University of Nebraska-Lincoln
Unmanned Aerial Vehicle Design Team

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ABSTRACT

The University of Nebraska-Lincoln International Aerial Robotics Design Team is creating an autonomous quadcopter platform that will allow for easier future development, with the intention of completing the mission in the coming years. The platform is a stack of hardware, embedded flight control software, and image processing and object detection software. Combining many different backgrounds, this design team is composed entirely of undergraduate students, with majors including computer science, computer engineering, mechanical engineering, and electrical engineering.

INTRODUCTION

Statement of the problem

Mission seven's goal is to push the boundaries of current aerial robotic behavior. The first challenge is to successfully initiate a reaction between an aerial robot and a moving object; in this competition, a Roomba. The next item to tackle is navigating an unknown environment without the use of GPS and only using the ground as a reference point. Finally, the aerial robot will need to navigate around moving obstacles. In summary, the aerial vehicle must be able to interact with other autonomous objects and avoid obstacles, all without the use of GPS.

Conceptual solution to solve the problem

The team has built a system that is quite generic, and able to be developed upon. Figure 1 shows the overall system architecture. The Jetson is used for the image processing, while the flight controller is completely separate. The flight controller is fed instructions from the Jetson, and has the ability to ignore instructions for the safety of the drone.

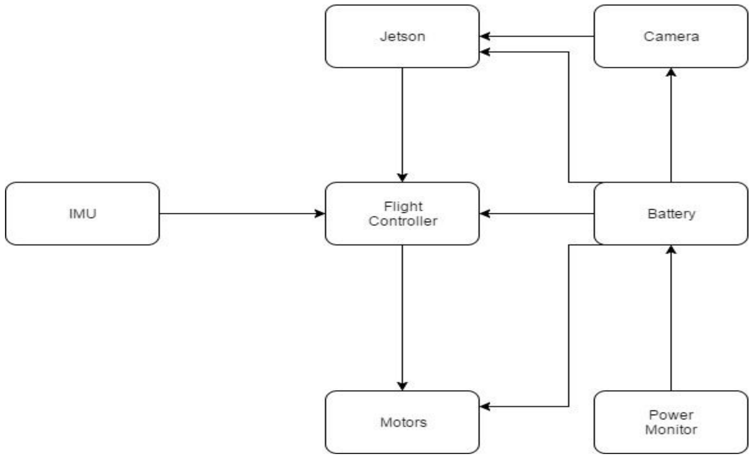

Figure 1. Overall System Architecture

The team designed a custom frame that has been entirely 3D printed out of PLA material, allowing duplicate parts to be printed and swapped out with minimal effort.The exploded view of the custom frame is shown in Figure 2.

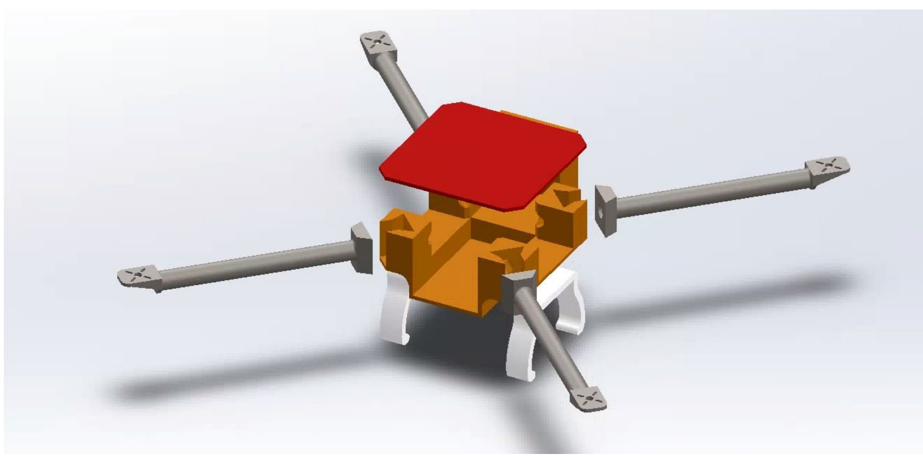

Figure 2. Custom Frame Design

The object detection and tracking is still fairly rudimentary, but the team has worked out a solution that should allow tracking, following and prediction of a single ground robot. In coming years, the algorithms used will be improved to facilitate tracking of multiple ground robots, interaction, and eventually more sophisticated course planning. Figure 3 shows the object detection and prediction control loop that will be feeding instructions to the flight controller.

