Multi-Object Tracking in Indoor Flight Environments: International Aerial Robotics Competition 2015

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ABSTRACT

This paper details the development and construction of a quadrotor unmanned aerial vehicle that is capable of tracking and guiding multiple randomly moving ground vehicles to the designated location. The University of Central Florida's autonomous vehicle VINCENT was designed to compete in the 7th Mission of the International Aerial Robotics Competition. VINCENT utilizes computer vision, optical flow analysis, and priority assignment programming in order to operate fully autonomously for the duration of its flight.

1. INTRODUCTION

1.1 Problem Statement

In Mission 7, the quadcopter is tasked with locating ten autonomous, randomly-moving ground vehicles within a four hundred square meter area. VINCENT must then herd the correct ground vehicles over a specified green line. In addition, VINCENT must prevent the vehicles from crossing the borders of the given area. VINCENT must accomplish these tasks without running into four obstacle robots roaming the area.

1.2 Conceptual Solution

The aerial robot is programmed to interact with the ground robots as follows:

1. It will determine the location of the ground robots
2. It will attempt to gather the robots to the center of the marked area
3. It will prevent the ground vehicles from leaving the marked area

In order to optimize vehicle performance for the given mission, competition rules were evaluated and prioritized by point value. It was determined that in order to score the most points, the position of the ground vehicles must be accurately determined and maintained. This ensures the ground vehicles remain in bounds for the duration of the run, and thus in play.

1.3 Yearly Milestones

As 2014 marked the initial entry of the University of Central Florida into the 7th mission, the primary focus during the first few months was the design of a stable and robust vehicle. After the finalization of an initial design, components were selected. The prototype design was then constructed and tested; it was determined to be sufficient for the purposes of the mission. However, due to irreparable damage that occurred during transport, the vehicle was unable to fly at the 2014 competition.

For the 2015 competition, power distribution boards and the auto piloting system were redesigned. An off-the-shelf system was purchased as a backup system in order to ensure that flight capabilities are maintained in the event that the main system fails for any reason.

2. AERIAL VEHICLE

In the design process, mass is a major consideration. Though the quadrotor was designed to be able to sustain flight with a larger mass, it was determined that a reduced mass would improve flight time and vehicle performance. In order to maximize the flight time, the mass of the frame was limited to 400g. This allows additional component mass to be added so that it minimally affects vehicle performance.

As fiberglass has a Young's Modulus of approximately 72 GPa, which is higher than that of carbon fiber, it was determined to be the most appropriate material for the frame. Young's Modulus, also known as the modulus of elasticity, is a property that represents the rigidity of the isotropic material. The higher modulus of elasticity allows for greater durability of the vehicle.

The offset of the arms of the quadrotor were determined to be desirable as it limits the "blind spots" in the camera views.

2.1 Propulsion and Lift

The quadrotor design utilizes two sets of identical, fixed-pitch rotors which act as narrow airfoils. The counter-rotational motion of these narrow airfoils allows for the generation of lift by the vehicle. Greater degrees of directional control can be achieved by varying the power and rotational speed of the rotors.

