“Thus With a Kiss I Die”

Team members:

Omri Green, Cole Parks, Timothy Rinaldi

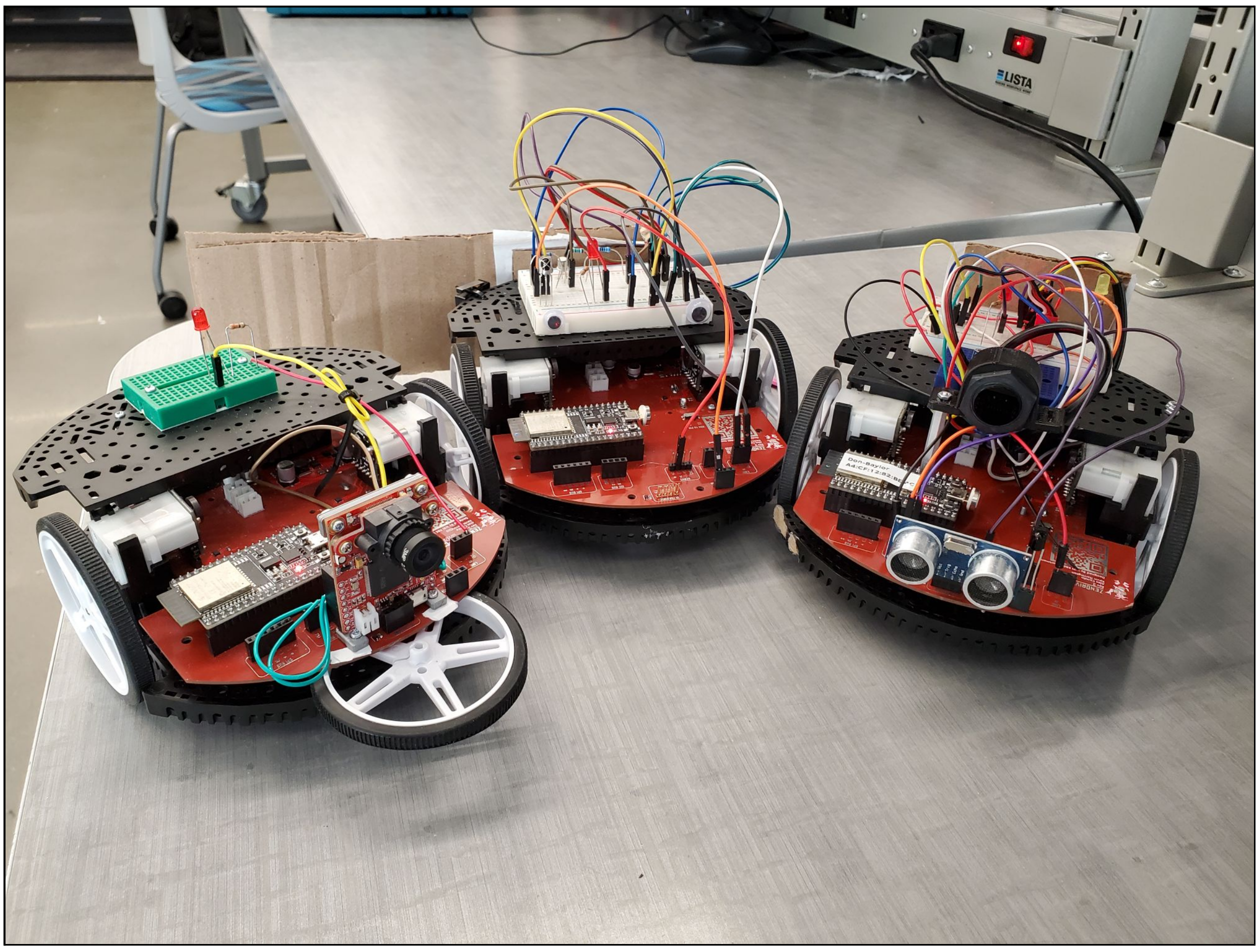

Figure 1: *Team 12’s three robots to represent the characters in Romi and Juliet*

Introduction and overview

Team 12 created three robots that utilize sensors, peripherals, and robot-to-robot communication to autonomously perform two scenes from *Romi and Juliet*.

