreviations

3D	**Three Dimensions**
A	Amps
AG	Andrei Gorun
AI	Artificial Intelligence
AW	Aimee Walker
BOM	Bill of Materials
CAD	Computer Aided Design
CNN	Convolutional Neural Network
DOF	Degrees of Freedom
DP1	Development phase 1
DP2	Development Phase 2
GG	Galen Greco
KS	Kieran Smith
KU	Kieron Underwood
OS	Operating system
PAT	Portable Appliance Testing
PID	Project Initiation Document
RGB	Red, Green Blue
ROS	Robotic Operating system
SOP	Safe Operating Procedure

Figures and Tables

1. Revised plan

In this section the revised plan is presented with changes from the original plan discussed. All original documents can be found in Appendix A – Git hub link

1.1 Revised Gantt Chart (AW)

Presented in **Error! Reference source not found.** is the revised plan. To see the expanded Gantt c hart please refer to Appendix C – Revised Expanded Gantt chart

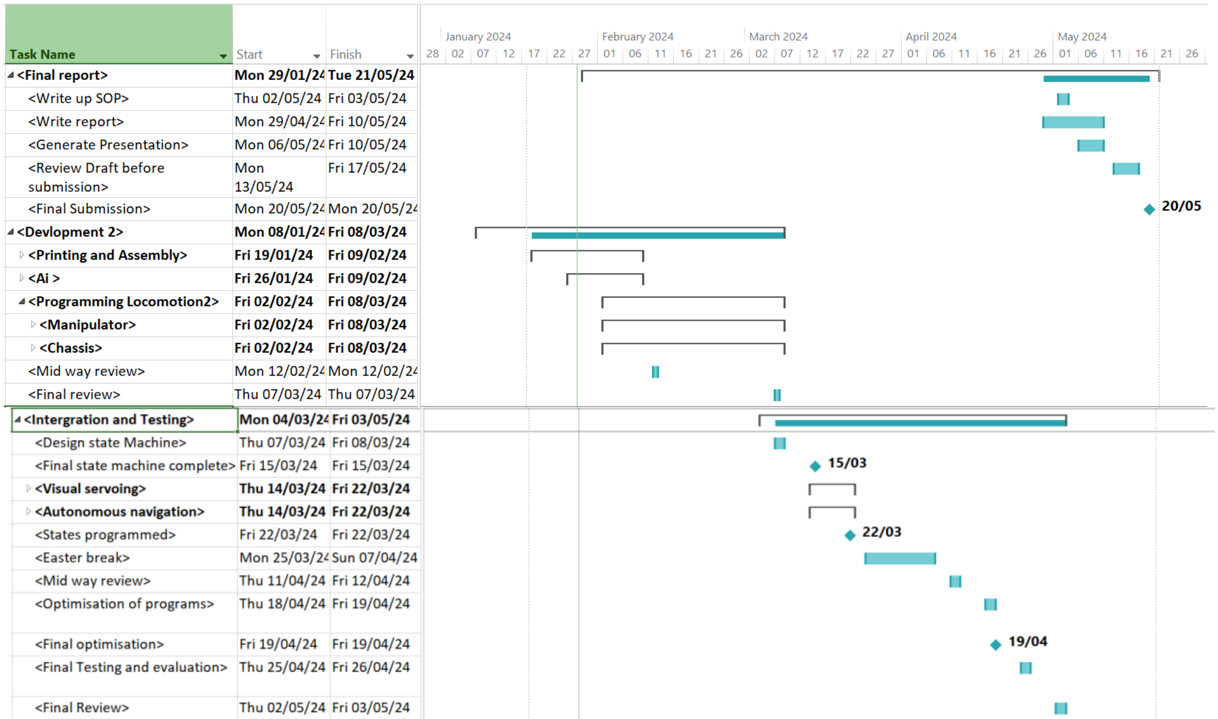

Figure 1- Summarized Revised Gantt Chart

1.1.1 Key dates of milestones

Key milestones are represented in the Gantt chart as diamonds. Not all are present in the summarised version, but all are presented in the expanded revised Gantt chart. The milestones are as follows:

1. Parts Manufactured — 2nd February 2024
2. Robot assembled. — 9th February 2024
3. AI trained with own data set — 9th February 2024
4. 4 Motors moving together. — 16th February 2024
5. Manipulator script complete — 8th March 2024
6. Final state machine — 15th March 2024
7. Program States — 22nd March 2024
8. Final optimisation — 19th April 2024

1.2 Additional considerations in revising the plan (AW)

As the team moved into the second half of the project, the plan was revised. This is because the team's schedule has changed alongside a series of other factors that have caused delays in the project. The plan was only set out for work going forward and was not backdated to reflect any changes that may have occurred during DP1.

When reviewing the plan after DP1, a set of requirements was identified and outlined in section 2. Project requirements. Reviewing this allowed the team to generate a set of minimum requirements to hold the project against, plan around and give priority to within the next development phase. To add more clarity to the plan, milestones for the project were identified to set more specific deadlines. This was informed by Nicholas & Steyn, 2020, which presents a structure in its appendices for planning documentation. This also allowed the team to see techniques that may help to inform the project and the review of the plan.

Considering various delays within the project, the tasks have been rescheduled and reassessed with the team, to fit within the project's deadline. The delays in the project can be found in section 3.2 Delayed Tasks.

One thing that was observed during DP1 were the team members working styles (e.g. in person or remote). Due to a hybrid working style, the team evaluated the work distribution to get the best results (Hart, 2022). The other factor that was observed is that most team members allocated specific days to focus on the project based around their timetables. This allows for each team member to also focus on their other projects alongside their group project work. As team members selected Thursday and Friday for DP2, those days have been selected on the Gantt chart instead of the original presentation of blocking out a week. Due to not knowing the deadlines for their other projects, other commitments haven't been included in the Gantt chart. The team are responsible for managing their own time and are expected to allocate their time accordingly, hence asking for what days they expect to primarily focus on this project. Team members time off has also been added to the plan, e.g. easter, to make sure that everyone gets an adequate break within the final phases.

When revising the plan, the level of detail was reevaluated as originally the tasks were presented in a step-by-step format. Therefore, some tasks were removed/reworked (e.g. test remote connection changed to implement remote connection) for the revised plan. This not only allows for more flexibly in the tasks, but also doesn't mean the plan needs revision if the way of completing a task change due to complications.

2. Project requirements

In this section the projects requirements shall be presented including a brief discussion on the safe operation of the robot.

2.1 Key Requirements

The key requirements of the project were derived from the project summary that was declared during the planning phase of the project.

"This project will Implement an omnidirectional-wheeled robot powered by a convolutional neural network AI to detect objects and autonomously navigate towards them. Having reached the object, the system aims to perform pick and place, utilising depth perception and visual feedback to control a 6 Degree-of-Freedom robotic manipulator."

- PID Introduction (KS)

This statement and the experience from DP1 generated the key requirements needed to have a successful robotic system. The requirements for the robot are as follows:

2.1.1 Designed and manufactured chassis (GG)

A chassis capable to support the weight of the overall system. This chassis will include an area to hold the boxes during transportation, as well as logical housing for the robots' internal components.

