Product: Pong Pickup Pro

Team: Ba11bot

Abstract

The intended functionality of our robot is to detect ping pong balls that have gone out of play and then move towards them so as to retrieve them via its vacuum suction mechanism and finally bring the ball back to the user, delivered to waist height, using a hover fan mechanism, for easy pickup by the user.

In the final demo, we showcased our progress with the robot's detection capabilities and demonstrated that it could now autonomously drive towards and track the balls on the ground and once near, vacuum them up reliably into its storage container. After this, the robot would either drive towards another ball within its field of view or turn on the spot in order to locate another ball for pickup.

Separately, we displayed the hover return feature but could not do this in tandem with its other functionalities due to technical issues with providing a unified power supply. All this with a more appealing design to allow for the sale of the product.

1. Project management update

1. This section lists our partially achieved and not achieved goals.

   - Core functionality tests and mechanisms reliability assurance (Partly Achieved)
   - Successful ball return and internal journey: from floor to waist height (Partly Achieved)
   - The robot should be able to detect obstacles around it and avoid them (Partly Achieved)
   - Achieve fast robot movement to allow for quick retrieval times (Partly Achieved)
   - Improve the look and marketability of the robot and hide electrical wiring and components (Partly Achieved)
   - Provide a unified power supply (Not Achieved)
   - Implement vehicle localisation and path planning (Not Achieved)

2. Core overall robot functionality testing was sidelined due to the individual parts working successfully but issues with unifying them proved to be much more challenging than anticipated. This was mainly due to difficulties unifying the power supply. So attention was placed on the ball collection process at the demo with its own dedicated power as collection is the first part of the outlined robot's requirements and this could be realised easily alongside the effective detection model. The power issues extended to the problems facing the ball's intended internal journey within the robot as several different components had to work in unison to move it up as desired to a reachable height. The decision was taken to therefore focus on powering the return fan manually as a proof of concept of the hardware's functionality as it is one of the unique selling points. Due to time constraints caused by the aforementioned, the sub-team focusing on the use of LiDAR decided to dedicate their time to other problems. This decision was taken because of the LiDAR's relative complexity and being of lower importance to the minimum viable product. In light of this, a satisfactory movement speed was achieved even after unexpected additional weight was introduced onto the robot, however, this still should be improved upon to meet certain of the target users' needs (professional players). Finally, despite having made a provisional space for where to hide the electrical components, out of the users' sight, this plan could not be followed through, again due to simulated electrical designs not working in practice. Regardless, between the 2 demos the appearance of the robot improved greatly and once a power solution is found sufficient preparations have been made to implement various possible configurations that can be hidden.

3. Our team employed many methods to ensure that we were highly organised and structured in our approach to achieving our goals.

   We recognised the importance of dividing large tasks into smaller more manageable sub-tasks with clear objectives. In doing so, we formed three specialised subgroups: robot movement, retrieval mechanism and object detection. Each subgroup was formed based on the skills and interests of our group members. By matching individuals with the most appropriate skills and interests to each task, we hoped the team could achieve better results and complete the task in a more efficient and timely manner.

   However, due to the complexities of our system, we had to work on different aspects of the robot in parallel to allow for efficient development. This meant each subgroup had to be flexible in their approaches to allow for smooth and continuous integration between subteams. For example, the robot movement team had to ensure a certain degree of accuracy that the robot could move to, so that when integrated with the retrieval team's mechanism, the whole system could be fine tuned to collect ping pong balls accurately. Likewise, the retrieval team had to make adjustments to their design such as enlarging the opening of their suction tube to allow for varying degrees of error in robot movement.

To facilitate efficient and continuous contact between teams, we made use of online messaging platforms such as Discord and WhatsApp. This allowed updates and information to be shared quickly and requirements for common goals to be addressed. We also made use of regular in person meetings. The whole team would meet with our mentor every Wednesday to update everyone on their progress and seek assistance if needed. Prior to the meeting, each group adds to the meeting agenda the topics they wish to discuss. During the meeting, we address these issues and take notes to keep track of our progress. Additionally, we review our progress since the last meeting to identify areas for improvement and plan for upcoming tasks. This meeting fosters an inclusive decision-making process that involves all team members. In addition to our main meeting, each subgroup also had at least two meetings a week to collaborate on their tasks and responsibilities. Team members were able to work more closely together, better delegate tasks and contribute their specific skills.

The tools we used to manage the development of our system include Jira and GitHub. Specifically, we used Jira to plan and keep track of progress, ensuring each member completed their tasks on time or gets help if needed. Jira also served as a platform for documentation, it allowed us to track our development timeline and provided a reference point for future use. We used GitHub for code development management. To ensure smooth integration and that our codebase was robust and reliable, at least one other member of the team would review code changes before it was merged into the main branch. This process not only allowed us to catch and resolve issues, but it also provided a learning opportunity for our members, as we were able to share coding knowledge. Lastly, GitHub also provided a means for testing and version control. This helped identify errors earlier and if there were any unexpected problems, we could revert back to a previous version if needed.

