University of Arkansas – CSCE Department
Capstone I – Final Proposal – Fall 2022

IEEE Robotics Competition Design

Nicholas Brown, Callum Bruton, Jase Cornett, Austin Flynn, Stephanie Stock

Abstract

Every year, the IEEE holds a regional robotics competition for colleges and universities. For us here at the University of Arkansas in region 5, the upcoming 2023 competition will be held in Denver. Our capstone team will be competing in this competition with the Robotics Interdisciplinary Organization of Teams (RIOT), a Registered Student Organization at the University of Arkansas. Our problem is that RIOT wants to compete in the IEEE Regional Competition and needs help designing the software aspects of their project. Our objective will be to help RIOT create a functioning robot and drone pair that will be able to compete in the IEEE competition in April 2023. We will approach the solution to this problem by working cohesively as a Capstone group and cooperating with RIOT to determine the best solutions to our problems. Our goal is to make a significant impact on the engineering community at the University of Arkansas by collaborating with engineers of different disciplines and showcase the ability of its students to design and implement a functional autonomous system.

1.0 Problem

The challenge of the 2023 Region 5 IEEE Robotics Competition focuses on the collaboration of two robots that will implement an autonomous system. The pair will communicate together for environment mapping as necessary for critical pathfinding. One of our jobs will require us to establish communication between the drone and ground robot so that they can effectively work together to complete the competition course. Another job we will do is to take this data collected by the drone and ground robot sensors and process it, onboard the ground robot's computer. We will then use this processed data to move the ground robot depending on where it needs to go next. Furthermore, we will also use the data from both to have the drone land and takeoff from the platform on the ground robot throughout the duration of the competition.

The importance of this design is its ability to translate to real-world designs. Several proposed autonomous designs, such as autonomous drone deliveries that stem from a delivery truck in urban areas or a ship that uses drones to monitor the status of stormwater outflows, are simply larger scale implementations of the IEEE competition. This competition provides a great deal of experience for several students to begin implementing autonomous robotics in our society. Autonomous robotics lessen several margins of error that humans introduce. With the introduction of robotics, productivity of nearly anything can be improved.

2.0 Objective

The objective of this project is to construct and program an autonomous duo that can be entered into the IEEE Robotics competition and hopefully win the entire competition. These two distinct types of robots will have separate functionalities that allow them to collaborate on a set of assigned tasks. The duo will consist of a ground robot designed similarly to an autonomous car. It will be able to navigate a course of boxes with a set order and finish the course within a given time limit of 10 minutes [5]. The drone will be responsible for providing terrain mapping data and scanning QR codes on top of the boxes that will aid the ground robot in calculating the path to the next objective. It needs to function as a normal flying drone while having constant communication with the ground robot, as well as the ability to take off and land from a platform on top of the ground robot. To successfully complete the course, the drone is required to land on the ground robot once all objectives have been completed [5].

There are virtually no physical aspects of the ground robot that need to be completed for the competition which means our biggest responsibility is working on the software of the ground robot. The only hardware part that our CSCE Capstone team will have to work on is the on-board computer for the ground bot, as well as the sensors that will collect data during the competition. We will also be sending information and data for the computer to calculate how the wheels should move so the ground bot can move throughout the competition. Since the drone comes pre-built, our role calls us to program its functionality to complete the given tasks. This will encompass programming it to scan the competition field and QR codes, as well as taking off, flying, and landing.

3.0 Background

Robotics encompass a wide variety of ideas and uses. These can range from little autonomous robots that vacuum your floor to the NASA Mars robots that roamed and mapped the planet [6]. The design of our robot and drone will not be as complicated as what NASA can do, but it will still come with obstacles and problems we will need to complete. To understand the scope of our project, there is background information that needs to be understood.

3.1 Key Concepts

For our ground robot to be able to move with directions, the course will need to be mapped. This will be done for us by using street view mapping. Our drone will be flying above the competition field with a camera pointing down on the field. This will allow us to create software to process these images into a 3D map of the terrain [1]. This data of the terrain will then be sent down to the ground robot. The ground robot will then be able to process this data to generate directions to the objectives.

Our ground robot and drone will need to be able to collect data, so they know where they are at any given time. This will be done by using various sensors to gather information and data. This data will be gathered via a stereo camera, a normal camera, a LIDAR sensor, and odometers on the wheels. The platform that the drone will be landing and taking off from will also use contact switches to know when the drone has landed. The drone will use its built-in camera to scan and record data about the competition course from above the ground robot. This camera will also need to have the ability of scanning and reading QR codes and relay that data to the ground robot, to help decide what box is next.

