Naval Aeronautical and Astronautical Institute Team Entry for the 2013 AUVSI International Aerial Robotics Competition

Kang Yuhang, Qiu Yangyang
Naval Aeronautical and Astronautical Institute

ABSTRACT

This paper describes the details of an autonomous aircraft capable of exploring cluttered indoor areas without relying on external navigational aids. The vehicle is capable of localizing itself using the SLAM algorithm, stabilize its attitude (pitch, roll and yaw) and altitude using PID controllers, plan paths around obstacles and navigate an unknown indoor environment with wall following guidance. There are two cameras and a manipulator in our aircraft, the front-facing camera is used to avoid some targets, the targets including LED light, laser trip wire label and doorplate can be identified, the downward one is used to identify the flash disk, and then the flash disk is replaced by the manipulator. The vehicle is intended to be Naval Aeronautical Engineering Institution's entry for the International Aerial Robotics Competition in 2013.

Ⅰ. INTRODUCTION

Most current Navigation systems use conventional navigation sensors such as standard IMU for orientation, GPS for localization. These systems may not be available in cluttered environments like urban and indoor environments. Furthermore, the substantial weight, computational and power constraints prevent the use of conventional sensors in such areas. On the other hand, visual sensors are passive, lightweight and can provide rich information about the aircraft self-motion and surroundings structure.

This paper describes technological details of our Quadrotor system, which is designed to be Naval Aeronautical Engineering Institution Team Entry for the 2013 AUVSI International Aerial Robotics Competition.

With the help of various onboard sensors, the MAV are expected to sense the cluttered indoor flight environment, implement obstacle avoidance flight, communicate with ground station, and replace the specific USB flash disk.

A. Statement of the Problem

The objective of the IARC 6th Mission is to create an air vehicle that can navigate into a secure location through a 1m x 1m window. The vehicle must search of a flash drive and, until finding the device, pick it up and replace it with a manipulator. Then the vehicle must exit the location. While performing the mission objectives the vehicle must avoid LED light, laser trip wire label and doorplate.

B. Conceptual Solution

Our Team has developed a MAV system to accomplish the task. The aircraft is capable of exploring unknown indoor environment and implementing specific operation without any external navigation aids such as GPS. An elaborate navigation algorithm is designed to provide attitude, altitude, velocity and relative position estimations of MAV within indoor area, by fusing information from laser range finder, inertial measurement unit and ultrasonic altimeter. We design a navigation strategy which can lead the MAV to explore the unknown environment for a reasonable time-consuming and avoid the obstacles in an appropriate way. When the aircraft finds the position of flash disk, the flight controller will stabilize the aircraft. Meanwhile, the servo system will drive the releasing device to put down the fake one. The *System architecture is shown in fig 1.*

