Product: Pong Pickup Pro

Team: Ba11bot

Abstract

This project consists of an autonomous robot tasked with collecting ping pong balls and delivering them to the user when prompted. This system relies on a few separate functionalities. The robot must be able to map its environment accurately. This is so that the robot does not travel out of the intended area during collection, correctly locates the specified location near the user for delivery and to remain idle at a specific location under the table when collection is not prompted by the user. An accurate representation of the environment is required for these tasks to be completed successfully. Next, for collection of the balls to be successful, the robot needs to be able to recognise the balls with a low rate of error and successfully plan a path to the balls while avoiding obstacles if necessary. The robot uses a vacuum mechanism to collect the balls and stores them in a compartment attached to itself. After collection is completed, the robot travels to a specified location and returns the balls by raising the compartment up to a reasonable height for the user to collect. It then returns under the table, so as to not interrupt play, and waits for further instruction. This project aims to greatly reduce the trouble of manually picking up ping pong balls, especially for people with lack/loss of mobility, thus maximising playing time for all players.

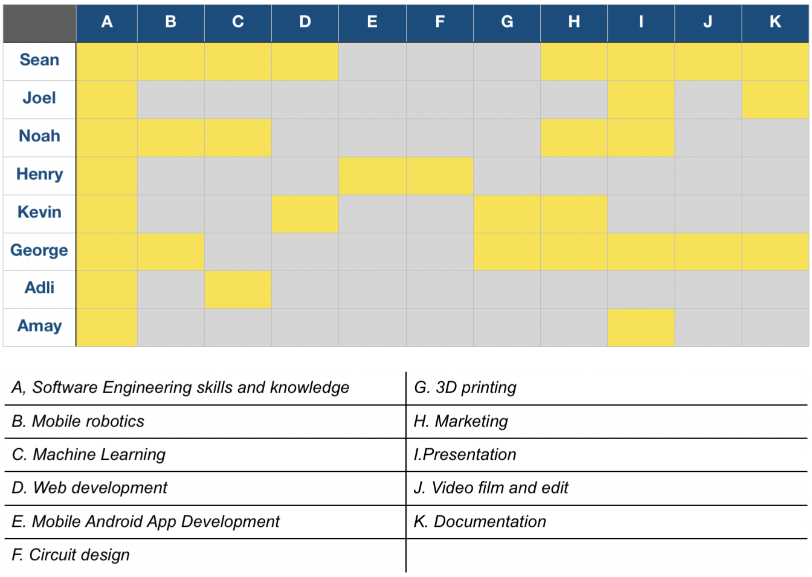
1. Pitch

While playing ping pong, depending on one's ability, a substantial amount of time might be spent tediously picking up ping pong balls off the ground. For example, when practicing a specific shot, players might fill up a basket with balls and practice until it runs out, they then must manually scour the space, bending down and picking up the balls one by one. This is an annoying task, even more so for people with decreased mobility. Take wheelchair users for example, we can imagine that it becomes an increasingly frustrating and time-consuming chore for these players to deal with, multiple times in every session. In an effort to reduce this, we have come up with an efficient, fully autonomous robot that collects and delivers the balls to the user. With this system, players can focus more on actually practicing/playing without worrying about picking up the balls as Pong-Pickup Pro solves all this for them. The Pong-Pickup Pro sits idle under the table so as to not interfere with the player's session and begins collection and delivery of the balls only when prompted by the user. When prompted, Pong Pickup Pro quickly scans the space, collects all the balls on the ground, stores them in a compartment and raises them up to a convenient level for easy collection. Instead of having to exert themselves when picking up all the balls off the ground, wheelchair users (and all other players) now simply have to press a button and wait for the balls to come to them, allowing a substantial amount of time and effort to be spent focused on playing the game.