Data processing will need to be done during the competition as well. The data that these various sensors collect will be processed by the ground robot using the onboard computer. The computer will then send back any needed information to the drone so that it knows its location and the ground bot's location. This data will determine where and how the ground robot and drone will move to their next location.

With a scanned map of a given area and the ability to move around, the robots need to know where they need to go next. This can be done using fiducial markers that give the robot or drone a location that they need to reach [4]. A marker is placed in the "image" of the field, giving the ground robot a distance that needs to be covered to make it to that point.

3.2 Related Work

Much background work has been done on the techniques and algorithms we will be working with to complete our project. We will be implementing the discoveries of documented research in robotic navigation using fiducial markings, sensor data, and terrain mapping via a 3D camera. These papers show problems that are applicable to autonomous robotics and how researchers in the field have solved them.

Dr. Karen Bradshaw and Luke Ross from Rhodes University have a research paper related to fiducial markers [2]. This paper shows the implementation of using robotic navigation and fiducial markers to find the most optimal route for a robot to move. The authors give insight to their design using algorithms, vision systems, and pattern recognition. Our group will aim to improve their work by testing and implementing new algorithms to find a more efficient path for movement.

Another research paper about sensor data and processing was done by Rajalakshmi Krishnamurthi and Dhanalekshmi Gopinathan from the Jaypee Institute of Information Technology, Adarsh Kumar from the University of Petroleum and Energy Studies, Anand Nayyar from Duy Tan University, and Basit Qureshi from Prince Sultan University [4]. Their paper dives into the problems of using sensors to collect data. They discuss how they use sensor data along with other data for rapid decision-making. Our project will differ from this slightly as it will be necessary to make rapid decisions, but communication needs to happen between the drone and robot, with their shared data they collected from their sensors.

Research has also been done in mapping a terrain using a 3D camera. This research was done by Justinas Miseikis, Kyrre Glette, and Jim Torresen from the University of Oslo, as well as Ole Jakob Elle from Oslo University Hospital [3]. Their research shows how 3D camera mapping could give a trajectory for a robot to travel. We will use the research of processing 3D images of a terrain for a map of the playing field. We will improve their designs by using the information from the images of the drone and data on board the ground robot to determine the best trajectory for our ground robot.

4.0 Approach/Design

4.1 Requirements and Design Goals

- Ground Robot Specifications
    - Only one ground robot will be allowed to compete (per team) each round. This ground unit must have a fixed landing pad located on the highest point of the robot.

The landing pad must be a minimum 20 x 20 centimeters. This unit must also be equipped with a master ON/OFF switch visible to a Field Judge [5].

- Ground robot sensors
  - On the ground robot we will need to use sensors to gather information and data to determine next movement. This will mainly be done using a stereo camera that gives us objects and their distance in the given field of the camera.
- Drone Specifications
  - Only one drone will be allowed to compete (per team) each round. Acceptable units include any commercially available (Ryze) DJI Tello model. No modifications to the factory propellers, propeller guards, motors, motor drive system, or batteries will be allowed [5].
- Communication between Ground and Aerial Units
  - Our units will need to be able to communicate with each other autonomously. These units will both require the ability to send and receive data communications. This will be done by Bluetooth and WIFI.
- QR Reading
  - Both units will need a method to read QR codes, as each of our objectives will have a different code on top and bottom. The inside of each box contains the ID number needed for the next objective, while the outside contains the box's ID number [5]. The drone will come equipped with a camera that will allow us to scan the outside of the box while the ground robot will need a vertically mounted camera to achieve this functionality [7].
- Route Mapping
  - After both units read the QR codes, the ground unit will need to calculate a possible route before enacting on it. The ground robot will take the data from the sensors located on both the ground robot and the drone. It will then process this data to determine the best route to traverse the course.
- Secondary "Poison" Objective
  - During the second round of the competition, two teams will be in the arena at the same time [5]. During this round, our ground and aerial units will need to complete the same tasks as before while also avoiding the opposing team. This round also adds an optional additional objective to the team that completes the course first. After completing the course, this team's aerial drone has the option to become "Poison." If the drone takes this objective, it will take off and search for the opposing team's ground unit. Landing on the ground unit's empty landing pad will end the round and cause the "Poisoned" team to lose all points collected in the round. If the total time for the round expires before either team is poisoned, there is no penalty awarded to either team.

