Autonomous Navigation of Quadrotors in GPS Denied Environments

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ABSTRACT

UAVs depend on GPS technology to accurately describe their position, and navigate to their objectives successfully. However, GPS systems can be rendered useless by modern signal jammer technology. Much research has been conducted to develop robust control systems for quadrotor formations. Most of this research requires off-board sensing to build an environmental map of the formation. In this work we demonstrate a formation control and waypoint navigation technique for quadrotors, using on-board sensing and off-board processing. We demonstrate the usage of on-board vision processing to construct a map of the environment and the formation's location in the environment. Our hardware platform is the Parrot AR Drone, which has a vast sensor suite including two on-board cameras, an inertial measurement unit, compass, and ultrasonic range-finder for altitude measurement. The drones are controlled using National Instrument's Labview 2011, and commands are issued wirelessly via a 802.11 WIFI network.

AIMS OF THE WORK

1. Develop a fully autonomous quad swarm, only using onboard sensors available on a commercial-grade quadrotor, capable of maintaining a determined formation, localizing itself in 3-d space, and navigating a given trajectory while avoiding obstacles

2. Successfully apply existing vision and control techniques, such that the system completes its mission independent of external ground-truth measurements.

RESEARCH PLATFORM

HARDWARE

The Parrot AR Drone 1.0[3]

On-board sensor suite:

-640x480 93° front-facing camera

-176x144 64° down-facing camera

-Ultrasound altimeter (up to 6 meters)

-6 DoF MEMS IMU suite:

- -3 axis accelerometer
- -2 axis gyroscope
- -1 axis yaw gyroscope

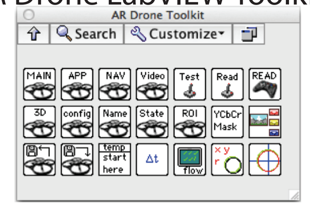
SOFTWARE

-Development on LabVIEW 2011[5]

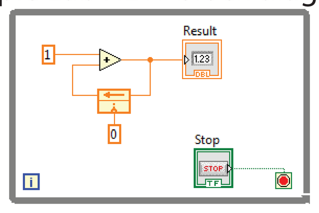
- -AR Drone LabVIEW Toolkit[4]
- -IMAQ Libraries

-Deployed on Dell Latitude E6400

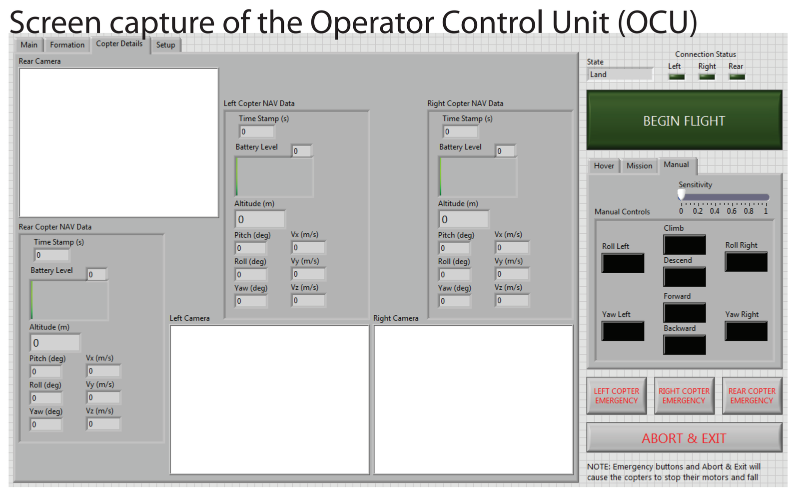
AR Drone LabVIEW Toolkit[4]



