Guided Nautical Rescue & Emergency Assistance (GNREA) Drone

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http://www.ece.cmu.edu/~ece500
/projects/f24-teama6

Product Pitch

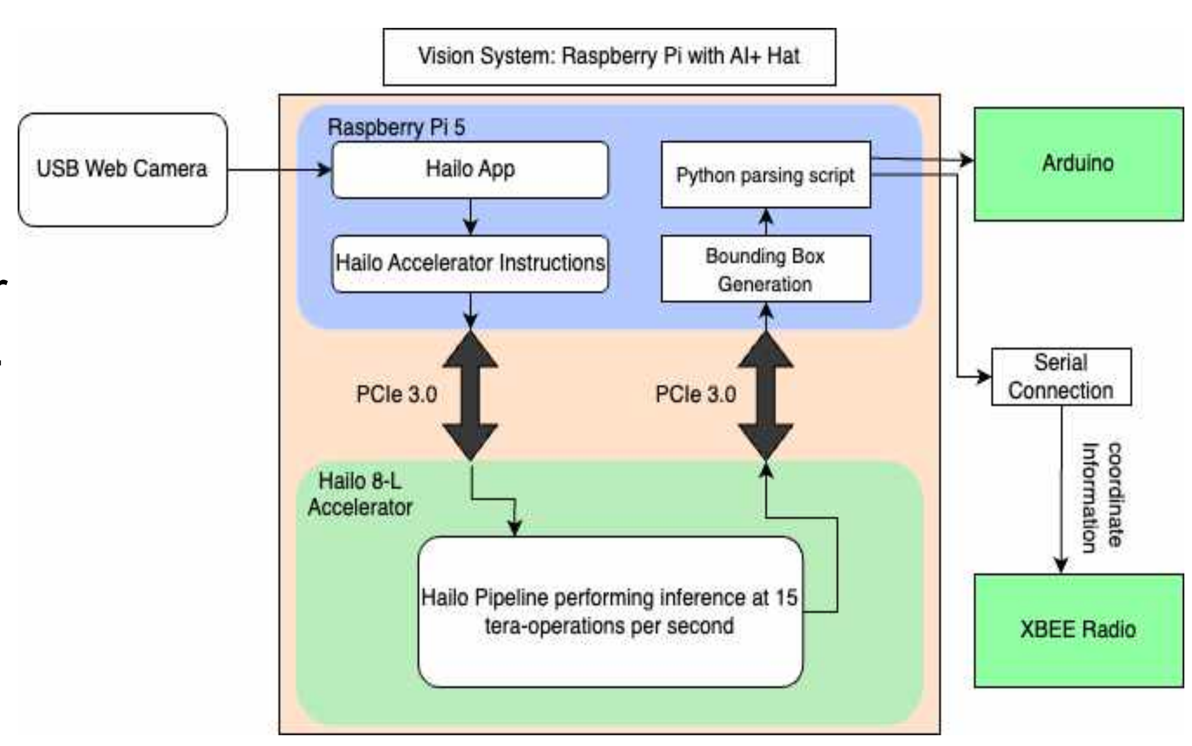
Search and rescue operations (SAR) over the ocean often face significant logistical and resource challenges. The large search areas coupled with a lack of manpower often lead to increased search times and increase the likelihood of a failed operation. Moreover, traditional methods such as manned helicopters and boats are a financial burden and require a lot of resources.

To address these SAR challenges, we aim to develop an affordable, autonomous drone equipped with a robust PID based control system, machine learning methods to autonomously identify and track individuals, and transmit coordinates back to rescue team members.

System Architecture

Vision Subsystem:

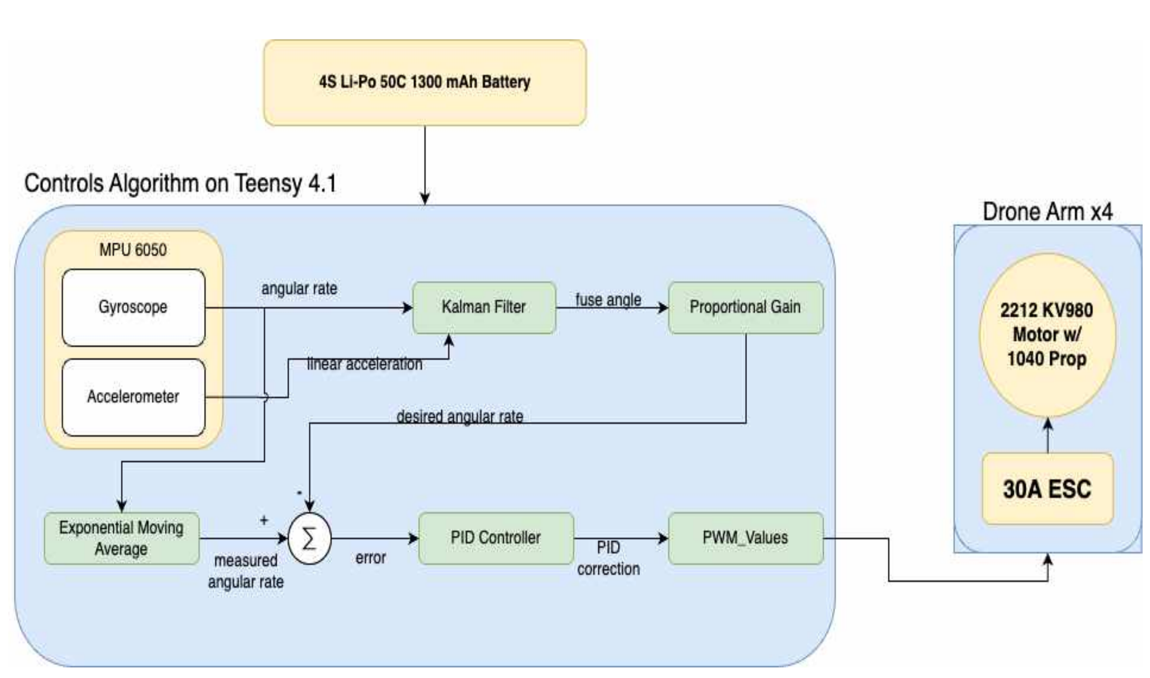
From the diagram, camera data goes from the webcam into the Raspberry Pi. That information is sent, along with instructions for the accelerator to the Hailo 8-L AI accelerator. At the Hailo accelerator, the chip will run the inference at a rate of 15 tera-operations per second, which leads to about 30 millisecond inference time on a 480 x 480 pixel image.



Finally, the bounding boxes for the desired item are sent back to the Raspberry Pi 5, where the coordinates of the box are sent over Serial to the Xbee radio. There is also a Serial connection with the Arduino, over which instructions for which direction the drone needs to move to center the item.

Drone Subsystem:

In order to keep costs down, we decided to create our own Arduino-based flight controller. To get this working, we used a rate-control PID in pitch and roll to control for any deviations from stable flight. To accomplish this, we need some measure of the drone's orientation. We used an integrated gyroscope and accelerometer onboard the MPU-6050 combined with a Kalman filter to achieve drift-free measurements.



The gyroscope provided noisy angular rate measurements which we noticed introduced high-frequency oscillations into our drone's PID system. As a result, to smooth this noise out, we implemented an Exponential Moving Average filter that worked quite well (see picture in System Evaluation). The PID for both roll and pitch were first tuned on a stand that restricted drone movement in just one axis, allowing us to tune the gain values independently. We then put these systems together for a hover test in the drone cage and achieved a stable hover.

Conclusions & Additional Information

Assessment: Overall, while we were not able to create a product that fully met all our requirements, we are very proud of the progress we were able to make and are confident that with more time we'd be able to create a fully functional product. Although we were able to develop a drone that can fly, as well as an optimized vision system that can detect people at 30Hz, we did not have enough time to properly integrate the systems. Throughout this project, we learned a lot about control theory, hardware design, accelerated machine learning, and general project management.

Lessons Learned: We learned the importance of consulting experts to learn more about the subsystems to minimize avoidable risk. Also, having a very heavy emphasis on design from the start helps to consider all factors and prevents small issues from snowballing. Finally, we learned to not give in to the temptation to jump to solutions without identifying the underlying problem.

System Description

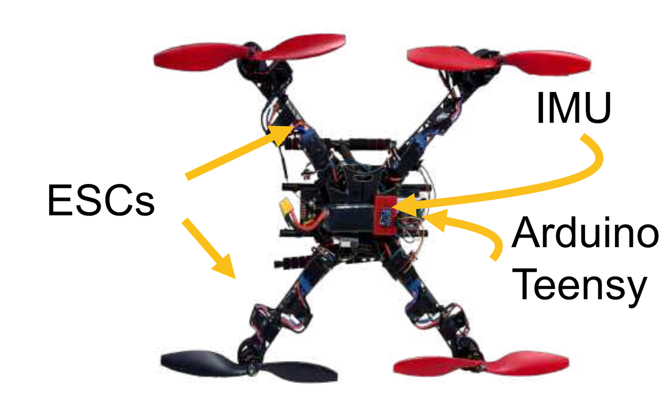
Drone Controller: PID-based controller that is fine-tuned for precise movements, stability and responsiveness during flight.

Navigation System: Employs a lawnmower algorithm to systematic scan the search area. The drone autonomously moves between checkpoints until the object is detected.