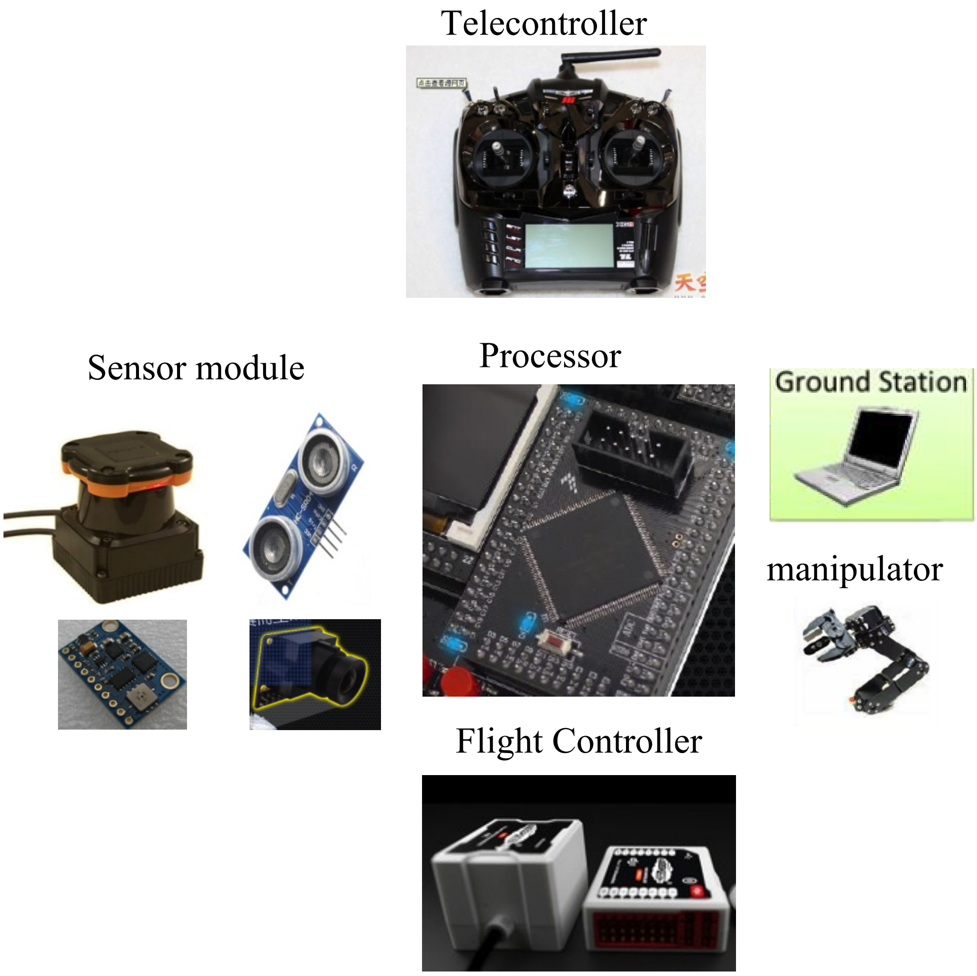


Figure 1:System architecture

C. Yearly Milestones

In our first attempt at this competition, we intend to develop an Unmanned Aerial Vehicle (UAV) capable of autonomous navigation in unknown cluttered indoor environment and complete IARC mission 6. Based on the work over the past 1 year, we focused on implementing the electronics package including the controllers and the sensor module. Refinements to the structure were made in order to ease electronics integration and reduce maintenance labor and time requirements. A drop-off and retrieval system was also designed and implemented.

II.AIR VEHICLE

Quadrotor is a good choice for MAV due to their relatively high flexibility and maneuverability. In 2013 IARC, Our quad-rotor is assembled by ourselves. The vehicle structure, motors, and rotors are bought. The microcontroller is a K60 core board based on ARM, the fight controller is commercial lightweight multi-axis control platform produced by *DJI-Innovations, named Wookong-M.* Owing to the fight controller is a commercial product, it can not provide navigation parameter, we add another sensor to offer us navigation parameter. The size of quad-rotor is 45cm×45cm×18cm with a safety margin, and with a 2200mAh Li-Po Battery. The quad-rotor weighs about 1.46kg.

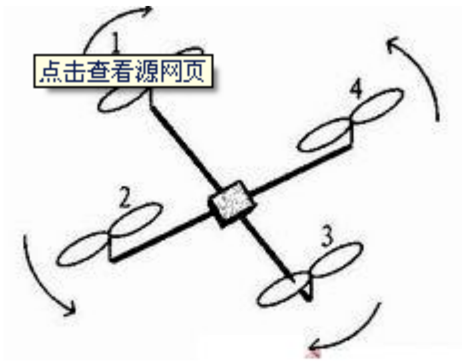


Figure 2:quadrotor and the propeller action

A. Propulsion and Lift System

The quad-rotor equipped with four brushless DC motors(Haoying) and four10in propellers, which distribute symmetrically at the end of four arms. And Unlike normal helicopters, the propellers of quadrotor shave fixed pitch angles. while the rotation of the motor 1 and the motor 3 are counterclockwise, the rotation of the motor 2 and the motor 4 are rotated clockwise, so when the aircraft flights evenly, the gyroscopic effect and the aerodynamic torque effect are offseted. It has six degrees of freedom in space(translational and rotational movements along the three axes), and the control of six degrees of freedom can be achieved by adjusting the motor speed. The basic state of movement: the vertical movement, the pitching movement, rolling movement, yaw movement, front and back movement, lateral movement. In short, we can control the quad-rotor by changing the motor speed.

B. Guidance, Nav., and Control

(1) Stability Augmentation System

The quadrotor, by nature, is an under-actuated system, it can determine its movement when the number of control input is less than the space dimension, the problem lies: the degree of freedom of direct excitation parts is coupled with the under-actuated non-linear. In order to make it move as expected, an attitude and heading controller is needed. Our flight controller's input is pulse wave, through sending the vehicle direct pulse wave, and when the duty cycle is 50%, it can balance. After our experiment, we find that PID control is the best control algorithm for our quad-rotor, the control block diagram is shown in Fig 3 .