Team 12's final system implemented three robots that covered: Romi, Tybalt/Juliet, and Mercutio/Friar Lawrence (two robots played two characters). The team's system heavily utilized the MQTT protocol for WiFi communication between the robots to coordinate cues and timing for the scenes in *Romi and Juliet*. Using WiFi helped replace other communication methods like using an IR emitter and receiver, which had multiple disadvantages, namely range, visibility, and . The team was also able to utilize the AprilTag tracking with theOpenMV camera, which allowed for the robots to consistently follow each other. The code of the system was organized in a way so each character had a "script" for the scene with the necessary tasks needed to complete. All robots also shared a common program that covered general functions for all due to having the same drive base.

Solutions and justifications

The two scenes that were reenacted in *Romi and Juliet* were (1) "The Fight Scene" (the stabbing of Tyablt and Mercutio) and (2) "The Balcony Scene" (The calling of Romi by Juliet, followed by a conga line).

For the first scene, "The Fight Scene," functionality includes having two robots circle each other, the stabbing of the two robots and detecting it, and having the robots watch each other's death, along with various performance cues. Some challenges faced included developing a way for Tyablt and Mercutio to consistently circle each other at the same radius and rate so that when they finished they were in the exact position as they started all while Romi watches. Another challenge was having Tyablt sense when he had impacted Mercutio (the stabbing), which he then had to communicate to Mercutio. The team also had to solve the problem of having each robot detect the other robot and consistently follow it, while it moves around for its dramatic death. Along with these challenges, Team 12 had to implement a way to communicate precisely between the robots for when to perform the necessary tasks.

For the second scene, "The Balcony Scene," functionality includes wall-following while driving up and down a ramp, and having Romi and Juliet follow Friar Lawrence at a constant distance. Challenges faced were having Juliet drive up the balcony ramp, while keeping a constant distance from the wall right next to it. In addition, Juliet had to use a complementary filter to effectively measure the pitch to determine if she was on the ramp or at the top. Another challenge was having Romi and Juliet consistently and reliably follow Friar Lawrence at a set distance.