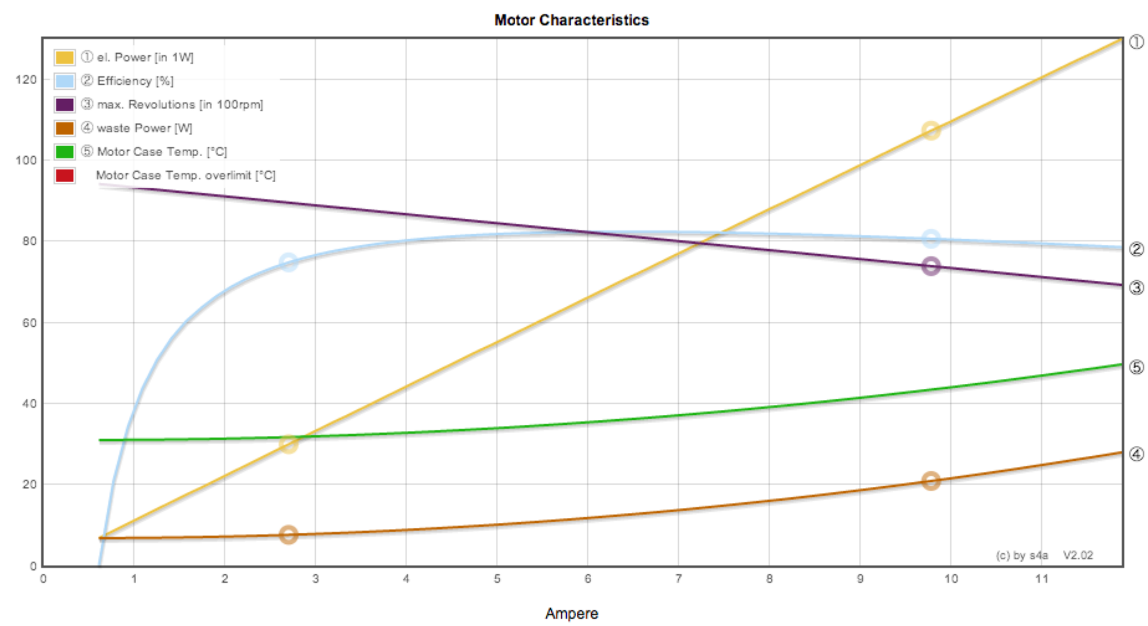
VINCENT utilizes four Turnigy 2217 20turn 860kV 22A Outrunners as the primary method of propulsion.

The initial propeller selection for VINCENT was a standard size 10 x 4.7 APC composite propeller. This propeller/motor combination at maximum efficiency generates 8.8N of thrust per rotor for an approximate overall thrust of 32N.

The 30A electronic speed controllers were selected in order to increase heat dissipation. By selecting an ESC with a larger amperage than what is being drawn by the motors, it is to ensure that heat does not build up as quickly, which allows for longer flight times with a reduced danger of overheating. The maximum calculated temperature of the system was calculated to be no more than 50°C.

The motor/propeller combination at optimum efficiency draws a total of 6.41A per rotor for a total of 25.64A.

A 4000 mAh battery was selected in order to provide up to 23 minutes of hover time for the quadrotor. When operating at maximum throttle, the current motor/propeller configuration can provide up to 8 minutes of flight time. The calculated mixed flight operating time is approximately 17 minutes.



The above figure shows the characteristics of the current vehicle design including: efficiency, revolutions per minute, power wasted, power drawn, and motor temperature.

2.2 Guidance, Navigation, and Control Systems

For guidance and control, VINCENT is equipped with an in-house designed custom autopilot board. In the event of failure, a backup Pixhawk 3DR will take over the functions of the autopilot.

2.2.1 Stability Augmentation

As VINCENT is not configured in a traditional X-configuration, the initial stability of the quadrotor left much to be desired. The offset of the arms of the vehicle required additional sensor in order to compensate for this.

VINCENT uses 3-axis gyroscope, 3-axis accelerometer, and 3-axis magnetometer in order to determine its position as well as its roll, pitch, and yaw. Combined with the inherent stability of a symmetric motor configuration of a quadrotor design, the design was deemed sufficiently stable for autonomous flight.

2.3 Flight Termination Systems

VINCENT's emergency termination system consists of several independent methods of flight termination. The primary method is the IARC standard "kill-switch" that is connected between the battery and the main control board. The "kill-switch" is remotely controlled by the third party using an RC transmitter.

3. PAYLOAD

3.1 Sensor Suite

VINCENT is equipped with (4) Maxbotix EZ-0 ultrasonic rangefinders, one sensor per arm, the sensor is capable of measuring up to a maximum range of 6 meters and 45 centimeters. A cap of three meters was set to limit the maximum altitude of the flight. The sensor is capable of providing either pulse width output, analog voltage output, or serial digital output.