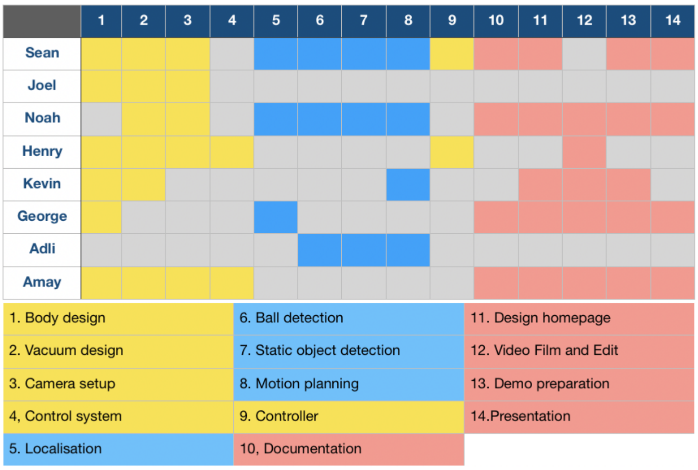
2. The Team

Our team members have very little hardware experience, but almost all members would like to take part in the hardware parts although the lack of experience would mean it will take more time to research, design, and make the robot work. Since Henry is the only person who has knowledge of circuit design and hardware from his courses, other members would need to learn and research hardware knowledge through individual studying. Furthermore, the Pong-Pickup Pro project cannot be carried out linearly because of the dependencies of each sub-task and the complexity of the task itself. This delegation, subsequently, might be the temporary plan, and we would expect that each part is organically intertwined. Thus, each sub-task would impact the others. The leaders of each part can communicate with that of the other part sharing about the current situation of their jobs. The leader also keeps their team members in the loop by avoiding the situation that a member can't catch up with the progress of the project. We know that all our plans and delegations would not work as we expect, but every member is aware of their roles and jobs by planning the project, hopefully helping our project as we aimed to.

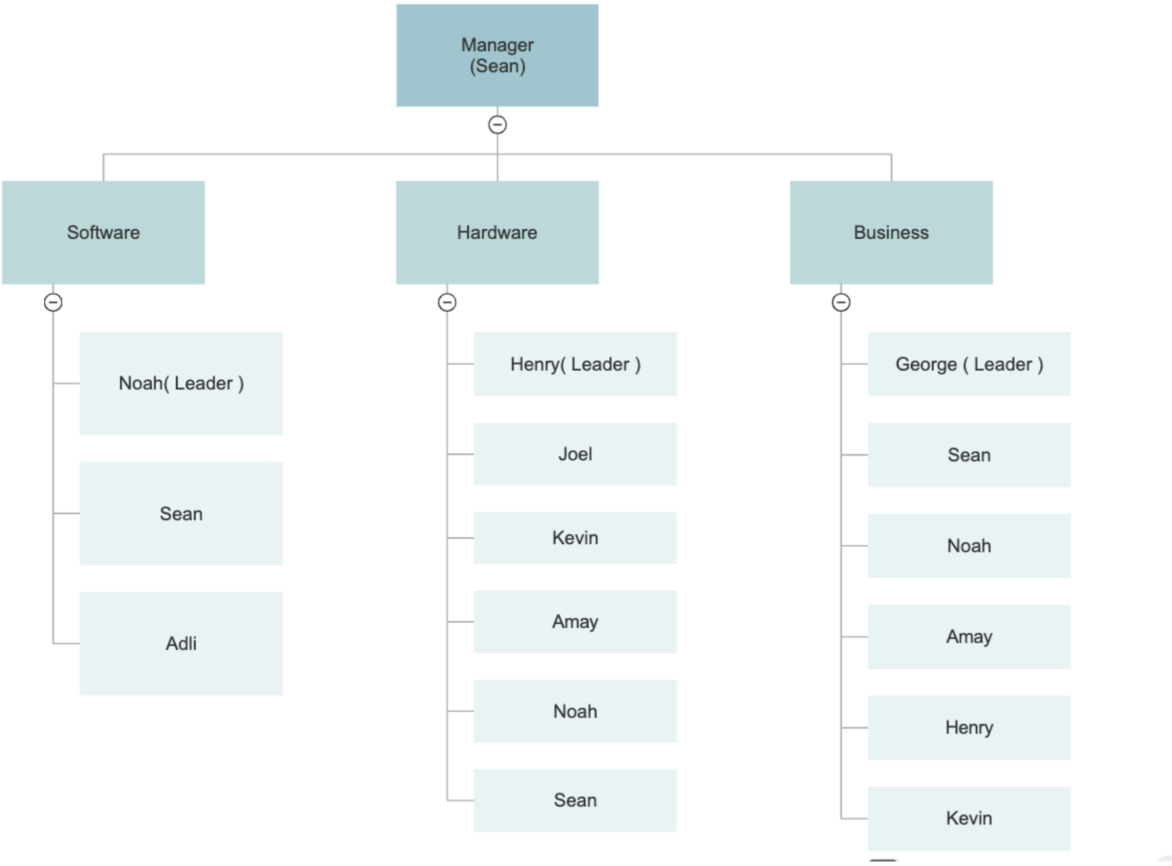
Our group has created a Discord server over which we communicate with each other, and we also intend to use the Jira agile project management software to allow us to keep track of the project deadlines. We will also utilise GitHub as a means of facilitating effective source code management and version control within our development process. Furthermore, we hope to improve accountability and transparency within the team by using Scrum ceremonies including Sprint Planning, Daily Scrum, Sprint Review, and Sprint Retrospective. We hope this will allow us to minimise inefficiencies through regular process updates, well defined and agreed upon goals, and opportunities for continual improvement. This will result in a more effective and streamlined development process. Some figures are shown on the next 2 pages outlying the team organisation, skill set and management structure.