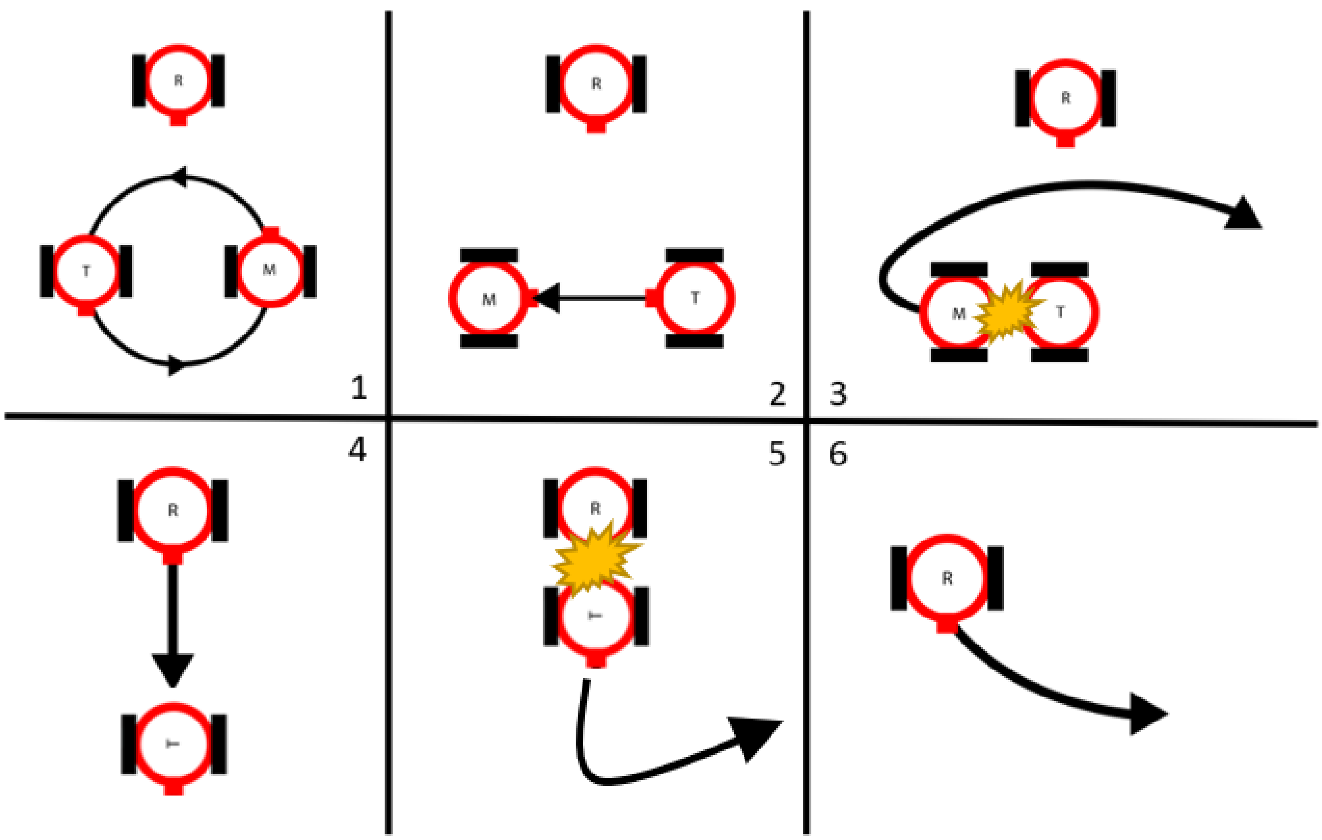

Figure 2: *Motion diagrams of Romi, Tybalt, and Mercutio in Scene 1*

For the first scene, the steps include:

1. Tybalt and Mercutio circle each other
2. Tybalt drives at and stabs Mercutio
3. Mercutio performs a dramatic death
4. Romi drives at and stabs Tybalt
5. Tybalt performs a dramatic death
6. Romi exits stage right

For step 1, the team decided on setting four points on a circle so that Tybalt and Mercutio could drive to them using inverse kinematics. This would result in a circling action by the two. The team considered other options like simply driving with differing speeds on each wheel, but this resulted in dead-reckoning, which was not preferred. Inverse kinematics was the most viable option because of that.

For step 2, when both Tybalt reaches his fourth point on the circle, he sends a signal through WiFi to Mercutio that he has reached their fourth point on the circle; they then stop and turn to face each other. Following this, Tybalt charges at Mercutio. The method the team decided on was to use the IR emitter on Mercutio as a strong IR beacon that Tybalt's IR camera could detect. While Tybalt drives forward, he uses his IR camera to track Mercutio and stay centered on him. The most obvious option for us to perform the charge was to use the AprilTags with the OpenMV camera. This was unfortunately discarded when the team realized Romi had to have the OpenMV camera, not Tybalt. Another consideration was to use the ultrasonic to detect distance as Tybalt charged. The reason the team decided not to use this was because of the unreliability in detecting position with a distance sensor. Tybalt would need to have a function implemented that turned the robot when a larger distance reading was recorded, but there would be no way to know which direction to turn. When Tyablt does reach Mercutio, there is an impact, and the robots need a way to detect this. The best option the team came up with was sensing a spike in the accelerometer in the IMU. This was relatively simple to implement, as an interrupt pin on the IMU exists for this reason. Other options considered were to detect a distance with the ultrasonic or SHARP IR, but quickly realizing from the tests formerly done in lab, the ultrasonic can read a minimum distance of about 10cm and the SHARP IR at 7cm. Seeing that we want both robots to collide, the distance would become close to zero, which at anything under the minimum distances, the readings would spike and become very unreliable. The distance sensors could be mounted farther back on the robots to mitigate this, but the IMU high acceleration interrupt was a much simpler solution to the collision detection problem.