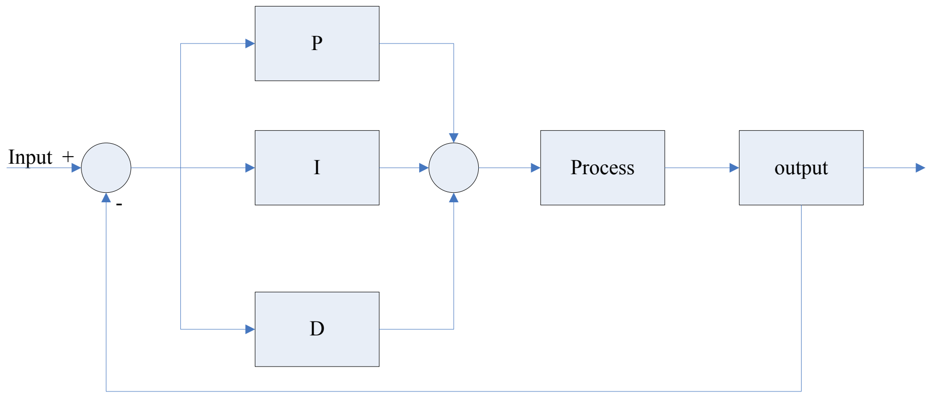


Fig.3 PID control block diagram

(2) Navigation

SLAM is a main algorithm for navigation in the indoor environment, and a variety of algorithms can download at the web site OpenSLAM.org. We study some algorithms, make a decision to use a SLAM algorithm based on feature map. On airborne processor, we can achieve the horizontal position and orientation estimation by matching the new scan data. Then, we fuse the relative position estimates from the GY-80 module(amount to a IMU) to compute the accurate absolute position. Using the algorithm, we send the vehicle global location periodically to the data fusion EKF to correct the drift of the position estimation caused byGY-80 module bias. On the ground station, its main role is to model the surrounding environment, and establish a global map. When entering the window, the vehicle will look for feature points, sunch as corner, break points and so on, through these points, the vehicle can find the next waypoint. When meeting with obstacle, the vehicle will check whether there is a door or a corridor to go through, otherwise the algorithm will sample different plots randomly in real-time map built by SLAM module and find a collision-free path for the vehicle.

C. Flight Termination System

There are two ways to achieve flight termination. The vehicle can be changed from autonomous to manual control by a switch on the RC transmitter, then the participator can take over control of the vehicle. When the height control goes wrong, threat the people's safety around, the participator can always take over control through one channel of the RC controller, then make an emergency landing. There is also a flight termination button in our ground station, if any emergency happens, the participator can click the button to control the vehicle right now.

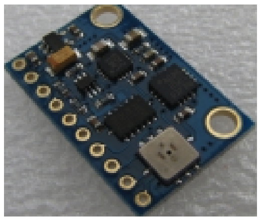
III. PAYLOAD

A. Sensor Module

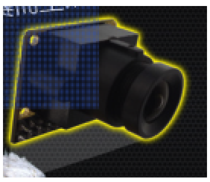
Wookong-M flight controller is produced by DJI-innovation, which is an extremely robust, stable, and safe platform. The onboard sensors include laser range finder, IMU(GY-80), digital cameras and ultrasonic altimeter. The IMU and ultrasonic altimeter are connected to the onboard core board, the data of laser range finder and cameras are transfered to the ground station computer. The onboard core board is a kind of SCM, has small size and light weight.

a1) Sensors

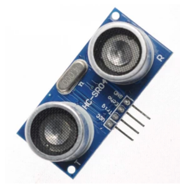
(a) Hokuyo Laser Range Finder



(b) IMU(GY-80)



(c) digital camera



(d) Ultrasonic altimeter

Figure 4. Various onboard sensors.

Hokuyo UTM-30LX Laser Range Finder: A laser range-finder returns a point cloud of 1080 points in a 270 degree, 30 meter range surrounding the vehicle at 40Hz, as shown in fig.4.a.