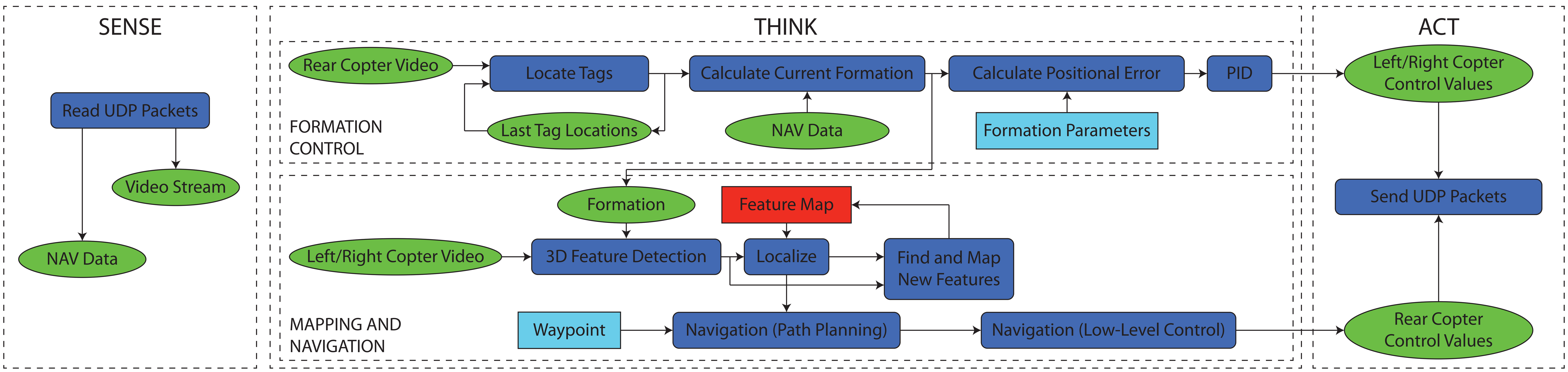
Simple LabVIEW block diagram



Screen capture of the Operator Control Unit (OCU)