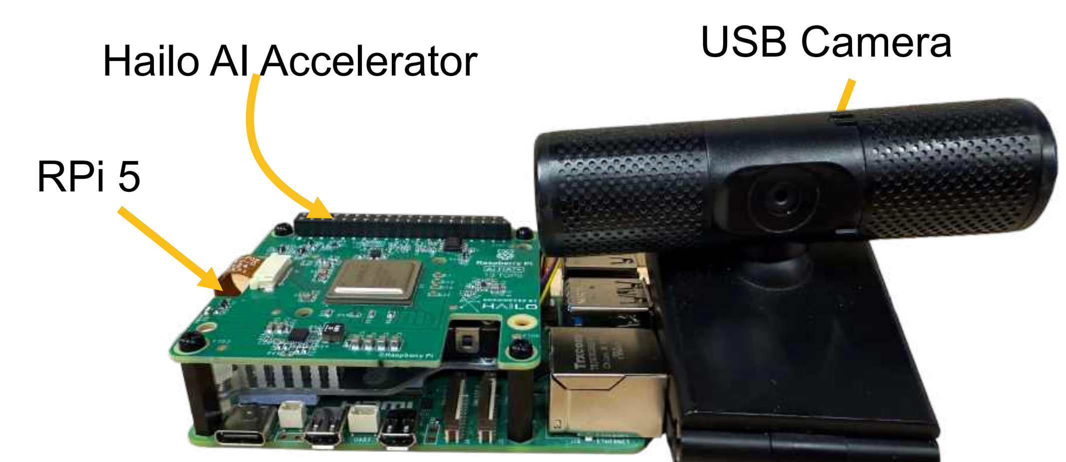
Computer Vision Detection: Deployed a quantized, Hailo optimized YOLOv8n model running on the Rpi5 with a Hailo AI accelerator. The model efficiently detects objects in real-time, balancing speed and accuracy.

Tracking System: Utilized computer vision (CV) detection output to guide the drone's movements. Implements a center-to-frame algorithm that determines the direction needed to keep the detected object centered within the camera's frame.

Radio Communications: We utilized two XBee X2 radios configured in a point-to-point setup. The radio sends bytes encoded in UTF-8 with information about object coordinates.



Drone System



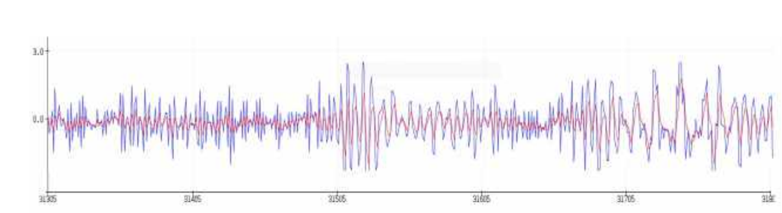
Vision System

System Evaluation

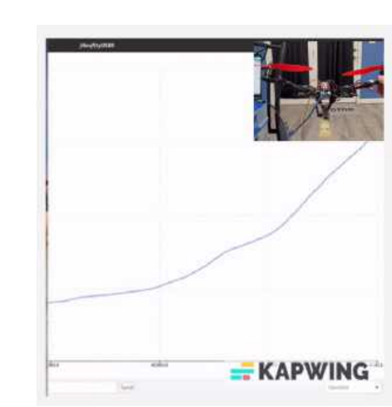
Drone Controls Testing:

Sensor Calibration + Drone Controls Controls

PID tuning on drone flight



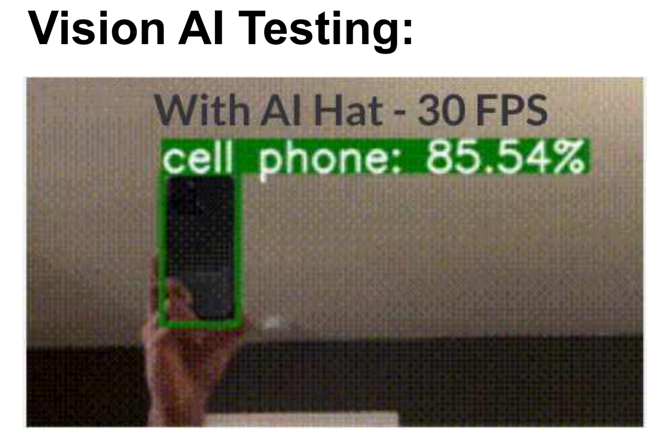
Exponential Moving Average Filter



Drift Stabilization

To test the drone, we created a rig to constraint the drone in its various axes. This allowed us to rigorously test our control software and perform PID tuning.

Vision AI Testing:



Object detection at 30 fps

Object tracking based on frame position & controlling the drone

To test our vison system, we placed various objects at different depths in front of the camera to measure its accuracy. Moved objects around the frame to evaluate tracking controls.

Use-Case Requirements:

Metric	Target	Actual
IMU Drift	No drift in >1 min	No Drift in >5 min
Drone Controls	Stabilizing on 3 axis	Stable on 3 axis
Movement Controls	Move in 3 axis	Controllable in 3 axis
Object Detection	≥ 90% Accuracy	91% Accuracy
System Notification	100% Transmission	100% Transmission
Tracking Rate	80% Tracking rate	92% Tracking Rate

Design Tradeoffs:

Design Choice	Tradeoff	Improvement	Sacrifice
Object Detection Model	Background extraction vs ML vision model	75% accuracy improvement	Higher computational resources
Object Detection Hardware	Hailo 8-L Accelerator instead of Kria KR260	15x processing improvement & lighter weight	About the same power consumption
Drone controls	Off the shelf drone controller vs hand tune	Lower cost & open-source software	Harder to implement and tune.

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