Aerial Docking Drone System

Latifah Almaghrabi, Adrián de la Iglesia Valls, Ayça Ermiş, Jiaqing Li, Lingfeng Zhou, **Advisor:** Dr. Jennifer Hasler

SkyIsland

Georgia Tech College of Engineering
School of Electrical and Computer Engineering

Introduction

SkyIsland is a drone system comprised of independent quadrotors with the ability to intelligently interlock and reconfigure into one collective drone structure that:

- Uses different reconfigurations to provide flexibility in unnavigable regions.
- Reassembles based upon evolving requirements of assigned task.
- Utilizes electro-permanent magnets as holding force to maintain the interlock between drones.
- Has the ability to carry specialized cargo or sensors on drones in the swarm.

Objectives

1. Design and prototype a system of two drones to perform stabilized self-docking and undocking mid-air.
2. Operate individual drones semi-autonomously until a docking command is received.
3. Achieve aggregation of drones together, mid-air docking, and operation in unity to perform a joint task.

Application

The product would be excellent for search & rescue, inspection, and customized applications involving:

- Power Distribution
- Mountainous Regions
- Dense Forests
- Inaccessible Climates

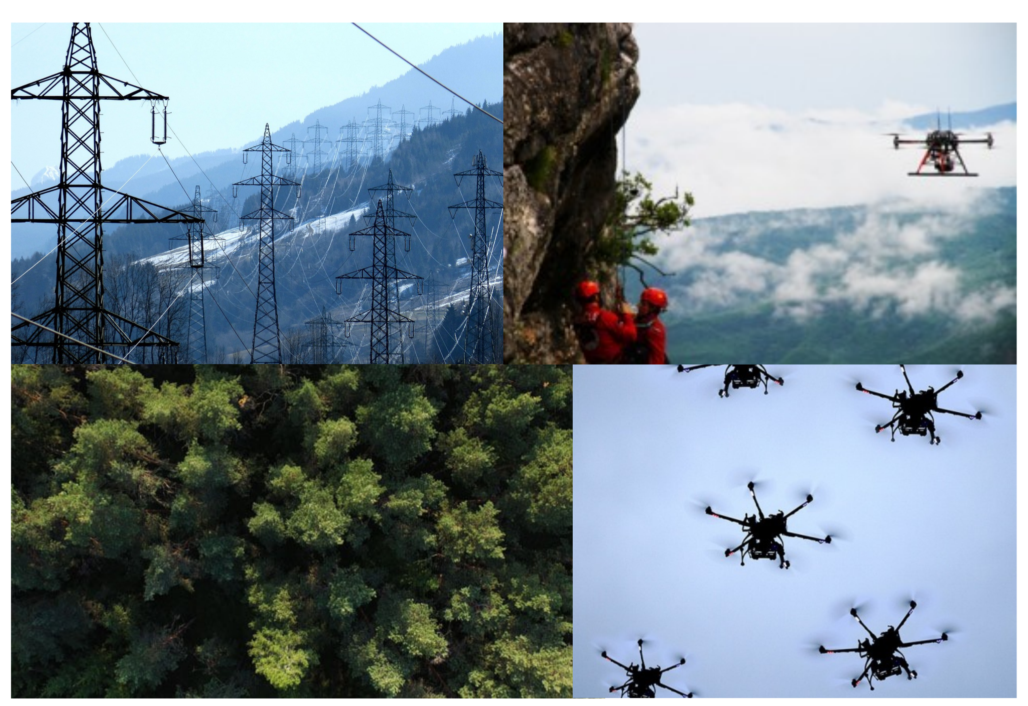


Figure 1. Drone swarms operating in search & rescue and inspection missions.

The ability to dock more than two drones together allows the system to maximize efficiency in rotor operation for a larger drone structure. This modularity allows the optimal utilization of current resources to diversify the capabilities of user. It also offers much more flexibility and optimization.

Results

Positioning Sensors

- A long range VL530x time-of-flight (ToF) sensor was implemented on each drone to receive feedback on altitude.
- Two close range VL6180x ToF sensors were connected to BeagleBone Black via I2C for relative orientation of two drones at the same altitude.