2.1.2 AI software able to identify an object and its position. (AW)

The AI will be able to locate objects within the frame, as well as provide the objects position in relation to the robot. The aim is to have the AI operating at a 60% success rate.

2.1.3 A robotic arm able to move to specified location. (AG)

The robot will be able to move to a specified location through software control, utilising the arm to pick up boxes in a controlled environment through the aid of depth perception cameras placed on both the chassis and the arm. Due to this operation requiring the blend of multiple systems working in tandem (AI, Computer Vision, Visual Servoing, Manipulator Software), the team is aiming for a success rate of 50% during the testing of the integrated system.

2.1.4 Locomotion and navigation (GG)

Implementing an efficient locomotion system capable of navigating towards the desired object, either autonomously or through a controller.

2.1.5 Safe operation of the robot (KU)

The system will require assessment for safe operation. To ensure that this is done sufficiently, the team will provide an SOP/operating manual for the final system. These documents will include:

1. RGB light indicators displaying what state the robot is in (e.g. navigation)
2. The fail safe/emergency stop switch/mechanism.
3. The safe operating conditions for use of the robotic system (e.g. spatial, electrical considerations)
4. Step by step guide for operation, from startup to shut down.

This safe operation document will be derived from risk assessment, in which the most up to date version can be found in section 4.3.3 Risks regarding the finished system.

3. Project progress

In this section the projects progress shall be presented including completed tasks, delayed tasks and reasons why this has occurred. This section also includes tasks which encountered risks initially anticipated within the PID. The original risk assessments are presented in Appendix B – Old Risk Assessment (GG)

3.1 Completed tasks.

In **Error! Reference source not found.**, includes a brief description of each task, what was involved and if any risks were encountered by the team.

Table 1 - Table of Completed Tasks

Number	Tasks Completed	Task Description	Risk encountered (Y/N)	Risk ref
		Chassis		
1	Initial chassis research and inspiration	Find numerous robots performing a similar task and review the chassis build. Identify what key points need to be considered in the design	N	N/A
2	Determine method of locomotion	Identify whether wheeled/ tracked system, further identify types of wheels.	N	N/A
3	Concept designs	Multiple sketches, indicating key features of the design.	N	N/A
4	Detailed final CAD design.	A CAD assembly of the final design, including all components, highlighting how the system is assembled.	N	N/A
5	Mathematical proof of final design	Proof that the robot will not topple. Calculate total mass and physical reach of the manipulator. Acceleration and Velocity calculations.	N	N/A
6	Appropriate materials chosen and ordered.	Evaluate weight/ costs for potential materials for the chassis frame. Create BOM and order components	Y	4.3.2 Risk 5

7	Chassis framework has been cut and drilled to size.	Engineering drawings sent to the mechanical workshop for the chassis framework metal to be cut and drilled to specified sizes.	N	N/A
8	Test motors with a wired connection	Connect individual motors to confirm all are working correctly and there are no faults.	N	N/A
		Robot Manipulator		
9	Determine number of DOF & calculate necessary requirements (torque, weight, power)	Make proper calculations to show reasoning behind the chosen specifications of the arm.	N	N/A
10	Initial manipulator research and inspiration	Research papers for other manipulators and compare data between findings.	N	N/A
11	Concept designs	Sketches that present the idea of a manipulator.	N	N/A
12	Detailed final CAD designs.	SOLIDWORKS detailed 3D CAD designs of all parts necessary for the completion of the manipulator.	N	N/A
13	Create Bill of Materials (including manipulator and chassis) & calculate cost of project	Put all components into one easily readable document, attach price and links for ordering.	N	N/A
14	Ordering components	Stay in contact with the staff and ensure the components on the BoM are ordered on time.	Y	4.3.2 Risk 5

15	Assembly	Assemble manipulator, as this comes in a box.	Y	4.3.2 Risk 3
16	Test Functionality	Connect to manipulator via necessary software and test functionality.	N	N/A
		Manipulator software		
17	Operating systems chosen.	The task was to look at operating systems to be used by the manipulator to co-operate with the operating systems and software of the whole robotic system.	N	N/A
18	Software flowchart made.	This task was to create a basic flowchart that goes through the operations of the whole system to demonstrate how it could logically work.	N	N/A
19	Choosing software libraries	task is about choosing the libraries that would be used for programming the manipulator. These could be libraries made by the manipulator's creator or other libraries that could be useful for the control the manipulator like ROS packages.	N	N/A
20	Setting up software	This task is to install the software onto the manipulator and the devices that control the manipulator for this task.	N	N/A
21	Calculating joint trajectory	This task is to calculate the range of motion of the robotic manipulator.	N	N/A
		AI		
22	Choosing AI	This task is to research upon the choice of CNN AI that specifically returns bounding boxes upon predictions of objects.	N	N/A
23	Chosen software	This task is the research upon the choice of environment for training the CNN AI, being PyCharm.	N	N/A
24	Environment setup	This task is about the setup of the environment for the AI training and implementation, with the correct libraries for running and training the AI.	N	N/A
25	Tested AI functionality	This task is to train a CNN AI that returns bounding boxes to determine direction.	N	N/A

26	Determine method of AI operation	This task is to plan how the AI will operate and integrate across the whole system.	N	N/A

3.2 Delayed Tasks

Several factors caused the plan to be revised which are outlined in Table 2- Delayed Tasks with Justifications

Table 2- Delayed Tasks with Justifications

Number	Task delayed	Why was it delayed	Actions taken to mitigate	Was the risk anticipated? (Y/N)	Risk Ref	Revised plan location or completed DP1
			Chassis (GG)			
1	Develop Circuitry diagrams for motor electronics.	Extra assistance and advice were needed in order to design the circuitry	Advice sought out from technical staff; diagram generated within DP1.	N	4.2 Risk 2	Completed in DP1
2	Acrylic components laser-cut to size	Technical faults with the laser cutter prevented us from prototyping when we had planned to.	Alternative equipment found; task revaluated within DP2.	N	4.2 Risk 1	Appendix C, Under printing and assembly summary
3	Finished assembly.	Due to a prolonged lead to time on wheels, clamping brackets, and aluminium extrusion.	Testing completed where possible; task moved to DP2	Y	4.1 Risk 3	Appendix C, Under printing and assembly summary
4	Set up appropriate software	Discussions around software compatibility took longer than anticipated. With initial development not requiring the jetson TX2, set up was tested on a raspberry pi. Also, SD cards didn't arrive on time to make copies of OS	Initial set up set up has bene done on the jetson regarding software, downloading appropriate packages has been moved to DP2	Y	4.2 Risk 6	Ongoing. Set up on personal machines completed DP1, needs copying to hardware in DP2

