# Interim Group Report

|  |  |  |
| --- | --- | --- |
| **Student ID Numbers:** | *F012632, F015848, F024665, F030764* | |
| **Company Name:** | *ASIMOV* |
| **Event Name:** | *Pied Piper* |

**How to complete the report**

(a) Just add your text in the places indicated with "*your text here*"; **leave the headings** and descriptions in place to remind your assessors what you have been told to do.

(b) The report must be **no longer than 8 pages**. This **excludes** the front cover page (this page), the *Activity Breakdown* page and the *References* page. An appendix is **not** needed.

(c) The report should be submitted electronically in .pdf form via the WSB013 Learn page. The filename should be your company letter and group number followed by “interim” (hyphenated) with the *.pdf* extension, **for example A2-interim.pdf**.

**Project aim:** *A single definitive project aim; it should state in one sentence what are you trying to do.*

To build and develop a robot that senses and moves towards a sound source in a room and comes to a halt as close to it as possible without touching it.

**Project objectives:** *What do you need to do to satisfy the aim? Objectives should be simple and measurable; ask yourself the question can I decide if I have achieved this or not? Note that personal objectives are not relevant; "learning to use a soldering iron" is not a project objective.*

* Examine existing robot to modify it for a minimalist design.
* Research the different methods the robot can use to follow the sound source.
* Select one method to implement as the main solution and one as a contingency plan.
* Research the different types of microphones and choose which type of microphone to use.
* Decide on a method to stop the movement of the robot as it approaches the sound source.
* Decide which sensor(s) to use to implement this stoppage.
* Calculate the quantity and dimensions of nuts and bolts required.
* Place order for sensors of the decided type.
* Draw up and submit a PORF for the determined mechanical hardware such as nuts and bolts.
* Design the bracket to hold the microphone(s) and sensor(s) using Siemens NX.
* Prototype the bracket using additive manufacturing.
* Connect the bracket to the chassis of the robot using nuts and bolts.
* Attach the microphone(s) and sensor(s) to the bracket using nuts and bolts.
* Write and test code to implement the chosen algorithms on the Rover v2 platform.

**Research and decision making:** *Detail the research and analysis you have done on different ways to solve the problem. Show a clear decision-making process for choosing the optimum solution.*

Research commenced by finding out how humans localize sound using distance and azimuth. To determine the horizontal azimuth, the human brain uses the duplex theory i.e., two different methods of horizontal localization for two different ranges of frequencies [1]. Below 1kHz the interaural time difference is used: the difference in time between the arrival of sound perceived by the two ears. The human ears are sensitive to phase differences between sounds received up to 700us (which is the period of a 1.4kHz tone) [2]. Since higher frequencies are absorbed by the human head, a barometric pressure gradient is used to estimate the azimuth. It has been proved that humans have difficulties in estimating the distance, so it is almost entirely determined by sound amplitude. By understanding how nature handles sound localization, the Pied Piper challenge could be resolved using fundamental biomimicry through electronics. Hence, various methods of sound localization using microphones were considered, with the following methods of post-processing:

1. The most intuitive approach is related to the difference in time of arrival of the sound, with **Cross-Correlation** algorithms. The cross-correlation algorithm outputs the phase difference of the samples taken from two or more microphones. If one of the signals was slightly delayed and it is a scaled version of the other, the task would be simpler. However, in real life scenarios, signals may be subject to ambient noise or reverberation. Typical cross-correlation is mainly affected by low frequency components of the waveform, where most of the natural sound energy is concentrated.
2. To overcome that, the **General Cross-Correlation** (GCC) algorithm has been introduced. It uses the same principles as cross-correlation but adds frequency weighting to the calculations [3]. This allows for more accurate angle estimations in real life scenarios. These weighting methods include:
   1. **PHAT** – makes the original signal robust against reverberation [4].
   2. **SRP** – this weighting is the mean of GCCs for microphone pairs in multiple sensor systems

Although using these weightings can help with reverberation, samples may be still sensitive to noise. By measuring signal-to-noise ratio before any calculations, a noise mask can be estimated. Applying this mask to later samples can make the system more robust and immune to most noise.