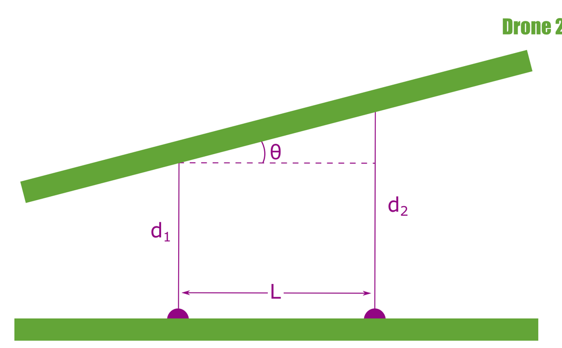


Figure 2. Mathematical formula for relative drone orientation.

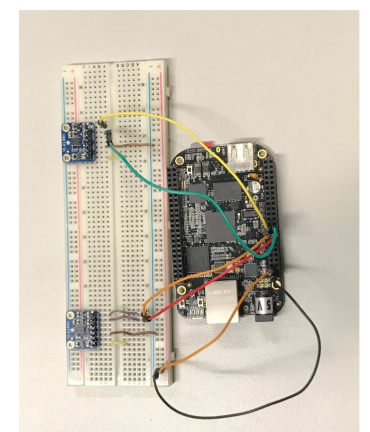


Figure 3. Hardware setup of close range ToF sensors.

Vision for Localization

- ArUco Marker on the drone was used for position and orientation detection in short range.

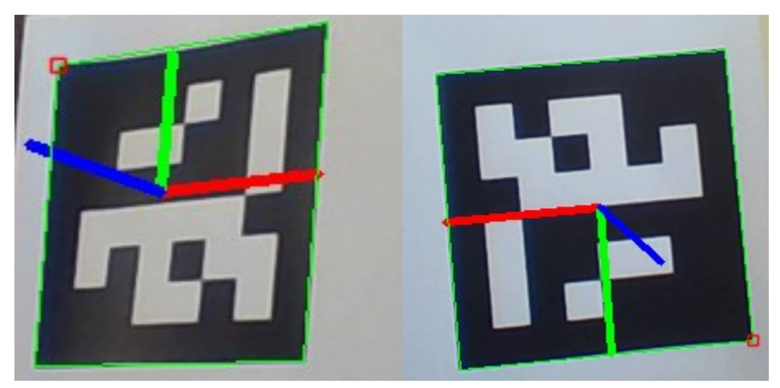


Figure 4. ArUco Marker for pose estimation.

- Kalman filter was used for tracking the drone and predicting its path from medium to long range.

Figure 5. Drone path tracking with a Kalman filter.

Shell Design

- The shell was designed to allow for safe and strong docking and to host the magnets and sensors.
- To achieve minimum weight, the shell was 3D printed using ABS high impact plastic.

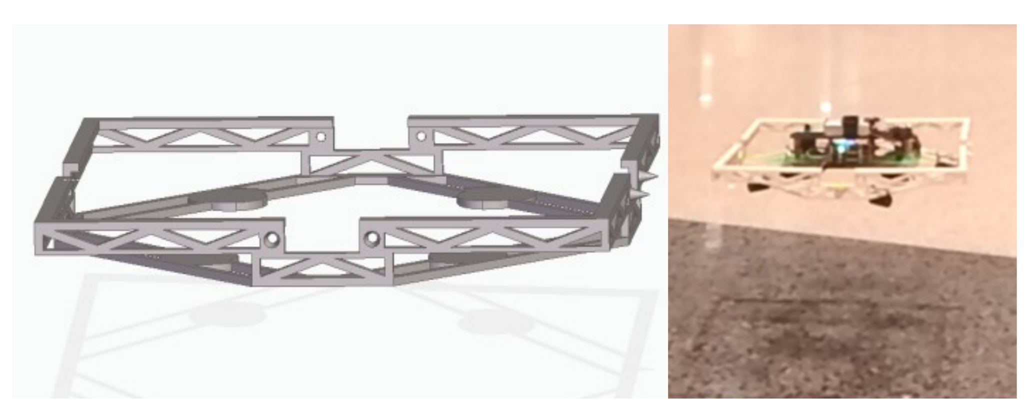


Figure 6. On the left the Solid Edge design of the shell. On the right the printed shell on a flying drone.

