GPS Denied Drone Navigation

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Mission Motivation

- Hostile environments can jam/spoof GPS data, making it harder to control an aircraft without positional data.
- ANPC's Transponder Landing System provides positional data based off of an aircraft's transponder pings which can be used for positional guidance.
- Currently only works on commercial/military aircraft, but can theoretical be used with autonomous aircraft

GPS Denied Navigation Solution

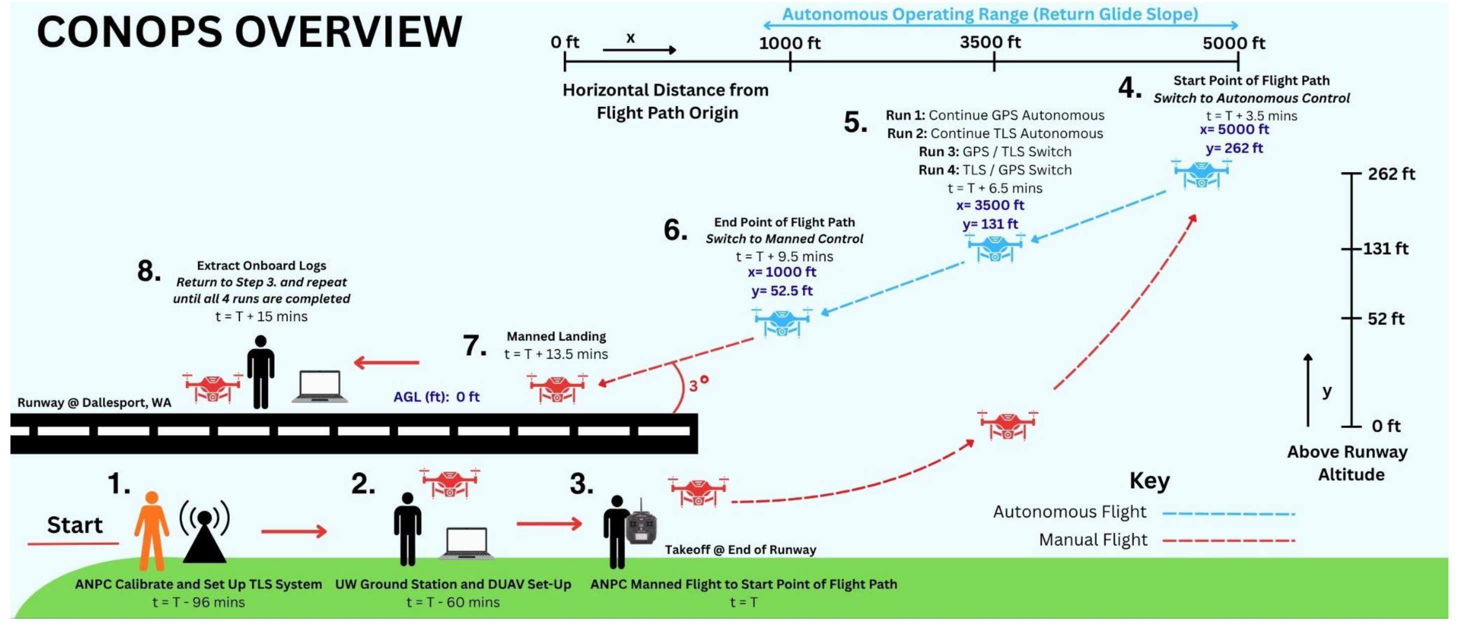
- ANPC develops a proprietary navigation system called Transponder Landing System (TLS)
- TLS is a replacement for a traditional Instrument Landing System (ILS)
- ILS occupies a large radio bandwidth to display a glide slope for a pilot
- In a GPS denied environment, TLS will interrogate the aircraft transponder and receive a squawk code back
- The TLS then uses an antenna array to triangulate the position of the transponder and transmits the position back to the aircraft to display a glide slope
- TLS is currently deployed to places where and ILS setup may not be feasible due to space limitations
- Our mission is to use the TLS to autonomously navigate a drone

CONOPS and Mission Objective

Our Mission Objective is defined as follows:

To demonstrate that **ANPC's Transponder Landing System** can be used for drone navigation, by developing a **navigation algorithm** with a **GPS-TLS toggle** that can safely and **autonomously control** a drone in a **GPS-denied environment**, with a **1000-5000 ft range** at an altitude of **100-400 ft AGL**, while keeping within **±30 ft of the flight path**, and keeping the navigation equipment **payload weight under 2 lbs**.