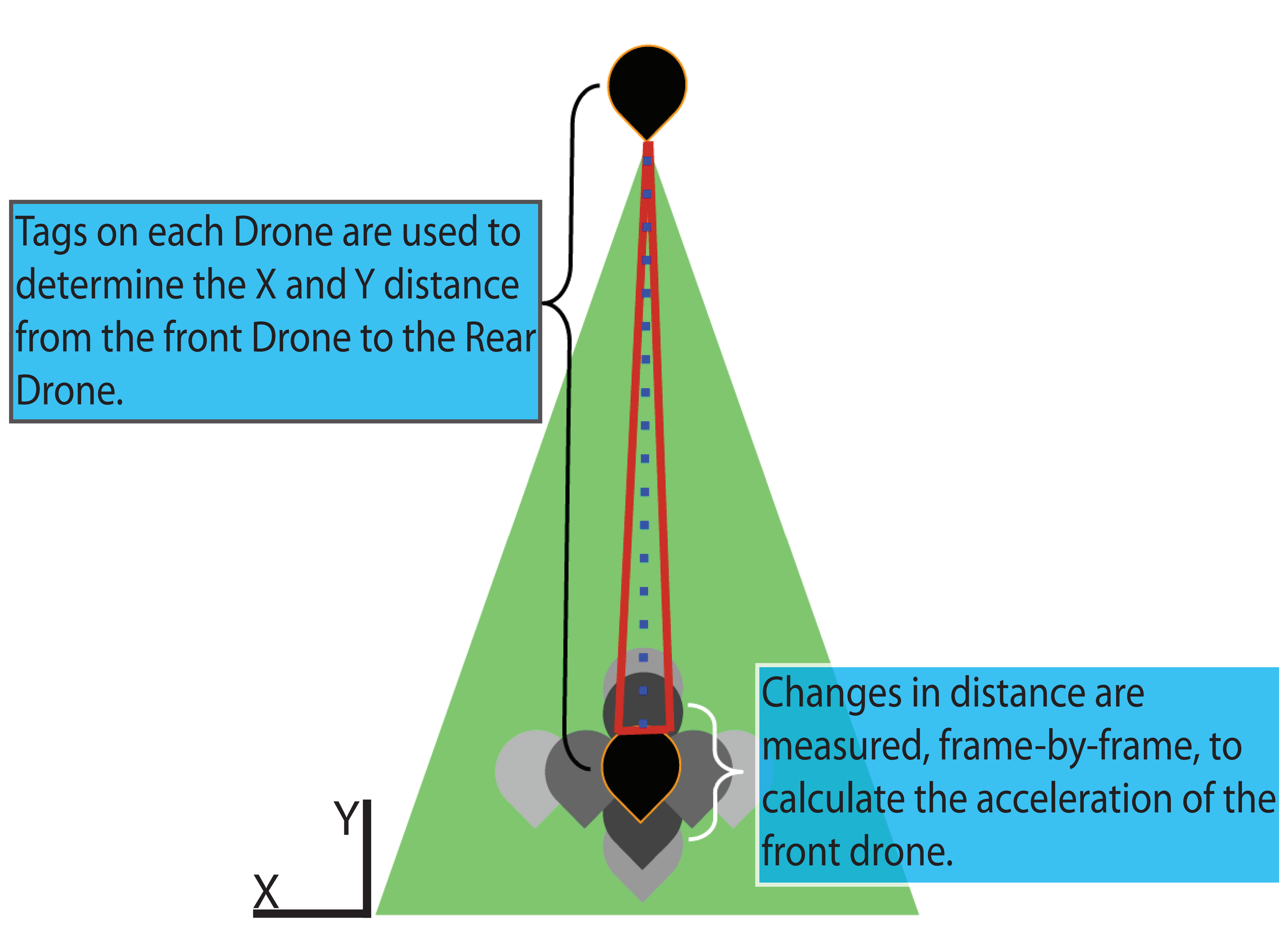


SYSTEM ARCHITECTURE



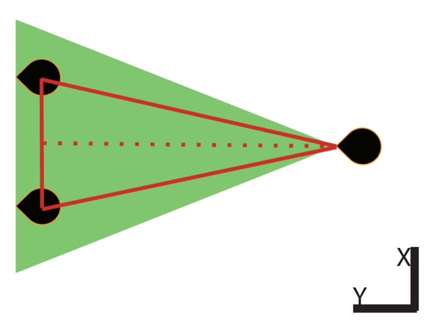
FORMATION CONTROL

Using Position and Acceleration Data, the velocity of each drone is controlled to maintain a position within the formation:



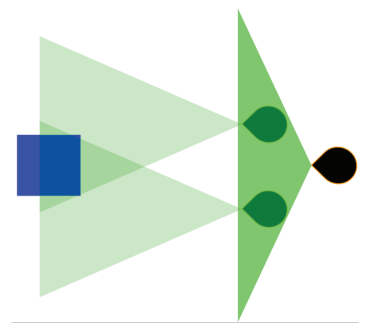
MAPPING AND NAVIGATION

1. Calculate Location of Epipolar Plane.



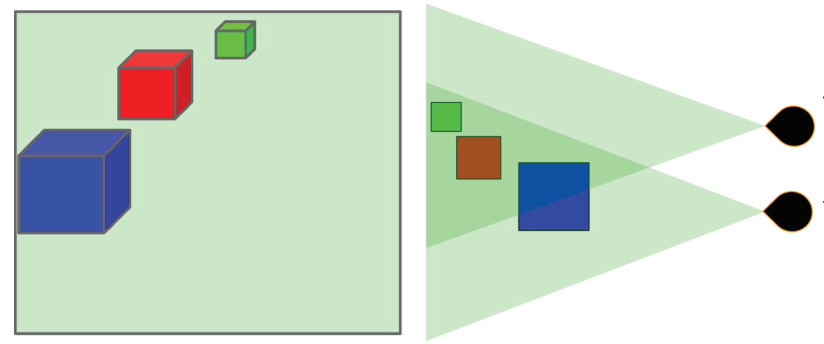
(i) Location in Z is determined by each drone's altimeter, and translated relative to the rear drone. Thus, X,Y,and Z for each drone are determined.
(ii) Using the 3-d location of each drone, the line between the two drones is calculated (Line A).
(iii) The Epipolar plane, the "origin" for stereovision-based distance measurements, is determined by the line between the right and left drones (Line A), and the distance (in Y) from the rear drone to the midpoint of Line A.

2. Locate Robust Features and Record Signature.



(i) Create a disparity map based on the images taken by the right and left drone.
(ii) Features are matched using epipolar lines. Relative positions are compared to determine distance from the epipolar plane.
(iii) (Feature,Position) pairs are stored in an array for future updating.

3. Locate New Features and Update System Position



(i) Once a robust feature has been determined, find another, and localize it relative to the first. This is known as Continuous Relative Representation [6].
(ii) System Position can now be determined relative to previously recognized features, and the formation is localized relative to its starting point.

DISCUSSION

This work successfully demonstrates that it is currently possible to create advanced autonomous systems with low-cost hardware. The vision and control techniques used to complete this project allow for a range of applications and advancements in the area of autonomous navigation, and are available for anyone to use. As commercially available UAVs become more advanced, students, researchers, and hobbyists will be able to implement advanced systems quickly and reliably.

This work also demonstrates that UAVs can operate reliably in GPS-denied environments at low cost,which suggests that it is worthwhile to develop the hardware and software systems used in this project to further advance the usage of such vehicles.

REFERENCES

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[4] Michael Mogenson, Tufts University, AR Drone LabVIEW Toolkit, (http://ardronelabviewtoolkit.wordpress.com/)

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[6] C. Mei, G. Sibley, M. Cummins, P. Newman, I. Reid, A Constant Time Efficient Stereo SLAM System, 2009, *Proceedings of the 20th British Machine Vision Conference*