

Live Camera and Time-of-Flight Telemetry for an Ant-Weight Combat Robot

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Abstract

We are building an ant weight combat robot for the ECE 486 Battlebots competition. The robot is built upon a custom PCB using an ESP32-S3 that streams 640x480 JPEG video from the camera and four flight of time sensors to the driver station over WiFi. The driver station takes the data and draws the proximity ring on top of the video feed;.

We target 20fps with no more than 150ms latency from the video feed and range accuracy of $\pm 50\text{mm}$. The robot starts the drive and weapon commands on board its microcontroller, so if the wireless link is intermittent mid match, the robot doesn't stop moving. We also implemented a hardware link-loss cutoff that kills motor power within 500ms if the link is fully disconnected. For the best video feed result, we plan on creating a dedicated access point on the ESP32-S3 in the arena.

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Problem

This Project is an ant-weight battlebot under 2lbs for the Fall 2026 ECE 445 competition, where two robots fight in a plexiglass arena in the ECEB Atrium, controlled by a laptop driver station. We are scored on agility, control, and damage [1]. The rule also requires camera and flight of time sensor telemetry. Our robot needs to deliver these goals.

Solution

We plan on building a custom PC around the ESP32-S3 and 4 time flight sensors. The ESP32-S3 grabs the 640x480 JPEG frames from the on board camera and streams it over WiFi to the driver station. On the driver station, the time of flight sensors create a proximity ring overlay on the camera feed. The same WiFi link also sends the motor commands from the driver station to the robot. The robot will continue to drive when the video feed is slow or intermittent, however it will immediately shutdown if the link is completely lost.

The chassis and shell of the robot will be 3d printed with PETG. We chose PETG over PLA since it's strong but flexible enough to survive hits without cracking. We plan on printing the spinning disc in PA-CF filament. This filament is a high-performance 3D printing material made of nylon (polyamide) reinforced with chopped carbon fibers. This disc will be spun using a BLDC outrunner motor with a commercial ESC.

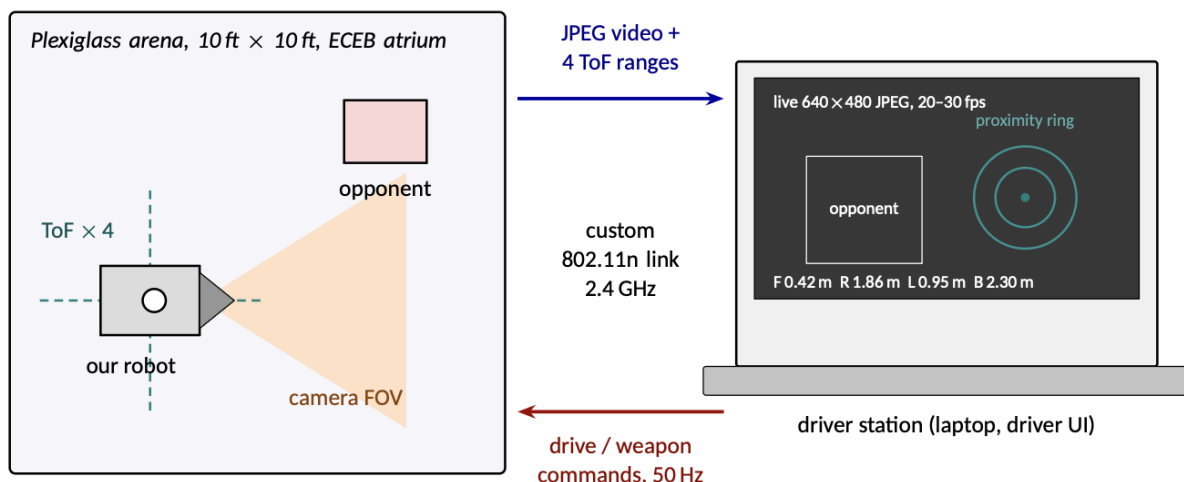


Figure 1

Visual aid of the robot in the arena and the data being streamed both ways.

High Level Requirements

1. The driver station needs to show a live 640x480 video feed from the robot with at least 20fps sustained for the full two minutes of the battlebots match in the ECEB atrium.
2. The driver station needs to draw the four time flight sensor data on top of the streamed video. Each within the range of ± 50 mm.
3. The robot needs to weigh under 2lb fully assembled with a battery. It needs to cut power from both drive motors and the weapon motor within 500ms of losing the connection to the driver station.