4. An overview of the task allocation for the project is summarised in the table on the next page.

Task	Status	Time (Hours per Person)
Project management (Sean)		
Manager note to remind sub goals and deadline	Completed	15
Scheduling	Completed	2
Research for designing projects	Completed	15
Robot movement (Joel, Adli, Sean, Henry)		
Robot base platform design and print	Completed	5
Build communication system with socket	Completed	5
Autonomous movement testing with detection model	Completed	30
Autonomous movement testing with detection model and suction function	Completed	55
Retrieval (Noah, Kevin, George)		
Protyping, research and evaluation of retrieval mechanism; hovering vs scissor lift (Decision: Hovering Mechanism)	Completed	42
Research and design of retrieval, container, and return mechanism	Completed	38
Testing A • how retriever, container, and return mechanism coordinate between each other while considering alternative designs. Their respective benefits especially with regards to power supply and circuit design. • Due to the complexity of designing circuit, couldn't proper test it	Completed	8
Testing B • Suction functionality testing	Completed	4
Circuit design and implementation • the complexity of designing a single circuit for 12V fan, 24V fan and 4 motors	Completed	43
Object detection (Sean, Adli, Henry)		
Research detection models	Completed	10
Jetson Nano setup	Completed	10
Activate GPU on the Jetson Nano	Completed	10
Decision of which cameras use and camera setup	Completed	3
Detection model programme development and improvement • Decided to use the Jetson Nano, achieving 5 FPS from 0.3 FPS	Completed	20
Trained model • Trained with 10,000 orange pingpong ball images	Completed	6
Detection model coding and maintenance	Completed	5
Implementation of using Raspberry camera • Find alternative wide angle camera having 88 degree of the field of view from 55 degree	Cancelled	5
Localisation & Obstacle Avoidance (Sean, Henry)		
Setup Lidar	Completed	5
Research	Completed	5
Obstacle avoidance coding	Completed	3
Testing	Completed	3
Marketing(Noah, George, Amay)		
Presentation	Completed	20
Market research	Completed	5
Logo design	Completed	3
Survey(Amay)		
Survey form design and distribution	Completed	2
Total Time		
387 Hours		

5. Our team aimed to make efficient use of our allocated budget in order to achieve our goals. We did this by comparing and contrasting the pros and cons of different options we could take in our purchase decisions, for example the cost-benefit analysis of using a more expensive but also more robust 3D printed material, in order to minimise costs while maximising results. Technician time was also made use of, we discussed which members of our group were free at which time in order to build up a timetable of when we could use our allocated technician time in order to resolve any technical problems we were having.

   The value of the materials we bought using our £300 budget are as follows

   - Raspberry Pi 3 Camera: £49.20
   - Jetson Nano Cooling Fan (EP-0113): £25.10
   - Suction Fan (ARX CeraDyna Series 12V DC fan): £27
   - LiDAR (RPLiDAR A1M8): £112.80
   - 3D printed material: £29
   - Laser Cutting: £10

   So overall we spent £253.10 out of our £300 budget.

   We used 8 hours of technician time. This included 2 hours for 3D printing, 4 hours for circuit design queries and 2 hours for general questions.

6. Overall, our project has gone relatively well, though there were areas we could have improved on. Our first strong point in this project was that we were able to use the cheaper Junior Runt Rover robot as our base rather than the TurtleBot Waffle which many other groups were using and this allowed us to pitch our robot at a much lower price of £649 which is almost 50% less than the TurtleBot Waffle that costs £1275.80. Moreover, this allowed us to have more control over the overall physical design of the robot which was necessary considering that most of its functionality required flexibility in the design process. This is because extensive research was needed for most of the deliverables before their implementations and therefore that the final design could not be finalised until much later in the process. In hindsight, this was the correct approach as even with this flexibility we faced many adverse challenges that indicated that our design was still slightly too rigid for the development of such distinctive processes.

   The intricacies of our project made it challenging. For example, we struggled initially to find a fan that was powerful enough and we had to alter our suction tube various times to maximise the suction pressure, we overcame these to create our unique robot. Furthermore, the return mechanism that we had designed was a fan that would blow balls back and hover at waist height for the player to collect. This is a novel alternative to other simpler methods such as a scissor lift mechanism that we had previously considered. Although we couldn't demonstrate this fully in the demo, we have since solved its shortcomings and so managed to successfully implement it.

   Another thing that went well with our project was that our detection model was able to detect ping-pong balls fairly accurately. During testing, our model successfully detected a ball 3m away from the camera source with a confidence of 59%. This is good, especially since the length of a table-tennis table is only 2.7m allowing the robot to detect balls further than its length. Furthermore, our model can still be improved with further training to detect balls at greater distances and with a higher resolution camera, something that is not possible with the time and budget of this SDP course.