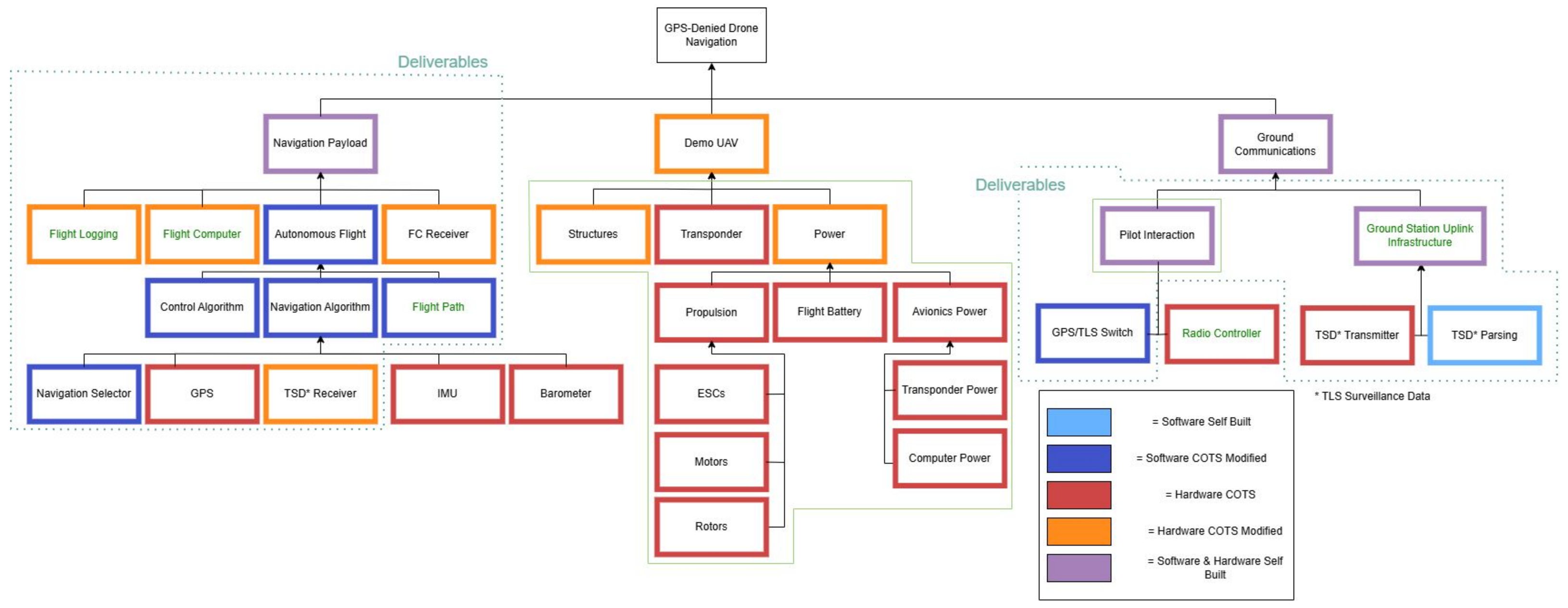
From this Mission Objective, our CONOPS was derived as shown below:



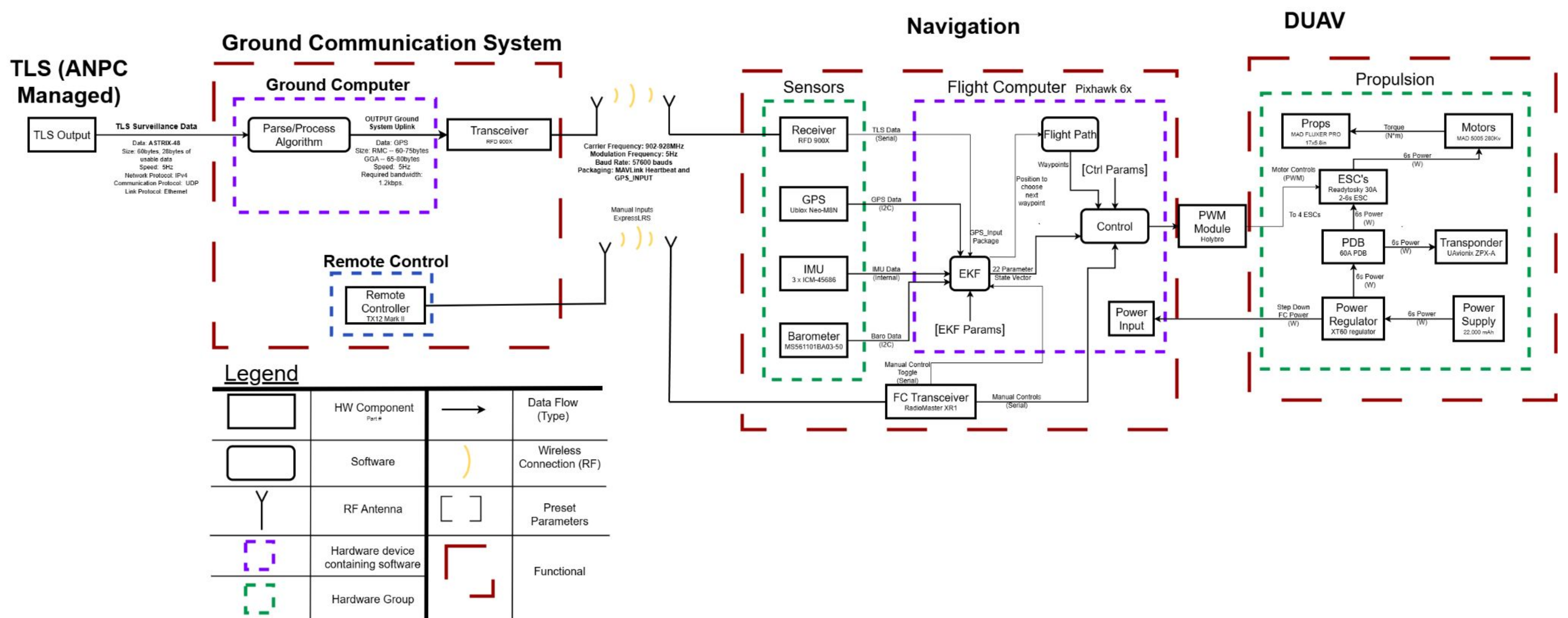
Implementation

- Build a 650mm quadcopter with a flight controller running ArduPilot
- Tune quadcopter control algorithm
- Tune Extended Kalman Filter for autonomous navigation
- Add autonomous waypoint navigation to quadcopter controller
- Install a UAVionics ADS-B Transponder.
- Design and integrate a wireless link that can relay TLS positional data from a ground station to the quadcopter during flight.

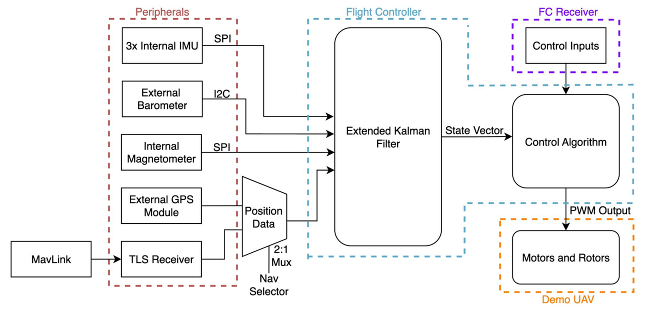
System Architecture and Subsystem Architectures