2. Design

2.1 Block diagram

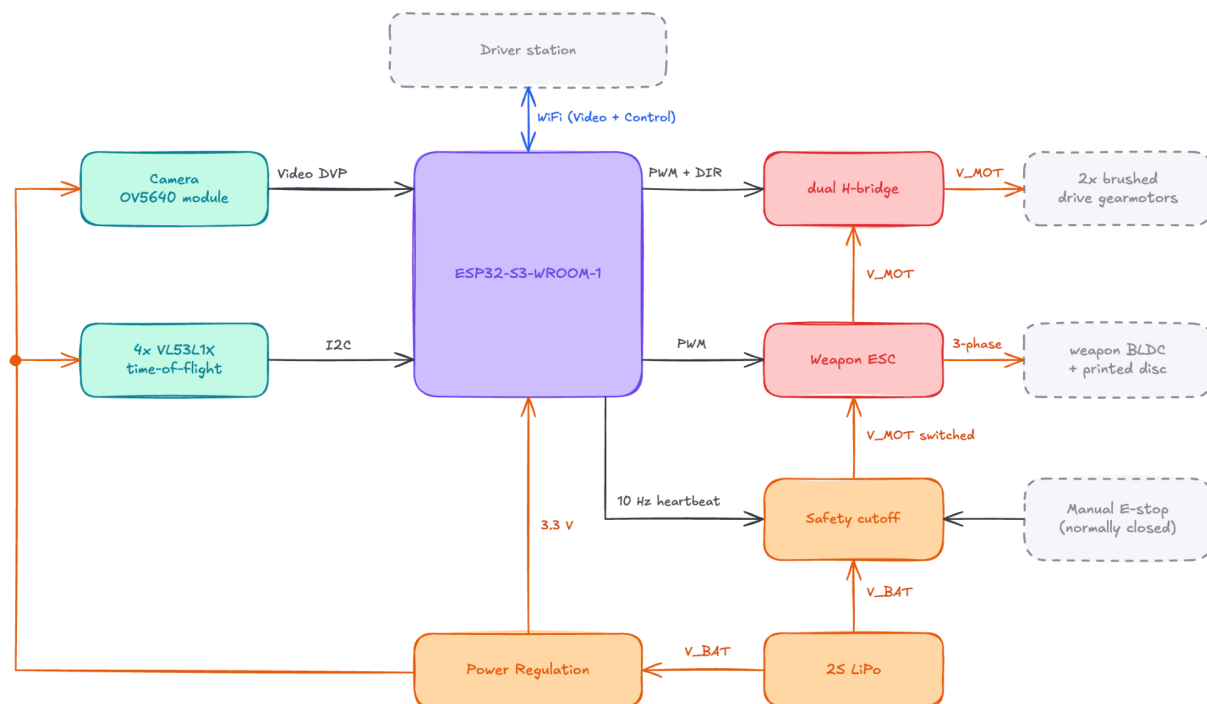


Figure 2: made with Excalidraw

Figure 2 shows the whole system. It shows the Camera and the 4 flight of time sensors, drive motors, weapon esc, power system, and the driver station.

There are 5 main connections to the ESP32-S3, DVP data line for the camera, i2c line for the 4 time of flight sensors, 2 pwm signals for the drive motors, a pwm signal for the weapon motor, and a wireless link over WiFi to the driver station.

There are two main power rails. Logic powerrail for the microcontroller and the sensors, and a powerrail for the motor systems. During an emergency/manual shutdown, the motor power rail will shutdown.