The quad-rotor has a simple self stable system, but owing to our flight controller is a commercial product, it can not offer us some navigation parameter, such as angular velocity and accelerated speed, thus, we add a simple IMU, namely GY-80, this component can provide angular velocity and accelerated velocity to us for navigation, as shown in fig.4.b

Digital cameras can provide 320×240 gray scale images as a speed of 150 fps, used for flash disk detection and the security identifier identification, as shown in fig.4.c.

an ultrasonic altimeter is used for attitude stability, as shown in fig.4.d

a2) Mission Sensors

The system will use a simple manipulator to grab the USB disk by Servo mechanism. After the quad-rotor flies into the target room and finds the USB disk, it will stabilize its position. When its position deviation is almost zero, the manipulator will loosen until the fake disk is down on the table, then it will grab the disk. Through controlling the servo mechanism's voltage polarity, the manipulator can loosen a disk or grab a disk. The manipulator weighs only 20g.

a3) Target Identification

USB identification: The system uses downward camera to extract disk features, Thanks to our camera is gray scale, it can only extract simple feature, so we adopt extracting simple points and lines. Compared with color camera, the digital gray scale has low accuracy.

Target Room identification: The system uses front-facing camera to detect the target room. The principle is similar to the use identification.

B. Communications

The flight controller has no compositive wireless WIFI module, we use a individual wireless WIFI module named XINLIWEI，it can transfer the laser data and camera data through SPI, IIC and serial port, we adopt SPI model, The vehicle can communicate with the ground station through the link.

C. Power Management System

The power management system is based on a dedicated microcontroller which provides energy to the four motor controllers, the on-board core board and a variety of sensors. Its energy source consists of a single Li-Po Battery (12.6V, 2200mAh) which allows approximately 15 minutes of autonomous flight. There is a power monitor, when the voltage is under 5V, a warning message will be sent to the ground station, meanwhile the vehicle will land by itself.

IV. OPERATION

A. Flight Preparations

a1) Checklist(s)

1. Check the hardware, especially RC transmitter;
2. Make sure the power of battery is full;
3. Check ground station;
4. Get on power, check the switch of control rights;
5. Check the software;
6. Make a simple test flight to make sure the vehicle works well.

B. Man/Machine Interface

There are two man-made interfaces in the vehicle system. One is the RC transmitter, and the other is the ground station. The RC transmitter is used to take over the control of Quad-rotor when emergence occurs, such as wrong ultrasonic altimeter's data, the discrete data of laser. The ground station is used for real-time display of Quadrotor flight status, including attitude, position, angular velocity, accelerated speed, the voltage of battery and so on, when above data is abnormal, the participator can enforce the vehicle land through the ground station.

V. RISK REDUCTION

A. Vehicle Status

a1) Shock/Vibration Isolation

The vehicle's equipments and sensor have limits of vibration. Apart from these, many measures have been applied when mounting the sensors, and if there is severe vibration in the vehicle when some sensors is measuring, it is likely affected by the vibration. So we have taken some protective measures. The vehicle can withstand a certain degree of impact, it is also fitted with soft pads below the arms to cushion impacts. The barycenter is in the center of the vehicle, to reduce the disturbance from the vehicle, and all sensor installation is very reasonable.

a2) EMI/RFI Solutions

EMI does harm to the vehicle, and we have taken some measures to protect the vehicle. The vehicle equips with brushless motors, and the IMU module (GY-80) is a integration module, so the EMI is relative smaller. Furthermore, the flight controller is mounted in the center of the vehicle where is relatively far from the interference source. Different sensors are installed in different part of the vehicle for the sake of reducing the EMI. Our RC transmitter and WIFI module work in different frequency, it can reduce the RFI.

B. Safety

In order to make sure the safety of the vehicle, we have taken many tests before this competition. Apart from this, we have designed two protection measures. If the vehicle is out of control in the flight in competition, we have taken some effective measures. First, we use RC transmitter to take over the control of the vehicle, and if it is still out of control, we can cut off the electricity supply through the ground station.
In a word, we have a safety operator who has the manual override capabilities to ensure safety.