1. A natural extension of the GCC method is **Steer-Response Power** (SRP). Compared to GCC which first calculates total time difference of arrival between signals, SRP becomes more independent of noise and reverberation [5]. The SRP method can be implemented in two steps:
   1. Compute cross-correlation between two signals
   2. Search for the source location over a grid of spatial points.

**Decision-making on Algorithms and Sensors**:  
Regular cross-correlation was settled upon for the primary solution (Plan A). Cross-correlation has been widely researched for many years, because of which, there is a lot of data available that can be used to perfect the software. It is a sufficient method on its own but has scope for improvement like GCC and weighted approaches, if there is enough time after finalising the core. This method is will be a challenging task, while still leaving some space for improvements if the team finishes it before the final deadline.  
The backup solution (Plan B) will directly use the difference in amplitude between microphones to determine the direction of sound.  
Since it is an extremely challenging task to determine the distance to the sound source using exclusively microphones, they will only be used to determine the azimuth. A separate proximity sensor or rangefinder will determine the distance to the sound source.

An infrared proximity sensor was chosen as it may be more sensitive to light from the red LED at the target. Testing various infrared proximity sensors from the Electronics Workshop, the sensors were found to be unreliable at near-range. For instance, the SHARP 2YAOAO2 F 6Y infrared sensor was unusable for this purpose as it became inaccurate when used above or below 10cm from the target as shown in the graph below.

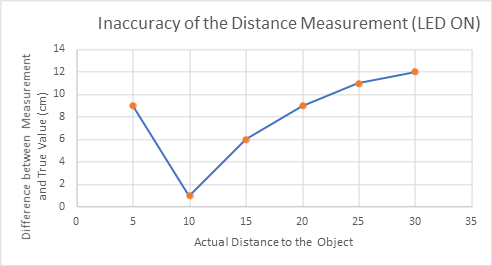


Figure 1: Inaccuracy of the SHARP 2YAOAO2 F 6Y IR sensor when operated at ranges beyond and closer than 10cm

Another crucial decision the team needed to make was how to integrate the IR sensor with the rest of the circuit as the Arduino has only one core, which is busy with the cross-correlation of microphone signals. The options considered were:

* Polling the input value of the infrared proximity sensor
* Scheduling processor tasks using RTX signals
* Designing a custom circuit which outputs a digital ‘HIGH’ when the voltage enters a certain threshold and using an Interrupt Service Routine on the Arduino to stop the Rover.

The last option was chosen, as it does not add any additional strain on the processor besides interrupting the program when the Rover is close enough to the target.

**Proposed robotic system:** *Describe the robotic system you plan to build, paying particular attention to the innovative and challenging aspects.*

1. **Description Overview of System**

The robot is based on the existing Rover v2 platform, but will include additional peripherals viz two microphones and one infrared proximity sensor. The existing system of tracks will be removed and replaced by a custom-fit wheel tread, to allow better manoeuvrability while skid-steering. To compensate for this, a third caster wheel will be added, and the direction of movement will be changed such that the motors are at the front of the robot.

1. **Functional Process of the Robot**

While the microphones allow the robot to locate the source of the sound and move towards it, the proximity sensor will stop it at the minimum possible distance from the speaker, before contact. The algorithm works as shown below:

Diagram

Description automatically generated

Figure 2: An overview of the Pied Piper’s functional algorithm developed in Visual Paradigm [6]