System Architecture Overview

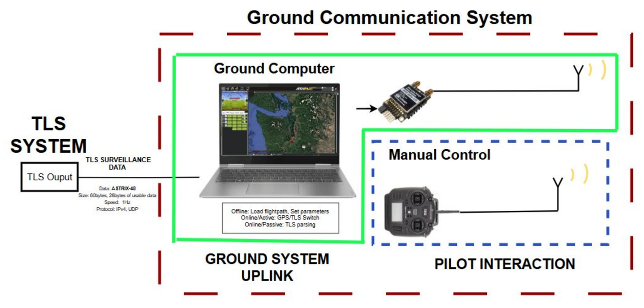


System Signal Overview



Navigation Algorithm Subsystem Architecture

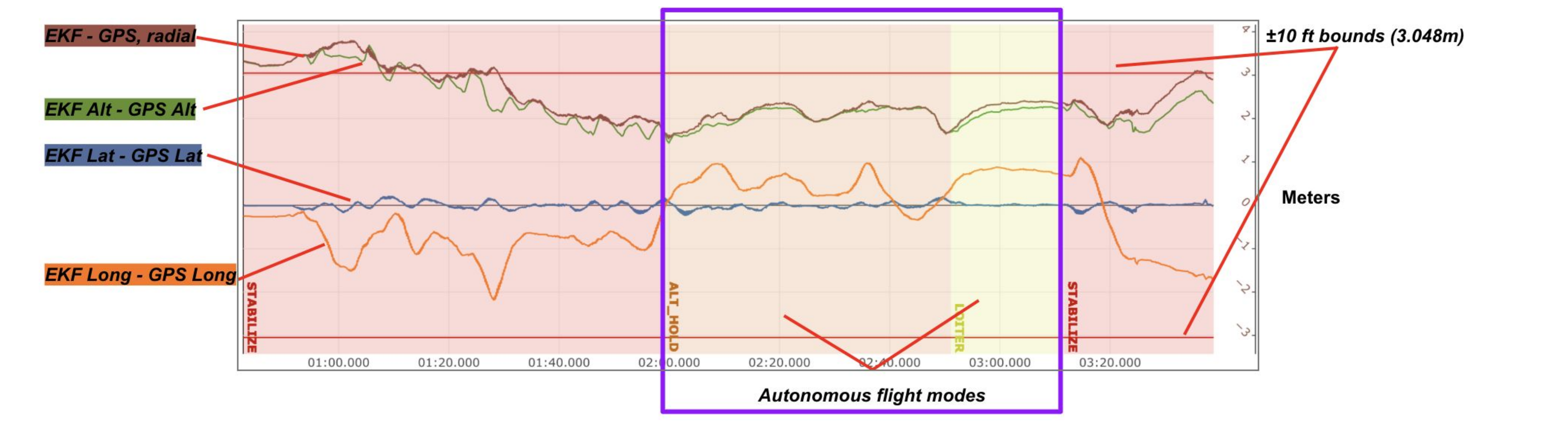
Demo UAV Subsystem Architecture



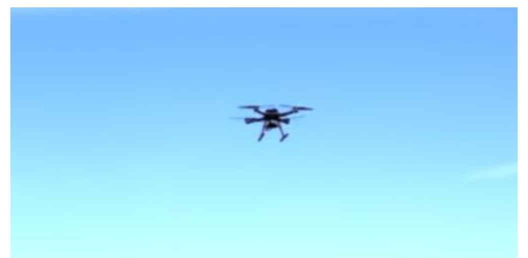
Ground Communication Station Subsystem Architecture

Testing and Analysis

- The Demo UAV, Extended Kalman Filter, Control Algorithm, and Ground Communication Station subsystems were each tested individually before full integration
- Tests were verified based on system and subsystem requirements
- Preliminary benchtop tests were first conducted, and systems began integrating from the bottom of the architecture up, leading to in flight testing and analysis



- Example EKF performance analysis and verification over various flight modes, ensuring ±10 ft positional accuracy **(Above)**
- All software and sensor subsystems were verified in this manner
- Example flight test, in this instance testing autonomous GPS navigation **(Right)**
- Testing frequently lead to the damage of drone components, which was solved by 3D printing pieces for expedited turnaround



Results

- Subsystem requirements were all met through testing and analysis
- Control Algorithm was proven to stably control the drone through winds up to 16 kts
- Extended Kalman Filter was proven to integrate sensor data and estimate position to within 10 ft positional accuracy
- Demo UAV was proven to carry 2 lbs. payload, sustain flight beyond the demonstration flight time, and autonomously navigate using GPS
- Ground Communication Station was proven to parse TLS data and transmit to the flight computer
- Full System Integration was a success and verified through simulation
- The system was able to meet all of the System Requirements in simulation
- Final system demonstration at the ANPC Dallesport Airfield showed field verification with full TLS integration

Future Work, References, and Acknowledgments

- Future scalability of this UAV will include autonomous calibration of TLS
- The authors would like to thank Amir Taghvaei for his lecture series on Extended Kalman Filters, and Doug Chappelle for loaning drone parts and a frame. We also thank ANPC for their technical support and for loaning a transponder, uAvionix for their technical support.

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SPONSOR: ANPC - Advanced Navigation and Positioning Corporation