UNIVERSITY OF HULL

H.A.R.P.E.R

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

Computer Science

at the University of Hull

by

Aimee Walker, Galen Greco, Andrei Gorun, Kieron Underwood, Kieran Smith November 2023

Student number: 202005595, 201911320, 201904829, 202003809,202019201

Project Supervisor: Professor Yong Sheng, Robert Finnis (MEng)

Word Count: 7880

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Abbreviations

3D	Three Dimensions
A	Amps
AG	Andrei Gorun
AI	Artificial Intelligence
AW	Aimee Walker
CNN	convolutional neural network
CV	Computer Vision
DC	Direct Current
DOF	Degrees of Freedom
GG	Galen Greco
KS	Kieran Smith
KU	Kieron Underwood
PLA	Polylactic acid
ROS	Robotic Operating system
RPM	Revolutions per minute
VAT	Value Added Tax

1. Introduction (KS)

This project will Implement an omnidirectional-wheeled robot powered by 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.

2. Statement of Resources

2.1 Hardware (AG)

Qty	Component name	Price	VAT	Shipping Fee	Lead Time
4	12V DC Motor 251RPM w/Encoder	£209.46	included	£12.94	20 business days
1	100mm Aluminium Mecanum Wheel Set (2x Left, 2x Right)	£82.40	included	-	3-10 business days
4	6mm Shaft Universal Aluminium Mounting Hub	£38.72	included	-	3-10 business days
4	33mm clamping motor mount 3D printed	£5.00	-	-	21-30 business days
8	RS PRO Silver Aluminium, Anodized Profile Strut, 20 x 20 mm, 6mm Groove, 1m Length	£68.32	£13.66	-	available for back order-10 business days
3	20x20mm Corner Brackets (Bag of 10)	£22.77	-	-	7 business days
1	3D Printed Manipulator Base, PLA	£6.89	-	-	3 business days
1	DFRobot 5V Electromagnet (3KG holding force)	£4.50	included (£2.84)	£12.55	3-10 business days
6	Electromagnet Counterpart	£30.90	£7.57	£6.95	7 business days
1	NVIDIA 945-82771-0000-000 Jetson TX2 Development Kit	£918	included	£7.95	14 business days
2	Raspberry Pi 4 Model B, 4GB	£110	included	£3.99	30-60 business days
8	Ultrasonic Distance Sensor HC-SR04 5V Version	£16.64	£4.72	£6.95	7 business days
1	Intel RealSense 435 Camera	£258.90	£65.87	£12.67	21 business days
5	5mm Clear Acrylic Sheet 500 x 500	£70.25	£15.71	£8.29	10 business days
1	3D Printed Gripper and Camera Support	£4	-	-	3 business days
65	M5 x 35mm Full Thread Cap Head Screws (DIN 912) - Stainless Steel (A2)				7 business days
65	M5 Thin Hexagon Nuts (DIN 439) - Stainless Steel (A2	total	for all components:		7 business days
12	M10 x 30mm Full Thread Cap Head Screws (DIN 912) - Stainless Steel (A2)	£25.71	£5.99	£4.25	7 business days
12	M10 Hexagon Nuts (DIN 934) - Stainless Steel (A2)				7 business days

1	RS PRO 12V T12 Sealed Lead Acid Battery, 20Ah	£82.12	£16.42	potentially free	10 business days
2	Cytron 20A 6V-30V Dual DC Motor Driver	£35.00	included	£6	11 business days
2	Micro SD Card	£18.00	included	£5	4 business days
1	Niryo One 6 axis Robot Arm	£3,529.00	£705.00	free	10 business days
1	Orbec Astra Camera	£130.00	included	free	10-20 business days

In the table listed above, the entire bill of materials of the project is presented in a format that provides the quantity, the name of the component, the cost broken down in 3 categories as well as the time each part requires for shipping.

Based on this list, the approximate cost of the system is £6615. In the Bill of Materials, there are several components highlighted with the colour orange, which signifies components that the team has gathered from the University storage, to minimize the cost of the project to only components that are necessary, as there are no alternatives that the University can provide for the project. This resulted in only needing approximately £738 to order the remaining required components for the system. Considering that the project budget is set to £1000 this has resulted in a drastic decrease in cost for the project, and with the team having set an overhead of 20% (£200 of the budget) there is, at the current state of development, approx. £260 that the team has at disposal for emergency expenditure.

The Motors used to drive the system are metal DC motors manufactured by DFRobot. The justification behind this selection is that these motors provide the system with sufficient torque to be able to push the robot with its current expected weight. These motors also present sufficient RPM that if for any reason, the robot would turn out to be significantly heavier than in its current configuration, the speed of the motors could be reduced to increase torque without affecting the robot's necessary operational speed. They are also equipped with wheel Encoders so that it is possible to track their speed and position. The motor drivers chosen are capable of driving two motors each at the same time, meaning that for the system, only two motor drivers are needed. These motor drivers are compatible with a wide variety of host controllers, including Raspberry Pi which is the team's choice for driving the chassis.

Two Raspberry Pi computers will be utilised by the team to develop the software required for the robotic manipulator as well as the motors of the chassis. The manipulator is a Niryo One robotic arm with 6 Degrees of freedom that is highly compatible with the Raspberry Pi controller and was therefore a clear choice for the development of the arm. From there, for simplicity and compatibility a raspberry pi was also chosen to develop the software required for the system to navigate around the controlled environment.

For the development of the AI & Machine Vision section of the project, A Jetson TX2 development board was chosen as it is very powerful and capable of handling image processing as well as AI computing. Connected to the Jetson will be two cameras, an Intel RealSense 300 and an Orbec Astra which are both capable of depth perception. This is a requirement as the development team will use the live feed from the camera to detect boxes within the controlled environment and also establish the distance from the robot to the box. The camera will also be used for visual servo-ing of the robot manipulator to ensure the manipulator is oriented in a way which allows for efficient pickup of the boxes.

The wheels chosen for the system are a set of omnidirectional wheels manufactured by NEXUS ROBOT. The team has decided on the use of omnidirectional wheels over standard wheels, as the team has concluded that omnidirectional wheels provide the robot with better movement on the horizontal axis that do not require the robot to turn in the direction of the axis. Therefore, the robot can maintain its orientation while traversing the controlled environment without needing to turn at specific angles during traversal. This will provide the team with better understanding of the system's orientation at all times during operation. This specific set of omnidirectional wheels is made of aluminium and are rated at a load of 15kg per wheel and are therefore more than capable of withstanding the weight of the designed system.

The 6 mm aluminium mounting hubs were chosen as they match the shaft of our motors and are necessary to connect the motors with the omnidirectional wheels. The 33mm clamping motor mounts are required to mount the motors on the chassis.

For the chassis of the robot, 20x20 mm aluminium struts with a 6mm groove have been chosen as they will provide the robot with the necessary structural strength to bear the weight of all the components needed for the completion of the project's objectives. Aluminium has been chosen over other alternatives (such as steel) to reduce the design's weight without having to sacrifice the structural integrity of the chassis (with materials such as PLA). To connect the struts, 20x20mm corner brackets will be used, as this minimizes the number of holes needed to be drilled into the struts.

When it comes to picking up objects, the team has decided on an electromagnet powered gripper. The reason for this choice over a more standard claw design gripper is that, for the purpose of stacking objects, an electromagnet gripper allows the robot to pick and place objects near one another without having to worry that the claw might interfere with the other stacked objects and can therefore, place the objects near one another at very close proximity.

In the development stages, each sector of the project will be powered via their individual wall power supplies , that once the system passes the integration stage, the team will look to power the entire system off a battery pack. The battery choice for this was made considering that the system requires an approximation of 14 A for one hour of utilisation, and therefore the 20 A battery chosen will be sufficient for the testing of the system.