4.2 High Level Architecture

4.2.1 Aerial Drone

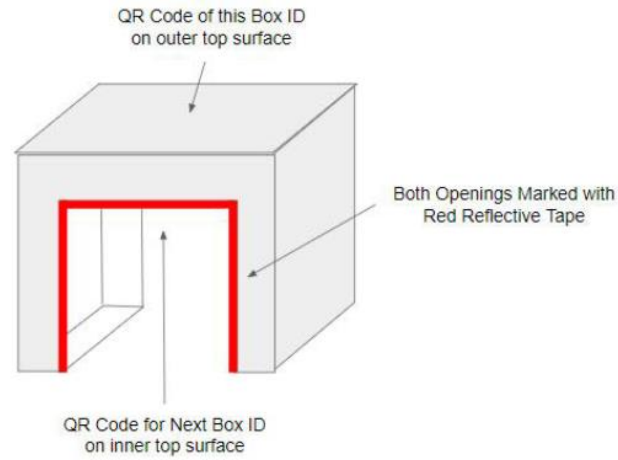
- For the drone, we will be using the Ryze Tech Tello Boost Combo. This package includes the drone as well as a few additional replacements and optional parts [7]. The drone itself is an RC Quadcopter with a 5MP Camera capable of 720p/30 HD video. This will be useful in mapping the arena as well as reading the QR codes involved in the competition. The flight time of this specific unit is 13 minutes, allowing our team to fly over the 10-minute round time.

- This drone's control unit is programmable through Python. The SDK included with the drone will allow us to customize the autonomous functionality of the unit. Ryze units come with a standard library that will allow us to interface with the drone and give it basic commands through pre-determined functions that we can adjust to the needs of the team.
- Additionally, this unit comes with propeller guards, four extra propellers, three batteries, and a charging hub.

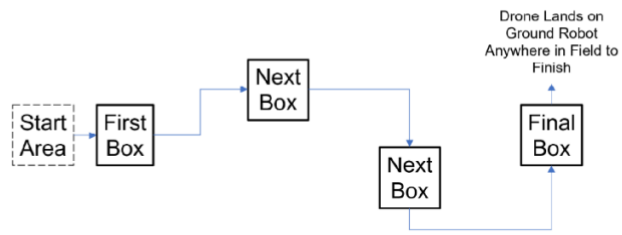
4.2.2 Ground Unit

- The ground unit will be much more personalized, as there are no model constraints.
- During the competition, the ground unit will be expected to enter and exit the objectives through 15x15 inch squares cut into two opposite sides of the box, thus limiting the max size of the unit [5].
- On the topside of the unit, there will be a 20 x 20 centimeter landing pad for the drone to land and take off from in between objective points. This pad must be flat with no indentations or protrusions larger than 1-millimeter and must not contain anything that would restrict a "Poison" drone from landing [5].
- Both the prototype and final designs will be controlled by an NVidia Jetson Nano, as this will allow for faster image processing than a Raspberry Pi. This FPGA board will oversee control of sensors in the unit as well as communications with the drone.
- The Nvidia Jetson Nano does not come pre-built with wireless communication, so we will be using Wireless-AC8265 Dual Mode Intel AC8265 Wireless NIC Module. This will allow communication between the ground robot and drone.
- Our current design utilizes an Intel RealSense Depth camera mounted to the front of the unit to help enter an objective. This camera will paint a picture from 0.5-9 meters.
- To cover the blind spot left by the RealSense camera, the ground unit will also be equipped with a Garmin LIDAR-Lite Optical Distance Sensor to detect both obstacles and objective entrances at a close distance.

- An LDROBOT D300 LiDAR Kit is a possible 360-degree replacement if the single point LIDAR proves ineffective.



- An upwards-facing camera will be mounted on the robot to read and communicate the QR codes located on the inside of the boxes.
- An odometer located near the wheels of the robot will be used to determine the distance covered by the robot. This will allow the robot to have a precise reading of its location on the field as it traverses objective to objective.



- Other location-based sensor options include SONAR sensors or light-based sensors for the finding outline of the objective entrances.

4.3 Risks

Risk	Risk Reduction
The drone landing on the robot incorrectly	The robot, per the prototype design, will take a slight pause before the drone attempts a landing.
The drone using inefficient Python language	Loops within the Python code will be limited to make the program as fast as possible
The robot hitting the entrance of the boxes	The sensors on the robot will ensure it correctly centers itself before entering the box.