5	Create functions for each direction of movement.	The motors took longer to arrive than expected, causing delays with a wired connection.	Individual testing of motors is complete, developing functions has been moved to DP2	Y	4.3.2 Risk 7	Appendix C, Under Programming locomotion2/chassis summary
6	Test a remote connection.	Software versions considered, delaying it until software decided Took time for SD cards to arrive delaying set up, task pushed by 3 weeks	Taks has been changed to implement a remote connection, moved to DV2	Y	4.1. Risk 3	Appendix C, Under Programming locomotion2/chassis summary, task adjusted to implement remote connection
7	Retrieve data form proximity sensors.	Circuit not assembled due to delay in parts along with external power source	Task moved to DP2 as awaiting on the development of software	Y	4.1 Risk 3	Appendix C, Under Programming locomotion2/chassis summary
Robot Manipulator (AG)						
8	Assembly of robotic manipulator	Due to a missing motor crucial to its assembly	Informed the staff to help find/acquire a new motor for the team. Started using an already assembled manipulator in the meantime.	Y	4.1 Risk 1	Delayed indefinitely until part arrives not included in plan due to not know when it will arrive, development continues on the second arm
9	Simulating the manipulator	Due to the arm and software being discontinued, there were no updated packages available to solve an error that was found with one of them, resulting in not being able to make scripts for the simulation.	The team moved on from trying to simulate the arm to trying to program the actual arm.	Y		Completed DP1

10	Attaching manipulator to chassis	Due to the parts for the chassis being delayed, the manipulator has not been integrated with the chassis at this time. Another factor is that, due to only having one working manipulator and it being used by others outside the group, the team does not have authority to permanently mount the manipulator to the chassis.	Waiting for the chassis to be assembled.	N	4.1 Risk	Appendix C, Under printing and assembly summary
Manipulator Software (KU)						
11	Inverse Kinematic Model	Need for more research into DH frames leading to knock on effects. This delays the creation of the inverse kinematic model.	From the previous plan, there were gaps between tasks to allow for some overlap in the task deadlines. Hence the action to fix this used up all the time to complete this before the next task.	Y	Risk number 1 in risk table 4.3.2	Completed DP1
12	Research into visual servoing.	The steep learning curve for visual servoing causes unexpected delays. This came from trying to understand the math and formula that make the visual servoing work properly.	A data was set to finalise on the feasibility of continuing with the use of visual servoing in the robotic project.	Y	Risk number 1 in risk table 4.3.2	Completed DP1
AI (KS)						
13	Gathering images for a dataset.	Box has not yet been created, nor has a camera between setup and calibrated for correct height.	Found an example dataset online that will be relevant for the use of a CNN AI returning bounding boxes.	Y	Risk number R2 in risk table 4.3.2	Appendix C, Under AI summary
15	Categorise the images for a dataset.	Categorising the taken images into a dataset for training and validating the AI has not been met until	Decided to train and validate the AI on one epoch for quick validation.	Y	Risk number R2 in risk	Appendix C, Under AI summary

		images for the dataset can be produced.			table 4.3.2	
14	Train AI.	Training of the AI has not yet been met due to the inability to make the dataset until the box is developed.	Used the example dataset to temporarily train the AI model Fasterrcnn_Resnet50_Fpn for preparation of a correctly functioning AI.	Y	Risk number R2 in risk table 4.3.2	Appendix C, Under AI summary

3.2.1 Chassis (GG)

Delayed tasks for the chassis have been documented in Table 2- Delayed Tasks with Justifications.

Whilst most of the early tasks regarding the design of the chassis were completed on time, ordering components and the assembly of the system suffered delays due to lead time of components (4.3.2 Risks to a successful completion of the project, Risk 6) and ordering issues documented in section 4.3.2 Risks to a successful completion of the project, Risk 5. The BOM with whether the components have arrived can be found in Appendix A – Git hub link

In addition to the assembly, there was an issue including selecting an appropriate power supply as the team had not anticipated that extra documentation for risks assessments that needed completion before allowed use of power supply. These can be seen in sections 4.3.2 Risks to a successful completion of the project, Risks 13 and 14.

3.2.2 Robot arm (AG)

Delayed tasks are presented in Table 2- Delayed Tasks with Justifications

After deciding to no longer build the team's own robotic manipulator due to budget constraints during the planning phase, the team opted to use a Niryo One robotic manipulator provided by the University. However, during assembly, it was discovered that the kit was missing a joint motor thus halting the process. Online replacements are not an option due to the model's unique driver board as well as the model being discontinued. The official Niryo team was contacted in hope of assistance. As of 19th of January 2024, there is no news of a replacement. In the meantime, the team is using a shared Niryo One manipulator, already assembled, that cannot be modified to fit the specific parts required for attaching it to the robot's base. Although functional through the Niryo client, an issue arose during testing with the in-built simulator, which might impact script-based operations. The team is actively seeking a solution to the problem, already having a contingency in place. This consists of using the arm in a scripted manner, with predetermined poses through the Niryo software.

Originally, the plan also included simulating the arm for initial testing, but due to errors having to do with the outdated and discontinued matter of the packages involved in the process, the team decided to abandon this task and fully commit to development on the physical manipulator.

3.2.3 Manipulation software (KU)

Presented here is extra information about the delayed tasks in Table 2- Delayed Tasks with Justifications for the manipulator software.

After making the inverse kinematic model for the robotic manipulator, a ready made function was found within the Niryo software. It's compatibility with future visual servoing implementation is doubtful, possibly resulting in more delays.

The purpose of visual servoing is to use images from a camera attached to the end-effector to adjust the position of the arm so it is in the required state for object pick-up. The research took longer than anticipated due to the time needed to understand the mathematical concepts required for its functionality. However, for this project, a walk through has been made that shows how to make the visual servoing work correctly in MATLAB. To be compatible with the other systems, this will require conversion to python. This is the reasoning behind the decision to continue using visual servoing in this project.

3.2.4 AI (KS)

Delayed tasks shown in Table 2- Delayed Tasks with Justifications regarding AI sectioned here.

With the research upon the choice of AI met; finding a CNN AI that can return bounding boxes has come sufficient in the choice of the fasterrcnn_resnet50_fpn by Pytorch January 2024.

Training the CNN AI has taken time using a personal computer. The team made use of an Uno card game dataset created by Adam Crawshaw October 2020 featuring Uno cards and their categories until an appropriate dataset for the 3D printed box can be made. So far, each epoch takes an estimate 8 hours (monitored) with the training section per epoch containing:

- 6295 training images.
- 1798 validation images.

Due to long training times, the CNN AI has been trained on 1 epoch to verify AI functionality. Whilst currently the team has not been able to implement an accuracy method for the AI, we aim to achieve a prediction accuracy of 60% - 80%. Upon inspection, the current estimate is 65% accuracy with good results on upright cards, and more wrong results on upside down cards.

Due to long training times, this has resulted in:

- PC powering off
    - Prolonged training times causes the PC to power off or going into standby which has stopped AI training or cause freezing upon interaction.
- Slow progress in Tweaking code for prediction quality.
    - Slowed tweaking of epochs, weights, and dataset training size and decision-making factors by 8 hours per epoch trained.
- Finding right time of day to train with monitoring.
    - With other tasks and responsibilities, finding an appropriate time frame becomes rarer due to training duration.

3.3 Project Management (AW)

Throughout DP1, the team had to adapt to ensure that communication was maintained and established throughout the whole process. The following section presents the structures involved and how the management has adapted to them.

3.3.1 Structures Followed

The structures established by the team, that have been respected, include the following:

- Weekly meetings
    - Where all team members provide updates on current work as well as any problems that they have encountered.
    - Agenda for each of these meetings are outlined on Trello.
- Using Trello and Microsoft teams
    - Trello is used to see allocated work and assignment of tasks for the weeks.
    - Microsoft teams chat used for general discussions online as well as virtual meetings.