The team is focused and determined to run the project in a sustainable matter and ensure that all the costs associated for this project are thoroughly investigated to be as cost effective as possible. Therefore the team has made it a priority to recycle/re-use a large number of components that the University possesses. This includes the raspberry Pis, the Jetson TX2, the Niryo arm which have been pulled out of storage. The two cameras have been taken off an unused Turtlebot 2i and have been repurposed for this project. For all the parts that the team has to order, we have tried to use as few suppliers as possible and grouped them based on suppliers to ensure low or no shipping costs as well as to reduce the number of orders.

2.2 Software (KU/KS)

Software resources			
Name	Link to recourse	Description/justification of use	Alternative software
CNN AI	https://github.com/tensorflow/models/tree/master/research/object_detection https://github.com/tensorflow/models/tree/master/research/object_detection	Convolutional Neural Network artificial intelligence (CNN AI) will be used in the identification and coordination of the mobile robot. The function for the CNN AI will take place in the process of searching for the target boxes, which when a target box is identified, will switch the state of the robot and change direction to move towards the robot. CNN AI works using kernels through an advanced algorithm which multiple kernels are randomly generated at a certain 2-dimensional matrix. Through these random patterns, curves are identified which are then reviewed in an advanced algorithm to determine why a certain category is labelled as it is. Based on these categories, the AI learns to recognise certain categories based on the familiarity curves in the original dataset.	– R-CNN ResNet 101 - RetinaNet ResNet 101 - YOLOv3 - Matlab CNN
OpenCV	https://opencv.org/about/	This is a set of libraries that are focused on computer vision and machine learning this is software made by others and can be used in this project in multiple areas like the computer vision part of the project to detect an object and the use of this set of libraries can help with the programming of the robot. This is very beneficial because it saves time and effort for us to use premade algorithms to speed up the time it takes to program the robot. This is also a free to use library and has a community to support for these libraries to better understand them.	– Microsoft Computer Vision API. – Google Cloud Vision API. – Amazon Rekognition. – scikit-image. – Azure Face API. – SimpleCV. – Deepdream. – Clarifai.
TensorFlow	https://www.tensorflow.org/	This software is used to make AI models this will primordially be used to program the AI from scratch, or it will be used to find a usable model and re-write parts of the model to best fit what the project requires of the AI. This website also has forums and tutorials to provide community support and dedicated help on some parts of the AI model making. This will help by creating the AI model that we need, and this will save time in the project.	- PyTorch - Keras - Torch - Deeplearning4j - Mlpack - CatBoost - Anaconda - Caffe
PyCharm	https://www.jetbr	This is a programming environment that tends to come installed with python. This is a common one	- Jupiter notebook

	ains.com/pycharm/	that is used by programmers. The reason it might be used in this project because the team member who has most experience in AI is most familiar with this coding environment and its links to AI programming it is also mainly focused on python programming language this means that it will be used to make the AI programming.	- Google Colab - Vs code
ROS	https://www.ros.org/	"The Robot Operating System (ROS) is a set of software libraries and tools that help you build robot applications" this is why we will be using this for the project because it is developed for the creation of robotic systems. It works by creating a messaging system to each part to get them to move how you wish for it and this is the structure that we will be using. With the libraries working and it is one of the beasts for multiple sensors and motors manipulation by programming.	- PyRobot - Orca - Yet another robot platform - genom3
Python	https://www.python.org/	This is a programming language that is to be used in this project the reasoning of this choice is that the controller hardware that is being used runs this language proficiently so there is no compatibility issues. That is not the only reason we are using this programming language some of the other reasons is that it is compatible with ROS, packages/libraries that are used for NIYRO arm and the AI programming that is being considered currently to promote unassisted movement in the robot.	- Arduino - C - C# - C++ - assembler (last resort if everything else fails)
NIRYO studio / ROS packaging / python libraries	https://docs.niryo.com/product/ned/v3.1.1/en/source/software/niryo_studio.html	This software is used to simulate the arm we have selected for this project it is because of the arm that we use needs to be simulated and this software dose this. It also allows them to program the arm to move as we need it. This is for programming the actual physical arm to move along a path to the destination that has been programmed using this environment and its libraries / Ros packaging.	- python programming libraries - the ROS packages There are few other options to programming the ned arm except coding it directly with python.
Rviz	https://wiki.ros.org/rviz	This is a simulation environment that works with Niryo studio to simulate the arm if we don't have the complete arm for reasons outside our control. Using this software, it can be used to simulate the arms movements, and this will better for programming control systems of the arm before the problem with it can be fixed. Hence the need for this resource for this project. Like with most ROS packages it is free to use by anyone.	- Gazebo - Webviz - Jupiter notebook - Matlab
Vs code	https://code.visualstudio.com/	This is a coding environment software that is used on a Lynex system, and it has a version on windows. The main reasoning for the use of this programming environment is because it is	- notebook++ - PyCharm - Vim - Sublime Text

		adaptable with the other software being used and that it is familiar to most if not all the team. Theis should allow for our team to not be slowed down when coding as well as provide a debug feature that can help find problems in the code and point them out for us.	
SOLIDWORKS 3D CAD	https://www.innova-systems.co.uk/solidworks-software-uk/	This software product is to be used in this project to facilitate the design process of the project. This software will allow us to make a 3D CAD (computer aided design) model of the project so that we have an idea of what we are making, and this will help with ordering parts for the bill of material and what hardware resources that will be needed. A benefit to this software compared to other alternative software is that it has a built-in statistic and dynamic calculations software to be used on the model or assembly that is made in this software. This can be of great use saving time with the calculations not being needed to be made by hand. This software cost for the licence key to use this software, luckily for this project the university/company is supplying us with the licence keys to use this software hence it is free for us to use.	- FreeCAD - Onshape - Fusion - Solid edge - Inventor - Sketch up - AutoCAD - Tinkercad - Creo Parametrics - NX CAD - https://www.g2.com/products/solidworks/competitors/alternatives
Cura	https://ultimaker.com/learn/ultimaker-cura-4-3-available-now/	This software is made by UltiMaker to interact with their 3D printers and other 3D printers so that the CAD models can be printed off. The software does this by converting your file into G code and other friendly formats that is used by most printers. Why use this software is because it gives a visual representation of your model on the build plate of the printer, and this allows you to add supports to your CAD model when printing so that it doesn't print wrong or brakes while printing hence why we will be using it because it also gives a good indication of how much filament is needed for the print and the time it will take for the print to take with the settings that you apply in the Cura software. The cost of this software is free to use because the idea is that you have bought a 3D printer from them already hence you will need this software, so they decided to make it free use.	- Tinkercad And a lot of the same as the ones for SolidWorks alternative because they can be used to produce 3d model and other file types like g code however in them you don't have as much control over it as you do with Cura hence why Cura is the one being used.
Microsoft project / office 365 and teams	https://www.microsoft.com/en-gb/microsoft-365/proj	This three software are bundled together because they come from the same company and the same bundle of software. Office 365 are used to make the reports and other document that are for the hand in task. The use of teams is to facilitate communication between team members that are working from separate locations and having	- Facebook messenger - Emails - Dropbox - OpenOffice(open source) - OnlyOffice

	ect/project-management-software	meetings from remote areas. The final piece of software is Microsoft project this software is manly used to create a Gannt chart and for time management purposes of the project to keep everything in order. When running the project by allowing for the detailed task list and time scheduling of them so that the project can be completed on time with the appropriate documents that are required.	- Mind view (for Gannt chart and time management) - ResourceGuru
Trello	https://trello.com/	Trello is a project management software it helpful to this project because it allows for the creation of virtual white board that will be helpful for the management of the project on a week-to-week basis. The reasoning behind the use of this is that we can take task from that massive Gannt chart and put it into this software each week and by doing this we get an easier to understand format only focussing on the task of that week or the next, making each team member less over whelmed and able to focus more on their task or deadlines that have been set. This can also be used to set meeting topics for meetings by putting questions in there. This is useful for project management for each team member on week-to-week basis and it is a free to use basic version which is enough for our project work.	- ClickUp - Asana - ProofHub - MeisterTask - Airtable - Basecamp And others from https://clickup.com/blog/trello-alternatives/

3. Plan of Work (AW)

When looking at the specification the project could be broken into 5 key development phases

1. Planning – this phase is the initial planning of the project which involves generating the projects task lists, Bill of materials, researching the necessary software's.
2. Development phase 1 - this first phase of development is centred around getting the masking functionality created. It almost acts as a proof of concept as simulations will be developed so that there is evidence that it would work on the hardware. During this phase the parts will be ordered and manufactured for the project. This phase was designed so that we wouldn't be depending on the parts that need ordering due to lead times and logistical issues (evaluated in risk assessment)
3. Development phase 2 - this phase is to refine the rough programs and where possible systems more reliable as well as implanting on the hardware as we construct the robot.
4. Integration- during this phase we will be combining individual development so that we can generate a cohesive system.
5. Testing and Evaluation - During this phase we will be doing final testing and evaluating the success of the project.