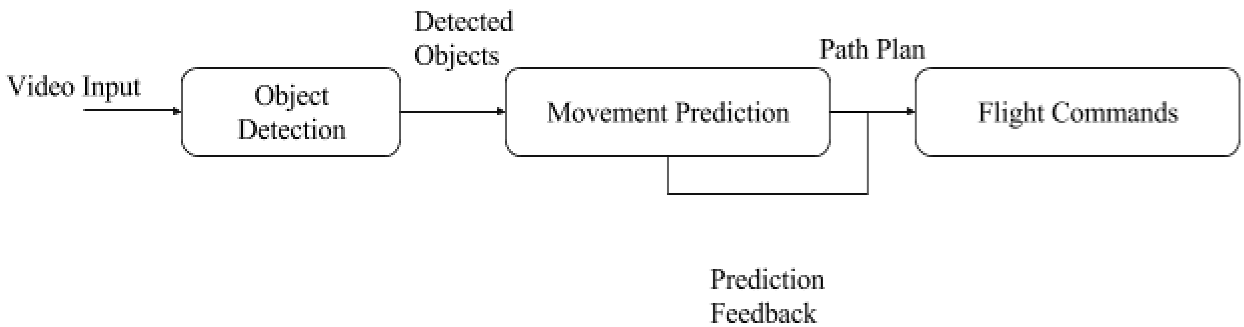

Figure 3. Object Tracking Software Design

The overall concept for the electronics of the drone was to have a fairly modular stack, with specific interfaces connecting the layers, as shown in Figure 4. Everything is based upon the hardware platform. The embedded flight and systems control is built upon that, and has full access to all of the various components of the system. This is the bare minimum needed for the system to be capable of flight. Object detection and tracking will be added in a separate layer on top of that, providing instructions to the flight controller in a standardized way. This enables the flight controller to maintain full control over all hardware systems, and can decide if the instructions from the object detection and tracking should be followed.

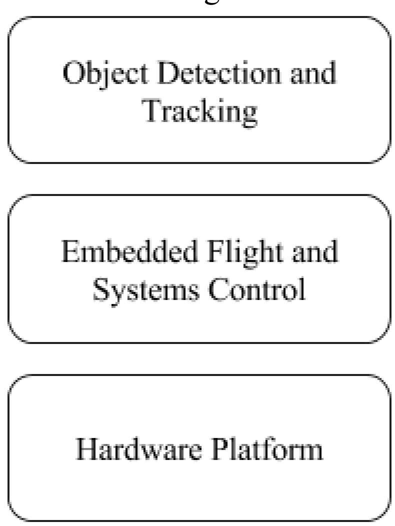

Figure 4: Complete Stack Design Concept

Yearly Milestones

A mission as complicated as this is not able to be completed in a single year. The team recognized this quickly and developed a three-year plan to complete the mission. A main focus within the team is to achieve full autonomous flight, and so milestones were set with the idea that it would be performed completely autonomously. This year, the first year the UNL team will compete, the team plans to demonstrate fully-autonomous single-object tracking. In the second year, the team plans on being able to interact with a single ground robot autonomously, while continuing to develop the object tracking algorithms and flight platform. In the third year, the team hopes to complete the challenge.

AIR VEHICLE

Propulsion and Lift System

The drone has four motors that are oriented in an ‘x’ shape and equally spaced. Each motor has a blade on it that spins and generates downward thrust. The downward thrust generates lift allowing the drone to fly.

Guidance, Navigation, and Control

Stability Augmentation System

The Stability Augmentation System is implemented in the Flight Control component. It implements a basic PID controller to keep the vehicle stable. Orientation information is used as the error which is retrieved from the IMU.