3.3.2 Teams Challenges

The team faced a series of challenges where structures were adapted. These are presented in Table 3 - Project Management Challenges.

Table 3 - Project Management Challenges

Problems	Actions taken	Why was it implemented	Risk anticipated. (Y/N)	Risk ref, 4.3.2 Risks to a successful completion of the project
Communication	Continued weekly project meetings, Adjusted Trello to suit needs of team members, use of Microsoft teams	To Maintain an open dialog, to keep team members up to date on current tasks	Y	Risk 10
Keeping product owner (first marker) up to date	Mid-phase reviews incorporated with mid, and end of phase reviews open to all supervisors.	To ensure communication between all parties involved within the project	Y	Risk 10
Maintaining technical support and communication	Fortnightly meetings arranged with lead technician	The team was requiring increased communication to ensure that nothing was missed between updates.	Y	Risk 10
Creating periodic review of risks	In weekly meetings an agenda point of review of risks was discussed and whether risks have been encountered by the team	To ensure risks were assessed, identified, and considered properly and the appropriate mitigations were followed	Y	Risk 10 Risk 1
Time management/ other deliverables	Plan revised to account for additional deadlines	Due to other deliverables requiring additional time to be completed this stalled the projects development. Therefore, the plan was revised to account for delays	N	Risk 1

The adjusted Trello structure is presented Figure 2. The figure shows the adjusted format for the Trello board. The team has access to the weeks work alongside the following weeks tasks this way if they are ahead, they can get started on the next weeks work. This change was discussed during the weekly meeting that the team have.

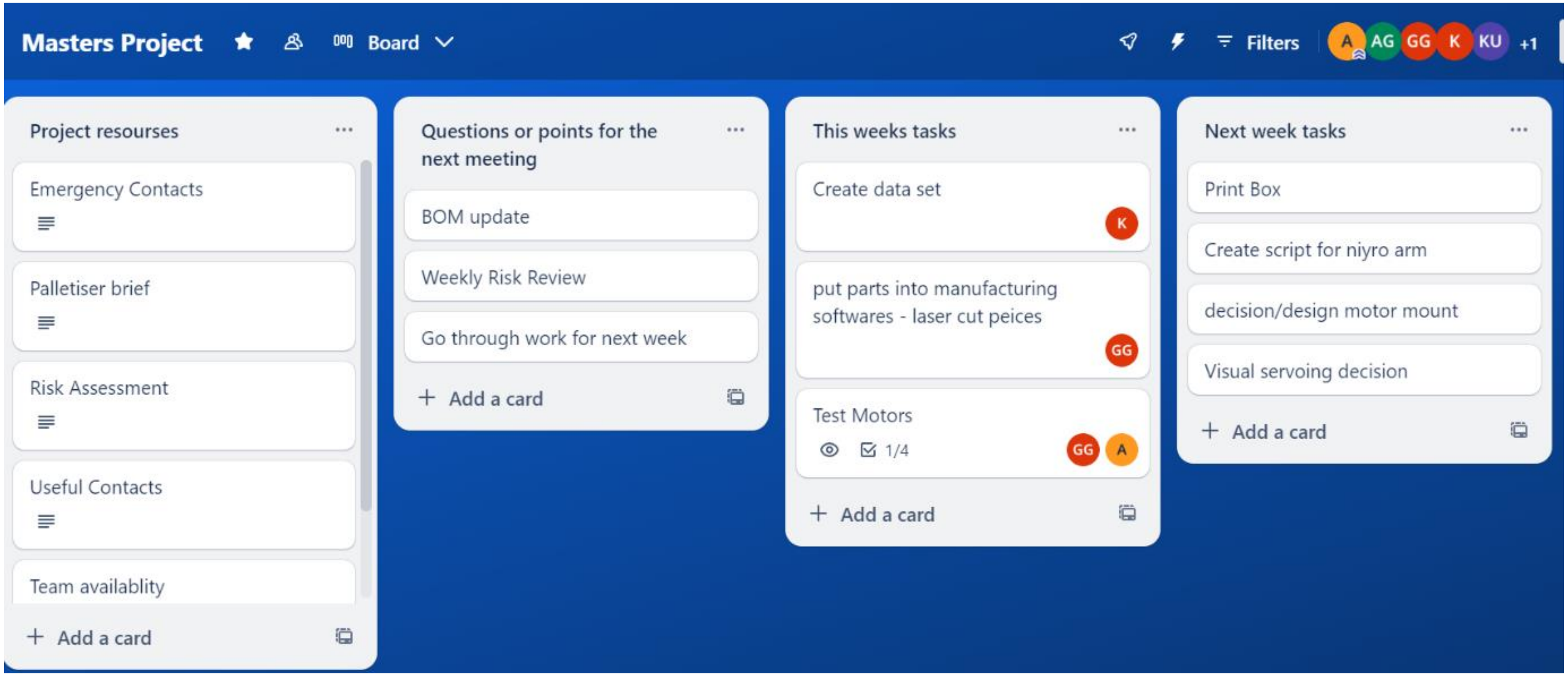

Figure 2 - Revised Trello structure

4. Updates to risk assessments (GG)

Upon the completion of project planning and DP1, the project has experienced several risks. While our initial risk assessment had effectively identified and addressed these potential challenges, it would be accurate to say that the project has also suffered the consequences of events that the team had not foreseen, having a substantial impact of the project as appropriate mitigations were not made early on.

4.1 Risks occurred that were anticipated (AG)

Table 4 - Anticipated Risks

Number	Risk	Reference in PID	Explanation	How this was identified	The team's response	Was the mitigation sufficient
1	Incomplete Hardware resources	5.1 Risk 4	There was a missing joint servo motor in the Nyrio kit.	By searching for the component in the Nyrio kit.	Immediately emailing the staff responsible of the kits and letting them know. Emailing the company making the kit directly and asking for a replacement. Using one of the already assembled arms until a resolution is reached.	Yes, as although a replacement motor is yet to be provided, the team could continue the project's development on one of the other kits.
2	Components not being readily available to order	5.1 Risk 14	We had to find an alternate supplier for the screws.	The staff member responsible of ordering our components let us know that the chosen supplier is not viable.	Provided the staff member with an updated Bill of Materials, with a more suitable supplier.	Yes, the part was ordered and arrived.

Number	Risk	Reference in PID	Explanation	How this was identified	The team's response	Was the mitigation sufficient
3	Lead time on ordering parts	5.1 Risk 15	Parts have been ordered in November, several of them still have not arrived at this date, three months later. Although technically not part of ordering parts, there was also a slight delay in printing the box for training, due to the white spool being connected to a 3D printer that had bed levelling issues.	By checking every couple of weeks with the staff member responsible of ordering the parts whether these have arrived or not.	Making sure that the parts have been ordered and checking frequently whether anything new has arrived. Raising the problem of the delay to the relevant staff members.	No, a number of parts have still not arrived which means the team cannot go ahead with the assembly of the chassis, at this time.
4	Lack of Communication, leading to misunderstanding and confusion	5.1 Risk 10	There have been communication issues between team members as well as the product owners regarding individual tasks and project milestones. There were also communication issues between the team and the technical support staff regarding ordering components and resources been readily available	This was identified through conversations with the team and the staff.	The project manager put together a series of meetings with the relevant parties, these meetings included technical support meetings with lead technicians and mid phase and end of phase reviews.	Continued evaluation throughout project, at the end of this phase it has been sufficient but will be reviewed through put the project.

