Functional Specification

Year: 2022 Semester: Fall Team: 8 Project: Hermes

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Assignment Evaluation:

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| --- | --- | --- | --- | --- |
| **Item** | **Score (0-5)** | **Weight** | **Points** | **Notes** |
| **Assignment-Specific Items** | | | | |
| **Functional Description** |  | x3 |  |  |
| **Theory of Operation** |  | x3 |  |  |
| **Expected Usage Case** |  | x3 |  |  |
| **Design Constraints** |  | x3 |  |  |
| **Writing-Specific Items** | | | | |
| **Spelling and Grammar** |  | x2 |  |  |
| **Formatting and Citations** |  | x1 |  |  |
| **Figures and Graphs** |  | x2 |  |  |
| **Technical Writing Style** |  | x3 |  |  |
| **Total Score** |  | | |  |

5: Excellent 4: Good 3: Acceptable 2: Poor 1: Very Poor 0: Not attempted

General Comments:

1.0 Functional Description

Hermes is an autonomous quadcopter drone that is intended for remote emergency response and search in a final use case. The drone will take off, navigate a room via optical sensors while stabilizing itself using IMU sensors, and visually search for and find an intended target, while maneuvering around the room. It will have remote and autonomous flight control modes, to accommodate various situations.

2.0 Theory of Operation

The drone platform will utilize a custom flight controller for aerodynamic stability and a navigation computer using GPS/computer vision for autonomous GNC and obstacle avoidance. The flight controller will ensure aerodynamic stability via IMU sensors, filtering and stabilization algorithms implemented on a microcontroller, and communication to the 4 channel brushless motor controller via a high bandwidth motor control protocol. It will respond to dictated flight control commands, i.e. height over ground, yaw, pitch, roll from the navigation computer via a digital communication link, or a remote control based on dictated flight mode. The remote control will be an off the shelf RC radio receiver implementing multi-channel one wire protocol. The navigation computer, a high processing power single board computer, will utilize camera vision to search for a desired object, and use lidar range information to navigate a room and compute flight commands to pass to the flight controller.

Due to the inherent instability of a drone flight platform such as a quadcopter, there must be a control system that takes as an input the desired attitude and elevation of the drone, and converts that into the motor commands that will orient the drone in that way. To accomplish this, the drone must have accurate knowledge of its orientation in 3D space, as well as the desired orientation.

Computation of the orientation is done via a sensor fusion algorithm such as the complementary filter or Kalman filter, where sensor inputs from accelerometer, gyroscope, magnetometer, etc., are used to make a prediction or estimate of the true attitude of the drone.

This attitude information is fed to PID loops which compare the estimated attitude with the desired attitude, and calculate a correction response for each axis. These corrections are then summed together to create 4 motor commands. Roll corrections increase thrust on one side of the drone, and decrease the thrust produced on the other side. Pitch works similarly, 90 degrees offset. Yaw is corrected by varying the thrusts produced by each of the diagonals of the drone motor pairs. To have net zero torque, the motors on a drone are installed so the motors on each diagonal spin in the same direction. Thus, the net torque produced is zero, yet any variation in torque made by decreasing one diagonal’s thrust vs. the other, to steer, acts orthogonally to any other correction input to the motors. I.e. a yaw correction should not interfere with a roll correction, or produce a deviation in the roll axis.

Both the sensor fusion algorithms and PID loops must be carefully tuned to provide good performance characteristics. Some can be determined via mathematical analysis of the system, but many times they are found most quickly via trial and error tuning.

The motor commands will be output to the motor controller via one of multiple widely used ESC protocols, the primary protocol being DSHOT. This is a digital one-wire protocol that is used to indicate to the ESC the desired output throttle level of the motor for that channel.

Once the motor commands are sent, the motors quickly react and change speed, resulting in, hopefully, a closure of the error between the desired/commanded attitude, and the estimated/sensed attitude. This control loops effectively accounts for disturbances, vibration, noise, wind, and changes in commanded attitude to maintain stability and control of the drone during flight.

Stereo Vision will create the depth map using the Stereo SLAM algorithm [1]. The stereo cameras will take frames that our algorithm will then detect important features of the landscape and their depth. Our algorithm will also detect the motion in the image and if there’s too much motion it will be utilized to map the area. If a keyframe is required and the quality of the frame is acceptable, then the features of the frame will be added to the selected keyframes that will be used to determine the landmarks and connections between landmarks. Finally, it will adjust the map by eliminating frames that have repeated information.

Path planning for the drone will be done by taking the point cloud generated by the stereo SLAM algorithm and generating a 2D occupancy grid from that data. This is then passed into the D\*Lite algorithm for the optimal path from the start to the goal point. This is done incrementally as the path traversed and updates the path based on the updating occupancy grid.

3.0 Expected Usage Case

Hermes in a final use case will be used in emergency search operations by any organization or department that regularly carries out search operations. Hermes is intended to be portable and can be used in both urban and rural environments for search and rescue so long as the weather is suitable for electronics. Hermes can be used in solo rescue operations, in conjunction with search parties, or ideally in the future multiple Hermes can search an area together. Currently, we plan to have Hermes always released by a person and manually set to autonomous mode when stabilized in the air, with intentions of having Hermes be fully autonomous on takeoff.

