Colorado State University Senior Design Program

Project Title: Zeta

Autonomous Drone-Based Beacon Classification and Navigation System

Team Members:

- Ethan Le, Electrical and Computer Engineering
- David Templonuevo, Electrical and Computer Engineering

Supervising Professor: Dr. Chandrasekar
Industry Mentor: Dr. Fritz

Summary:

Project Zeta aims to design and implement an autonomous drone system capable of identifying and navigating toward distinct RF beacons operating in the 915 MHz ISM band. Using software defined radio (SDR) and machine learning based classification, the system will distinguish beacon signals, determine the beacon's location, and autonomously pilot the drone to it. Additionally, the drone will generate a map of the RF environment during flight, providing valuable situational awareness for defense, search and rescue, and field operations.

Why is This Project Important?

This project addresses the challenge of reliable RF beacon localization in environments where GPS or visual cues may be unavailable, providing a robust tool for defense, emergency response, and autonomous navigation.

Revision History

Date	Comments	Version	Approved by:
9/20	Initial Document	1.0	Ethan
9/25	Revised Document	1.1	David

Problem Statement

Autonomous drones are widely available but typically rely on GPS and vision based systems for navigation. In many field conditions dense forests, urban canyons, disaster zones, or jamming environments GPS and optical signals are unreliable. This creates a critical need for drones that can localize and respond to RF beacons, which can operate reliably even in challenging environments.

Background Research:

- **Commercial drones (DJI, Parrot, Skydio):** Optimized for GPS and camera-based navigation; no integrated RF localization.
- **RF localization systems:** Existing systems often rely on large antenna arrays or stationary equipment, not suitable for small UAVs.
- **Gap in the market:** No lightweight, low-cost drone solution exists for real-time RF beacon classification and autonomous flight toward identified beacons.

Zeta addresses this gap by integrating SDR-based classification, machine learning, and autonomous flight control into a single compact system.

Primary Objectives (S.M.A.R.T.):

1. **Autonomous Takeoff and Navigation:** Drone shall autonomously take off and fly to a beacon within 500 m in less than 3 minutes.
2. **Beacon Classification:** The system shall distinguish at least three different beacon signals with >95% classification accuracy.
3. **Localization Accuracy:** The system shall achieve ≤5 m error radius in 95% of trials.
4. **Failsafe Operation:** If beacon signal is lost, the drone shall safely return home or land within 30 seconds.
5. **Endurance:** The system shall operate for ≥20 minutes on a 6S 2200 mAh LiPo battery.

Secondary Objectives:

- Generate a real-time RF heat map as the drone navigates.
- Mitigate wind disturbances and sensor noise using filtering and control loops.

General Design Requirements:

- **Processor:** Must support GNU Radio and real-time ML inference.
- **Antennas:** Directional antennas tuned for 915 MHz.
- **Platform:** Lightweight drone frame with total payload capacity ≥ 1.5 kg.
- **Software:** GNU Radio, ML classification scripts, flight controller firmware.

Budget Justification

Component	Description	Estimated Cost ($)
Jetson Nano	Single Board Computer for ML model as well as sending signals to FC for autonomous flight	$249.00
6s 2200 mAH LiPo	Battery to power entire system	$80.00
Transmitter	In case CSU Drone Center can't supply a radio transmitter	$260.00
Patch Antenna	yes	$28.97
BP filter	Filter out noise	$0.95
Attenuator	Protect SDR	$0.12
SSD or SD card	To store heatmap	$21.99
LoRa Beacon	ESP32 integrated with a LoRa module	$19.90
Dipole Antenna	To transmit beacon signal	$19.49
1s Lipo	To power beacon	$8.54
SMA F-M	Connecting and mount antennas	$2.94
Magnetometer	What we'll use for orientation to pair with the signal strength when processing signal	$46
Filament PLA+	To house the beacon and support payload	$45

Budget Notes:

- Reserve funding allows for crash-related repairs or additional RF components.
- Purchasing will be coordinated by Ethan Le.