   A key factor that lead to the level of success achieved by our team was our ability to research and justify the choices made in the development process to each other and in thus in the final demo. Although this was time consuming, it lead to a deeper understanding of what we working on and decreased the complexity of the problems we faced. This is evidenced by the way we designed the return process of the ball, both options were considered (scissor lift and hover fan) and understood intricately by different team members and so their pros and cons could be analysed fully. Even once one option is chosen, the acquired knowledge (in this case of aerodynamics) greatly assisted in speeding up the further development of that option.

   One thing that went wrong with our project was that due to the high computational requirements of our detection algorithm, we had to use another NVIDIA Jetson Nano to perform the machine learning tasks and send the location of the ball, relative to the camera, to our Raspberry Pi. However, initially, we could not utilise the GPU of the Nano and maximise the performance from it and we were averaging approximately 1fps, though we eventually figured out how to utilise the GPU and increase it to 5fps. This still resulted in some latency and hence the Pi occasionally received the previous response as to where the ball was. In order to improve, we could have used a better device such as a Raspberry Pi 4 that has a more capable CPU and processing performance or we could have switched to another detection algorithm such as OpenCV rather than Yolov5.

   Another significant issue that we faced was managing the power supply of the electrical components. After having identified our targeted users, we hoped to provide them with a unified battery to ease the recharging of the robot as examined when outlining our users' use cases. Notable preparation was made to devise preliminary circuits: where the components would go, weight distribution, accessibility for wiring, understanding of motor boards requirement/limitations and voltage/current needs. Moreover, once closer to having a more finish product, we simulated 4 different designs of electrical circuits online using Falstad. This was to get a circuit where components could be controlled independently from the Pi while operating at the desired voltage and current ensuring they run safely and reliably. Despite this, when done practically this did not occur. In future, we would seek help from an electrical expert sooner and not rely on online simulations as such a guarantee of correctness. Finally, testing physically earlier would have allowed us to order the needed parts to solve these issues that were not at our disposal from the technicians lab.

2. Quantitative analysis and testing

Retrieval

The success rate for hover action is 100% The user can pick the ball from the hover 100% of the time. The suction tube can suck balls from 7cm. The hover fan hovers the ball at at total height of 80 cm. The container can hold 24 balls.

Detection

In our previous model, we used YOLOv5s on 837 images and achieved 99.1% mean average precision, 98.7% precision and 95.8% recall. To improve our last model, roughly 7000 new images were added for training, and we prepared a validation set containing 1252 images. Despite a slight decrease in the results when compared to our previous model, we found that our current model performs better for our specific use-case mainly due to the increase in range.
New model results:

mAP	Precision	Recall
98.1%	96.7%	93.8%

This decrease in performance might be due to the test/validation set of the previous model containing ping-pong balls from a closer range compared to the newly added images. The above metrics do still indicate that our model works well. However, when we tested in real conditions, we found that our robot was rather inconsistent with its detection. We decided to test our robot further by directly running the detection model in real-time on the actual camera of our robot and placing the objects to be detected under different conditions. Test 1: Confidence of ping-pong classification for certain distances. We tested various distances, angles, and lighting conditions to get the average confidence of detection. We sampled each category with 20 different orientations.

Lighting Condition	Distance (m)	Avg Confidence
1	1	97%
1	3	53%
1	5	24%
2	1	94%
2	3	48%
2	5	15%
3	1	62%
3	3	15%
3	5	0%

*Lighting conditions 1 -3 refer to well-lit, moderately lit, and poorly lit respectively. Well-lit is defined as having clear, even light on the ping-pong balls with no obstructions such as shadows or glare. Moderately lit refers to having less light than the condition above with minimal shadows and glare. Poorly lit refers to dim lighting conditions with minimal illumination or with strong shadows. *- indicates that our model could not successfully detect the ping pong ball under that condition.

When considering the size of the playing area, 8m x 4m, we aim to have a reliable detection range of approximately 3 - 5 meters. By meeting this benchmark, we can confidently mark certain areas as checked with a certain probability of a ping-pong ball being present from a greater distance. This test demonstrates that our robot, in its current state, may have a hard time detecting ping-pong balls further away especially in moderately/poorly lit lighting conditions and therefore must get closer to a certain area to confidently conclude the presence of a ping-pong ball. This is not ideal as it increases the time required for the robot to scan the entire playing area. Note that cases where the colour of the background of the image was similar to the colour of the ping-pong ball were not considered. We aim to improve our model incrementally, so these cases were not tested in this iteration. Test 2: Precision We tested the detection model on various objects that might look like a ping-pong ball. We define a detection as having confidence > 70% for at least 15 frames in a 20-frame window. Each image contains one ping-pong ball and one other object in well-lit conditions. Each object is tested 20 times from different angles and a maximum distance of 1 meter. Each ping-pong ball was successfully detected.