C. Modeling and Simulation

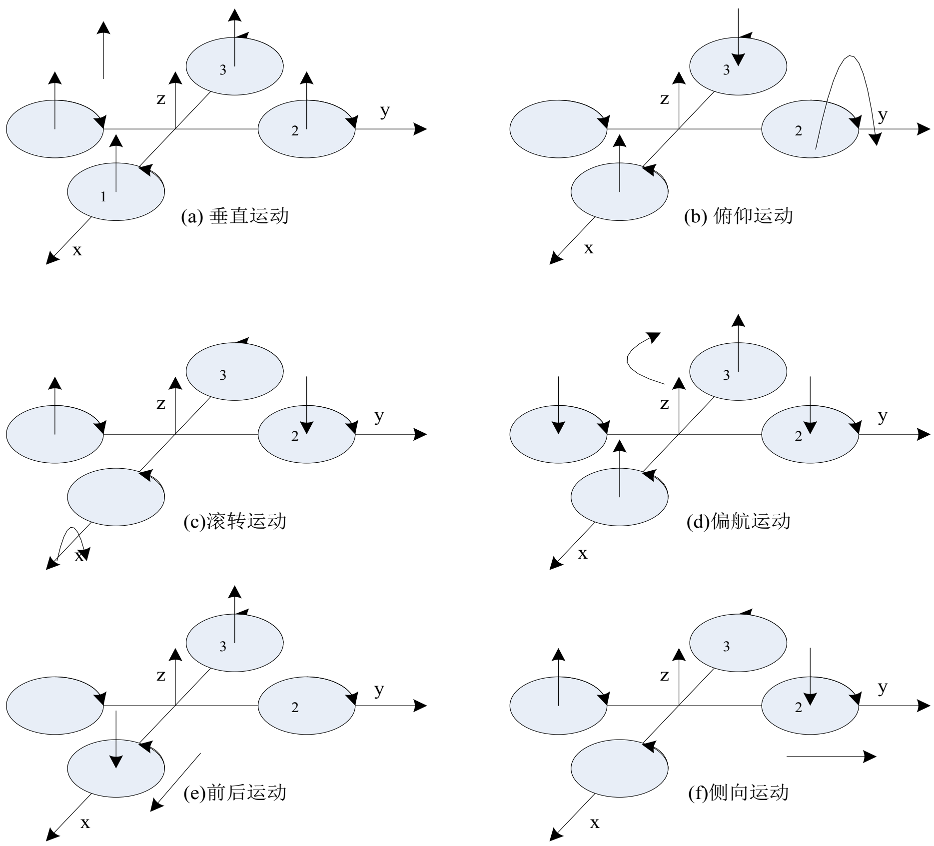


Figure 5. The quad-rotor along the various degrees of freedom of movement.

The vehicle can be regarded as a rigid body with six degree of freedom, which includes the movement along the line of body's three axial and the angular motion around the three axes of the vehicle. World frame is related to the ground, and the body frame is fixed to the quad-rotor. The vehicle's movement modeling as shown in figure 5.

（1）Vertical movement: vertical movement is relatively easy, as shown in Fig.5.a, because two of the motor is turned to the contrary, it can balance the body's anti-torque, while increasing the output power of the four motors, the rotor speed increases, so that the total pulling force increases, when the total pulling force is sufficient to overcome the weight of the four-rotor, the four-rotor can be off the ground vertically; Conversely, while reducing the output power of the four motors, four-rotor aircraft vertical drop until balance landing, along the vertical motion of the z-axis. When external disturbances zero, simultaneous the lift is equal with the weight of the aircraft, the aircraft can maintain a hover state. Guarantee the four rotor speed increase or decrease synchronous is the key of the vertical movement.

（2）Pitching movement: In Fig.5.b, the speed of the motor 1 is increased, the speed of the motor 3 is decreased, the speed of the motor 2 and motor 4 remain unchanged. In order not to cause four-rotor torque and pulling force overall change because of the change of rotor speed, the speed changes of motor 1 and motor 3 should be equal. Due to the lift of the rotor 1 is increased, the lift of the rotor 3 is decreased, the unbalanced torque which is generated by it will make the machine rotate around the y-axis direction (direction shown), the same, when the speed of the motor 1 is decreased, the speed of the motor 3 is increased, the machine will rotate around the other direction of the y-axial rotation.

（3）Rolling movement: the same as the principle of the Fig.5.b, in Fig.5.c, when the speed of the motor 2 and the motor 4 are changed while the speed of motor 1 and motor 3 are unchanged, the machine to rotate around the x axis (forward and reverse).