Proposed FMEA Table:

PROPOSED FMEA TABLE

Process Step	Potential Failure Mode	Potenetial Failure Effect	SEV1	Potential Causes	OCC2	Current Process Controls	DET3	RPN4	Action Recommended
What is the step?	In what ways can step go wrong?	What is the impact on the customer if the failure mode is not prevented or corrected?	How severe is the effect on the customer?	What causes the step to ho wrong (i.e. how could the failure mode occur)?	How frequently is the cause likely to occur?	What are the existing controls that either prevent the failure mode from occuring or detect it should it occur?	How probabale is detection of the failure mode or its cause?	Risk priority number calculated as SEV x OCC x DET	What are the actions for reducting the occurenece of the causes or for improving its detection? Provide actions on high RPNs and on severity ratings of 9 or 10
Signal Aquisition	SDR fails to capture beacon signal	Drone cannot classify or navigate	9	Antenna misalignment, SDR overload	4	Manual calibration, SDR gain monitoring	5	180	Add redundant antenna paths; automate gain control
Beacon classification	Misclassification of beacon type	Drone navigates to wrong beacon	8	Insuffcient training data, noise	5	Model validation, confusion matrix checks	4	160	Expand dataset, implement confidence threshold logic
Navigation	Beacon location estimated incorrectlly	Drone flies off course, potential crash	9	GPS loss, multipath interference	6	EKF sensor fusion, flight controller failsafe	6	324	Improve filtering, integrate IMU redundancy, refine conrol loops
Power system management	Battery drains unexpectedly	Drone crashes mid flight	10	Faulty battery, poor monitoring	3	Voltage telemetry, flight time estimation	3	90	Add redudant battery alerts, set conservative power margins
Failsafe return	Failsafe does not trigger	Drone lost or crashes	10	Software bug, hardware fault	2	Manual override, watchdog timers	4	80	Extensive testing of failsafe logic, add hardware based safety switch

1. Severity : Severity of impact of failure event. It is scored on a scale of 1 to 10. A high score is assigned to high-impact events while a low score is assigned to low -impact events

2. Occurrence: Frerqunecy of occurrence of failure event . It is scored on a scale of 1 to 10. A high score is assigned to frequently occuring events while eith low occurrence are assigned a low score

3 . Detection : Ability of process control to detect the occurrence of failure events. It is scored on a scale of 1 to 10. A failure event that can be easily detected by the process control is assigned a low score while a high score is assigned to an inconspicuous event

4. Risk priority number: The overall risk score of an event. It is calculated by multiplying the score for severity, occurrence and detection. An event with a high RPN demands immediate attention while events with lower RPN are less risky

Process Step	**Potential Failure Mode**	**Potential Failure Effect**	**SEV1**	**Potential Causes**	**OCC2**	**Current Process Controls**	**DET3**	**RPN4**	**Action Recommended**
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Proposed Risk Analysis:

#	Risk Event	Probability/100	Impact, weeks	Score, weeks	Effect	Risk Mitigation Plan	Person responsible for implementing control
1	Hardware delivery delays	30	3	0.9	Pushes back integration and test schedue	Place early orders; use reserve budget for alternate suppliers	Ethan
2	SDR/ML integration slower than expected	40	4	1.6	Delays classification testing	Start integration in parallel; assign backup developer	David
3	Drone crash during testing	20	5	1	Hardware loss, replacement needed	Conduct incrementall indoor testing; maintain spaare parts	David
4	Beacon interference in test environment	25	2	0.5	Reduced classification accuracy	Test in multitple environments; add shielding/filtters	Ethan
5	Team member unavailable	15	2	0.3	Reduced profress on assigned tasks	Cross train team members; maintain shared documentataion	Ethan
			Total risk :	4.3			

Project Timeline

Fall Semester (detailed, 2-week phases)

- **Weeks 1–2:** Requirements finalization, SDR + GNU Radio setup.
- **Weeks 3–4:** ML pipeline design, synthetic beacon data generation.
- **Weeks 5–6:** Hardware integration (SOC, SDR, antennas).
- **Weeks 7–8:** Indoor autonomy tests with simulated beacons.
- **Weeks 9–10:** Midterm checkpoint; refine ML models.
- **Weeks 11–12:** Outdoor RF localization tests (≤100 m).
- **Weeks 13–14:** Failsafe implementation.
- **Week 15:** Final fall semester presentation.

Spring Semester (higher-level phases)

- **Phase 1:** Advanced ML training and RF classification optimization.
- **Phase 2:** Long-range flight tests (up to 500 m).
- **Phase 3:** RF environment mapping integration.
- **Phase 4:** System validation with 95% accuracy benchmark.
- **Phase 5:** Final demo and handoff.

Conclusion

Project Zeta will deliver a drone platform that autonomously classifies, localizes, and navigates toward RF beacons while generating a real-time RF map of the environment. The design addresses a gap in commercial UAVs by enabling robust operations in GPS-denied or visually obstructed environments. Through careful planning, budgeting, and risk analysis, the team aims to complete the project within the allocated 9 months and $5000 budget, producing a reliable system ready for defense and search-and-rescue applications.