Each of the phases will have a review at the end and roughly the mid-point of each phase. During these reviews any/all work will be presented at the end of each week. The team will meet to run through each other's work to ensure that the whole team are aware of progress of each team member. This will also allow the Project manager to evaluate the plan as the project progresses.

These phases are shown in the Gantt chart shown:

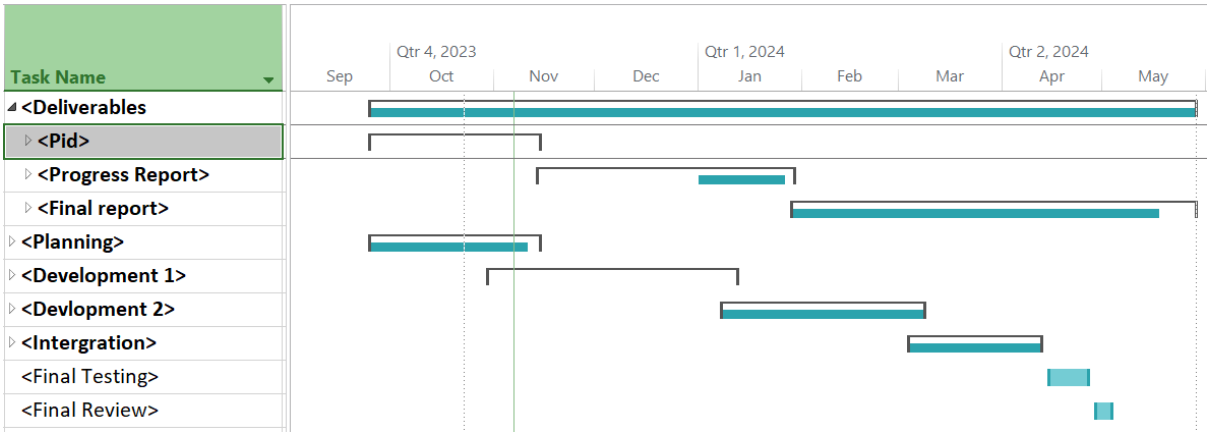


Figure 1- Overview Gantt Chart Outlining the deliverables and phases.

The Gantt chart outlines the time frames that each of the phases will take place in as well as the time that we will be working on the deliverables. The full task list can be found in Appendix A - Full Gantt chart and Task list.

The team members will be able to see the tasks that are coming up and that they should be working on through a software called Trello. Trello is an open-source software that allows us to assign tasks. As you can see on the Gantt chart in Appendix A - Full Gantt chart and Task list as tasks are assigned on Trello or in weekly progress sessions, then the project manager can reflect that on the tracking Gantt chart.

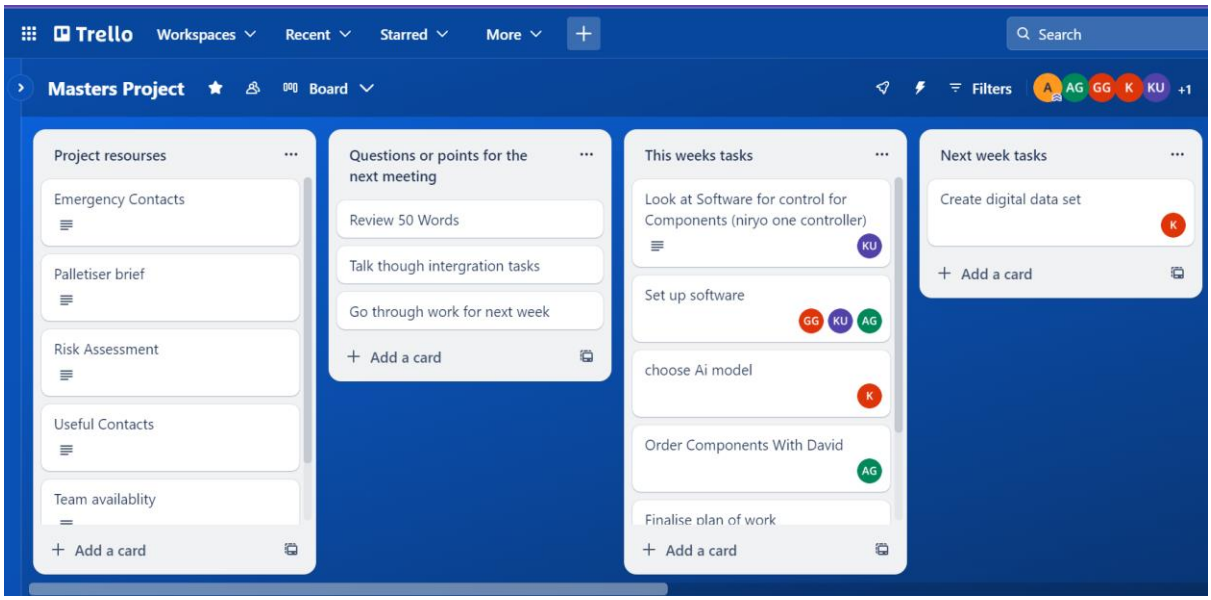


Figure 2 - Trello Dashboard

Figure 2 shows the board created for the project. using this software team members can be assigned tasks as well as communicate by adding comments and descriptions to individual tasks. This software also allows the project manager to assign deadlines and monitor progress. This is helpful as it more readable for the team members rather than the Gantt chart.

4. Ethics Consideration (KU)

Ethical considerations for working as a team in this project are:

1. **Bereavements** – if one of the team members have a death of a close relative/friend then they are expected to take time off for such occasions. This is to allow said team member to come to terms with their situation and loss before they start work again. Work should be diverted to other team members to facilitate this however it is within reason for explanations to be provided for the work they have already done to be provided if asked. (Everyone should be up to date with the work lessoning the need for this)
2. **Work you are doing** – this is you should be doing the work that is assigned to you by the deadline and if this is unlikely to happen then you will be required to inform the team as soon as possible. This is not to shame team members for not keeping up with deadlines but to make them aware of the need for either additional support or extra time. This is not to be abused by the team members and only when it is necessary should the extra time be allotted. Examples of when time should be allotted to the team member is when they and the team has misjudged the scale of the task undertaken, if they are testing software just before deadline and running into unexpected bugs, so the need for more time to fix these bugs.
3. **Theft of intellectual property** – this team will take information from sources that they have properly referenced and given acknowledgement to the sources for the work that has been done by others and has then been used in the team's project. When working in a group, it is important to make sure that credit is given when ideas benefit the project to maintain a positive working environment.
4. **Law/University policy** – this consideration is for the project team members to follow the laws that are in place in the country this is being made in and deployed in. Laws like the data protection act and other such laws are what need to be considered when working on the project. Outside of this the university will have policies and procedures that the team will need to follow. The laws and policies that affect our project will be discussed in the team so everyone is aware of them and hence no own would be blindsided by them to end up crossing them.
5. **Losing team members** – this can come from the team member quitting the course for whatever reason or even them requesting to do a masters project alone and getting permission from the university to do so. Leaving team member will not be held responsible for this in any way because sometimes things happen that make leaving the best choice for that team member and in the rear situation for the team as well, this is why they will not be held responsible for this action.
6. **Team member absence**- the team members in the case of abscesses should be able to tell the team why they are absent. If this information is confidential like a doctor's appointment, they can keep it that way by just saying they are at the doctors. However, if they are ill then they can say that with the expectation they will return with in the next 48 hours or go seek perfectional aid and update the team of this. As for other absences if they are reasonable like traffic and accidents then a message informing the team you will be late and why is perfectly acceptable. For longer abscesses then they will need to be able to supply evidence of the reason and an expected return date so that plans can be made to lessen the impact of the longer absences of the team member.
7. **Respect and trust** – this are an ethic consideration because each team member should respect each other and their opinions while working as a team this includes inside and outside the working space during the time they are working together. In this respect

consideration it includes respecting the teammate's ability to complete task and have the work done for the deadlines as well as giving them trust that they will accomplish what they are tasked with, or trust to ask other teammates for aid if they are in need for it.