VINCENT is equipped with (5) complementary metal oxide semiconductor cameras, otherwise known as CMOS camera in VGA resolution. One camera was placed on each arm and the body of the frame. All CMOS cameras are downward facing. The camera attached to the bottom of the frame performs optical flow analysis, tracking of the ground vehicles, the line indicating the border of the course, and alignment of VINCENT to the ground vehicle when necessary. While the CMOS cameras on the arms are in charge of the tracking of the ground vehicles and the line indicating the borders of the course.

3.2 Communications

VINCENT communicates with the ground station using an ASUS AC-1200 Wireless Adapter. The ground station is an ASUS AC-1900 Dual Band Gigabit Router, connected to our ground computer(s).

On board of VINCENT, a single board computer, powered by either an ARM architecture microprocessor or a low-power Intel Atom is installed. This SBC will communicate with the ground computers via the WiFi adapter. This computer will aggregate the video streams and sensor data and send it, via WiFi, to the ground computer, where computer vision processing will occur. Then, the data will be transmitted back to the on board computer in order for the vehicle to make decisions and track the ground vehicles.

3.3 Power Management

The power is supplied by a 4000mAh 11.1V lithium polymer battery with 20C discharge. The battery is connected to a power distribution board which redistributes the power from the battery to the (4) electronic speed controllers and the computing hardware onboard.

4. OPERATIONS

4.1 Flight Preparations

Prior to any scheduled flight, a set of stringent safety procedures are followed. The pre-flight procedure is as follows:

1. Inspect wiring to ensure connections are secure
2. Inspect vehicle body for damage or defect
3. If RC-controlled run, power RC transmitter
    a. Verify power to RC transmitter
    b. If autonomous flight, continue to (4).
4. Ensure emergency flight termination is properly connected
    a. Verify function of emergency flight termination
5. Power ground control station

6. Connect vehicle battery
    a. Ensure proper battery position
    b. Ensure that voltages are within acceptable parameters
7. If autonomous flight and prior conditions are met, initiate mission protocols

4.2 Man/Machine Interface

At ground control, the off board computing program is providing visual feedback from VINCENT. Displaying five windows of video live streaming from VINCENT with optical analysis running in the background. The diagram provides the orientation of VINCENT in 3-dimensional space. The logging of sensor data is done in the background during each flight. Initialing and emergency landing can be done using the graphical user interface for starting of autonomous flight and an alternative option to the hardware “kill switch”.

5. RISK REDUCTION

5.1 Vehicle Status

In order to enter user-controlled flight, the receiver must first be powered. After the receiver is powered, the main power board is turned on, followed by the quadrotor battery. In the event that things are powered in an order other than the previously stated, the quadrotor will fail to launch and activate an error alarm.

Real-time diagnostics for the quadrotor are sent to the ground station for analysis.

5.1.1 Shock and Vibrations Isolation

In order to reduce the effect of vibrations on the quadrotor, four damping wheels were added to the vehicle design.

5.1.2 EMI/RFI Solutions

This design does not utilize components that will be heavily affected by magnetic or radio interference. Any radio links will be using a digital modulation scheme, which will be able to easily compensate for any possible interference.

5.2 Safety

During the design process, safety was considered to be of the utmost importance. The development of the final design of VINCENT revolved around the safety of human and the unmanned vehicle interaction that would occur during the test flight and the mission itself.

Installation of propeller guards for the mission is highly desirable. The design of propeller guard is still in progress, it is essential for the propeller guard to shield the propellers from humans around the vehicle while not adding negative constraints to the flight of the vehicle.

Team members are notified at least 24 hours prior to any scheduled flight. The team members that need or wish to be present at the testing site, must dress accordingly. During test flights, team members were required to wear closed-toed shoes, jeans, protective eye wear, and tie back long hair. The immediate surrounding of the test site were to be cleared of any bystanders and/or debris.

Due to the sensitive nature of lithium-polymer batteries, the charging process was tightly controlled. Batteries were fully discharged prior to being recharged. During the charging process, the batteries were monitored to ensure that overcharging and/or overheating did not occur. Once a complete charge was attained, the batteries were immediately disconnected from the balancer.