1. **Challenging Elements Requiring Novel Solutions**

* Preventing the tracks from slippage on rough/carpeted surfaces made the consistency of spot-turns difficult to guarantee. This can be solved by replacing them with normal wheels, but needs to be done without replacing the wheel’s central hub as it is fixed onto the existing motor shaft. This will be solved by removing the entire track assembly including the remaining smaller wheels, and fitting a custom-made rubber tyre around the primary wheel on the motor shaft. To balance the robot, a caster wheel will need to be added.
* The microphones need to be located at a precise distance from each other, relative to the wheels. This is best achieved by positioning them as close as possible to the axis of rotation during a spot-turn, angled outwards, at 90 degrees to each other. This can be achieved by 3D printing a mounting bracket for the sensors, with integrated guards around the microphones to shield them from interference, as well as an open surface at the top, on which to mount the proximity sensor.
* An external sensor breakout board is required to securely connect the cables from the microphones and proximity sensor to the I/O pins. The simplest way to do this apart from using a breadboard, would be to make a Veroboard circuit in the form of a two-sided Arduino Shield which fits directly on top of the existing I/O pins. However, since the Rover v2 platform is based on the Arduino UNO, the female headers for the Analog Input pins are 2mm apart from the set of power supply headers, rather than following the conventional 2.54mm spacing. In order for the headers on both boards to align, a custom PCB needs to be fabricated taking this into account.
* The sensors’ cables use a proprietary design of female header pins with 1.84mm spacing, so the standard 2.54mm header pins in stock will need to be modified or a new set of header pins will be purchased taking these measurements into account.

**Current project state:** *Explain clearly where you are in your project and what you have done to date. Include evidence to support your claims. This can include photos, initial results, diagrams etc.*

**Mechanical Hardware**

1. **Three-Wheel Configuration**

As mentioned in the proposed plan, the tank-tread configuration was unsuitable for taking multiple spot-turns on rough surfaces. This caused the treads to slip off the primary wheel after every four to five turns. The solution was to remove the entire tank-tread assembly and replace it with a three-wheel configuration, wherein the primary wheels connected to the motor shaft were fitted with a custom-made rubber tread and an omni-directional caster wheel was added to the opposite end of the robot for stability.

A picture containing indoor, orange, toy

Description automatically generatedA picture containing person

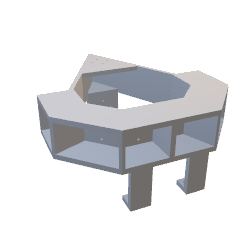
Description automatically generatedA carved pumpkin on a table

Description automatically generated with medium confidence

Figure 3 (L-R): The primary wheel being fitted with a new rubber tread

1. **Sensor Mounting Bracket**

The bracket has three possible positions for the microphones at the front. To shield the microphones from external interference, guards were added surrounding the microphones. It was not seen as necessary to include guards for the rear microphone as it function is to indicate the position of the sound source relative to the two microphones at the front; this does not require precise measurement. Due to some inaccuracies in measurement though, this unfortunately did not fit the robot. However, it was close enough that holes could be drilled into the legs (shown below) in line with the screw holes on the chassis, allowing the bracket to be attached to the chassis of the robot.

A picture containing red

Description automatically generated

Figure 4: (L-R) The CAD model designed in Siemens NX was 3D printed and additional screw holes were manually drilled for ease of mounting on the robot

1. **Caster Wheel Adapter**

Since the robot’s chassis did not have the required mounting position for the caster wheel, an adapter was designed in AutoCAD, to be laser-cut from a 5mm acrylic sheet. This would allow the robot smooth and stable movement during spot-turns. The wheel was attached to the adapter with 4mm screws while the adapter was fitted onto the chassis and sensor mounting bracket with 3mm screws.

A close-up of a guitar

Description automatically generated with medium confidenceA picture containing indoor, wall, floor, cluttered

Description automatically generated

Figure 5: (L-R) Omni-directional caster wheel on a custom-made 5mm laser-cut acrylic mounting adapter, which was then bolted onto the main chassis and sensor mounting bracket to provide stability.

**Electronic Hardware**

1. **Sensor Shield Breakout PCB**

The sensor shield was designed to fit as securely as possible onto an Arduino UNO, since the same pinout configuration would apply to the Rover v2’s I/O pins. The proprietary cable from Grove Seed Studio which used 1.84mm pin spacing was measured manually, and the design was adjusted according to this to ensure a perfect fit.