8. **Testing considerations** - the testing of this robot will not be done on children at all during this project. The reason for this is that we are testing the functionality of the robotic system in a controlled environment, with this testing the adding of uncontrollable influences on the testing is not conducive to the success of the test. Hence why children will not be involved with the testing or in this project at all. What this means for ethical considerations is that no further in-depth considerations need to be taken since they will not be involved in the project as for future ethical considerations if for certain reasons later in the project it is decided to use children in the testing. Then a full formal ethical document will be written up at that point in time and be subjected for review by the university and any other authorised body to make the decision to allow the testing to commence, without their sign off from at least the university testing with children is not to commence in any circumstance

5. Risk Assessment (GG)

5.1 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 an accurate project plan	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	
Added workload or time requirements because of a project new direction	• Look at Gantt Chart to determine the current flexibility of the schedule and the workload can be increased if possible	Team	L	

Scope				
Project schedule is not clearly defined	• Hold 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 lack of understanding, leading to confusion	• Use the most appropriate channel of communication (Trello, Teams, ect)	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	
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	

5.2 Robot Lab Risk Assessment

What is the Hazard?	Who might be harmed and how?	What are you already doing to control the risk?	What further action do you need to take to control the risk?	Who needs to carry out the action?	Risk Level L / M / H	Done
3D printing	Operators in the lab • Minor injuries (burns, nausea) • Major injuries (intoxication)	1. Adequate ventilation required for printing. Making sure that the system is turned on to extract fumes and/or window ventilation is possible. 2. Allow 30 minutes after printing to allow the printer to cool before removing the print. 3. Any burns should be irrigated with cold running water. 4. Appropriate PPE to be warn when working with finished prints. Finished prints can be sharp and cause lacerations if this occurs should be reported to the H&S Officer. 5. All operators to complete training and acknowledge a Safe Working Practice.	1. First aid box available in the area. 2. Prints printed with ABS should be undertaken out of normal working hours to neglect the effect on individuals (COSHH).	Operators	M	
Furniture	Operators in the lab • Minor injuries (skin penetration)	1. Check all wheels on moveable furniture is secured properly and not lose. 2. Do not exceed the weight limit on desks. 3. If the source is faulty this should be reported to the H&S Officer and moved to a safe location and using Safe Code of Practice to remove the	1. Provide spare equipment if the current is faulty or inadequate to the purpose. 2. Labelled faulty furniture.	Operators	L	

What is the hazard?	Who might be harmed and how?	What are you already doing to control the risk?	What further action do you need to take to control the risk?	Who needs to carry out the action?	Risk Level L / M / H	Done
Hazardous substances	Operators in the lab • Minor injuries (headaches, nausea, rashes) • Major injuries (Poisoning, chemical burns, nervous system disorders)	1. If any hazardous substances are used COSHH risk assessment must be completed.	1. Adequate PPE to be provided. 2. Clean-up procedures and other control equipment to be followed/provided.	Lab Technicians	L	
Fire	Attendees in the lab and external people in the area • Minor and Major injuries (Smoke inhalation, severe burns)	1. Storage of flammable material should be kept to a minimum (carboard etc.) 2. The fire alarm is installed properly and maintained/tested. 3. Fire Stewards must be appointed to cover the robotics lab. 4. Everyone must be acquainted with the Fire Routine Procedure for their area. 5. Equipment should be switched off if not being used for a prolonged period. 6. All portable equipment must be tested for electrical safety.	1. Fire extinguishers in the vicinity to control fires. 2. Fire doors to be accessible. 3. Security number to be published to report a fire. 4. Batteries being charged must not be left unattended.	Lab Technicians	L	

What is the hazard?	Who might be harmed and how?	What are you already doing to control the risk?	What further action do you need to take to control the risk?	Who needs to carry out the action?	Risk Level L / M / H	Done
Manual handling of heavy objects	Operators in the lab • Minor injuries (musculoskeletal injuries in the back)	1. A risk assessment must be completed for lifting heavy and bulky loads that present a risk of injury. 2. A trolley should be used to transport boxes of paper or other heavy items. 3. High shelves for light items only. 4. Training in lifting techniques should be provided for anyone who undertakes the lifting of heavy loads.	1. Ensure that the use of trolleys and crane arm are checked before use as to not damage the item or environment causing subsequent damage to the operator.	Lab Technicians/ Operators	L	
DSE (Display Screen Equipment)	Operators in the lab • Minor injuries (hand pain, headaches, back pain) • Major injuries (seizures)	1. Frequent breaks are taken to ensure that the user gets adequate rest to reduce hand and eye strain (5 min break for every 1hr of continuous use). 2. External monitors used at a proper ergonomic position is used to reduce eye strain and reduce back and neck pain.	1. Arrange desk space so that it is comfortable for use and provides best posture for the operators. 2. Arrange desk space so that it is comfortable for use and provides best posture for the operators.	Lab Technicians / Operators	L	

What is the Hazard?	Who might be harmed and how?	What are you already doing to control the risk?	What further action do you need to take to control the risk?	Who needs to carry out the action?	Risk Level L / M / H	Done
Electronic equipment (electric shocks and burns from faulty electrical equipment)	Operators in the lab • Minor injuries (low level electrical shock) • Major injuries (burns, spasms, heart failure)	1. All portable electrical equipment must be tested for electrical safety at correct intervals and labelled with the date of the test. 2. Electrical cables and plugs should be regularly visually inspected by the user for damage. 3. Any defective equipment should be reported immediately to the H&S Officer, then labelled and taken out of use until repaired. 4. Electrical equipment must always be operated in accordance with manufactures' instructions.	1. Inspect all electrical equipment before switching in it on for exposed hazards. 2. Keep all fluids away from electrical equipment. 3. Make sure that all power sources will be generating 0 amp/voltage when switched on (bench top power supplies etc.)	Operators	L	
Trapping, Impact/Crushing	Operators in the lab • Minor injuries (finger bleeds/swollen/bruised bones) • Major injuries (concussion/broken bones)	1. Only authorised persons may work with robots. 2. Robot users must read the Safe Code of Working Practice for each robot type. 3. Where appropriate the work envelope should be sufficiently guarded and signed to prevent unauthorised entry.	1. Restrict those who can enter certain parts of the lab. 2. Provide two people present when working with robots without force feedback. 3. Have an operator hovering the E-Stop.	Lab Technicians / Operators	M	