The robot and drone have a break in communication	The robot will finish its last given command. Once that is complete, the robot will stop and attempt to reconnect. If the robot fails to connect after several retries it will have an LED to alert the operator.
Battery reliability	Extra batteries will be brought for both the robot and drone.
The robot will have limited computing power.	Well optimized code will be written for anything running on the robot.
Intel® RealSense™ Camera have blind spots for closeup objects.	Going to use LIDAR sensors detect anything that falls within the blind spots.
Angle of the drone's camera	We will program the drone to fly at an angle to ensure we can view the QR codes on top of the boxes.
LIDAR sensor has limited resolution	Planning on setting up the robot to be square with the box to minimize the chances of contact.
Mapping the field might not possible	Planning to build a test course and devising a different way to accomplish navigation if mapping is not possible.
Rotating LIDAR will be obstructed by parts of the robot.	The plan is to isolate the bad data and have a way to sample from the areas that have a clear view.

4.4 Tasks

1. Send intent to compete to IEEE
2. Understand rules of the competition and brainstorm possible solutions
3. Create an initial design to pick and order the parts necessary
4. Gain understanding of drone operation, such as how to use the SDK to control its movements
5. Learn about physical robot design
6. Learn ROS for robotic programming
7. Test stereo camera and LIDAR being used for the robot
8. Assemble a prototype robot
9. Implement HTTP in Nvidia Jetson to send commands to the drone over Wi-Fi
10. Use Tello SDK to send camera data from drone to the robot over Wi-Fi
11. Implement QR code reading functionality to received drone camera data
12. Add QR code reading functionality to camera mounted on the robot
13. Implement SLAM algorithms in drone to map surroundings
14. Implement MediaPipe to recognize boxes in video
15. Implement PyTorch machine learning to teach the robot how to avoid hitting the boxes
16. Do final testing and debugging
17. Compete

4.5 Schedule

Tasks	Dates
1. Send intent to compete to IEEE	10/2
2. Understand rules of the competition and brainstorm possible solutions	10/2-10/15
3. Create an initial design and pick and order the parts necessary	10/16-10/29
4. Gain understanding of drone operation	10/31-11/6
5. Learn about robot design	11/14-11/18
6. Learn ROS for robotic programming	11/21-12/2
7. Test stereo camera and LIDAR being used for the robot	12/5-12/9
8. Assemble a prototype robot	1/16-2/3
9. Implement HTTP in Nvidia Jetson to send commands to the drone over Wi-Fi	2/6-2/17
10. Use Tello SDK to send camera data from drone to the robot over Wi-Fi	2/20-3/3
11. Implement QR code reading functionality to received drone camera data	3/6-3/10
12. Add QR code reading functionality to camera mounted on the robot	3/13-3/17
13. Implement SLAM algorithms in drone to map surroundings	3/27-4/3
14. Implement MediaPipe to recognize boxes in video	3/27-3/31
15. Implement PyTorch machine learning to teach the robot how to avoid hitting the boxes	4/3-4/11
16. Do final testing and debugging	4/12-4/20
17. Compete	4/22

4.6 Deliverables

- Design Document: Contains a sketch of what the overall robot design will look like. Key design details with the reasoning behind them, a list of hardware that will make up robot itself. Lastly, this will include information on what software and programing languages we are planning to use, to give the robot autonomy.
- Website code: The website should be broken down into a static site and blog. The main page should give a general view of the project. We should aim to highlight key features and demos we want to show. On the blog portion we should share the milestones and give a more detailed and technical analysis of that portion of the project.

- Milestones: On our website, each milestone will have a blog post to accompany it. A milestone should include visual aids such as sketches, pictures, and videos. A brief write-up about the experiences and challenges faced during that milestone should also be included.
- Code: There will be Python code for anything the drone is doing due to the availability of an official SDK. The robot's main logic will be a mix of C, C++, and Python. The language will depend on what real time operating system we go with. The robot will have code for movement and object detection. Movement commands will be figured out from information given by the drone and sensors on the ground robot. Each waypoint will have a value that can direct the robot to the next segment.
- Final Report: Should be a deep technical overview of the entire project. Each milestone should be its own paragraph at least. Near the end it should focus on the results of the competition along with changes we wished we could make.

4.7 Use Cases

- Due to our project being designed for a specific competition, the overall project does not have many use cases. Though certain parts could be applicable in other cases.
- Autonomous robotics are become more prevalent as time goes on. These can be used for a variety of tasks ranging from factory and warehouse operations to space exploration.
- Drone mapping used in our project can be used to map a variety of locations like national parks, the Moon, and Mars.
- Another use case would be used in disaster relief efforts. An autonomous robot could be used to navigate tight spaces while searching for survivor.
- Delivery services could use autonomous drones and robots to delivery packages to various locations.

