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Gimbal Unit for UAS – Real Time TSPI Generator

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White Sands Missile Range

Mission/SOW

Task: WSMR requested our capstone team to design, develop, and prototype a lightweight gimbal unit for integration with the DJI Matrice RTK Drone.

The system was required to:

- Weigh less than 15 lb.
- Integrate a wide FOV camera, zoom camera, thermal camera, and a laser rangefinder.
- Includes user-defined object selection, allowing the operator to select and box a target of interest within the video feed.
- Utilize a custom video tracking algorithm to generate TSPI at 20 Hz for a tracked target.
- Capable of storing on board and transmitting the TSPI data.

Our team developed a modular, multi-sensor gimbal system that reliably tracks moving targets in real time. This project emphasized performance, reliability, and seamless integration with WSMR's existing platforms.

Research

- **Gimbal Stabilization and Dynamics**: Investigated gyroscopic stabilization principles and multi-axis gimbal configurations (pitch, yaw, roll) to ensure precise orientation and smooth tracking under variable flight conditions.
- **Sensor Integration**: Researched the operational characteristics of thermal cameras, laser range-finders, wide-angle, and zoom cameras, with a focus on optimizing their placement for uninterrupted data acquisition.
- **Time Space Position Information (TSPI) Generation**: Studied the STANAG 4601 (ST-0601) format used by the Department of Defense for real-time telemetry, enabling seamless data transmission from UAV to ground station.
- **Video Tracking Algorithms**: Evaluated several real-time object tracking approaches using OpenCV, leading to the development of a custom Python-based solution for identifying and tracking moving targets and generating TSPI at 20 Hz.
- **Drone Systems and Onboard Computing**: Analyzed existing UAS platforms and edge computing systems, including Raspberry Pi 5 and Pixhawk, to handle onboard data processing, sensor fusion, and motor control.

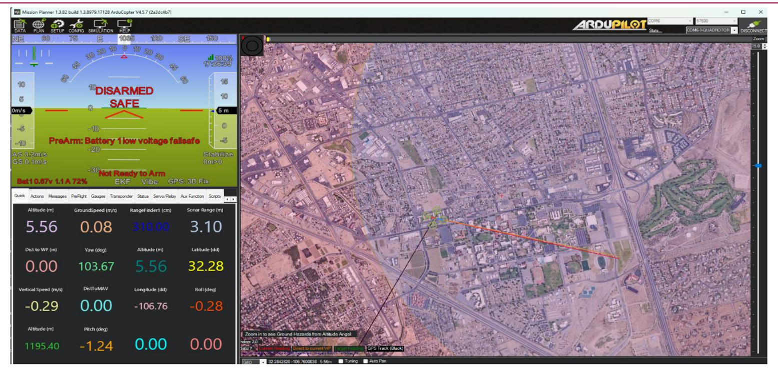
Final Design

```python
from pymavlink import mavutil
import csv
from datetime import datetime

# 👇 This line is critical: it connects to the Pixhawk!
master = mavutil.mavlink_connection('/dev/ttyAMA0', baud=57600)

# Wait for the first heartbeat from the vehicle
master.wait_heartbeat()
print("Connected to system:", master.target_system)

# Open a CSV file to log GPS data
with open("gps_log.csv", mode="w", newline="") as file:
    writer = csv.writer(file)
    writer.writerow(["Time", "Latitude", "Longitude", "Altitude"])

    # Continuously read GPS data
    while True:
        msg = master.recv_match(type='GPS_RAW_INT', blocking=True)
        if msg:
            timestamp = datetime.utcnow().isoformat()
            lat = msg.lat / 1e7    # Convert to degrees
            lon = msg.lon / 1e7
            alt = msg.alt / 1000 # Convert to meters
            writer.writerow([timestamp, lat, lon, alt])
            print(f"{timestamp} | {lat}, {lon}, {alt}")
```

Python script that transfers GPS data from the Pixhawk to the Raspberry Pi to generate real-time TSPI.

DJI Matrice 300 RTK

Side view of the physical gimbal unit showing the dual-axis stabilization mechanism.



Mission Planner software providing real-time feedback on aircraft state, GPS lock, sensor health, and orientation.

Video Tracking Subsystem

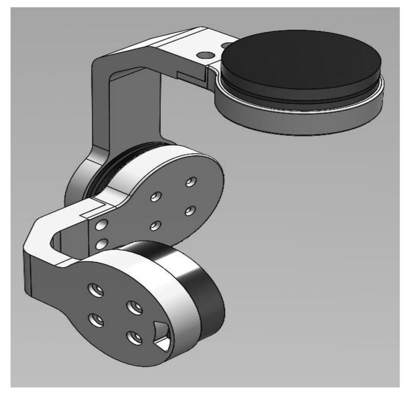
Purpose: Enable the gimbal to follow and generate TSPI data points for a selected target.