What is the Hazard?	Who might be harmed and how?	What are you doing to control the risk?	What further action do you need to control the risk?	Who needs to carry out the action?	Risk Level L / M /H	Done
Slips and Trips	Operators in the lab • Minor injuries (punctured skin) • Major injuries (concussion)	1. Work areas should be kept clear of obstructions. 2. Any spillages should be cleaned up immediately. 3. All areas well lit. 4. Any hazards such as torn carpets, trailing cables, defects to floor coverings, faulty lighting etc. should be reported to the H&S Manager.	1. Cable tying leads and securing them in cable chains out of the way. 2. Keep all moveable robots and power/internet leads for robots to the side of the room.	Lab Technicians / Operators	L	
Soldering	Operators in the lab • Minor injuries (inhaling fumes) • Major injuries (Burns, Flying solder in eyes)	1. When soldering fume extraction must be used. Every user must be familiar and adhere to the soldering risk assessment and safe code of working practice. 2. Suitable PPE must be worn in case of debris.	1. Supply training to new operators so they are safe. 2. Supply adequate safety equipment (eye protection). 3. Soldering stations must have a holder to place the iron when not in use.	Lab Technicians / Operators	M	

5.3 Soldering Risk Assessment

What are the Hazards?	Who might be harmed and how?	What are you already doing to control the risks?	What further action do you need to take to control the risks?	Who needs to carry out the action?	Risk Level L / M / H	Done
Electrical	Operators in the lab • Minor injuries (Low level electric shock) • Major injuries (Burns/spasms/heart failure)	1. Do not handle soldering irons if visibly they are damaged, either to the soldering iron, cable, or plug. 2. All soldering irons to be PAT tested before use.	1. Soldering iron station is free of cables to prevent damage from the heated tip. 2. Use a grounded outlet to stop a short circuit possibility.	Lab technician /Operators	M	
Waste	Operators in the lab • Minor injuries (asthma, rashes) • Major injuries (dermatitis)	1. Collect waster solder in a lidded container. 2. Label as hazardous waste.	1. Used solder spongers and contaminated rags should be placed in a sealable bag for hazardous waste disposal.	Lab technicians / Operators	L	
Fumes	Operators in the lab • Minor injuries (nausea, fever) • Major injuries (kidney failure, hypertension)	1. Soldering using rosin is only performed in controlled conditions. 2. Fume extraction should be though an enclosed hood. 3. Bench top filter extraction systems for rosin-free soldering. 4. Do not solder if extraction using it not working - report immediately to the H&S Officer.	1. Vent outside for fume extraction. 2. All extraction systems to be tested annually and maintained. 3. Solder 20-25cm away from face if possible.	Lab technicians / Operators	H	

What are the Hazards?	Who might be harmed and how?	What are you already doing to control the risks?	What further action do you need to take to control the risks?	Who needs to carry out the action?	Risk Level L / M / H	Done
Rosin Exposure	Operators in the lab • Minor injuries (asthma) • Major injuries (dermatitis)	1. Wear gloves and appropriate PPE to reduce the effects of the rosin. 2. Fume extraction to eliminate solder fume.	1. Temperature-controlled soldering irons. 2. Local exhaust ventilation.	Lab technicians / Operators	L	
Lead exposure	Operator using equipment. • Minor injuries (gastrointestinal problems) • Major injuries (kidney failures, hypertensions)	1. Wear gloves if directly handling solder. 2. If contaminated with lead, remove with appropriate lead removal system.	1. Use lead free solder. 2. If concerned about lead poisoning, check for a blood lead level test (BLL).	Lab technicians / Operators	L	
Soldering Iron	Operator using equipment. • Minor injuries (Mild burns) • Major injuries (3rd degree burns)	1. Never touch the soldering iron 2. Hold wires with tweezers or clamps (helping hands) 3. Keep the cleaning sponge damp when in use. 4. Always return the soldering iron to its stand when not in use, do not set it down on the work bench. Turn the unit off and unplug when not in use.	1. Water station on hand to compensate burns (run burn under cold water for 15 minutes). 2. Report to first aider if deep or extensive.	Lab technicians / Operators		

What are the Hazards?	Who might be harmed and how?	What are you already doing to control the risks?	What further action do you need to take to control the risk?	Who needs to carry out the action?	Risk Level L / M / H	Done
Solder, flux, cleaners	Operators in the lab • Minor injuries (asthma, rashes)	1. Eye wear is worn as solder can spit. 2. Trousers to be warn as solder can be spit. 3. Use rosin-free and led-free solders when possible. 4. Always wash hands after soldering.	1. Keep cleaning solvents in dispensing bottles.	Lab technicians / operators	M	