Navigation

The primary input for the navigation system is a video feed from an onboard camera. The video feed is processed by the Video Processor component outputting a desired change in direction. This is fed into the Flight Controller along with orientation data from the IMU. The Flight Controller then takes this input and transforms it into different values for each motor. The motors spin and the specified value moving the drone in the desired fashion.

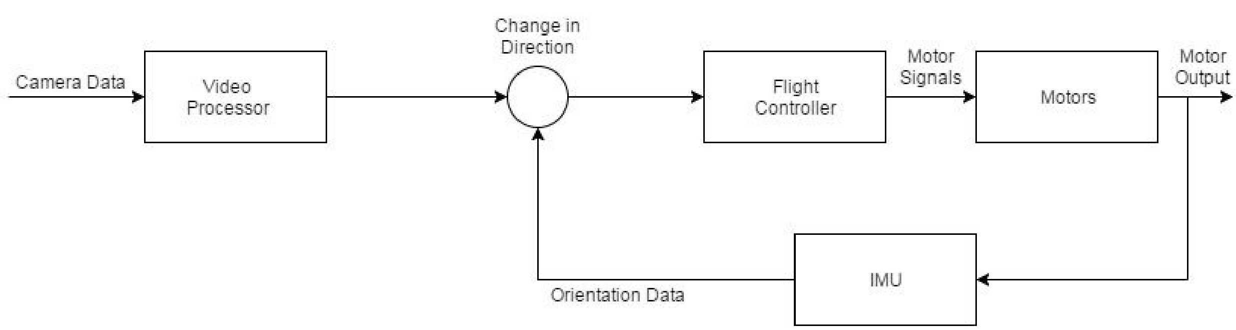

Figure 3. Quadcopter Control Loop

Flight Termination System

The Flight Termination System, or kill switch, is a series of mosfets that control power provided to the motors. The kill switch can be triggered by any component in the payload, and kill a message is sent to all other components in the system so they can send redundant kill commands to the kill switch. In order to detect a component failure the power monitor component periodically sends heartbeat messages which the other components must acknowledge. If no ack is received a kill command is sent. Similarly if the Image Processing of Flight Control components do receive a heartbeat message before a certain time a kill command is sent. The kill command shuts off the mosfets killing power delivery to the motors and only the motors, the rest of the processing components. This allows the other components to continue to perform logging activities or shutoff other non-critical components.

PAYLOAD

Sensor Suite

GNC Sensors

The aerial vehicle detects its current orientation and position using an IMU, a barometer, and a sonar sensor, all the GNC sensors are part of the flight controller component. The IMU is a gyroscope, accelerometer and magnetometer, together the 3 sensors give an accurate reading of the aerial vehicle's current orientation which the flight controller then uses to stabilize itself. The barometer and sonar sensor are used to calculate the current altitude of the drone. The sonar sensor is used when close to ground because it gives a highly accurate reading, while the barometer is used when hovering. We also use the accelerometer to help detect sudden changes in air pressure which cause large changes in the barometer reading. If the accelerometer height reading doesn't drastically change as well this is a sign to calibrate the barometer with the current height.

Mission Sensors

The aerial vehicle detects Roombas by running the video feed through a color detection program to detect the colored plates attached to the Roombas. This creates contours, or outlines of the colored plates. A minimum bounding circles is then drawn around each plate with the center point of the circle being treated as the center of the Roomba. The aerial vehicle tracks up to 10 colored objects above a certain size, to eliminate noise, for use by the guidance system.

Threats are detected by a sonar array forming a sonar bubble around the vehicle. If a threat enters the bubble the flight controller will ignore inputs from the Image Processing component and will move to avoid the incoming threat. Once all threats are a safe distance away the flight controller will begin listening to the Image Processing component again resuming normal operation. In future releases of the vehicle's object detection and tracking software the vehicle will actively plan paths to avoid threats, not only react to imminent threats.

Communications

The communication and power distribution board is responsible for implementing the physical layer of all communication channels for the system. It is implemented through a standard PCIe x16 connector although, the protocol and pin out are custom to the system. It supports four SPI, I2C, and RS232 it also supports ten amps of power per rail. The communication board is also responsible for the modularity and flexibility of the system to be reorganized and hot swappable. The communication board also has the ability to allow for debug and development modules to be added to allow for easy software and hardware debugging and upgrading.