(a) The skill set of our team



(b) Task delegation (yellow: hardware, blue: software, red: business)



(c) Team management structure

3. Users

The primary user of our system is table-tennis players who could be casually playing a game with their friends or families or who maybe train by themselves. For example, a member in our group plays table-tennis casually with their grand-mother and he often has to go and collect the table-tennis ball when it goes out of play because his grandmother is less mobile and struggles to bend and collect the ball. Our Pong Pickup Pro would be beneficial in this scenario as it would go and collect the ball for them while they are playing so our member wouldn't always have to go and fetch the ball so they can enjoy playing the game. Since the user may struggle to bend and collect the ball, we have to design our robot so that it provides the ball to a suitable height for the players. Moreover we have to ensure that the robot is not a trip hazard as the players are playing and they may not realise the robot in their way. This will be a high priority requirement and means we have to program the robot to stay under the table when idle. We also asked another member doing this course who also plays table-tennis regularly with a friend. He stated how he wished he had a robot like the one we are creating as he often plays with several balls and often has to spend several minutes collecting the balls after each game. Our robot would eliminate this problem by collecting the balls for him and saving him time which he could spend playing the game.

A secondary market for our product could be disabled ping pong players who would have trouble bending over to pick up the ball, we feel there is no real conflict between these two primary and secondary users as our product is intended to do the same task for both users, however it would primarily be a product of convenience for able bodied users and a product of great assistance for disabled users. The product will have to be reliable and be able to collect the ping pong balls from the floor in a timely fashion to ensure the best user experience, it will also have to be not too big in terms of size in order to not cause an inconvenience to the players. Whilst conducting research, we discovered that wheelchair sports are more popular than ever right now. Due to the benefits from the competitive and recreational aspects but also the rehabilitative rewards behind wheelchair sports, more wheelchair users are taking up sports.

Trends in wheelchair tennis have shown a rise from 50 people playing in 2011 per week to 500 people playing in 2015 per week and it is continuing to grow (Knittle, 2017). Whilst we could not find data specifically for wheelchair ping pong, we can assume the demand has been rising at a similar rate as well, especially since the rise in demand has also been noted in wheelchair basketball. This would mean our Pong Pickup Pro would be beneficial for a growing number of users who participate in wheelchair ping pong. Another user of our robot could be gymnasiums that offer ping pong as a sport. This robot would be beneficial for them as they could offer this robot as an additional cost optional service for their users. This would allow them to make monetary profit and ensure their customers are satisfied as they have a revolutionary robot that will collect their ping pong balls for them which many other gymnasiums may not offer. Furthermore, it will save staff time to perform other tasks rather than collecting stray ping pong balls that may have been left behind by previous users of the gymnasium.

4. Impact

The Pong Pickup Pro can be used in many settings, from recreational games to competitive training. The use of this technology has a wide range of social impacts such as improving the accessibility of ping pong, prevention of injuries, and supporting education and youth development. One main potential wider social impact of this technology is improving access to sports and physical activity. The utilisation of Pong Pickup Pro reduces the need of manually collecting ping pong balls and makes it easier for people of all ages and abilities to practise and play. A study shows that only a third of adults aged over 55 are meeting guidelines for minimal levels of regular physical activity and 44% are prevented from doing so due to injury or disability. Thus, our robot is especially beneficial for people with disabilities or young children and older adults who might find it more difficult to collect balls manually and consequently be put off the sport. Furthermore, ping pong is a physically demanding sport that can improve cardiovascular health, bone mineral content and muscle strength (A. et al., 2018). Physical activity is also heavily correlated to mental health, as noted by several studies (S.J. et al., 2019) (N. et al., 2020). Therefore, improving accessibility through the use of Pong Pickup Pro allows more people to reap both its physical and mental health benefits.

Another potential benefit is the prevention of injuries amongst active ping pong players or individuals with back problems. Lower back pain is associated with factors such as bending, twisting and lifting, and above 60% of all people have suffered from low back pain during their lives (GB., 1981). Furthermore, a study found that 50% of high level ping pong athletes reveal lower back pain at least once a week (SWÄRD et al., 1990), and a survey showed that in sports like tennis, lower back pain has caused 38% of players to lose at least one week of participation (Marks et al., 1988). The utilisation of the Pong Pickup Pro removes the need for athletes to constantly bend over to collect balls, thus reducing strain on their lower backs, lowering the risks of injury, and improving safety of the sport.

The ping pong ball collector robot could also be used in an educational setting such as schools, local communities, and sports centres where there may be a lack of staff. In these settings, the robot will allow teachers and coaches to focus on developing important skills of the students, including coordination and focus, rather than spending time doing tedious ball collecting tasks. Sports events run by these organisations will also benefit, as our robot will allow ping pong programs to be managed easier, with higher efficiency.