4.2 Unforeseen Risks (GG)

Table 5- Unforeseen Risks

Number	Risk	Description	Assessed / Addressing	Future Mitigations
1	Not following up effectively on external services	• An order for corner brackets was effectively cancelled by the supplier within a few days of ordering.	• Our realisation of this event was 8 weeks after it had happened. We realise that ordering the brackets again will delay the assembly of the robotic chassis. • We communicated with the lead technician and put through another order. We are also now 3D printing the components as to reduce the impact if the order is cancelled again.	Going forward any external services that the development team require, whether it be ordering components or requesting to have material drilled or laser cut will be followed up 2 days later by the development team as to check the status of the request. A secondary follow up would also take place between 5-7 days later.
2	Manufacturing resources not readily available when required.	• 3D printer was not levelled correctly and required further inspection by a technician, not allowing us to 3D print the box. • Technical faults with the laser cutter prevented us from developing acrylic components when we had planned to.	• It was understood that a delay in printing the box may delay the development of the CNN as we required a dataset of images for the box. • We communicated with project supervisors and the 3D printer was promptly up and running. We spoke the lead technician who explained the status with the laser cutters.	Technicians will be advised several weeks before manufacturing equipment is needed, allowing time to review the machines and fix any issues within a given time frame. When planning manufacturing, alternate sources/ companies should be reviewed and prepped if the required machines are unavailable.

Number	Risk	Description	Assessed / Addressing	Future Mitigations
3	Knowledge gap in developers	• The team member responsible for designing the electronic circuit for the wheel motors did not have an appropriate level of understanding.	• This event was realised a week prior to the scheduled task. • The team realised this didn't have a substantial impact on the team. • As a result, the project manager reviewed the task allocation and promptly assigned the task to a member with a stronger understanding of the topic and arranged a meeting with an expert in the subject.	Discuss the future tasks in the team's weekly reviews, evaluating what tasks are scheduled for individuals in 2-3 weeks' time. Allowing team members to voice their concerns, creating mitigation plans early as to reduce the impact of this risk.
4	Requiring additional components after the BOM is submitted.	• Need to acquire alternative components because of discontinued components. • Redesigning components after the original BOM has been sent off leading to new components being ordered.	• Find alternatives for components, on a case-by-case basis. If possible, order replacements, if not, investigate options such as internal manufacturing.	Do research into the component to assess the quantity of components available from supplier
5	Additional documentation required for the use of resources	• Where additional equipment has been required, the generation of new risk assessments has been required. (e.g. mains power supply)	• As soon as the team was informed of this requirement, the risk manager drafted the risk assessment and communicated with lead technical staff until it was accepted	Where possible discuss future activities with technical staff to identify if any additional documentation is required for use of equipment.
6	Stalled progression with tasks and milestones.	• Members of the team have struggled to balance the assigned workload of multiple tasks, as delays in tasks have caused stalled progression	• This was addressed collectively in group meetings	Discuss as early as possible in order to review the plan and adjust for any additional work.

4.3 Revised risk assessment (GG)

Below are the revised risks assessments. The table headings have been changed in efforts to focus the risks more on the developers, successful completion to the project, and the risks effecting a finished system. The likelihood and impact scores recorded in this tables were calculated before mitigating actions.

4.3.1 Risks to the developers

Table 6 - Risks to the Developers

No.	Description	Mitigating actions	Who is responsible?	Likelihood Score 1 – Low 5 – High	Impact Score 1 – Low 5 – High	Risk score (Likelihood x Impact)
1	Electrical shock when working robot electronics	1. All electrical equipment should be visible and should be inspected before switching on to identify any exposed hazards. 2. Keep Fluids away from electrical equipment. 3. Maintaining equipment and PAT testing once a year.	Aimee Walker Galen Greco Andrei Gorun Kieran Smith Kieron Underwood	2	3	6
2	Pinching, Cutting, Crushing injuries during system assembly and operation	1. Identify an appropriate operating distance when the robot is powered on. 2. Implement a fail-safe switch which will immediately cut the power of the robot. 3. Ensure the equipment is on a stable surface when maintaining / assembling.	Aimee Walker Galen Greco Andrei Gorun Kieran Smith Kieron Underwood	4	3	12
3	Collision injuries during robot operation	1. Identify an appropriate operating distance when the robot is powered on. 2. Implement a fail-safe switch which will immediately cut the power of the robot. 3. Ensure the equipment is on a stable surface when maintaining / assembling.	Aimee Walker Galen Greco Andrei Gorun Kieran Smith Kieron Underwood	3	2	6

4	Developer burnout (Stress and Anxiety)	1. Set and maintain realistic/achievable deadlines. 2. Maintain clear communication regarding milestones and project deadlines.	Aimee Walker Galen Greco Andrei Gorun Kieron Underwood	3	4	12

In addition to these risks identified, we are also following pre-planned risks assessments for 3D printing (Australia, 2016) and Soldering (Manchester, 2015) .

4.3.2 Risks to a successful completion of the project

Table 7- Risk to a Successful Completion of Project

No.	Description	Mitigating actions	Who is responsible?	Likelihood Score 1 – Least likely 5 – Most likely	Impact Score 1 – Low Impact 5 – High Impact	Risk score (Likelihood x Impact)
1	Stalled progression with tasks and milestones.	1. Major concerns with task workload and difficulty are discussed in weekly meetings. 2. Frequent group discussions to evaluate the task difficulty and workload making sure it is realistic and achievable within the given time frame.	Aimee Walker Galen Greco Andrei Gorun Kieron Underwood Kieran Smith	3	5	15
2	Manufacturing resources not readily available when required	1. Checking processes ahead of use. 2. Alternate sources/ companies should be reviewed in advance if the required machines are unavailable.	Galen Greco Andre Gorun	2	5	10
3	Incomplete/ missing kit	1. A thorough check of kit prior to development 2. Bring the issue to the attention of the project supervisor, so that a replacement can be arranged as soon as possible.	Aimee Walker Rob Miles Rob Finnis	3	5	15
4	Components not being readily available to order	1. Find 2/3 possibly suppliers for each part. 2. Find alternate components of similar specification to act as a substitute. 3. Modify the project design to fit around possible new components.	Andrei Gorun Galen Greco Aimee Walker	2	5	10