Docking Mechanism

- A coil of wire was wound around an AlNiCo magnet housed next to another magnet forming a pair of switchable magnet to enable docking of the two drones.

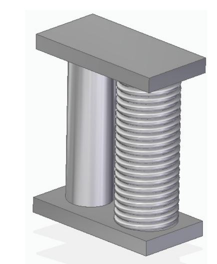


Figure 7. A 3D model of the electro-permanent magnet housing showing a pair of AlNiCo magnets, one encased in a coil.

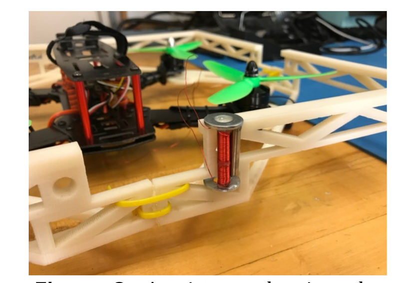


Figure 8. A picture showing the electropermanent magnet on the drone shell.

- With the use of a custom designed boost converter and n-channel MOSFET switches controlled by an 8-bit PIC18F27K42 microcontroller or Arduino Micro.

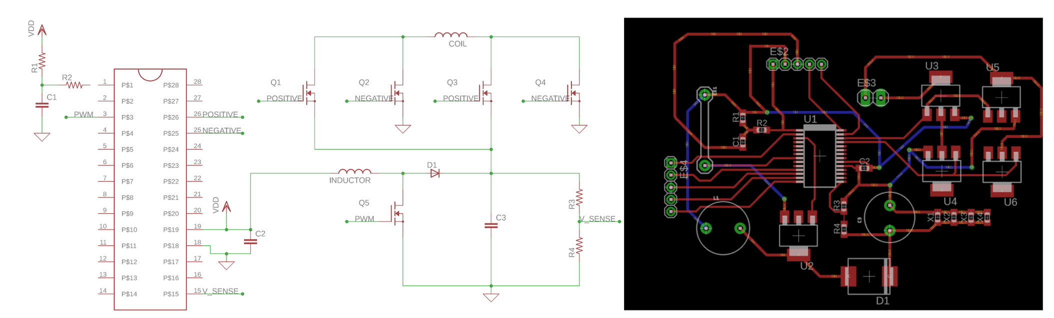


Figure 9. Schematic and PCB layout of the magnet repolarization circuit

- Voltage was stepped up from 5V to +50V for repolarization.