Lastly, this technology could also be adapted to assist in other racket sports such as tennis and badminton. These sports are also greatly popular, as shown by their inclusion in the Paralympics. They also provide great physical and mental health benefits and involve potential back strain when retrieving the ball or shuttle, which can be prevented by the use of our robot.

5. Outcomes

Having outlined our primarily targeted user to be someone who plays Ping Pong, we have to start by admitting that this is a very wide ranging definition. This can differ from the one-off casual player, to those who like to regularly play at a leisure centre and to others who play it professionally at sports events like the Olympics. Even amongst these categories huge variations of play can occur. The casual player, not being overly fussed with knowing the exact rules to classic Ping Pong may be content with making their own adaptations. Indeed, this can be observed frequently within drinking culture games with the inconsistency of rules such as for beer pong. The different budgets and space constraints at leisure centres lead to variable sizes in tables, multiple matches per space and different playing styles such as doubles competition or others playing alone against a wall for training. At the highest level, we have serve speeds of up to 54 km/h (C., 2022) and short rally times, 4 - 5 strokes per rally on average with approximately 2 strokes per second (E., 2018). Differing rules and standards at Ping Pong championships add additional complexity to catering for the pro market. All the aforementioned creates stark differences between the environments that our robot could operate in (for example the ball would be wet in beer pong) and the ways it could best cater to its users needs. Another aspect mentioned in our users analysis relates to our desire to design our robot to enable further inclusion of people with disabilities within the Ping Pong community. With this all considered, we have taken the approach of focusing on a scaled down environment and sticking to a set of agreed upon rules and standards that we will set out and justify the reasoning for below.

Before prioritising specific user needs to cater to, we have researched characteristics of the game, that are relevant to our project, that match between different markets of Ping Pong to use as standards. As references we have used the International ping pong Federation (ITTF) and Paralympic's guide, both of which are large and important sports bodies within their respective ping pong divisions. Of key importance to us, as the core functionality of the robot is its ability to retrieve the ball and therefore when to do so, is defining when the ball is 'out of play'. According to our references, from casual to pro play and in all divisions of Paralympic table tennis, the rules for this are the same. (Federation, 2022) (Committee, 2021) Therefore, we have decided that the robot should detect any ball that falls to the ground to be retrieved. We ignore other ways the ball could go out of play such as double bounce on the table due to the robots designed limitations (not going onto the table), this does mean that players are left responsible for balls out of play on the table. This detection should be done using computer vision and object detection. Again we have used the standard definitions of the ball given by the ITTF. In terms of the environment, the regulations for the size of the court and table dimensions are the same, this extends to the flat level of the surfaces, freedom from obstructions and the bright/even lighting conditions. For these reasons, we will start with the same assumptions for our test environment where possible.

In terms of the other functionality of our robot, they have been prioritised as follows. After detecting the ball the robot should navigate toward it by mapping out its environment and by tracking the ball if it moves. LiDAR could be used for mapping and avoiding obstacles, which in its current state should only be the human beings and any extension of themselves and the table. A digital stereo camera could be used for object detection and depth estimation. A successful operation of this feature would be that the robot is able to perceive when the ball has fallen below the table to the ground at any point in the space within a low amount of ball bounces and estimate where in 3d space relative to it the ball currently is. With this estimation, it will move toward the ball while avoiding obstacles and periodically update its estimation of the ball's whereabouts and hence its own trajectory. When considering our user base, the time frame within such a feat should be achieved varies. We will begin with a higher time window before attempting to reduce it. The next goal is for the ball to be suctioned up by the robot using its vacuum functionality. The success of this is measured by whether the ball is held after one attempt to suction it. If our robot fails to do this consistently we would include a sensor (potentially a weight scale) to detect if it has succeeded with the intention of trying again if not. Lastly from our core functionality, the robot would have to steer itself back to a position near one of the players to allow for a return again while avoiding obstacles and maintaining awareness of its position in space. Again, the entire process would be expected to be conducted within a set time frame to be considered viable and beneficial.

Although we already believe such a robot would be very marketable, beneficial and allow for a more diverse range of players to feel included when playing Ping Pong, the next functions we will propose would develop this further. We hope to add a system where the robot would return the ball in a more accessible way than just bringing it to the feet of the player or only at the end of the match like other robots on the market for tennis balls who do not employ a vacuum mechanism (out, 2023). This same vacuum would be reversed to be used as a fan and propel the light ping pong ball upwards through a separate opening. At this point, depending on our tests, the ball would either be thrust onto the table or hover over a horizontal opening as can be done with a hairdryer

(Headquarters, 2021). We will measure its success on its consistency/accuracy with multiple different players with differing needs to ensure it is beneficial to those with disabilities and not an extra burden. If we can meet the goals set out above in the 'standardised' environment we would look to replicate the functionalities in a more home-like setting with more variability in the obstacles and dimensions of the space and table. Moreover we would like to make it function in a practice mode for one player. All of these would increase the products marketability while assisting a greater number of people.