5.0 Key Personnel

Nicholas Brown – Brown is a senior Computer Engineering major in the Computer Science and Computer Engineering Department at the University of Arkansas. He has completed relevant courses such as Digital Design, Computer Organization, System Synthesis and Modeling, Software Engineering, and Programming Paradigms. He has experience prior to his college career in robotics and computer system design as a research assistant. Brown will be responsible for the architecture of the computer on board the ground robot, as well as the communication of the drone and the ground robot.

Callum Bruton – Bruton is a senior Computer Engineering major in the Computer Science and Computer Engineering Department at the University of Arkansas. He has completed relevant courses such as Computer Architecture, System Synthesis and Modeling, Software Engineering, Programing Paradigms, and Computer Organization. Bruton will be responsible for communication between the ground robot and the drone, as well as working on the computer processing on board the ground robot.

Jase Cornett – Cornett is a senior Computer Engineering major in the Computer Science and Computer Engineering Department at the University of Arkansas. He has completed relevant courses such as Computer Architecture, Embedded Systems, GPU Programming, Programming Paradigms, and Software Engineering. He has experience with an Automation Engineering internship at Texas Instruments. Cornett will be responsible for sensor data processing and movement of the ground robot.

Austin Flynn – Flynn is a senior Computer Science major in the Computer Science and Computer Engineering Department at the University of Arkansas. He has completed relevant courses such as Programming Paradigms, Software Engineering, and Computer Networks. He will be responsible for programming the autonomous movement of the drone and robot using computer vision and various sensors and the communication between them.

Stephanie Stock – Stock is a senior Computer Engineering major in the Computer Science and Computer Engineering department at the University of Arkansas. She has completed relevant courses such as System Synthesis and Modeling, Software Engineering, Computer Architecture, Programming Paradigms, and Embedded Systems. She has experience as an undergraduate research assistant. Stock will be responsible for drone communications with the ground bot and computer visions.

Dr. Jeff Dix – Dix is an Assistant Professor in the Department of Electrical Engineering at the University of Arkansas. He is co-advisor of the Robotics Interdisciplinary Organization of Teams, and he will be overseeing the progress made by the RIOT participants involved.

Mr. Robert Saunders – Saunders is the Assistant Department Head of the Department of Electrical Engineering at the University of Arkansas. He is co-advisor of the Robotics Interdisciplinary Organization of Teams and the sponsor for this Capstone project. We will be reporting our progress and justification for design choices to him.

6.0 Facilities and Equipment

The rules of the competition require the use of a Ryze Tello model drone [5]. The official specification of the drone states its detachable battery can power the drone for approximately 13 minutes of flight time and it can take 720p video at 30 frames per second with the equipped camera. It also has a built-in barometer, range finder, and 2.4 GHZ 802.11n Wi-Fi [7].

Through RIOT, we will have access to a variety of equipment tools, that will allow us to design the parts of the robot. This includes, but is not limited to a drill press, drill, and 3D printer.

Facilities that we will be utilizing for the project will be across the University of Arkansas Campus. These rooms, the Senior Design Lab, where we will design parts of the robots, the ELEG Lounge in Bell, where we meet with RIOT, and the Acxiom Lab where we have our Capstone group meetings, are where we will spend most time working on our project.

7.0 References

[1] A Beginner's Guide to Drone Mapping Software, https://www.dronepilotgroundschool.com/drone-mapping-software/

[2] Bradshaw K., Ross L., "Fiducial Marker Navigation for Mobile Robots", 2012

[3] J. Mišeikis, K. Glette, O. J. Elle and J. Torresen, "Multi 3D camera mapping for predictive and reflexive robot manipulator trajectory estimation", 2016 IEEE Symposium Series on Computational Intelligence (SSCI), 2016

[4] Krishnamurthi R, Kumar A, Gopinathan D, Nayyar A, Qureshi B. "An Overview of IoT Sensor Data Processing, Fusion, and Analysis Techniques", MDPI, 2020

[5] IEEE, "2023 IEEE Region 5 Annual Conference Rules for a Student Robotics Competition", 2022

[6] Map a Mars Rover Driving Route, https://www.jpl.nasa.gov/edu/learn/project/map-a-mars-rover-driving-route/

[7] Tello *Specs*, https://www.ryzerobotics.com/tello/specs