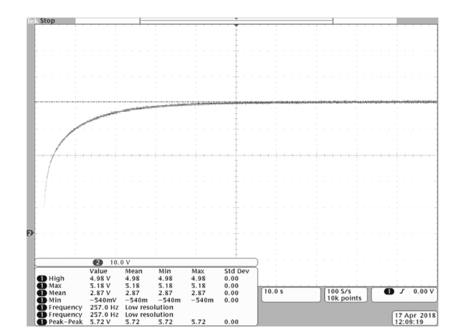
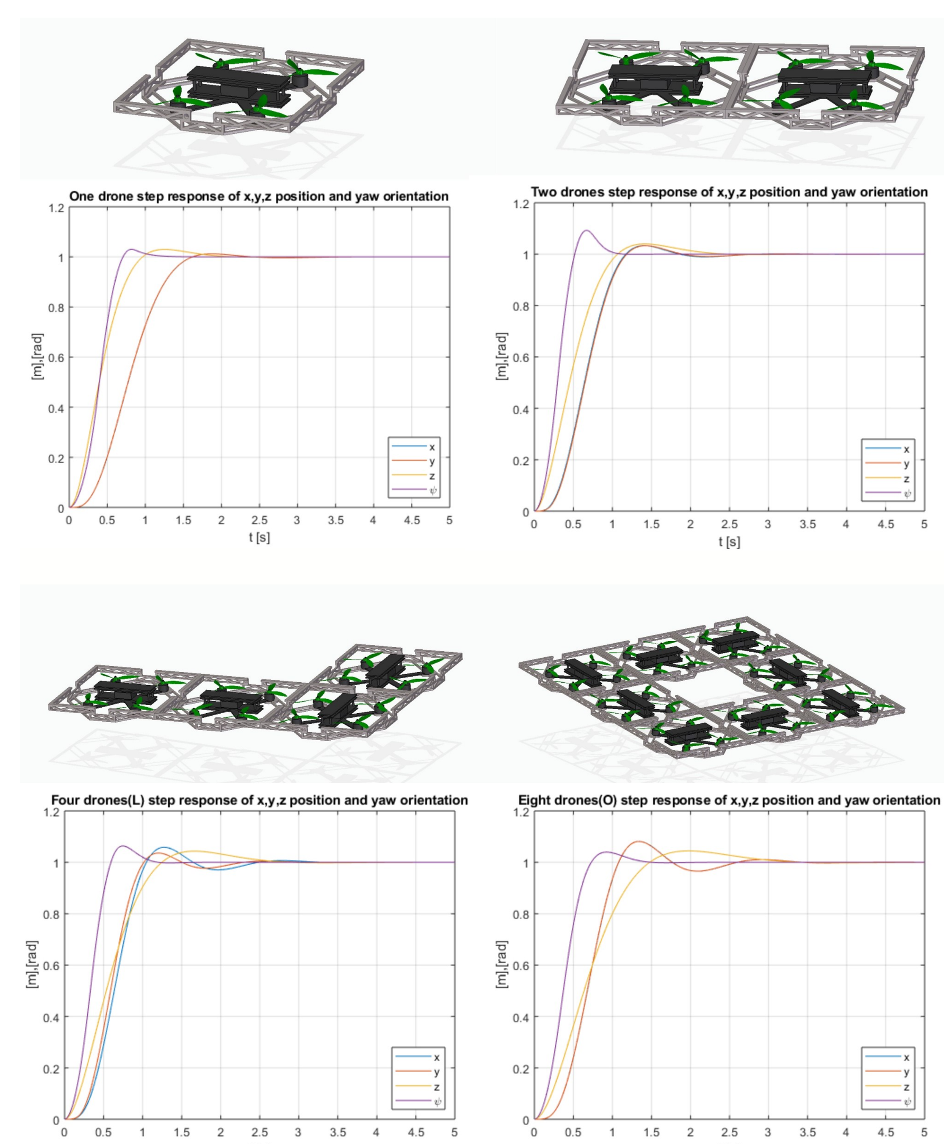


Figure 10. An oscilloscope capture showing the stepped up voltage.

Control System

- One single controller could fly any possible formation.
- State-Dependent LQR control was implemented for stability.
- Non-linear solver was used for optimal power distribution to motors.



1 drone	x	y	z	Ψ
Rise time [s]	1.6	1.6	0.96	0.7
Overshoot [%]	1.2	1.2	3	3
Settle time [s]	2.4	2.4	2.2	1.5

2 drones	x	y	z	Ψ
Rise time [s]	1.2	1.2	1.1	0.52
Overshoot [%]	3.3	3.3	4	9.3
Settle time [s]	2.8	2.8	2.5	1.2

4 drones (L)	x	y	z	Ψ
Rise time [s]	1	1	1.2	0.6
Overshoot [%]	6	3.5	4.3	6.3
Settle time [s]	2.5	2.2	2.8	1.2

8 drones (O)	x	y	z	Ψ
Rise time [s]	1.1	1.1	1.5	0.73
Overshoot [%]	8.1	8.1	4.5	4
Settle time [s]	3.4	3.4	3.5	1.5

Figure 11. Graphs and tables comparison between four different formations.

Conclusions

- Localization, control and electromechanical components of the project were completed.
- Environment setup on BeagleBone Black was achieved.
- Simulink code block remains under development for integrating close range time-of-flight sensors.
- ArUco marker accurately detected position and orientation in short proximity.
- Stabilization of control system with simulated disturbances was achieved.

Future Work

- Integrate OpenCV in MATLAB & Simulink.
- Generate and compile code base of control system and sensors for BeagleBone Black controller in MATLAB & Simulink.
- Integrate positioning sensors, magnet mechanism and camera system on the drone.
- Fabricate a unibody shell.
- Replace PIC18F27K42 microcontroller chip on the PCB with an alternative for prototyping.
- Test more inductors with various duty cycles and clock rates to optimize the polarization strength.
- Implement a full nonlinear control system.

Acknowledgements

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For Further Information

Visit: http://ece4012y2018.ece.gatech.edu/spring/sd18sS17/

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