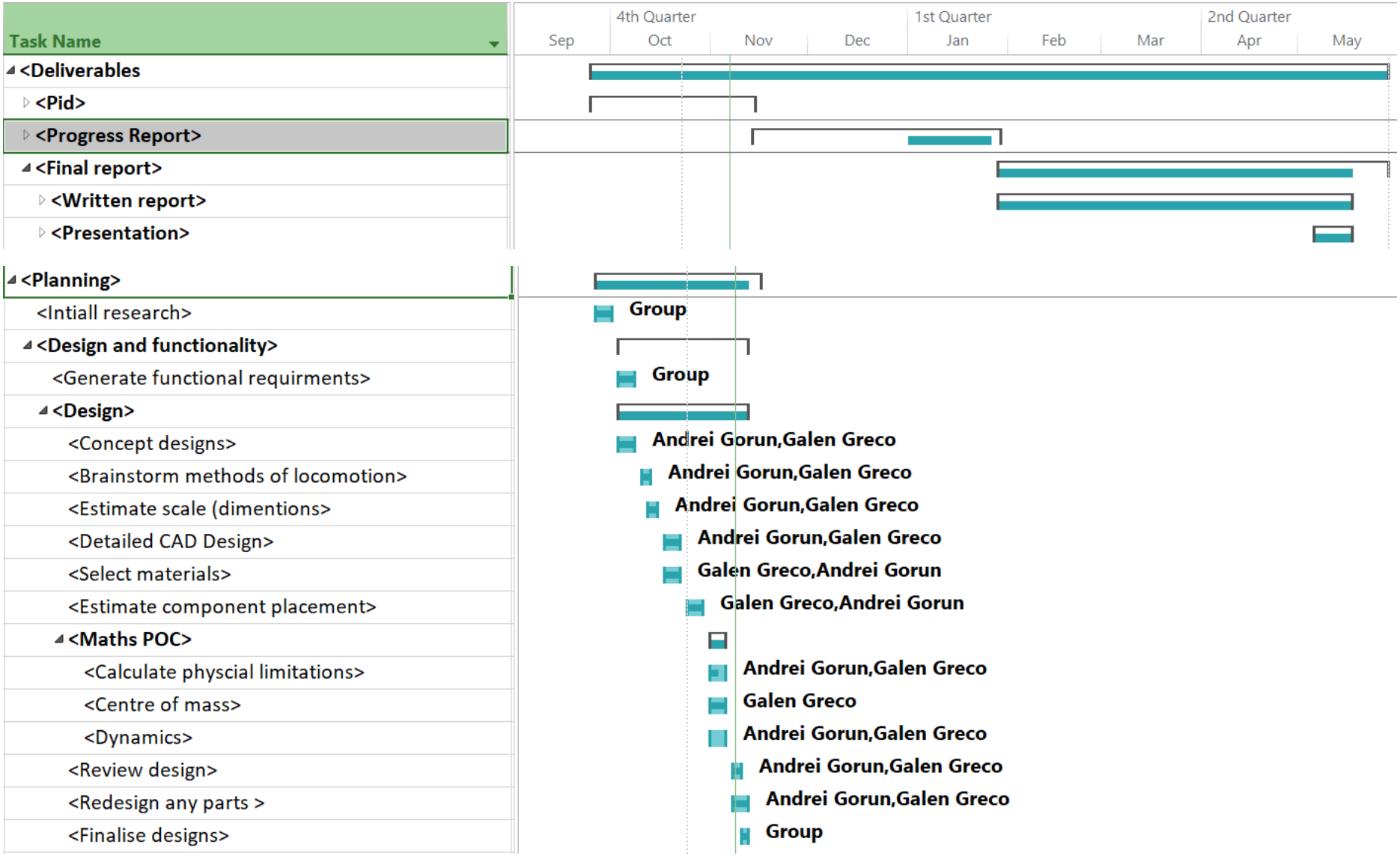
5.4 Mobile Manipulator Assessment

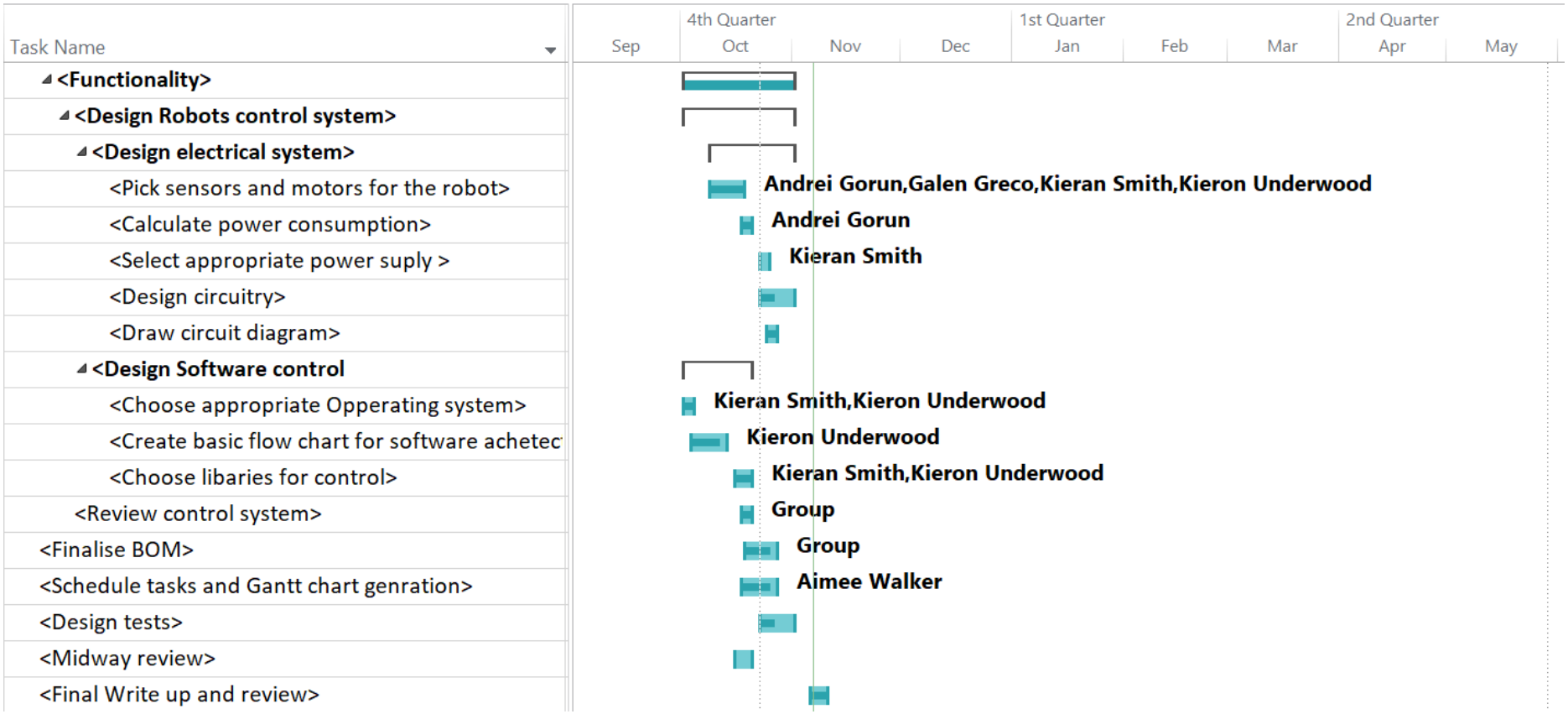
What are the Hazards?	Who might be harmed and how?	What are you already doing to control the risks?	What further action do you need to take to control the risks?	Who needs to carry out the action?	Risk Level L / M / H	Done
Actuators	Operators • Minor injuries (Trapped fingers)	1.Correct specifications have been carried out prior to purchasing to make sure they are adequate. 2.Design of the circuitry to prevent the sudden lurching of driven objects.	1.Make sure that all power is cut off before disassembling any equipment and that it is grounded. 2.Tighten threads with the proper tightening torque.	Lab technicians/ Operators	M	
Brushless Motors	Operators in the lab • Minor injuries (electric shock) • Major injuries (electrical burns /loss of muscular control/ thermal burns	1.Check the operating temperature of the motors 2.Check the integrity of the motor before powering on, check for loose adapters/ shafts.	1.Test mobility thoroughly before assembling the motor onto the mobile manipulator.	Operators	M	
LIPO/ NiMh batteries	Operators/Environment • Major injuries (electrical burn/ explosion)	1. Do not leave batteries unattended when charging as LIPO batteries can explode. If the battery deforms in anyway when charging, you must immediately unplug and notify the Health and Safety Officer. 2. Remove batteries from the device for long term storage. 3. Do not overcharge or over-discharge the batteries.	1. Store the batteries away from the combustible materials. 2. Store the batteries at temperatures between 5^{O}C - 20^{O}C. 3. Visually inspect battery storage areas regularly. 4. Do not parallel charge batteries of a different age and charge status. 5. Charge or discharge the battery to approximately 50% capacity before long term storage	Lab technicians / Operators	H	

What are the Hazards?	Who might be harmed and how?	What are you already doing to control the risks?	What further action do you need to take to control the risks?	Who needs to carry out the action?	Risk Level L / M/ H	Done
Motor Drivers	Operators • Minor injuries (electrical shock)	1.Connect the power source first and turn it on to avoid inrush current. (No motor attached) 2. See documentation to avoid creating a ground loop. 3. Ensure proper soldering to all solder pads to ensure there is good contact and no bridging causing a short circuit.	1. Anti-spark connectors applied to the motor drivers. 2. Anti-static straps to be worn to ground the operator.	Operators	M	
Environmental Collision	Operators / Bystanders / The build of the Robot • Minor injuries abrasions and cuts/ bruises and contusions • Mechanical damaged to actuators the robots' actuators	1.Define safety zones and restrict the robots testing to certain areas. 2. Implement an emergency stop button as a safety measure to immediately power down the system. 3. Extra cautious user control when teleoperating the robot.	1.Implement collision detection and avoidance systems, proximity sensors to slow the robot down / stop when it detects a close object.	Operators	L	
Pinching and crushing	Operators • Minor injuries, cuts / abrasions and bruises and contusions.	1.Ensure the off when performing close maintenance on the system. 2. Train the operator team to be aware of potential pinch points and how to work safely around the robot.	1. Use protective markings/ barriers to keep operators and bystanders at a safe distance when the robot is being tested.	Operators	L	

What are the Hazards?	Who might be harmed and how?	What are you already doing to control the risks?	What further action do you need to take to control the risks?	Who needs to carry put the action?	Risk Level L / M / H	Done
Electrical / circuit faults	Operators • Minor injuries electrical shock, muscle spasm, electric / thermal burns	1.Conduct regular electrical inspections and maintenance 2.Implement electrical safety standards and grounding procedures	1. Provide training for operators working on the physical maintenance of the system	Operator	L	
Electromagnet (magnetic field exposure)	Operators • Major injuries, strong magnetic fields interfering with medical devices such as pacemakers or other implanted devices.	1.Identify and assess the strength and range of the magnetic field generated 2.Ensure personal working near the electromagnet are aware of the potential risk	1.Establish restricted zones / safety perimeters for operator access/	Operator	M	