2.2 Physical Design

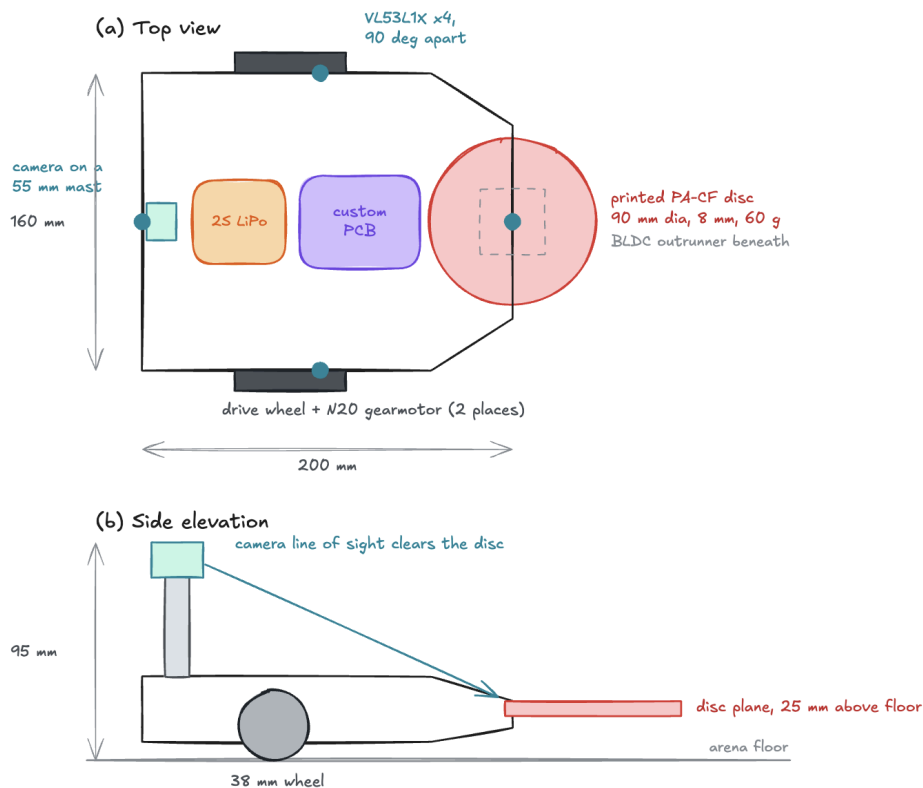


Figure 3: made with Excalidraw

Figure 3 shows the mechanical design of the 3d printed robot. The camera sits on the rear, angling down such that it can see over the rotating disc. The 4 flight of time sensors are placed 90 degrees of one another over each side of the robot.

Item	Mass (g) Estimate
Printed chassis, shell, mast (PETG)	250
Drive gearmotors, 2 × N20	70
Wheels, 2 × Ø38 mm	20
Weapon BLDC outrunner	32
Weapon disc, printed PA-CF	60
Weapon ESC, 30 A	10
Custom PCB, assembled	25
Camera module and mast hardware	12
4 × VL53L1X and harness	12
2S LiPo, 850 mAh	50
Fasteners, wiring, E-stop switch	40
Total	581
Margin to limit	327

Table 1

Shows the mass budget against the 2lb (908g) inspection limit

2.3 Subsystems

2.3 Subsystem Overview

The robot uses an ESP32-S3 as the main controller. It receives video from the onboard camera, reads four time-of-flight sensors, sends telemetry to the driver station over Wi-Fi, and receives drive and weapon commands in return.

The vision subsystem uses an onboard camera to provide a live view from the robot. The ranging subsystem uses four time-of-flight sensors placed around the chassis to measure nearby obstacles and provide distance information to the driver.

The actuation subsystem controls two drive motors and a brushless weapon motor. A hardware safety cutoff removes motor power if the wireless control link is lost or the emergency stop is activated.

A 2S LiPo battery powers the robot, with regulated supplies for the microcontroller and sensors. The driver station is a laptop application that displays the live video and range information and sends drive and weapon commands to the robot.

A rough cost estimate for the major components is:

ESP32-S3-WROOM-1: about \$8

OV5640 camera module: about \$10

Four VL53L1X time-of-flight sensors: about \$20

TB6612FNG motor driver: about \$5

30 A weapon ESC: about \$15

Two N20 drive motors: about \$15

BLDC weapon motor: about \$15

2S LiPo battery: about \$15

Voltage regulators and power components: about \$10

Safety cutoff components, MOSFET, and E-stop: about \$10

Custom PCB fabrication and assembly: about \$20–30

Wiring, connectors, headers, and miscellaneous electronics: about \$10

Wheels and small mechanical hardware: about \$10

3D-printed chassis and armor material: about \$10–20

The complete robot is therefore expected to cost roughly \$175–200, excluding the laptop and reusable lab equipment.

2.4 Subsystem Requirements

The system shall stream at least 640×480 video at 20 fps with no more than 150 ms latency.

The system will measure obstacle distance with approximately ± 50 mm accuracy.

The system will send drive and weapon commands from the driver station to the robot.

Motor and weapon power shall be removed within 500 ms of link loss or emergency-stop activation.

The complete robot shall remain below the 2 lb weight limit.

The system shall operate continuously for the duration of a two-minute match.

3. Conclusion

Three design consequences drop out of $C_{min} = 4.92$ Mbps.

The transport is supposed to drop frames, not queue them. Over TCP, a channel slower than the offered load keeps growing the send queue indefinitely. Latency grows, offering a smooth stream of video that is increasingly outdated, which is not useful compared to the most recent information about our location and the actions of our opponents. We therefore choose to send over udp with at most one frame in flight and and throw away any information less current than the most recent frame. The channel will always choose to compensate by losing frame rate in place of adding delay. Table 3 is the design's supposed degradation curve following from these variables.