No.	Description	Mitigation actions	Who is responsible?	Likelihood Score 1 – Least Likely 5 – Most Likely	Impact Score 1 – Low Impact 5 – Most Likely	Risk Score (likelihood x Impact)
5	Not following up effectively on external resources required	1. When external resources have been requested by the development team, a follow up email will be sent two days later for confirmation of the resources/services. 2. If no confirmation has been received, a secondary follows up email will be sent 5-7 days after request.	Andre Gorun Aimee Walker	3	4	12
6	Lead time on ordering components being longer then scheduled	1. Review and plan work as to not be dependant or the arrival/assembly of components. 2. Set out early to review the components are required and determine a realistic lead time.	Aimee Walker Andrei Gorun	4	4	16
7	Short term absence for a team member (1-28 days)	1. Planning involving all team members, establishing key strengths and weaknesses. 2. Weekly team meetings, reviewing members abilities in relation to upcoming tasks. 3. Upcoming tasks are assigned a standby member overseeing task progress so that they can take over in case of short absence.	Aimee Walker Galen Greco Andrei Gorun Kieron Underwood Kieran Smith	3	3	9

No.	Description	Mitigating actions	Who is responsible?	Likelihood Score 1 – Least Likely 5 – Most Likely	Impact Score 1 – Low Impact 5 – High Impact	Risk Score (likelihood x Impact)
8	Long term absence for a team member (28 days +)	1. Refer to external authority on the project. 2. Weekly meeting for members to share the current progress made in their assigned tasks. 3. Individuals documenting their weekly progress and challenges in a shared domain such as one drive, allowing anyone taking	Aimee Walker Galen Greco Andrei Gorun Kieron Underwood Kieran Smith	2	4	8
9	Scope Creep	1. Continuously refer to the PID document throughout the project. 2. Regular review of the project requirements in weekly group meetings.	Aimee Walker	1	3	3
10	Lack of Communication, leading to misunderstanding and confusion	1. Weekly meetings to discuss individual work, challenges, and ideas. 2. Streamline communication through Microsoft teams, ensuring messages have been received with message reacts. 3. Weekly updates to a Trello board so that all members can see everyone's assigned work.	Aimee Walker Galen Greco Andrei Gorun Kieron Underwood Kieran Smith	3	4	12

Number	Description	Mitigation actions	Who is responsible?	Likelihood Score 1 – Least Likely 5 – Most Likely	Impact Score 1 – Low Impact 5 – Most Impact	Risk Score (likelihood x Impact)
11	Knowledge gap in developers	1. Review the upcoming tasks for team members 2-3 weeks in advance in weekly meetings, allowing members to evaluate. 2. Encourage a cross training environment, team members sharing their expertise with each other. 3. Implement paired work, in which a second member of the team can assist a given task.	Aimee Walker Galen Greco Andrei Gorun Kieron Underwood Kieran Smith	4	4	16
12	Developers being unfamiliar with new technology.	1. Discussions within weekly meeting to identify which members are confident with specific technology to reassign tasks.	Aimee Walker Galen Greco Andrei Gorun Kieron Underwood Kieran Smith	3	4	12
13	Requiring additional components after the BOM is submitted.	1. Order any materials as soon as possible 2. Evaluate budget for additional costs 3. Communicate with staff if cost result in going over budget, in order to order as soon as possible.	Aimee Walker Galen Greco Andrei Gorun	2	3	6
14	Additional documentation required for the use of resources	1. Communicate with staff as soon as possible. 2. Allocate work accordingly	Aimee Walker Galen Greco Andrei Gorun	2	2	4

4.3.3 Risks regarding the finished system

Table 8 - Risks Regarding the Finished System

Number	Description	Mitigating actions	Who is responsible?	Likelihood Score 1 – Low 5 – High	Impact Score 1 – Low 5 – High	Risk score (Likelihood x Impact)
1	Collisions and entanglement hazards resulting in system damage	1. Implement a fail-safe switch that will instantly kill the power of the robot when in operation. 2. Test within an appropriate environment	Aimee Walker Galen Greco Andrei Gorun Kieron Underwood Kieran Smith Future developers	3	4	12
2	Robot performing poorly due to changes in predetermined environment.	1. Robot is always operating in the predetermined operating conditions (level flooring, suitable lighting conditions, specific box colour) 2. Use of a fail-safe switch to immediately kill the power of the system when in operation.	Aimee Walker Galen Greco Andrei Gorun Kieron Underwood Kieran Smith Future developers	2	3	6
3	Camera and electronic disruption due to use of electro-magnet.	1. Implementation in the code to maintain an appropriate distance between the electromagnet and camera/ electronics when the magnet is turned on. 2. Choose an electromagnet with an appropriate magnetic-field strength.	Aimee Walker Galen Greco Andrei Gorun Kieron Underwood Kieran Smith	2	4	8

Number	Description	Mitigating actions	Who is responsible?	Likelihood Score 1 – Low 5 – High	Impact Score 1 – Low 5 – High	Risk Score (likelihood x Impact)
4	Cyber Security Risks	1. The robot will be operated on a closed network to reduce the possibility of hacking. 2. All hardware devices must be added to the network by a member of technically staff through the device's mac address. 3. IP and MAC addresses are kept private.	Aimee Walker Galen Greco Andrei Gorun Kieron Underwood Kieran Smith Josh Gibson (Lead Network Technician)	1	2	2
5	Risk of faults developing after finished building of the robotic system	1. Store the robotic system in a controlled environment to best protect the system. 2. The system should be periodically inspected/tested for new developing faults in the mechanical and electrical systems. 3. Users access the damage that could have been caused by fault.	Aimee Walker Galen Greco Andrei Gorun Kieron Underwood Kieran Smith David Stavenau (Technician staff)	4	3	12

5. References

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Appendix A – Git hub link

Git hub location: https://github.com/andrei-gorun/MASTER_PROJECT

In the Git hub are all documentation that the team has used within the Project. Files that needed to be directly referenced in this document have been added to the appendices.

Appendix B – Old Risk Assessment (GG)