Appendix A - Full Gantt chart and Task list

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1st Quarter
2nd Quarter
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
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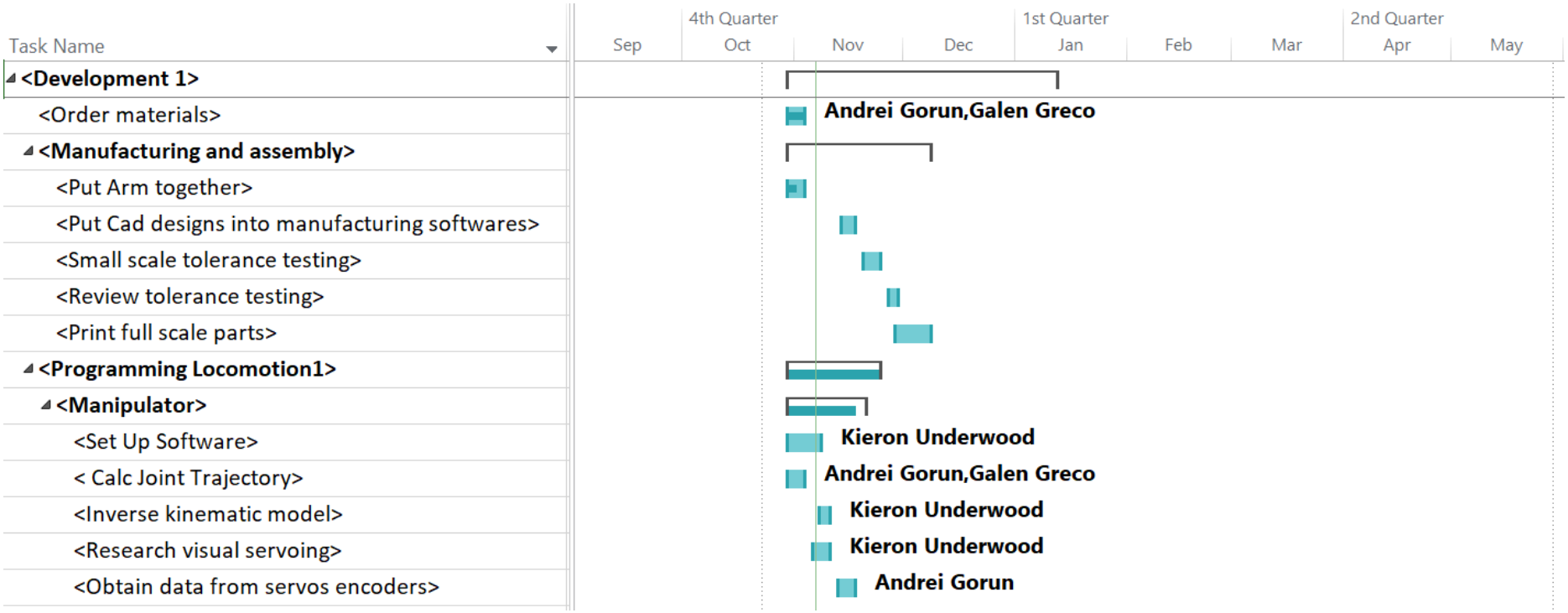
<Design Robots control system>
<Design electrical system>
<Pick sensors and motors for the robot>
<Calculate power consumption>
<Select appropriate power suply >
<Design circuitry>
<Draw circuit diagram>
<Design Software control
<Choose appropriate Opperating system>
<Create basic flow chart for software achetec
<Choose libaries for control>
<Review control system>
<Finalise BOM>
<Schedule tasks and Gantt chart genration>
<Design tests>
<Midway review>
<Final Write up and review>
Andrei Gorun,Galen Greco,Kieran Smith,Kieron Underwood
Andrei Gorun
Kieran Smith
Kieran Smith,Kieron Underwood
Kieron Underwood
Kieran Smith,Kieron Underwood
Group
Group
Aimee Walker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2nd Quarter
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Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
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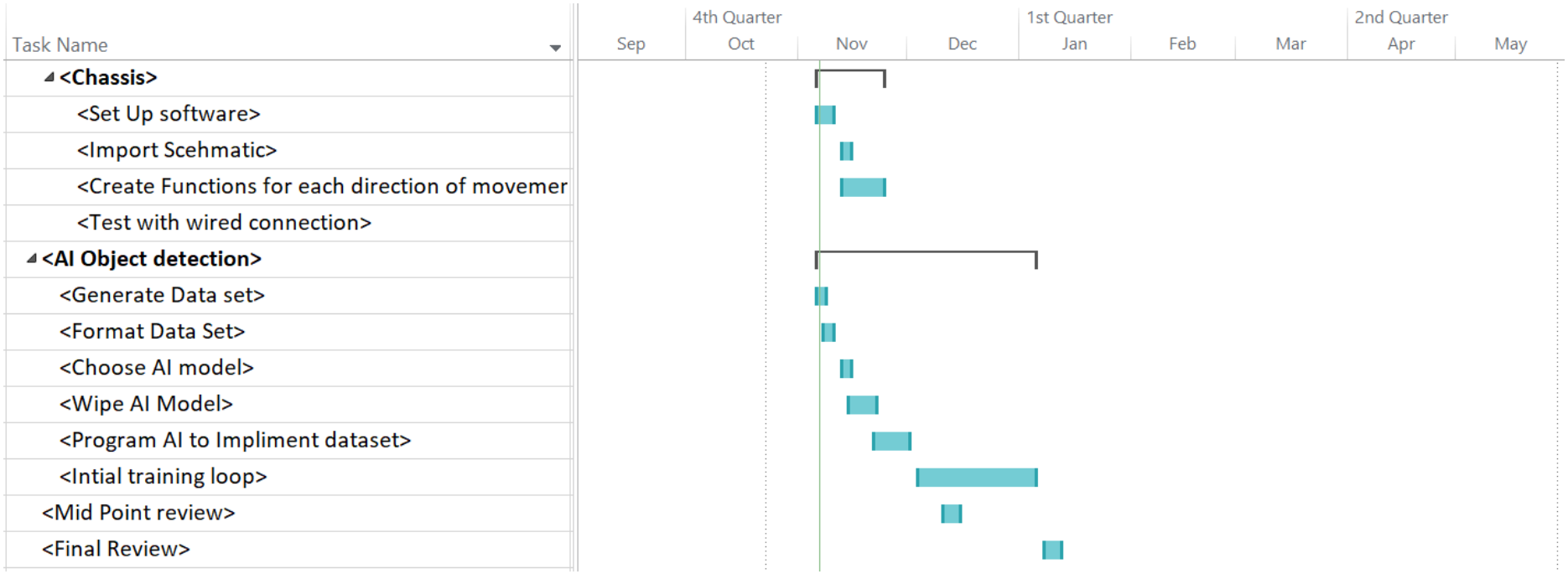
<Manufacturing and assembly>
<Put Arm together>
<Put Cad designs into manufacturing softwares>
<Small scale tolerance testing>
<Review tolerance testing>
<Print full scale parts>
<Programming Locomotion1>
<Manipulator>
<Set Up Software>
< Calc Joint Trajectory>
<Inverse kinematic model>
<Research visual servoing>
<Obtain data from servos encoders>
Andrei Gorun,Galen Greco
Kieron Underwood
Andrei Gorun,Galen Greco
Kieron Underwood