Diagram, schematic

Description automatically generatedA picture containing person, indoor, floor

Description automatically generatedA picture containing electronics

Description automatically generated

Figure 6: (L-R) The PCB was designed in Fritzing and exported to an industry-standard Extended Gerber file set for fabrication. Signal quality for each individual sensor was then tested on an OrangePip Kona-328 before being mounted onto the Rover v2 as shown.

1. **Infrared Proximity Sensor**

Diagram, schematic

Description automatically generatedChart, histogram

Description automatically generatedAfter thoroughly testing three different infrared sensors, it was concluded that none of them was suitable this robot, as they weren’t accurate for distances shorter than 10cm. A new infrared sensor is to be ordered from an online supplier, the purchase order request form (PORF) for which is ready to be sent for approval. As quoted online, the new sensor (Grove Infrared Reflective Sensor v1.2) should be able to accurately measure distances between 4-15mm. To integrate the infrared sensor with the Rover and the rest of the peripherals, a custom breakout circuit will be used to convert the analogue voltage from the sensor to a digital ‘HIGH’ when the voltage reaches a certain threshold. The digital signal will then be the trigger for an interrupt, which causes the Rover to stop.

Figure 8: The simulated behaviour of the prototyped 1-bit ADC breakout circuit, where V(input) is the analogue signal from the sensor

Figure 7: Prototype for the custom 1-bit ADC breakout circuit

Figure 9: Prototype for the custom 1-bit ADC breakout circuit

Chart, line chart

Description automatically generatedChart, line chart

Description automatically generated**Software Development**

Figure 9: Same signal, orange delayed by 5 samples

Figure 10: Cross-correlation factor(x-axis), compared to phase offset(y-axis)—cross correlation peaks at 5 samples phase difference

Development of the software has been mainly focused on developing a reliable cross-correlation algorithm. Part of the software has been successfully developed and the code works well on samples generated by the computer. However, it struggles when it comes to real world data because of the ATMEGA328’s limitations – it is unable to sample multiple microphone samples in parallel. Current work is focused on creating an environment that would allow sampling from two microphones simultaneously.

Code has also been developed for measuring the distance from the Rover to the target using the voltage output by the infrared proximity sensor. Using online documentation for the specific device, the distance (to the nearest centimetre) can be calculated from the voltage, with the aid of an external library. This program can be integrated into the ‘master script’ which will be running on the Arduino.

**Project management:** *Detail the steps you have taken to effectively manage all phases of the project, including aspects related to quality, communication, data, resource, time, sustainability etc. Show that you are following the plan.*

Diagram

Description automatically generated

Figure 11: Outline plan devised in accordance with the Lean Agile methodology for each member to use as a guideline in a recursively looped manner of phased sub-system development, while keeping in mind the required deliverables from the team as a whole [7]

* By using the weekly company meetings as a motivation to complete Lean Sprints, the team has been able to maintain a high level of efficiency in terms of hardware and software development. Communication between team members does not require the entire team to be present for every meeting, and this ensures optimal usage of limited time during each weekly sprint.
* Using a Gantt chart for organisation of work over a longer period of time ensured that only the most pertinent tasks are undertaken each week, so they can be given maximum focus, such as hardware development. In tandem, one member of the team would initiate the weekly presentation and the others would add their data to it from the relevant sub-systems.
* All data storage for images, task lists and presentations has been centralized on the MS Teams channel, while codes are maintained on GitHub. A copy of this repository is backed up each month on the MS Teams channel as well.
* The budget is monitored on a weekly basis to check that there are requisite financial resources in case of last-minute purchases for backup equipment or hardware components. At present, the team has utilised approximately 60% of the budget and projections indicate that 95% of the budget will be used for project completion.
* The robot was designed with a minimalist framework in mind, using only the most essential components from the kit provided. Apart from the 3D printed sensor mounting bracket, the caster wheel’s adapter and the PCB, most other components in the robot have been utilised from the original kit provided. The caster wheel itself, was sourced from a within the personal belongings of a team member, to avoid unnecessary purchase of material which would later go waste. It has been budgeted for, accordingly. Although the main wheels have been fitted with new rubber treads, this rubber was sustainably sourced from waste material that was due to be scrapped by Wolfson’s EA workshop. In this manner, the team has been able to reduce the waste generated, repurpose existing components and ensure that all other parts that would be recycled are RoHS compliant.