Table 3- Project Risk Assessment

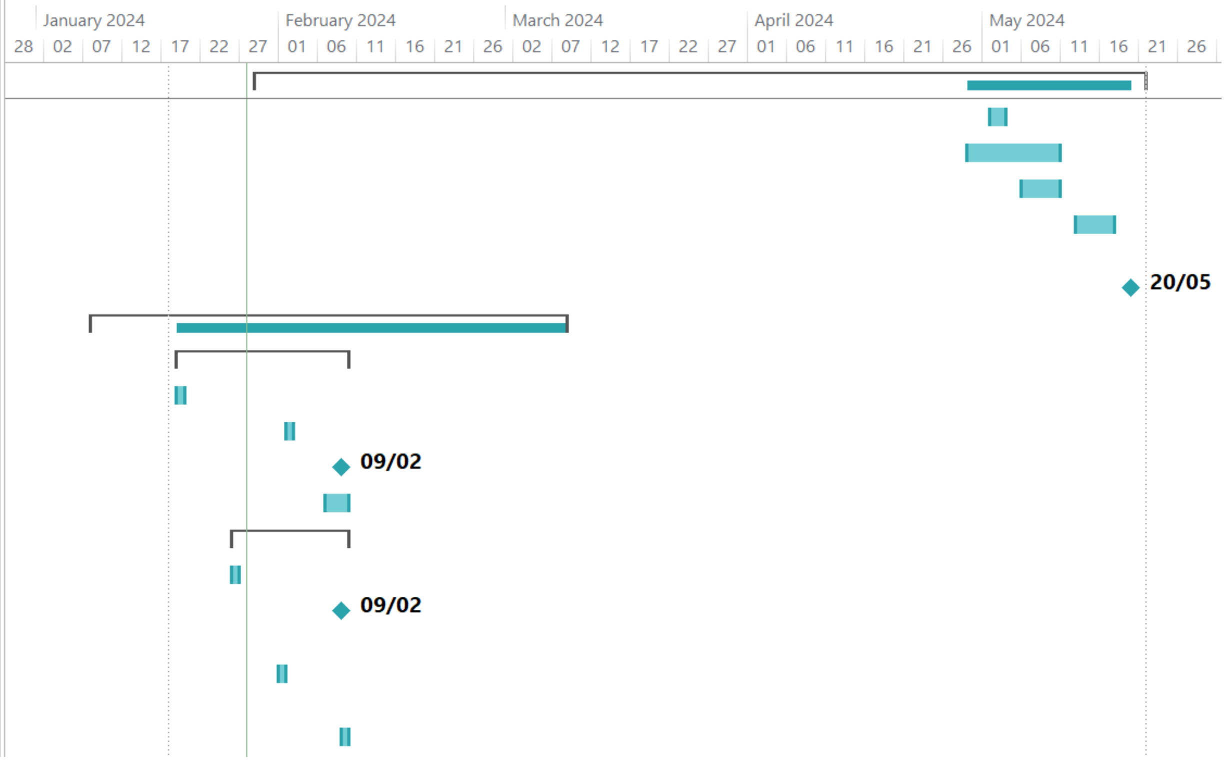
Risk Description	Mitigating Actions	Who needs to carry out the action?	Risk Level L / M / H	Done
Project				
Delay in previous project phases compromises future deadlines	• Develop a Gantt chart to baseline the project, carefully follow it to identify early delays in the schedule. • Create a project plan that reflects the teams understanding of the project scope and the resources available.	Team	M	
Resources over-allocated	• Create a resource chart to clearly understand which resources are available/ needed from the beginning of the project	Team	M	
Theft of materials, equipment, intellectual property	• Enforce security measures, keeping hardware in a locked room overnight. • Track equipment when in use	Team	L	
Incomplete hardware resources	• Bring the issue to the attention of the project manager so that a replacement can be arranged as soon as possible.	Team	M	

Changes to the scope and project direction.	• Any changes can be addressed in consultation with the project manager. • Look at Gantt Chart to determine the current flexibility of the schedule and the workload can be increased if possible	Team	L	
Risk Description	**Mitigating Actions**	**Who needs to carry out the action?**	**Risk Level L / M / H**	**Done**
Scope				
Project schedule is not clearly defined	• Meeting with the full team so that everyone understands the forthcoming plan and the likelihood of missed tasks. • Share the schedule so that all the team have access to it and can see the upcoming tasks and go through them at weekly project progress meetings	Team	M	
Project scope is not well-defined	• Develop an overview of the project, ensure that it is well define in the PID	Project Manger	H	
The projects scope could change	• Construct a Project Initiation Document • Continuously refer to the PID document throughout the project	Team	M	
Team				
Team members may be absent from the project	• Everyone is aware of everyone else role within the team. • A second member is on standby for a section of the project if the primary team member is absent on their section	Team	M	
Lack of communication, further causing mis-understanding and confusion	• Use the most appropriate channel of communication (Trello, Teams, etc.)	Team	M	
Design				
Estimating and/or scheduling errors	• Estimation and tracking of costs and forecasting costs to adjust where necessary. • Build in stages to minimise large costings. • Routinely track schedules and review them as an agenda point in project progress meetings	Team	M	

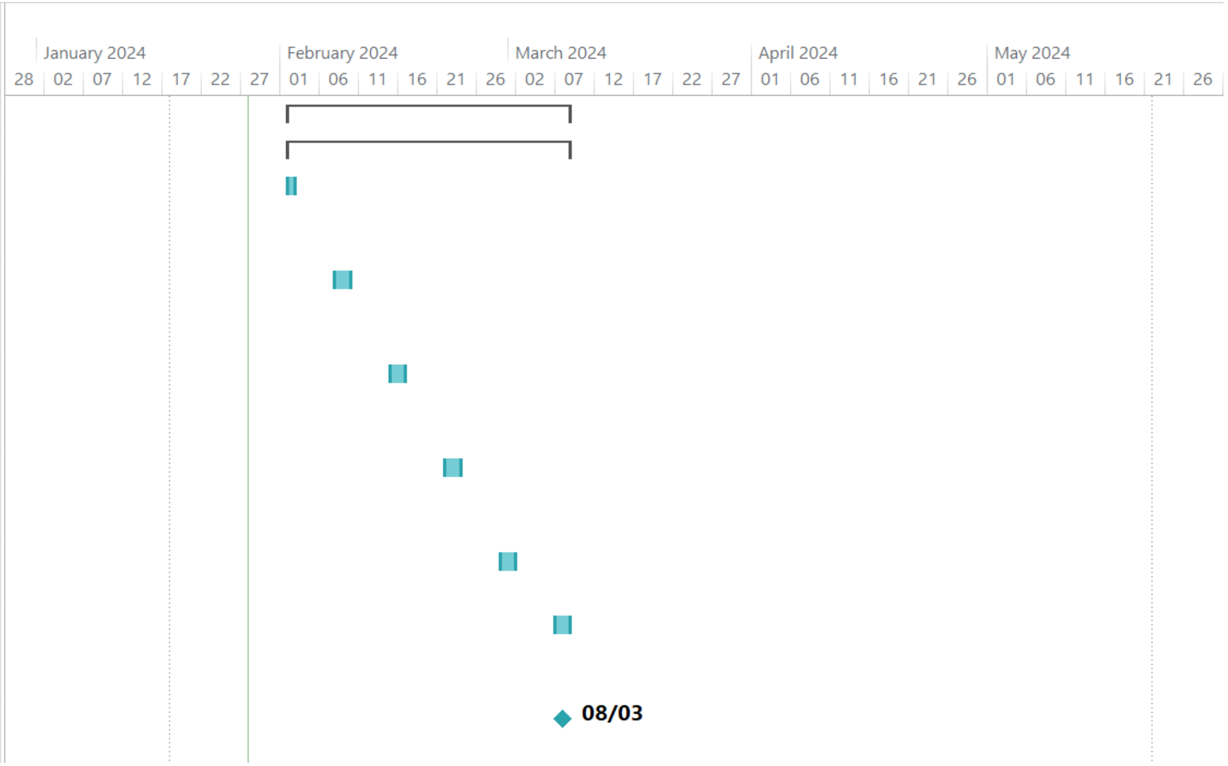
Unplanned work that must be accommodated	• Document any assumptions made in planning/ meetings before the project starts. • Frequently host project scheduling meetings	Team Manager	M	
Project design and deliverables are incomplete	• Define in detail the scope of the project with design workflows and input from all team members	Project Manager	H	
Risk Description	**Mitigating Actions**	**Who needs to carry out the action?**	**Risk Level L / M / H**	**Done**
Financial/Ordering				
Components not being readily available to order	• Find alternate components of similar specification, or as close to as possible to work as a substitute. • Re-design parts of the project to fit around new alternate components	Team	H	
Lead time on ordering parts	• Allow for simultaneous work to be carried out on the project, testing/assembling parts that be constructed independent of the awaiting components. • Order components prior to when they are required	Team	M	
Overspending from the budget	• Research vendors before purchasing, choosing the most reliable and best suited vendor. • Reallocated resources where applicable from previous projects	Project Manager	L	
Budget of the project being cut	• All team members should analyse the external factors that hinder the projects working and keep some of the budget aside in case of the event of budget cutting.	Project Manager	L	