When working on the electronics, all maintenance was done on an anti-static mat and using anti-static wristbands. This ensured that the electronic components remained functional during routine maintenance of the vehicle.

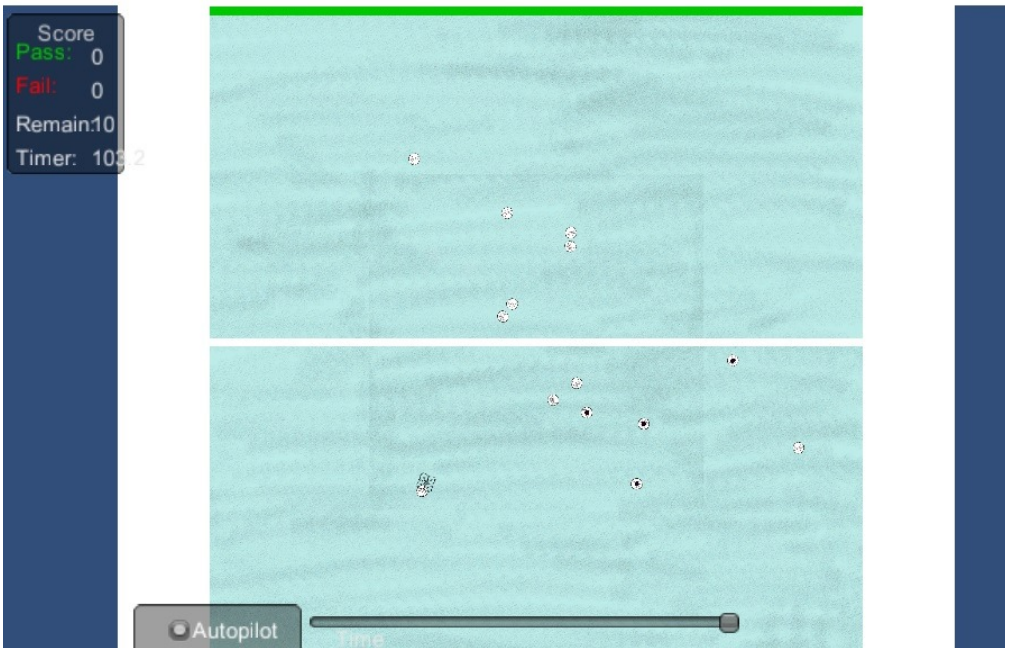
5.3 Modeling and Simulation

Finite Element Analysis was performed using Siemens NX 8.5. The use of this Product lifecycle Management (PLM) software allows for renderings of components and systems to be modeled and analyzed using the same software in order to limit compatibility issues between CAD softwares.

Vibration analysis and mathematical calculations were completed using Mathworks Matlab and Simulink.

Two-dimensional ground robot behavior and aerial vehicle flight path simulation was performed using Unity2D. The software for ten ground robots and four obstacle robots were emulated on an accurately simulated Mission 7 field. These simulations were used to analyze patterns in the ground robots in order to create flight path algorithms for the aerial vehicle.

The aerial vehicle was then simulated in the 2-D environment along with the ground vehicles testing different flight path algorithms. These algorithms searched for and rotated the ground vehicles and avoided the obstacles according to the official Mission 7 rules. The simulation calculated and tracked the scores of each algorithm and compared them in order to find the most efficient and optimum flight path algorithm.



2-D Ground and Aerial robot path simulation

5.4 Testing

Prior to any planned flights, rigorous testing was performed on each subsystem. Theoretical data was taken and compared against the experimental data in order to ensure reasonability. In order to ensure a safe landing in the event of an emergency flight termination, a light-wire tether was affixed to each arm and held taut in order to ease the quadrotor to the ground to prevent the frame from fracturing.

6. CONCLUSION

In conclusion, the University of Central Florida has developed a fully autonomous aerial vehicle capable of multi-object tracking and basic priority assignment programming. It is the hope that in future versions, VINCENT will be able to better track a larger number of ground vehicles with greater accuracy than is currently implemented.

7. ACKNOWLEDGEMENTS

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