**Test plan:** *Detail how you will test sub-systems as the project progresses as well as the complete system at the end.*

After any change to a sub-system, the individual(s) working on it tests the change and relays the information to the team for discussion. The functionalities the team plan to test are as follows:

* **Code inspections:** A form of static testing will be carried out on the entire program to ensure that most bugs are removed, and the logic of the code is correct. Code inspections, for each section of code, will *not* be completed by the individual(s) who it was written by. The code written so far has been designed for testability, by using good practices (such as using portable integer types and avoiding floating point numbers and dynamic memory allocation) and ensuring the code is readable to other members of the group.
* **Interrupt Service Routine (ISR):** Once it has been programmed, the ISR will be tested with a simple program which prints the current time to the ‘Serial Monitor’ when the interrupt is triggered. A delay can be added to print the time every 5 seconds using the ISR to prove it functions correctly.
* **Accuracy of the new IR proximity sensor:** The test for the new IR proximity sensor will be the same as for the old one, so direct comparisons may be made between the two. Using a ruler, the distance measured by the IR sensor will be compared with the ‘true’ distance from the target; the difference will be recorded at various distances and the results will be graphed.
* **Microphone bracket:** The microphone bracket will be fitted to the Rover and the other sub-systems will be tested to ensure the bracket does not inhibit their functionality. The optimal placement of the microphones on the bracket will also be tested.
* **Caster wheel adapter:** The adapter juts outwards, increasing the length of the robot. This makes the adapter prone to damage as acrylic is brittle and, with a force applied, such as by the caster wheel, it can easily snap. Therefore, it is important to ensure that the acrylic is thick enough to withstand any forces acting upon it.
* **Custom ADC Circuit**: This will be tested on a separate Arduino and will require the new IR sensor and the interrupt service routine to be functioning. The IR sensor will be connected to the circuit, which will output to one of the digital pins on the Arduino, which will trigger the ISR. Again, using a ruler, a comparison will be drawn between the distance at which the ISR is triggered and the ‘true’ distance from the target.
* **Fast Fourier Transform Algorithm:** The algorithm can be tested using ‘**black box’ dynamic testing;** by inputting a signal formed of a summation of sine waves of different frequencies. Once the FFT algorithm has been performed on the signal, either the frequency peaks can be read from the result plotted using the Arduino serial plotter, or the highest peak can be calculated and that, along with every peak within a certain range (such as 20%) can be output to the serial monitor. It is not necessary, however, to manually calculate the peaks for the final solution, as the cross-correlation algorithm requires the entire result of the FFT computation, upon which it can perform the algorithm.
* **Integration of the Peripherals:** Once the testing of individual sub-systems has been completed, integration testing may proceed. The concurrence of this system can be tested by printing to the serial monitor in the Arduino IDE when each ‘thread’ is entered each peripheral is given its own thread. The integration will be observed to be successful if the serial monitor shows that each thread is running concurrently without unwanted bias towards any thread.
* **Final Testing:** During the final stages of the implementation of the project, the final testing will be carried out to see if the Rover can complete the challenge. The Rover will be tested by placing a sound source behind the wooden ‘LED target’ and recording the time it takes for the Rover to stop in-front of it. The distance between the target and the end position of the Rover will also be recorded. For each new test, the Rover will be placed in a different orientation and position, and the performance on difference surfaces will also be tested, along with different volumes of music being played. Once the tests have been complete and the results observed, the design may be tweaked if necessary and the tests repeated.