Overall the bot should allow ALL players to focus on their game play and remove the burden upon them to locate, retrieve and pick up the ball to provide a more enjoyable playing experience than having someone going to pick up the ball themselves. All the while, it should be competitively priced, its battery should last the whole game and its materials of good quality so as to last a reasonable duration of time after purchase.

6. Tasks

A quite simple separation of the tasks would be into software and hardware. The software team could be designing the user interactions with our robot whilst the hardware team is developing the actual movement of the robot. The hardware team can be further separated into the section of the robot that deals with the collection of the ball. For example, we are planning to use a vacuum to collect the ping pong balls and one part of the hardware team can be dealing with this area whilst the other half deals with the movement of the robot and obstacle detection. The software team can be divided into a group that deals with the detection of the ball going off the table and another group that deals with the software behind the robot. This may interlink with the hardware team who is controlling the robot and performing obstacle detection and hence these two teams may need to work together to produce a functional robot. We split the team into half and assigned half of the team to work on the software and half of the team to work on the hardware and this depended on the interests of each member and their experience. For example, some members had experience with hardware in electronic engineering courses and preferred to be on the hardware team.

For the hardware part, as mentioned earlier, one of the service objects of our robot is the disabled or the elderly with limited mobility. They may be physically unable to bend over to pick up a dropped ball or may be slow to move. Therefore, we think that the core requirement of such people when playing ping pong is to have a mobile robot that can help them collect ping pong balls at any time and return them to the player after collection. It will include three core elements, namely the collection part, the delivery part, and the mobile part. For the collection part, we use a vacuum machine driven by a powerful fan, which can suck ping pong balls into the body like a vacuum cleaner. Compared with traditional machine design, we think it is more efficient and easier to maintain. The transfer part is completed by the mechanical part of a lift structure. We hope that after collecting all the ping pong balls, our robot can raise itself to reach an adult's thigh position. Our players can take the collected ping pong balls without bending over. The final moving part consists of a susceptible 4-wheel-drive car that does a good job of detecting objects and moving towards them, as well as avoiding obstacles including the player.

For the software part, we used a Raspberry Pi as the master control. It controls the power on/off switch for every part of the robot, and a camera to detect ping pong balls, static objects like ping pong tables, and dynamic objects like players. Pong-Pickup Pro at a software level starts with localisation and object detection. Localisation refers to the process of determining where a robot is located and constructing a map of an unknown environment around a robot. In our case, the unknown environment might be a table tennis court. This court would follow the official table tennis court size according to ITTF as we refer to above, so this size of each individual court ideally would be similar although our bot locally constructs a map of the entire court.

Furthermore, object detection means that the robot will analyse whether there is a ping pong ball within the range of the camera and if so, it will calculate the corresponding orientation based on its own position. Our bot would face a variety of unpredictable situations when detecting objects in a real-case scenario. The Pong-Pickup Pro is meant to detect ping pong balls, static objects like tables, and dynamic objects like players. Additionally, there is likely to be a piece of trash or obstacles like boxes on the court ground. Obstacle avoidance works with the camera and the sensors on the robot. When the robot is moving, it will intelligently avoid obstacles that are impassable or approachable. In our test environment, we expect to first focus on improving well-performed basic functionalities, so that our test would be carried out under a controlled environment where it is clean and there are no obstacles. Hopefully, our team expects to add more functions related to dealing with the unpredictable environment if our time deadline is allowed.

The Pong Pickup Pro, subsequently, can do motion planning with the map, its position within the map and the position information of the objects detected. Motion planning can be divided into three stages; mission planner, behaviour planner, and local planner. Those three stages are linearly connected, so we finally get the planned trajectory after three stages are sequentially complete. In motion planning, the robot will find the closest route to the target according to whether there are obstacles in front of the camera view. Our team would expect to use A* algorithm when finding the shortest path. Afterward, a robot that has the planned route needs to control velocity and steering before actuation. Finally, the Pong Pickup Pro can be operated after object detection, localisation, motion planning, and setting controller. (Lu, 2022).