（4）Yaw movement: Four-rotor yaw movement can make use of the anti-torque. The process of the rotor will form the anti-torque which is contrary to the rotational direction due to the role of the air resistance, in order to overcome the effect of the anti-torque, we can make the two of four motors rotate forward, the other two inverse, and the rotation of the respective rotor on the diagonal direction are the same. The anti-torque is related with the speed of the rotor, when each rotor has the same speed, the anti-torque can balance, four-rotor does not rotate; When four motor speed is not exactly the same, the imbalance of the anti-torque cause four-rotor rotate. In Fig.5.d, when the speed of the motor 1 and the motor 3 is increased, the speed of the motor 2 and the motor 4 is decreased, the anti-torque of the rotor 1 and the rotor 3 on machine is greater than the anti-torque of the rotor 2 and the rotor 4 on the machine, the machine will rotate around the z-axis under the action of the surplus anti-torque, so that achieve the yaw movement of the aircraft, the direction is opposite to the motor 1 or the motor 3.

（5）Front and back movement: In order to achieve aircraft move back, forth, left, right in a horizontal plane, a certain force is put on in the horizontal plane. In Figure 2e, increasing the speed of the motor 3, so that the pulling force is increased, decreasing the speed of the motor 1, so that pulling force is decreased, while maintaining the two other motor speed be constant, the anti-torque still maintain balance. According to the theory of Figure 2b, at first the aircraft must be in a certain degree of tilt, so that the rotor pulling force generated horizontal component, therefore four-rotor can achieve the forward flight. Backward flight and forward flight are just the opposite. Of course, in Fig.5.b and Fig.5.c, while the aircraft generates pitch, Rolling movement, it can also generated along the x, y-axis horizontal movement.

（6）Lateral movement: In Fig.5.f，due to the structure is symmetrical, lateral flight is the same as front and back movement.

The vehicle’s navigation algorithm is tested in matlab and C++.

D. Testing

Before the navigation system is completely done, we test our height control in our lab firstly, then we test the process of entering the window, subsequently, position control in a environment which is similar to the competition field is tested, finally, we test the effect of horizontal position and orientation estimation in a room. The result of scan matching is very well.

VI. CONCLUSION

In this paper, we presented the technical details of a quad-rotor system capable of autonomous navigation and control in the unknown environment to accomplish some specified tasks such as obstacle avoidance, online path programming and target identification without relying on any external navigation aids. The quad-rotor uses various sensors onboard. Two digital cameras are mounted on the vehicle, the front-facing one is used to detect the target room, and the downward one is responsible for USB disk identification with a simple manipulator to replace it. We also take some measures to prevent contingency happening effectively .

So far, we have acquired some achievement, but we still have a long way to go, and we are confident in our own. The Naval Aeronautical and Astronautical Institute Team intends to compete in the 2012 IARC competition with this vehicle.

VII. REFERENCES

[1] Scott D. Hanford, Lyle N. Long, and Joseph F. Horn. A Small Semi-Autonomous Rotary-Wing Unmanned Air Vehicle (UAV). American Institute of Aeronautics and Astronautics, Infotech Aerospace Conference. 2005.

[2] A. Bachrach, R. He, and N. Roy. Autonomous flight in unstructed and unknown indoor environments. In Proceedings of EMAV, 2009.

[3] T. Templeton, D.H. Shim, C. Geyer, and S.S. Sastry. Autonomous Vision-based Landing and Terrain Mapping Using an MPC-controlled Unmanned Rotorcraft. In Proc. ICRA, pages 1349–1356, 2007.

[4] G.M. Hoffmann, H. Huang, S.L. Waslander, and C.J. Tomlin. Quadrotor helicopter flight dynamics and control: Theory and experiment. In Proc. of GNC, Hilton Head, SC, August 2007.

[5] J.F. Roberts, T. Stirling, J.C. Zufferey, and D. Floreano. Quadrotor Using Minimal Sensing For Autonomous Indoor Flight. In Proc. EMAV, 2007.

[6] S. Bouabdallah, P. Murrieri, and R. Siegwart. Towards autonomous indoor micro vtol. Autonomous Robots, Vol. 18, No. 2, March 2005.

[7] R. He, S. Prentice, and N. Roy. Planning in information space for a quadrotor helicopter in a gps-denied environments. In Proc. ICRA, 2008.

[8] T. Hamel, R. Mahony and A. Chreitte, Visual servo trajectory tracking for a four rotor VTOL aerial vehicle, ICRA'02, Washington, pp 2781-2786, 2002.