For step 3, Mercutio had to perform a dramatic death after reading that he had been hit (through WiFi). Two points were defined for Mercutio to drive using inverse kinematics. For the other two robots, it was decided that they should watch Mercutio as he dramatically drives on his path to his death. This meant that Tybalt and Romi had to track Mercutio's position from their stop and rotate in place to view him. To accomplish this the team decided that Romi would use his OpenMV camera to track Mercutio's AprilTag, while Tybalt tracks Mercutio's IR emitter with his IR camera. These two options were the most reliable when tested. Other options included using Romi's IR receiver to detect Mercutio's emitter, but as described earlier, seeing only on or off makes it very difficult to impossible to track position. Another method that was considered was for Tybalt to use the SHARP IR or ultrasonic sensor, but as described earlier, tracking position with a distance sensor is difficult especially due to Mercutio's changing rotation as he wanders around.

For step 4, Romi was to charge at Tybalt and "stab" him, just as Tyablt previously did to Mercutio. Romi's sensors included the OpenMV camera and IR emitter, which for charging, it was clear that the OpenMV camera tracking Tyablt's AprilTag was the best option for this. Emitting an IR signal and trying to follow that with the receiver is almost impossible for this due to only seeing if it sees an on/off signal, thus the OpenMV camera was selected for this.

For step 5, Tybalt performed the exact same dramatic death as Mercutio previously did, which was decided as using inverse kinematics. As described in step 3, this was the best choice. For Romi to watch Tyablt's path, just like earlier, Romi uses his OpenMV camera to track Tybalt's AprilTag. As described earlier, using the OpenMV camera was the most accurate for this application out of all the other options.

Finally, for step 6, Romi had to detect Tybalt's death through WiFi and then drive off the stage. Another method the team considered was using the IR emitter on Tybalts and IR receiver on Romi to detect his death. This worked, but after the team figured out how to utilize MQTT WiFi communication, WiFi was much preferred. IR signals can be lost with orientation of the receiver or emitter, and any obstruction could alter the signal too. WiFi is not hindered by orientation or range, so this was the best option. For leaving the stage, just like we used earlier, using inverse kinematics to go to a set position was the best option for this. Other options were dead-reckoning or the OpenMV camera. Dead-reckoning is not allowed and the camera is quite overkill and could result in misalignment when tracking the AprilTag, which in this case the task was as simple as to leave the field so just inverse kinematics was simpler and more reliable due to direct encoder tracking.