**Risk assessment:** *List the risks associated with the successful completion of your project, your assessment of their severity and likely effects and your suggestions for their mitigation. Show how the Health and Safety of the team and the wider public have been considered.*

The following risks have been quantified using a **Risk Factor**, which is the product of the **Likeliness** and the **Severity**, which each have a rating 1 (Low) – 5 (High).

* **Team Illness or Injury:** An illness or injury preventing a team member from committing to the project may have a serious impact on the progress the team makes. By communicating frequently regarding individual progress in-person and online, it may be possible to transfer the workload to a healthy team member.

**Likeliness 3 x Severity 3 = Risk Factor 9**.

* **Government COVID-19 Guidelines:** If the guidelines change it is important each team member stays up to date with the news so a contingency plan can be prepared for whatever this may affect. If the nation goes into another lockdown, team meetings will be held exclusively on Microsoft Teams, and the robot will be left in the communal locker so team members can access it if they need to, without physical interaction with the rest of the team. COVID safety guidelines should be followed when conducting in-person meetings. Social distancing should be practiced, and face masks should be worn. **Likeliness 4 x Severity 3 = Risk Factor 12.**
* **Limited progress over Christmas Break:** During the Christmas break, the team will be unable to meet in person and schedules of team members will be very different during this holiday. There may also be less time to dedicate towards the project considering the upcoming Semester 1 exams, and it is very unlikely that transferring equipment between team members will be possible. To maintain some progress over Christmas, each team member will be given an individual task to complete; upon completion, any progress should be communicated with the rest of the group. Before any team member leaves Loughborough, it will be decided who should keep the various pieces of equipment. **Likeliness 2 x Severity 2 = Risk Factor 4.**
* **Equipment not arriving in time:** In the case that equipment (such as the 3D printed microphone bracket) takes longer to arrive than expected, progress may be seriously hindered as the equipment may be necessary for the next stage of the implementation to begin. By ordering the equipment as early as possible, and by checking the estimated delivery date from online suppliers, the risk may decrease.

**Likeliness 2 x Severity 4 = Risk Factor 8.**

* **Exceeding the budget:** It is important that the team frequently monitors the spending such that the budget is (ideally) never exceeded. Equally important is the communication regarding the equipment required for each sub-system, so compromises may be made to stay within the budget.

**Likeliness 1 x Severity 5 = Risk Factor 5.**

* **Electrical injury:** There is a very low risk of electrical injury as the voltages used are very low; despite that, care should still be taken, and the system should be switched off when rewiring. There should also be no uninsulated connections on the final product, which may electrically shock users.

**Likeliness 2 x Severity 1 = Risk factor 2.**

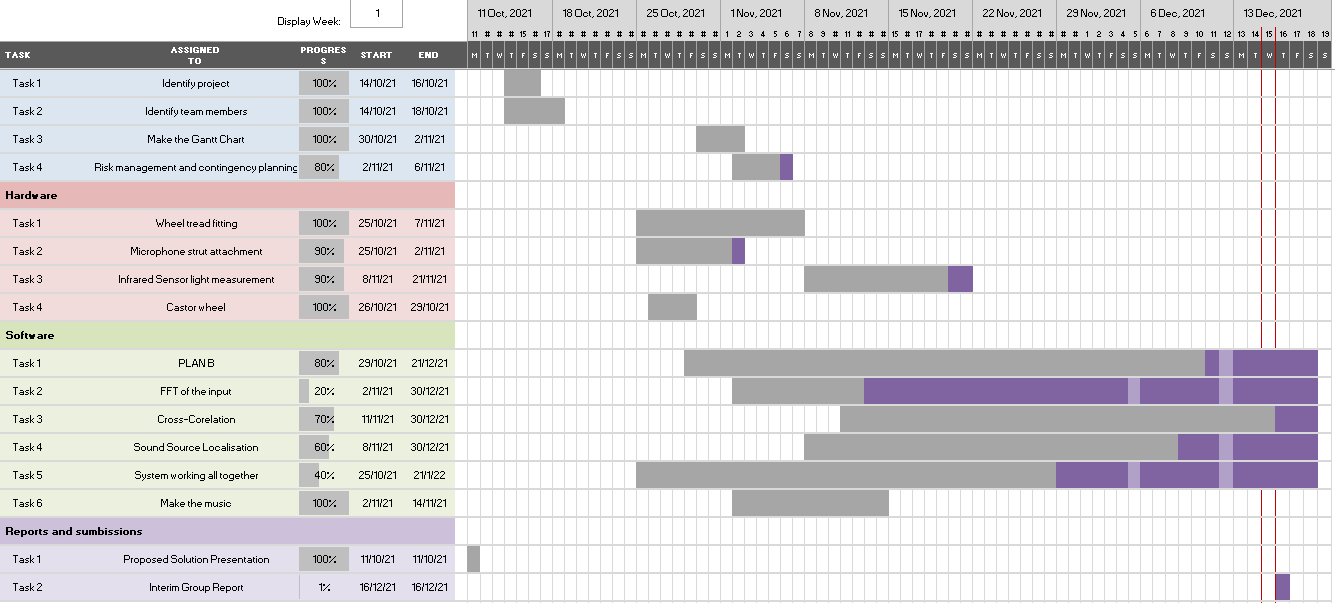
* **Burns from soldering:** Soldering will be involved at some stages. During soldering, it is important to take care that the soldering iron does not come into contact with bare skin as it can cause serious burns to skin.