SDP	start	end	0h	10%
Idea generation(16 Jan - 20 Jan)	**01/16/23**	**01/20/23**	**0h**	**100%**
brain storm	01/16	01/17	0	100%
Idea discussion	01/18	01/20	0	100%
pitching session	01/20	01/20	0	100%
pitching pdf completition	01/20	01/20	0	100%
Project Plan(23 Jan - 27 Jan)	**01/23/23**	**01/27/23**	**0h**	**100%**
final idea decision	01/23	01/23	0	100%
prototype design	01/24	01/25	0	100%
report revision	01/26	01/26	0	100%
Plan report submitted	01/27	01/27	0	100%
Mid course demo & report(30 Jan -...	**01/30/23**	**02/17/23**	**0h**	**0%**
mobile design	01/30	02/03	0	0%
body design	02/06	02/10	0	0%
vaccum design	02/13	02/17	0	0%
report revision	02/16	02/16	0	0%
mid course demo	02/15	02/15	0	0%
report submitted	02/17	02/17	0	0%
Peer demo & poster design(20 Feb ...	**02/20/23**	**03/22/23**	**0h**	**0%**
assembling robot	02/20	03/03	0	0%
camera setup	03/06	03/10	0	0%
object detection & avoid obstacles	03/06	03/17	0	0%
localising	03/06	03/17	0	0%
motion planning	03/06	03/17	0	0%
controller	03/06	03/17	0	0%
actuation	03/06	03/17	0	0%
poster design	03/21	03/22	0	0%
peer demo	03/15	03/15	0	0%
poster submitted	03/22	03/22	0	0%
Final demo & report(23 Feb - 31 F...	**03/20/23**	**03/31/23**	**0h**	**0%**
final testing	03/20	03/24	0	0%
final report	03/23	03/31	0	0%
final demo	03/29	03/29	0	0%
final report submitted	03/31	03/31	0	0%
Industry day(3 Mar - 5 Mar)	**04/03/23**	**04/05/23**	**0h**	**0%**
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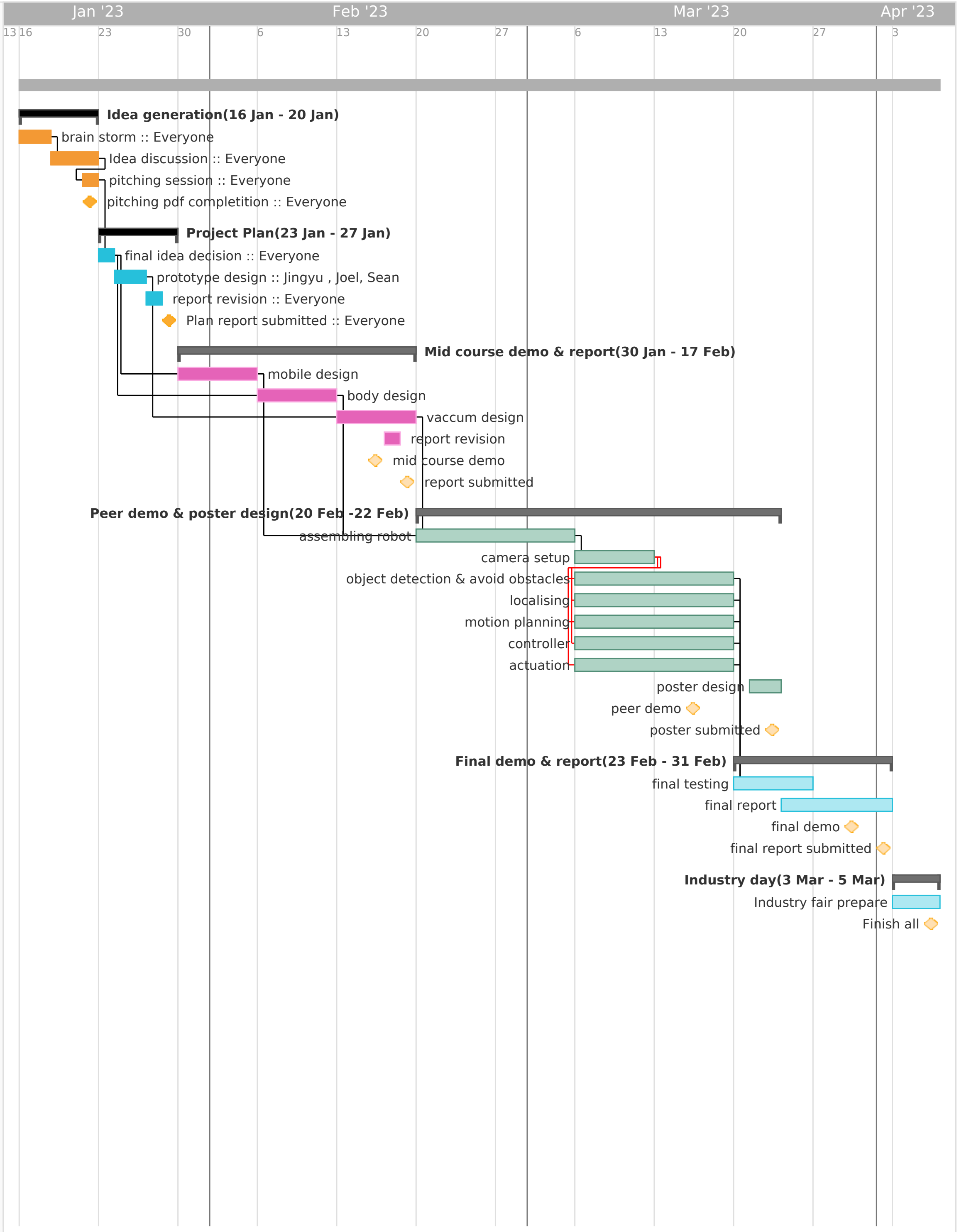
Finish all	04/05	04/05	0	0%