Appendix C – Revised Expanded Gantt chart

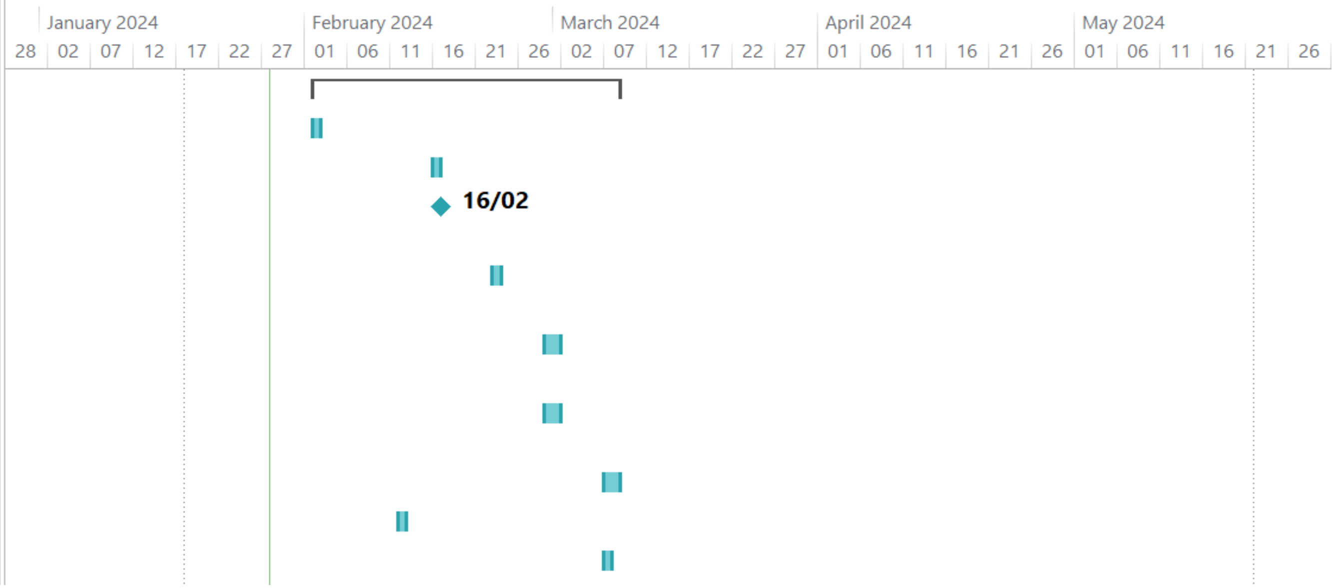
Task Name	Start	Finish
<Final report>	**Mon 29/01/24**	**Tue 21/05/24**
<Write up SOP>	Thu 02/05/24	Fri 03/05/24
<Write report>	Mon 29/04/24	Fri 10/05/24
<Generate Presentation>	Mon 06/05/24	Fri 10/05/24
<Review Draft before submission>	Mon 13/05/24	Fri 17/05/24
<Final Submission>	Mon 20/05/24	Mon 20/05/24
<Devlopment 2>	**Mon 08/01/24**	**Fri 08/03/24**
<Printing and Assembly>	**Fri 19/01/24**	**Fri 09/02/24**
<Print Box>	Fri 19/01/24	Fri 19/01/24
<laser cut parts>	Fri 02/02/24	Fri 02/02/24
<Parts amnufactture d>	Fri 09/02/24	Fri 09/02/24
<Put chassis together>	Wed 07/02/24	Fri 09/02/24
<Ai >	**Fri 26/01/24**	**Fri 09/02/24**
<Generate Dataset>	Fri 26/01/24	Fri 26/01/24
<AI Programmed with own data set >	Fri 09/02/24	Fri 09/02/24
<Run loops and adjust for efficnecy>	Thu 01/02/24	Thu 01/02/24
<Review>	Fri 09/02/24	Fri 09/02/24



Task Name	Start	Finish
<Programming Locomotion2>	**Fri 02/02/24**	**Fri 08/03/24**
<Manipulator>	**Fri 02/02/24**	**Fri 08/03/24**
<Create Script that comunicates with Niryo One Controller>	Fri 02/02/24	Fri 02/02/24
<Create comands that control position of joints>	Thu 08/02/24	Fri 09/02/24
<Create feedback loop to get position from encoders>	Thu 15/02/24	Fri 16/02/24
<Impliment mirco adjustments for alinmnet with object>	Thu 22/02/24	Fri 23/02/24
<Test accuracy of joint control>	Thu 29/02/24	Fri 01/03/24
<Allow for connection between control-script and main system>	Thu 07/03/24	Fri 08/03/24
<Manipulator Script complete>	Fri 08/03/24	Fri 08/03/24



Task Name	Start	Finish
<Chassis>	**Fri 02/02/24**	**Fri 08/03/24**
<Create fucntions for single	Fri 02/02/24	Fri 02/02/24
<Generate functions for 4 w	Fri 16/02/24	Fri 16/02/24
<4 Motors moving together>	Fri 16/02/24	Fri 16/02/24
<Implement remote connection (ssh)>	Fri 23/02/24	Fri 23/02/24
<Get data back from sensors>	Thu 29/02/24	Fri 01/03/24
<Intergrate sesnors with contol comands>	Thu 29/02/24	Fri 01/03/24
<Program controller>	Thu 07/03/24	Fri 08/03/24
<Mid way review>	Mon 12/02/24	Mon 12/02/24
<Final review>	Thu 07/03/24	Thu 07/03/24



Task Name	Start	Finish
<Intergration and Testing>	Mon 04/03/24	Fri 03/05/24
<Design state Machine>	Thu 07/03/24	Fri 08/03/24
<Final state machine complete>	Fri 15/03/24	Fri 15/03/24
<Visual servoing>	Thu 14/03/24	Fri 22/03/24
<Combine with object detection>	Thu 14/03/24	Fri 15/03/24
<Create adjustment state>	Thu 21/03/24	Fri 22/03/24
<Autonomous navigation>	Thu 14/03/24	Fri 22/03/24
<Combine with object detection>	Thu 14/03/24	Fri 15/03/24
<Create navigation state>	Thu 21/03/24	Fri 22/03/24
<States programmed>	Fri 22/03/24	Fri 22/03/24
<Easter break>	Mon 25/03/24	Sun 07/04/24
<Mid way review>	Thu 11/04/24	Fri 12/04/24
<Optimisation of programs>	Thu 18/04/24	Fri 19/04/24
<Final optimisation>	Fri 19/04/24	Fri 19/04/24
<Final Testing and evaluation>	Thu 25/04/24	Fri 26/04/24
<Final Review>	Thu 02/05/24	Fri 03/05/24