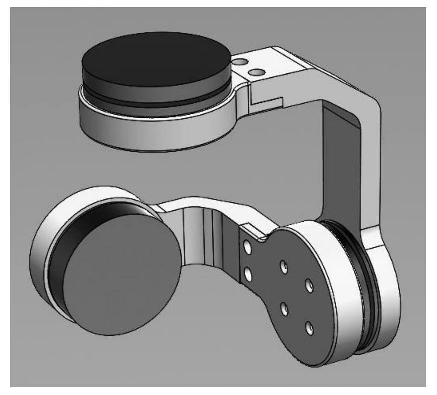
- **Image Processing**: Live video frames from the gimbal-mounted camera are pre-processed to enhance clarity. Frames are resized, converted to grayscale, and filtered to reduce noise—improving visibility of key features for selection.
- **Object Selection**: Not knowing what objects will need to be tracked, the algorithm was designed to allow the user to select the target. Once selected, a bounding box is placed around it, confirming that the target is locked.
- **Target Tracking**: Once selected, the system applies the *CSRT (Discriminative Correlation Filter with Channel and Spatial Reliability)* algorithm. This tracking method continuously updates the object's position, even when partially obscured or in motion.
- **Calculation:** 3-step process
  - *Determine the position of the Gimbal* – Uses the Pixhawk and the Here3 GPS, which is mounted on the gimbal.
  - *Determine distance to the object* – Utilizes the laser range finder, which is mounted to the gimbal and pointed at the target.
  - *Combine the first two parts* – Mavlink allowed the Raspberry Pi to interface with the Pixhawk to bring in all the above information and calculate the TSPI points for the target.

Mechanical Test Results (Motors)

Purpose: To evaluate the mechanical stability and motion control of the gimbal, the motors were tested for responsiveness, torque consistency, and smoothness of motion.

- **Motor Selection**: The team selected iPower GM5208-24 brushless gimbal motors due to their high torque-to-weight ratio ideal for stabilization tasks.
- **Range of Motion**: Each axis was tested independently to confirm full rotation capability within the desired limits. The gimbal achieved sufficient pitch and yaw.
- **Responsiveness Testing**: Motor response to algorithm-generated orientation commands was tested using manual inputs and simulated tracking data. The motors demonstrated minimal lag and stable movement, essential for real-time object following.
- **Vibration and Load Testing**: Preliminary load testing confirmed that the motor and mounting structure could support the sensor weight without excessive vibration or drift, maintaining orientation under simulated drone conditions.





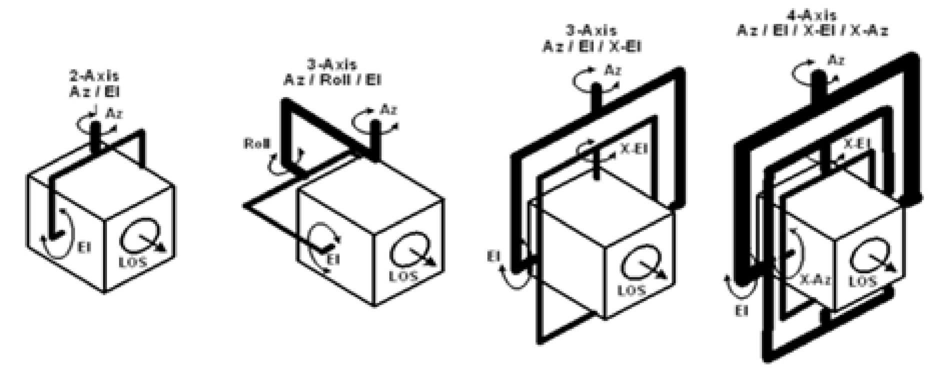
Concept Development

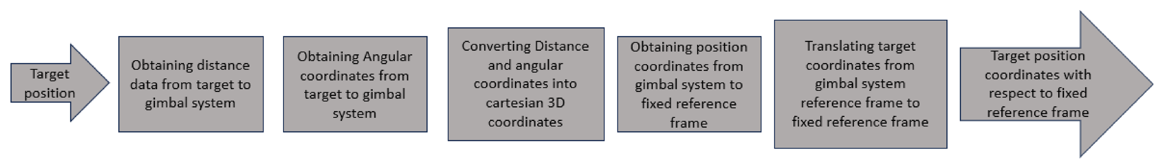
The design phase began with evaluating weight constraints, gimbal motion, and sensor selection requirements.

Design Concepts Considered:

- **Material Selection**: Selected Polylactic Acid (PLA) and Carbon Fiber materials to ensure the full gimbal unit remained light weight without compromising structural strength.
- **Multi-Axis Stabilization**: Designed a 3-axis gimbal (pitch, roll, yaw) to ensure smooth target tracking in dynamic flight conditions.
- **Sensor Integration**: Evaluated placement and orientation for a wide FOV camera, zoom camera, and laser rangefinder to ensure unobstructed fields of view.
- **Custom Video Tracking**: Implemented a Python-based OpenCV algorithm to track targets in real time and generate TSPI at 20 Hz.

The final design reflects a balance between electrical integration, algorithmic control, and mechanical performance to ensure real-time aerial tracking capabilities.





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