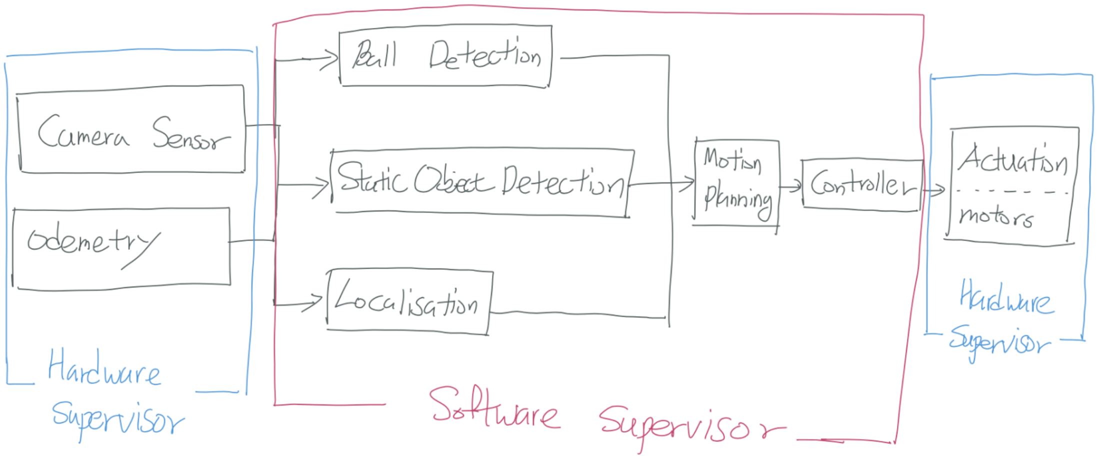


Figure 1. System Block Diagram (Lu, 2022)