Kieron Underwood
Andrei Gorun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Sep
4th Quarter
Oct
Nov
Dec
1st Quarter
Jan
Feb
Mar
2nd Quarter
Apr
May
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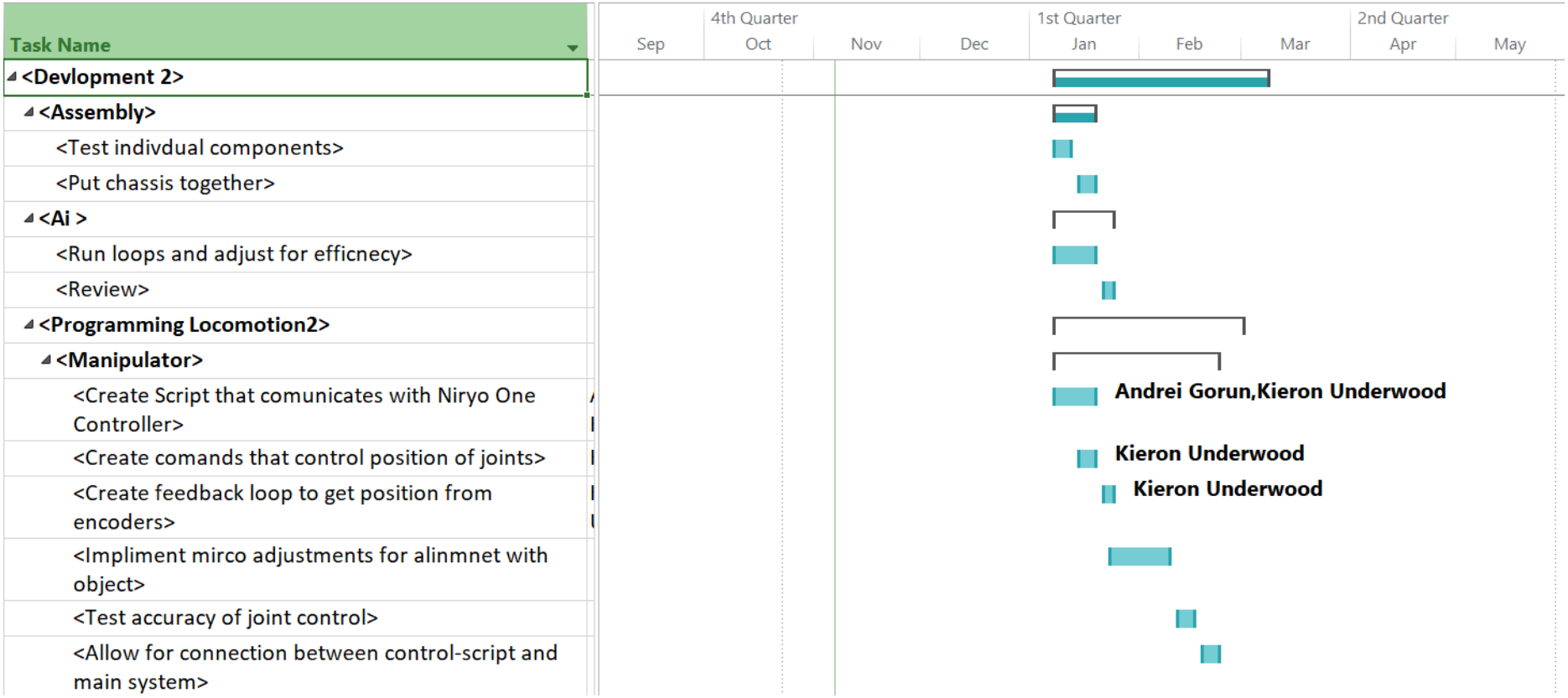
<Import Scehmatic>
<Create Functions for each direction of movemer
<Test with wired connection>
<AI Object detection>
<Generate Data set>
<Format Data Set>
<Choose AI model>
<Wipe AI Model>
<Program AI to Impliment dataset>
<Intial training loop>
<Mid Point review>
<Final Review>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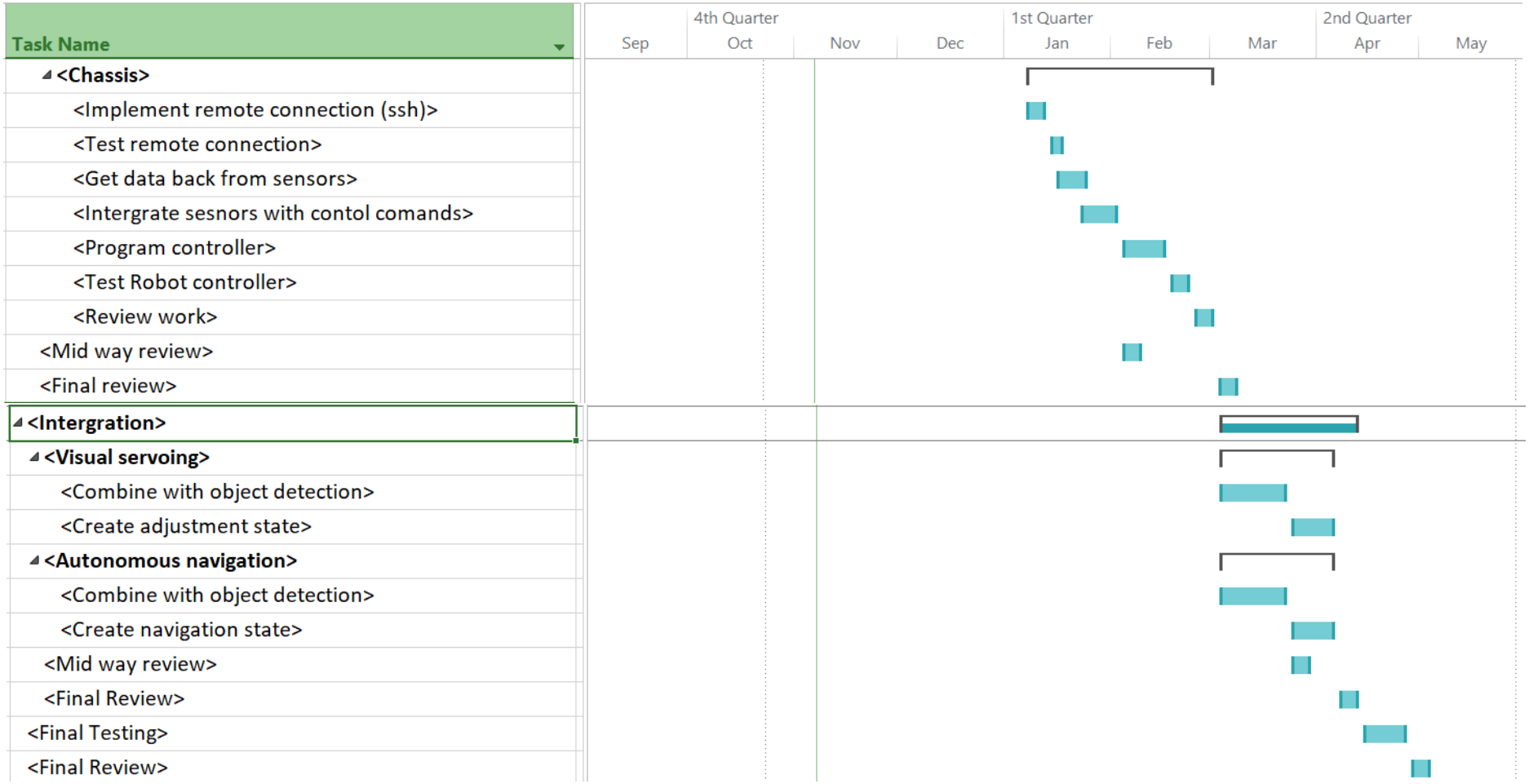
<Put chassis together>
<Ai >
<Run loops and adjust for efficnecy>
<Review>
<Programming Locomotion2>
<Manipulator>
<Create Script that comunicates with Niryo One Controller>
<Create comands that control position of joints>
<Create feedback loop to get position from encoders>
<Impliment mirco adjustments for alinmnet with object>
<Test accuracy of joint control>
<Allow for connection between control-script and main system>
4th Quarter
Sep
Oct
Nov
Dec
1st Quarter
Jan
Feb
Mar
2nd Quarter
Apr
May
Andrei Gorun,Kieron Underwood
Kieron Underwood
Kieron Underwood


Task Name
4th Quarter
1st Quarter
2nd Quarter
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
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<Test remote connection>
<Get data back from sensors>
<Intergrate sesnors with contol comands>
<Program controller>
<Test Robot controller>
<Review work>
<Mid way review>
<Final review>
<Intergration>
<Visual servoing>
<Combine with object detection>
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