Power Management System

Power management is done by the power management component which was designed specifically for this project. It also serves as the backplane for the other daughterboards to slot into, providing the various voltages required. It's features include voltage monitoring of each individual cell of the LiPo battery, current monitoring of the entire system, and full reporting of these statistics on the common bus. An AtMega 328p is used to monitor all of these and relay the data as requested to the bus.

This microprocessor also computes total charge remaining in the battery pack. This is possible because each battery has it's own AtMega that interfaces with the power board to relay identifying information. This information includes cell count and capacity, as well as maximum current. This data is constant and does not change as the battery is used.

The power board can also relay messages to the common data bus. These messages are a capacity warning, a capacity exceeded alarm, a voltage alarm, and a current alarm. These are used by the flight controller to relay back to the drone's controller. These may also be used to determine if an immediate emergency descent and landing should be performed.

Beyond the power board, the actual motor control is done with removable ESCs that are standard among quadcopters. They run directly from the power board to the brushless motors. This is done because the ESCs are the most likely point of failure in the power system.

OPERATIONS

Flight Preparations

To prepare for flight, the team follows the pre-flight checklist. First the battery is examined, making sure it is connected and charged. Props are checked next, making sure they are secured properly. The kill switch operation is verified next, followed by confirmation that the radio is connected and transmitting properly. Finally, the drone is visually inspected one more time, assuring that all modular components are solidly secured to the frame.

Man/Machine Interface

There are 2 interfaces for man/machine interaction. The first is the kill switch which is part of the transmitter/receiver. The kill switch is the only form of communication this interface facilitates. The second interface is the logging system which uses a 900Mhz radio to send logs to a base station computer.

RISK REDUCTION

Vehicle Status

Shock/Vibration Isolation

The legs of the drone are designed to reduce shock on the drone's frame when the drone lands. The legs have a curved almost horseshoe design allowing them to give slightly on impact. The slight give in the legs will help reduce the force felt on the frame during impact with the ground. The legs also have a modular design so the legs can be replaced if they get damaged or break completely. Since the legs are modular we designed them to be the part of our overall frame that would break first for high falls. This allows us to just have to replace two legs for unintentional crashes instead of the entire frame. The breaking of the legs for high falls will also dissipate even more of the energy thus reducing the force on the frame. Which allows our main frame to stay intact and will only need to replace the broken legs with new legs for repairs by taking out a few bolts.

EMI/RFI Solutions

To counter RF interference our kill switch is integrated into our 3rd party transmitter receiver which uses proprietary communications techniques to guarantee data transfer. Our radio logging system uses some basic cyclic redundancy checks to perform basic bit corruption detection and error correction.

Safety

Several safety measures are taken when flying the drone. Aside from general safety rules such as eye protection and keeping everyone back at least 50 feet, the main safety feature is a kill switch. This kill switch is detailed elsewhere.

The flight controller also listens for a kill radio signal that can be sent from many locations such as the pilot or any spectator with a radio module. These radio modules are a box with a single button that will immediately activate the internal kill switch until the quad is power cycled. These are intended to be passed out to team members and judges.

Modeling and Simulation

The frame was designed using Solidworks 3D modeling software. Solidworks simulation was used to get a preliminary feel for the structural integrity of the frame. Once a satisfactory design was complete, the separate parts of the frame were printed on a Makerbot Replicator Z18. As field testing continues, the frame design is updated.

Testing

The flight controller was tested on a custom PID tuner of varying degrees of freedom. Once pitch, roll, and yaw were properly tuned, we began to test actual flight. The frame components were tested individually and then in assembly in Solidworks.

CONCLUSION

Working towards completing this mission has been a massive undertaking. Countless hours have been spent thus far, trying to figure out the intricacies of building a platform like this, and countless more have been spent trying to develop a solution that will be easily extensible in the future. The team is proud of the work thus far, excited to demonstrate the progress made this year, and already planning for future years and what can be accomplished.

REFERENCES

OpenCV Library. Web. <opencv.org>.