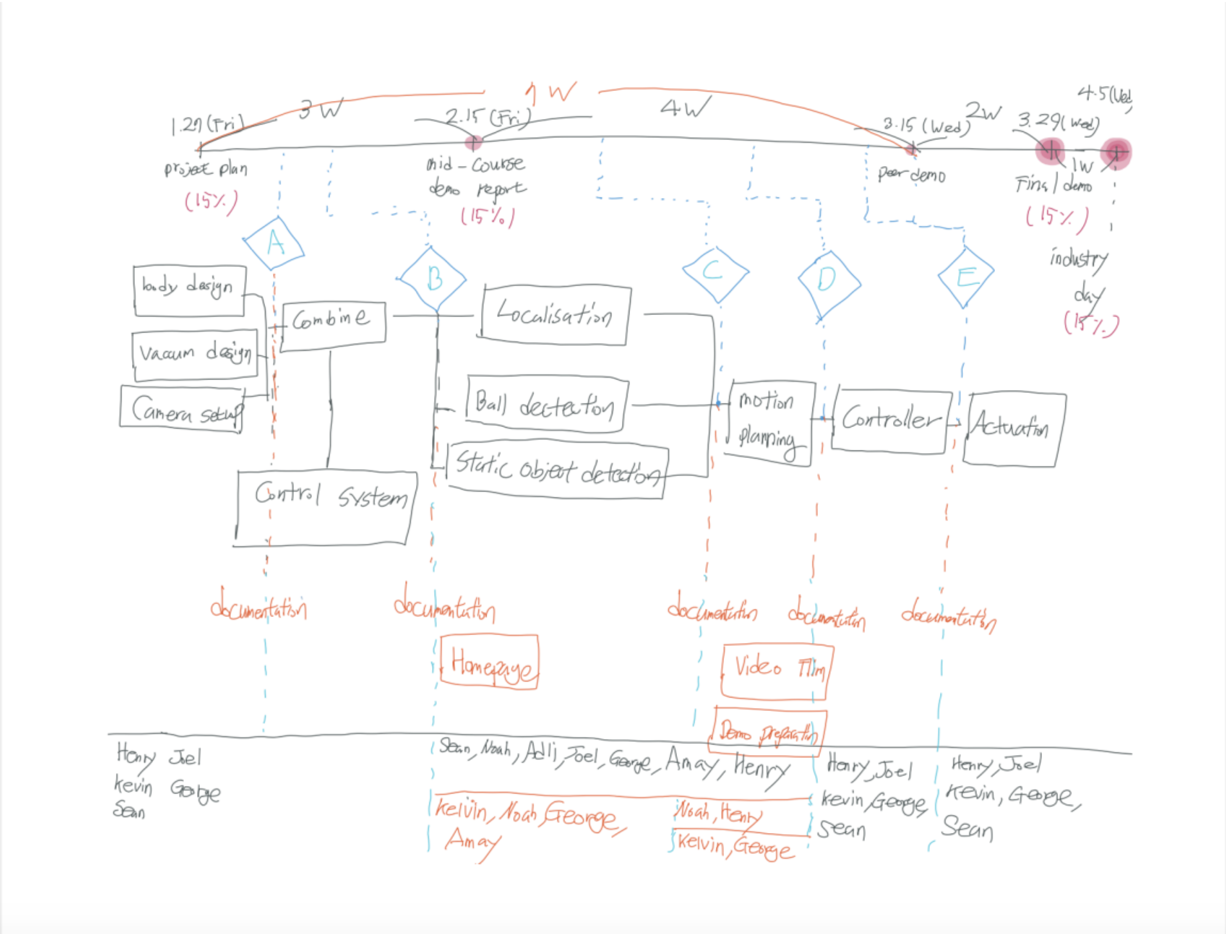


Figure 2. Blueprint of our project

7. Risks

One major risk we are taking in our project is to implement the vacuum feature on our robot in order to collect the ping pong balls. We are deciding to take this risk for the sake of making our product unique. We believe a vacuum suction device will be more time efficient for the user and it makes our product stand out from the rest. However, making a vacuum function from scratch is an incredibly complicated feat to undertake, and therefore why it is our number one risk. It is highly likely that something may break with this part of the robot, especially the fan. This document (Benson et al., 1989) mentions that if proper upkeep of the fan within our vacuum is not maintained then power will be reduced and the effectiveness of our product will be set back. If this part breaks then our robot will not function at all and deliver its intended end use case. To reduce the risk, we have made backup designs to incorporate an arm feature that scoops up the balls into a bucket for the case if the vacuum feature were to fail.

A small further risk to the vacuum is, vacuums suck whatever is in its path and not just ping pong balls. Obviously, this is not ideal, especially if this is either an expensive item or a sentimental item to a young child. We will need to carefully develop our vacuum to sort items and have a way to get these items back out of the vacuum storage.

A risk in our project is that we may not be able to develop the technology in order to use computer vision to detect what is a ping pong ball and what is not a ping pong ball. Therefore it will be hard to collect the balls from the floor if the robot cannot detect where they are. We believe this risk is very unlikely as we know this kind of technology is possible to create and has been created before. However, the impact of this risk becoming a reality would be detrimental to our project. The robot could still work by systematically sweeping a whole area and hoping the vacuum will suck up any ping pong balls within the close vicinity. If this is the case we would have to change our product slightly to fit accordingly with this change.

Our robot will be using a battery of some sort in order to power all of the cameras, sensors, vacuum, collection container lifting system, etc… and obviously, batteries are prone to danger. Batteries can contain lead, sulphuric acid and cadmium and all of these are dangerous to human life if handled incorrectly (Battery-University, 2023). If batteries fail on our project then we will need to act in a safe way according to guidelines to handle and dispose of the infected materials.

Our robot is planning to use several sensors in order to map the area and detect objects, including where the ping pong balls are. These sensors are very important to the robot and failure to these will mean our robot cannot function at all. This is a risk we will try to eradicate by using good quality sensors and testing them regularly to maintain them to ensure our robot is not essentially blind, as this would create all sorts of extra risks as one would be able to imagine.

Furthermore, during our SDP project we will have some limitations on where we can test our robot, and this means we will not have access to a realistic, lived-in room. So our robot will only ever be tested in a safe, predictable environment. If our product is to be used in another setting, it will be more likely to crash and damage furnishings and potentially induce further injuries to human life.

When making our project, we are constantly researching everything, however some things are researchable, or the only research available is outdated. Depending on what the research is in correspondence to, the risks could be of varying sizes. We will always try to ask experts or look for further research before doing a task that could be dangerous. This is the only way to minimise this risk, it can never be fully avoided.

Some safety risks that could be of potential harm when using our product is that the robot could manoeuvre itself into dangerous situations with pets or young children. Children can get seriously hurt through vacuums, as found out by Jade Bishop (S., 2017). We will add a very clear safety instruction to not let unsupervised young children/pets near our robot. Additionally, we will need to add a kill switch for it to stop when these instances occur.

Another safety issue of use is that our robot could be a trip hazard. When playing ping pong, often the player would not look to the floor to check there are no trip hazards before attempting to return the ping pong ball to keep the rally alive. And if our robot is not in the same place every time, this could lead to the player potentially tripping on our robot. To eliminate this risk as much as possible, we can make a feature for the robot to go back to its home/safe space whilst play is active. This will most likely be under the table in the centre of the room.

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