Object	False Positives
Orange	20/20
Golf Ball	18/20

True positive: 40/40
False positive: 38/40
Precision: 51%
This test demonstrates that our robot has trouble distinguishing ping-pong balls from objects that appear similar. With a false positive rate of 38/40, this is a strong indication that our robot is prone to identifying non-ping-pong ball objects as ping-pong balls and therefore might attempt to collect it. This is a significant finding as it highlights the limitations of the robot's current object recognition capabilities.

So, we improved our dataset. We start by adding a portion of the environment image that does not contain a ping pong ball, which allows our model to recognize that there is not necessarily at least one ping pong ball in the frame. Second, we added some pictures of similar objects, which will make our model recognize that these objects are not ping pong balls. Finally, we also added some pictures of ping pong balls and similar objects together, which will allow our model to learn how to distinguish between the two. After training again, we repeat test 2.

Test 3: Precision As same as last test, we tested the detection model on various objects that might look like a ping-pong ball. We define a detection as having confidence > 70% for at least 15 frames in a 20-frame window. Each image contains one ping-pong ball and one other object in well-lit conditions. Each object is tested 20 times from different angles and a maximum distance of 1 meter. Each ping-pong ball was successfully detected.

Object	False Positives
Orange	5/20
Golf Ball	0/20
Lemon	2/20
Tangerine	3/20

True positive: 40/40
False positive: 10/80
Precision: 80%

3. Budget

We aim to make our product as cheap and accessible as possible, which is why we have decided to make our robot from individual parts and integrate these parts together, as opposed to using a pre-built robot. At the start our estimated budget was around £270. However, we found that our product's performance did not meet our expectations as we had multiple issues regarding the movement, suction, and returning mechanism. We decided that to improve the quality of our product, we had to buy higher quality parts. Our current model is estimated to cost £495. Although a large increase from our previous estimated cost, we feel that it is justified given the equally large increase in performance. Currently, we do not have any direct competitors in the market for ping-pong/table tennis products. However, our tennis robot counterpart, the TenniBot, is currently priced at $2195. By contrast, our product is significantly more affordable, which expands our customer base and enhances our competitive edge.

Component	Cost
Raspberry Pi 3	£30
Jetson Nano	£121
LiDAR (RPLiDAR A1M8)	£112.8
Camera (Crosstour CW100)	£20
Chassis (Junior Runt Rover)	£50
Mechanum Wheels	£20
Container	£30
Electronics	£30
Fans	£27
Printing Costs	£29
Total	£494.90

4. Miscellaneous

Ping pong was the most watched sport in China at the 2020 Olympic games [1], showing the Ping Pong market worldwide is a big industry. However, in England, only 111,000 adults and 279,000 children play weekly [2]. 97% of the UK have played ping pong and over half say they react positively to the sport [3].

47% of adults do not participate in sports [4]. This is due to a lack of time and the fear of injury. Physical inactivity is linked to 1 in 6 deaths in the UK [5], which costs the UK £7.4bn annually . The number 1 reason for participation in sports is enjoyment [6].

This is where our product comes in. Our product is here to encourage participation in the sport of Ping Pong by increasing the enjoyment of it. According to a survey we sent out to our fellow students, 74% said they would enjoy ping pong more if they didn't have to pick the balls up and 68% said they would play ping pong more if they had our product to do that for them. But this is only for the casual market. For the professional market, our product is also useful for them too. During competitive matches, every 6 points the players stop for a break. This is the time in which our product would pick up the balls for the players. There are no 'ball kids' in ping pong like there are in tennis due to a lack of space in the playing arena. Our product would be the "ball kid". And the other reason for not playing sports other than time is the fear of injury. Our product removes the need to bend down, therefore alleviating any stress of pulling back muscles bending down.

From the get-go of this project, we have always wanted to keep our raw material costs as low as possible. This was the main reason for not using a Turtlebot. Our raw materials costs are £500 per unit and our sale price is £649. Over time, when we start to bulk buy raw materials we hope to reduce our costs to increase our profit margins. You may be thinking that £649 is an expensive price, however, ping pong tables themselves cost anywhere between £100 all the way to £1000, so a one-time payment of £649 is very reasonable, especially when our product is designed to last many years. In terms of competitors' pricing, there are no alternatives for ping pong, however, the tennis equivalent Tennibot sells for $2195 [9]. Our price is much more reasonable than that. In our survey to our fellow students, 25% said they would be willing to pay our price or higher. Since our target market is wealthier than the average student, including professional players and ping pong enthusiasts, we believe we can sell our product for that price.

References

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