**Likeliness 3 x Severity 3 = Risk factor 9.**

* **Inhalation of toxic fumes:** Solder is also coated in flux, which releases fumes when melted that can be dangerous if it makes contact with unprotected eyes or if it is inhaled. Therefore, all soldering should be performed wearing safety glasses, and in a well-ventilated room with an extractor fan nearby. **Likeliness 4 x Severity 2 = Risk factor 8.**
* **Software Failure:** A failsafe needs to be designed, such that the Rover stops moving if it runs into serious software issues or an accident causes the software to be corrupted during operation. This would help to prevent inadvertent injury to the user.

**Likeliness 1 x Severity 4 = Risk factor 4.**

**Activity Breakdown:** *In landscape format, include a Gantt chart or equivalent. Make sure it is legible. Use only* ***one*** *page*



**References:** *Include a list of references here formatted in IEEE style. Remember to cite them in the text.*

1. E. L. Benaroya, N. Obin, M. Liuni, A. Roebel, W. Raumel, and S. Argentieri, “Binaural localization of multiple sound sources by non-negative tensor factorization,” *IEEE/ACM Transactions on Audio, Speech, and Language Processing*, vol. 26, no. 6, pp. 1072–1082, 2018.
2. J. Zhang and H. Liu, “Robust acoustic localization via time-delay compensation and interaural matching filter,” *IEEE Transactions on Signal Processing*, vol. 63, no. 18, pp. 4771–4783, 2015.
3. C. Knapp and G. Carter, “The Generalized Correlation Method for estimation of time delay,” *IEEE Transactions on Acoustics, Speech, and Signal Processing*, vol. 24, no. 4, pp. 320–327, 1976.
4. R. Lee, M.-S. Kang, B.-H. Kim, K.-H. Park, S. Q. Lee, and H.-M. Park, “Sound source localization based on GCC-phat with diffuseness mask in noisy and reverberant environments,” *IEEE Access*, vol. 8, pp. 7373–7382, 2020.
5. P. Pertila and E. Cakir, “Robust direction estimation with convolutional neural networks based steered response power,” *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 2017.
6. “Visual paradigm online - suite of powerful tools,” Visual Paradigm Online - Suite of Powerful Tools. [Online]. Available: https://online.visual-paradigm.com/. [Accessed: 15-Oct-2021].
7. S. Blake, “Understanding lean agile and the 5 lean principles,” Understanding Lean Agile and the 5 Lean Principles, 02-Jul-2021. [Online]. Available: https://www.easyagile.com/blog/lean-agile/. [Accessed: 14-Oct-2021].