To accomplish this we will require a quality controller. We will prioritize trading S for frame rate and adjust a quantizer to keep the in-flight time around one frame period. At QVGA fallback (res=320x240, S 10kb, 20fps) the load will fall to 1.6 Mbps to give us best-case control in the worst channel that we're likely to encounter. A 20 MHz 2.4 GHz channel gives 15–20 Mbps of application goodput, so $C_{min} = 4.92$ Mbps could brace about 70% of airtime being taken by other traffic before the frame rate requirement breaks.

A ranging read is circa 20 bytes including register addressing, which is roughly 190 clock cycles including framing; At 400 kHz gives 0.48 ms. 4 sensors x 50 Hz yields 200 transactions per second, giving 9.5% bus utilization. This means that the shared bus doesn't interfere with the 40 Hz-per-sensor requirement. The worst-case age of a range sample when a frame renders is one ranging period plus transport; inside the 100 ms alignment requirement of high-level requirement 2.

For a disc weapon of mass $m = 60$ g and radius $r = 45$ mm modelled as a uniform disc,

$$I = \frac{1}{2}mr^2 = 6.1 \times 10^{-5} \text{ kg} \cdot \text{m}^2, \quad E = \frac{1}{2}I\omega^2 = 48 \text{ J at } 12,000 \text{ rpm.} \quad (4)$$

At 7.4 V with a 15 A current and around 60% of electrical power reaching the disc as kinetic energy, $t = E/\eta P = 48/67 = 0.72$ s, less than half of the 1.5 s allowed by requirement A2. The 48 J figure is what drives the safety component of Section 3.2.

The monostable period is given by $t = 0.45RC$ with $R = 2.2 \text{ M}\Omega$ and $C = 0.33 \text{ }\mu\text{F}$, $t = 327$ ms. worst possible delay is 427 ms(100 ms link-loss detection window plus the monostable period). Allowing give or take 10% on both R and C gives a worst case of about 460 ms, inside the 500 ms of high-level requirement 3. This is admittedly close and we can verify timing on the physical prototype to adjust.

4. Ethics, Safety and Societal Impact

The first item of the IEEE Code of Ethics is the commitment to “hold paramount the safety, health, and welfare of the public” [2]. In order to take care of public safety, the weapon will be off at power-on, the motor cutoff will be hardware based so that a bug cannot threaten safety, and we won't activate the weapon anywhere that risks the safety of others.

The same section includes a commitment to be honest and realistic in stating claims [2]. All this

means is that we should be honest that every number in Section 2.4 is an estimate. We will report our numbers in the final document as we measure them and record honestly when we fall short of our own expectations.

The robot also carries a camera into a public atrium. The video is streamed point-to-point to the driver's laptop over our own access point, it's not recorded or retained beyond the match. In this scenario we believe that we meet a standard of reasonable privacy given that attendees are aware that the robots will use cameras in some capacity.

Safety

From equation (4), the disc could use about 48 J at 12,000 rpm making it the most dangerous aspect of the bot. The way we address this is as follows: the disc only spins inside the arena or a closed containment fixture since the weapon is disarmed by default at power-on and needs an explicit arm command, and nobody will touch the robot until the connector is physically removed (not just when software says disarmed). The same will apply in testing.

A robot that keeps driving or attacking is the primary danger of the competition we are required to prevent [1][3]. See hardware cutoff from Section 2.3.4, with timing verified in Section 2.5.3 at a worst case of about 460 ms against the 500 ms requirement. Every failure we can imagine from the provided design would end in the motor turning off.

The battery pack could also be dangerous outside the arena, so we'll make sure we store it at storage voltage and keep it away from fire hazards and not charge unattended. We will make sure to dispose of damaged or dysfunctional batteries in the manner mentioned in our required safety training.

We will follow the lab safety guidelines in the Senior Design Lab safety assignment and printed on the lab walls and manuals in all tasks we do.

Future Work

Future work could use this platform beyond combat robotics to inform teleoperation for dangerous inspection and disaster-response applications. Because the design relies on cheap parts, a single microcontroller, and 3D-printed body, it could also serve as an affordable robotics plan in education. In general, our project provides a practical way to teach real-world constricted power electronics, RF communication and embedded systems that many students only see in streamlined homework problems until they enter the workforce.

Climate considerations could also be a direction to look towards. Replaceable armor panels already limit the amount of material discarded after damage, however we could think more about battery choices and eco-friendly materials.

References

- [1] V. Gruev, "Ant-weight, 3D printed Battlebots competition," ECE 445 course materials, Univ. of Illinois Urbana-Champaign, Fall 2026.

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