4.0 Design Constraints

4.1 Computational Constraints

Primary computational constraints for the flight controller:

* Read in sensor data from accelerometer, gyro, magnetometer, barometer
* Process sensor data
  + Low pass filter
  + complementary filter, etc. predict true orientation
* Read RC receiver channels
* Read and parse command packets from navigation computer
* Transmit necessary sensor data back to navigation computer
* Compute motor outputs via PID loops for yaw, pitch, roll, throttle
* Output motor commands to brushless motor controller
* Entire sensor read -> sensor fusion -> PID update -> motor output loop must run fast enough such that it will respond to disturbance quickly enough to stabilize the drone. I.e. the loop plus the time for the motors to respond must leave the system transfer function with positive phase margin.
  + Sources indicate that for many applications, a ‘loop rate’ or update frequency above 100 Hz is needed for minimal stability, and above 500Hz for optimal stability.

Primary computational constraints for the navigation computer:

* Read image frames off stereo camera modules
* Compute depth map from compositing stereo images together
* Process Stereo SLAM algorithm to correlate depth map with previous dataset of terrain
* Create an occupancy grid on horizontal plane corresponding to obstacles in path
* Use D\* Lite planning algorithm to generate and update path
* Decompose path into flight commands for flight computer
* Send flight computer commands

4.2 Electronics Constraints

Primary electrical components:

* Battery
* 4 channel brushless motor controller
* RC radio receiver
* Flight controller
* Navigation computer

Flight controller components:

* IMU
* STM32F4 microcontroller
* USB-serial converter
* Oscillator – must be properly configured to microcontroller specs
* Programming header
* Serial connection to navigation computer
* USB connector
* Buck Dc-Dc converter
* Linear LDO regulator
* Interfaces:
  + PPM (radio receiver)
  + DSHOT (motor controller)
  + SPI
  + Serial

Constraints

* Routing for SPI and DSHOT busses must be capable of passing high frequency (over 1MHz) signals, will need care taken when routing traces

4.3 Thermal/Power Constraints

Since our project is computationally expensive on a battery, our expected flight times are short. Within the limits of this semester, we expect a minimum flight time of 30 seconds and a target of a 3 to 4 minutes. Due to the nature of our project thermal constraints are not a primary issue. We are only limited by the maximum operating temperature of our electronics which would be bottlenecked by our battery at 60°C.

The approximate minimum battery specs have been calculated via a minimum flight time, and approximate weight, and current at the necessary thrust for hover.

|  |  |  |
| --- | --- | --- |
| Minimum Flight Time | 90 | seconds |
| Jetson Nano weight | 241 | grams |
| Approximate kit weight | 400 | grams |
| Typical 4S 1200mAh battery | 160 | grams |
| total weight | 891 | grams |
|  |  |  |
| thrust from typical 2306 brushless motor | 1400 | grams |
| amps at above thrust | 26 | A |
| amp/g thrust | 0.018571429 | A/grams |
|  |  |  |
| total thrust necessary | 2673 | grams (3x drone weight) |
| thrust per motor | 668.25 | grams |
| current at given thrust | 4.136785714 | A |
| total current | 20.54714286 | (4x motor current, plus 4A for electronics) |
|  |  |  |
| hours of flight time | 0.025 | h |
|  |  |  |
| mAh necessary | 513.6785714 | mAh |

4.4 Mechanical Constraints

Hermes is intended to stay as physically small as possible to achieve an optimal weight to thrust ratio. Our greatest constraint is that we need to be able to fit our NVIDIA Jetson onboard. We plan to use Hermes in near ideal conditions during this prototype phase because it will not be resistant to the elements.

4.5 Economic Constraints

The Hermes autonomous drone has plenty of competitors from companies such as DJI, Parrot and Skydio [2]. Most commercially sold drones either have limited autonomous features or are exclusively sold to large companies and as a result are extremely expensive. Most commercial drones with limited autonomous features cost in the range of $1000-$2000 per drone. Having Hermes limited to the budget of around $500 makes the product competitive in the overall autonomous drone sector.

5.0 Sources Cited:

[1] S. Ye. “Stereo Visual SLAM.” <https://shangzhouye.tech>. <https://shangzhouye.tech/featured-projects/stereo_slam/#overview> (Accessed Sep. 1, 2022)

[2] A. Banik. “Top 10 Autonomous Drones in 2022.” <https://www.analyticsinsight.net> . <https://www.analyticsinsight.net/top-10-autonomous-drone-companies-to-watch-in-2022/> (Accessed Sep. 1, 2022)

[3] Marketing Team. “6 Important Parameters for the Design-In of Lithium Polymer Batteries.” <https://www.jauch.com>. <https://www.jauch.com/blog/en/6-important-parameters-for-the-design-in-of-lithium-polymer-batteries/#:~:text=By%20default%2C%20lithium%20polymer%20cells,above%20or%20below%20this%20range>. (Accessed Sep. 1, 2022)