Hardware Design and Low-level Device Control for an Autonomous Quadrotor Robot

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I. INTRODUCTION

This paper focuses on the hardware design, sensor selection, low-level actuator and sensor control for a micro aerial vehicle (MAV), also known as quadcopter. MAVs are becoming popular in fields such as photography, environmental monitoring and structure inspection. Theoretically, we could operate the mav stable based on the ground truth data pre collected, However, the real world environment is dynamic, partly unknown, GPS-denied, no database. Therefore, it is necessary to implement fully autonomous navigation algorithm, and we are designing a hardware platform that could run such methods.[1]

II. PROBLEM STATEMENT

The robot should have ability to sensing the environment around itself, with at least 5 minutes battery life, maintaining its pose and compute trajectories onboard. We are selecting components to ensure these requirements. Necessary parts include a set of sensors, a frame, ESC, motors, propellers, a flight controller, an Intel NUC board and a battery. Because of flying in the air, the quadcopter should be limited to compact size, weight, and with high acceleration. Ideally our device should within the size of 375mm(L) x 375mm(W) x 250mm(H) (excluding propellers), and weight of 1.6-2.0 Kg to obtain high thrust-to-weight ratio.

III. TECHNICAL APPROACH

A. Hardware Design

We would like our quadcopter fly smoothly and reach the speed up to 20m/s and acceleration of 10 m/s due to our sensor range is 20m. Reaching such flight parameter and maintaining the hover pose the quadcopter should have the thrust-to-weight ratio of about 1.5, even 2.0 to achieve margin control.

We selected the DJI 450 as base, and DJI E310 motors, Snail 430-R Racing electronic speed controllers (ESC), propellers. Each fine tuned motor and propeller could provide 0.8 Kg thrust force, thus 4 motors will generate about 3.2 Kg thrust force as total. As we are estimating the weight of whole robot is up to 2 Kg, this motor-propeller set could keep the minimum thrust-to weight ratio of 1.5. For the low-level control, we chose the pixhawk as flight controller. It is an open-source autopilot system, and when applying algorithms the controller could send signal to ESCs to control the motor's speed. The motors are powered directly from battery, as it requires 30 Amps when accelerating. The on-board computer requires 12v or 19v 40w pure and steady power supply while the motor needs 12v/30Amps at its most demanding condition, so it is necessary to design a power distribution board to power main device respectively, and ideally to replace one plate on frame to reduce weight.

B. Sensing, computation, communication

The quadcopter flies in unconstructed 3D environment, we are using two cameras as our primary state estimation sensors, and a VN-100 internal measurement unit (IMU) with downward pointing lidar (Garmin Lidar-Lite) for state estimation. The IMU is also used to trigger the capture from cameras to have time synchronization between the cameras and IMU. I designed a holder to mount the IMU and cameras, and printed with 3D printer. The structure was strengthened by ribs and interfaces between the axis and holder is incomplete to to ensure stable relative position. The specific main components and corresponding functions are listed in table I .

TABLE I

Name	Function	Weight (Kg)
DJI 450 frame	Support all other equipment	0.359
E310 Motor ($\times 4$)	Drives the propellers	0.129
Snail 430-R Racing electronic speed controller ($\times 4$)	Control the motor speeds	0.01
Pixhawk Cube 2	Provides low-level control	0.039
Matrix Vision Bluefox 2 ($\times 2$)	Global shutter stereo camera for visual sensing and pose estimation	0.06
Hokuyo 2D Lidar	Measures distances to obstacles and allows mapping the robot's surroundings	0.13
VN-100 Inertial Measurement Unit	Provides linear acceleration and angular velocity measurements for attitude estimation	0.015
Intel NUC	Handles all computations for estimation, mapping, planning, and control	0.34
Garmin Lidar Lite v3	Downward facing lidar for sensing height	0.034
11.1 v 3-cell 5000 mAh battery	Supplies power to all quadrotor components	0.35

C. Software Architecture and Configuration

To handle all the computation for control, sensing, planning on the robot, we are selecting Intel i7 NUC board. This single-board computer is equipped with i7-8650u processor, 16GB RAM and 250GB M.2 SSD for storage. It is mounted on top of the quadcopter and should along with a cover to prevent accident.

All the sensors' raw data are processing by the NUC board. We are using Robot Operating System (ROS) kinetic for quadcopter software development, based on Ubuntu 16.04. ROS is a flexible framework with collection of tools, libraries that provides a variety of possibility to develop and test robotics control, function or algorithms. Nodes are the smallest unit run in ROS. We treat nodes as executable program, ane they can mutually talk if some were assigned with publisher and subscriber.

D. Communication

As the quadcopter flies in air, it is necessary to operate and monitor its statues and parameters in local computer. We are setting SSH connection to remote control. The wireless network adapter on NUC board cannot transmit signal through long distance, so we selected the Ubiquity Networks Picostation M2 for the robot side receiver, which could provide about 50 Mbps speed up to 200 m.

IV. Results and Evaluation

The framework of our quadcopter has been setup, parts are assembled together and are able to communicate with each other. We can open the ROS on the quadcopter from local computer and observe the two cameras' image transmitted via SSH connection. One incomplete task is the power distribution board, since we are lack of equipments at this time.

The whole system is shown in fig. 1.

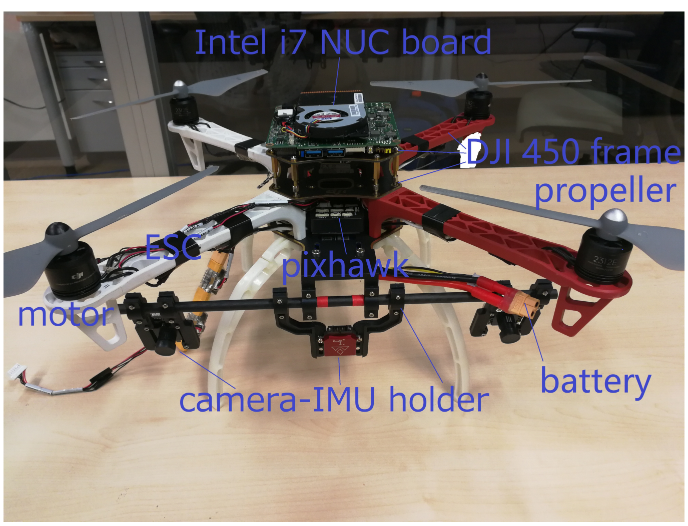

Fig. 1. Whole System

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References

[1] Kartik Mohta, Michael Watterson, Yash Mulgaonkar, Sikang Liu, Chao Qu, Anurag Makineni, Kelsey Saulnier, Ke Sun, Alex Zhu, Jeffrey Delmerico, and et al. Fast, autonomous flight in gps-denied and cluttered environments, Dec 2017.