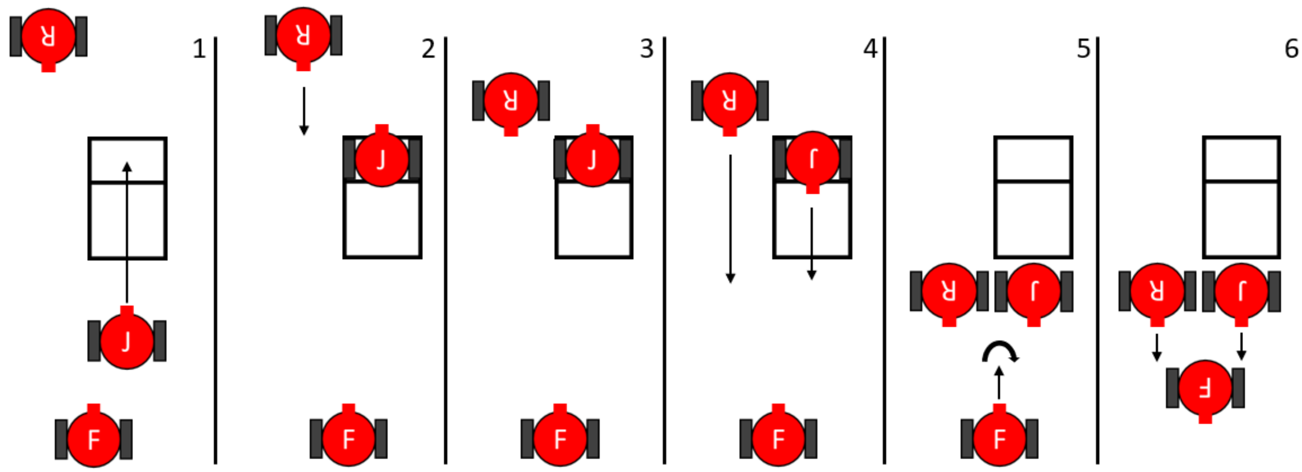

Figure 3: *Motion diagrams of Romi, Juliet, and Friar Lawrence in Scene 2*

For the second scene, the steps include:

1. Juliet drives up the ramp
2. Romi drives to the balcony
3. Romi and Juliet send signals (visually and through WiFi)
4. Juliet drives down the ramp and waits, while Romi drives to Juliet
5. Friar Lawrence enters
6. Juliet and Romi follow Friar Lawrence

For step 1, the team initially decided that Juliet should wall-follow with a SHARP IR sensor, and detect if she was climbing the ramp with the BNO055 and a complementary filter. However, due to time constraints, the wall-following idea was not used as it could not be implemented in time, so Juliet simply drove up the ramp until the IMU detected that she reached the flat surface of the ramp. When driving up the ramp, Juliet's pitch angle was dramatically greater than zero (level). Similarly, when she drove to the top, the IMU read zero, indicating she did reach the balcony, and should stop. After this, Juliet sends a signal to Romi to indicate he should come to the balcony. The team decided the best option for this was to utilize WiFi communication, which worked reliably in testing. Other options that the team considered included having Juliet send a signal with her IR emitter and having Romi receive it with his IR receiver. This method was not used because of the potential to not be detected by Romi if he were facing the wrong direction or not in Juliet's line of sight. Having Juliet elevated posed challenges for having Romi see her IR signal, thus WiFi was utilized.

For step 2, Romi drives into the scene to meet Juliet at the balcony. The team used inverse kinematics for Romi, seeing that the other options included dead reckoning, similarly to previous steps.

For step 3, both Romi and Juliet send signals to each other to confirm their positions and instruct the other to start the next section. Romi does this first by telling Juliet that he arrived at the balcony, and then Juliet messages to Romi that he should meet her at the bottom of the ramp. Again, the method chosen to convey this signal was WiFi, as we had determined that IR communication could be unreliable due to needing a direct line of sight between the robots, and the elevation change and robot orientations could make that more difficult. In addition, in this step, Romi needed to send a signal, which had not happened yet in the scene. This meant that if IR communication had been used, Romi would have needed another IR emitter. However, each group was only given one IR emitter, so again WiFi was chosen.

For step 4, the team initially decided for Juliet to drive backwards down the ramp, but to keep her SHARP IR on the same side as the wall. If she turned around and then drove down her SHARP IR would be facing the wrong side and thus she would have nothing to wall-follow. However, this method was not used due to time constraints, so Juliet ended up rotating around and driving down the ramp. Juliet also used the IMU to detect pitch as described in Step One of this scene. After Juliet reached the bottom of the ramp, using the IMU to detect that she was on level ground, she stopped and signaled Romi to come to her. Receiving the signal, Romi drove next to the base of the ramp to meet her using inverse kinematics.

For step 5, Friar Lawrence, using inverse kinematics, drives forward and turns around 180 degrees to face away from them. Friar Lawrence then turns on his IR emitter for Juliet to follow. Friar Lawrence also has an AprilTag attached to his back, which faces Romi, which will allow Romi to follow.

For step 6, Romi and Juliet drove to Friar Lawrence using distance and position tracking. For Romi, this was done by utilizing his OpenMV camera to track Friar Lawrence's AprilTag. This allowed Romi to calculate the distance from height of the tag, and position from the absolute (x, y) coordinates of the tag. For Juliet, she utilized her IR camera to track the position of the IR emitter on Friar, along with reading the distance with the HCSR04 sensor reflecting off Friar's back plate. For Juliet to track Friar Lawrence, other options that the team considered were using her IR camera or SHARP IR, but after seeing that the SHARP IR was attached to the side of her and the fact that Mercutio has only a single IR emitter, Juliet cannot track the distance of a single emitter with the camera. Another option that was considered was using two IR emitters to enable Juliet's IR camera to track both position and distance, similar to how tag distance is calculated with the AprilTag and OpenMV camera. This was unfortunately not utilized due to time constraints in the final project.

Performance

For the demonstration of the first scene, the robots all performed as expected through MQTT (WiFi) communication. The WiFi communication did pose challenges however, seeing that sometimes the robots would "forget" to start or miss their signal. Resetting the ESP32 boards was also very finicky, but in the end the team was able to demonstrate the scene without errors. For the fight scene, the IMU high acceleration interrupt (with the IMU on Tybalt) consistently registered when Tybalt and Mercutio hit each other, but only if Tybalt had been initialized with a wired serial connection before beginning the scene. Multiple groups ran into this issue, but we found that pressing the reset button on the ESP32 instead of power cycling the robot between runs would preserve it and Tybalt would still be able to utilize the interrupt. Romi and Tybalt's tracking with the OpenMV camera and IR camera worked for following Mercutio as he wandered to his death, which was a big accomplishment for the team. Finally, Tyablt was also able to perform his dramatic death when stabbed by Romi, with Romi fleeing the scene successfully. All of these functions correctly worked together and consistently ran. The technical glitches only occurred with the MQTT signaling and IMU interrupt sensing.

For the second scene, WiFi was also utilized, but from the previous scene, the team was able to control some of the glitches from the starting of the scene and various other mishaps. A flaw did occur when Juliet's IMU spiked as she began driving down the ramp, which resulted in a false reading of being on the ground. This resulted in her consistently starting her "FOLLOW_FRIAR" sequence, while still on the ramp. Due to time, the team focused on the next task, which was following Friar Lawrence with Romi and Juliet. This did work with some tweaking and remained consistent throughout. Overall, the team accomplished most of the second scene, save for the IMU errors when Juliet drove down the ramp.

For both scenes, the team didn't quite know how well the WiFi communication was able to work, due this being the first time using it. It did however surprise us how reliable it was when it did work. The thing the team had to work around were the numerous glitches it came with, which could be solved with more time and tests with the system.

Some items that could have been even more improved were the filtering of the IMU for Juliet coming down the ramp. This was a major flaw for tracking pitch, so with more time the team could fine tune the complementary filter to read more accurate results. This would have fixed the pre-mature signaling of Juliet getting to the "FOLLOW_FRIAR" state. Another problem that could have been tested and researched was the WiFi signaling through MQTT protocol. Using this protocol resulted in many glitches, which could have been looked at and understood more fully with more time. In addition, on the last day of the term, we learned about another communication method called ESP Now, which is a non-wifi protocol developed for ESP to ESP communication. A few teams used this, and they said it worked much more reliably than MQTT.

Appendices

Appendix A: Team 12 Github Repository

github.com/RBE200x-lab/RBE2002Code12

Appendix B: Team Contribution Breakdown

The members of RBE 2002 Team 12 are Omri Green, Cole Parks, and Tim Rinaldi.

- Omri Green was able to utilize his C++ coding knowledge for the project by providing a fair portion of coding for the project. Omri was able to design and 3D print the necessary components and additional parts for the robots.
- Cole Parks was able to showcase his C++ coding knowledge for the project by providing a fair portion of coding. Cole helped build and work on the wiring portion of the robots.
- Tim Rinaldi was able to utilize prior C++ coding knowledge to help provide coding for the project. Tim was able to help build, wire, and perform extensive tests on the robots.

Allocation for percentage of work:

- Omri Green: 35%
- Cole Parks: 35%
- Timothy Rinaldi: 30%