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The Analysis of Collision Detection and Avoidance Systems for Quadcopters

Introduction

For our senior design project, we were tasked to add autonomous functionality to a quadcopter drone. The main objective is rather open-ended since autonomy can be defined in many ways, e.g., does the drone hover, self-navigate, or execute a preprogrammed task with autonomy guiding its flight? However, our group narrowed the down the goal to designing a drone such that it could autonomously navigate in new surroundings. We will have to explore diverse concepts from image processing to quadcopter flight dynamics, and collision detection and avoidance will be a vital component of the drone's success. While the quadcopter utilizes onboard sonar and camera modules to map its surroundings, there will surely be moments where the drone has a "blind" spot and cannot foresee an oncoming collision. To circumvent the dangers of a collision, I propose that we add additional sensors along the perimeter of the drone that are solely used to check immediate surroundings in real-time. The drone can then take evasive action to avoid the collision.

Applications

Collision detection and avoidance are relatively well-researched and documented, especially given the recent rise in automotive technology. People seek to protect themselves and their belongings, and in our case, we seek to protect the quadcopter. Almost all modern cars have a form of collision detection that uses embedded sensors to prompt the driver when a car in front immediately halts to a stop. The popular manufacturer, Tesla, has even gone so far as implementing collision detection and evasive action in their fleet using 12 ultrasonic sensors to provide 360° detection [1]. Since automobiles don't involve a change in altitude, collision detection and avoidance can be simplified to merely steering away or braking. On the other hand, to implement this feature on a quadcopter, we will have to consider objects above and below the drone before invoking the appropriate evasive protocol. Upon doing some background research on the technology, I came across a company called Terabee that sells various time-of-flight LiDAR modules with the cheapest going for $60. The company had a specific page devoted to demonstrating their LiDAR sensors for drone collision avoidance, and their design specified, "a single time-of-flight sensor attached to the bottom of the drone functions as a precision altimeter to maintain a constant height; while a multidirectional LiDAR time-of-flight sensor array provides up to positional monitoring" [2]. They focus more on automatically avoiding static objects while a human is remotely flying the drone, but the logic for detecting and avoiding collisions is still applicable to our project. Using an array of sensors, when the drone sees an upcoming object, it immediately sways towards the opposite direction while maintaining its altitude. While the company's use of LiDAR sensor arrays is not feasible for us in terms of cost, a couple of important take-aways were that collision avoidance is definitely possible with accurate sensors and that we will need six sensors at the least: one above, one below, and four in the cartesian plane. An article from the Sensors journal, that successfully tested collision avoidance between multirotor drones themselves, points out that "non-cooperative sensors can help avoid collisions with static objects, but they do not allow for a fast react enough to avoid collisions with moving objects" [3]. This again confirmed that proximity sensors will be sufficient because we will not be concerned with moving objects around the drone.

Mechanism

From the current state of collision detection and avoidance in the market, it is obvious that sensors will be the backbone of the detection system. For the response system, however, we will need to devise a program that brings the drone to a halt and carries out the necessary maneuver to escape. The European New Car Assessment Programme has a section describing that most autonomous emergency braking systems "use radar, (stereo) camera and/or lidar-based technology to identify potential collision partners ahead of the car. This information is combined with what the car knows of its own travel speed and trajectory to determine whether or not a critical situation is developing" [4]. I did not consider the drone's own travel speed when I planned on using proximity sensors to foresee an upcoming obstacle. Terabee's example displayed a hovering drone that lightly swayed to avoid objects, but our project is going to be focused on mapping as well as collision detection; therefore, the drone's frame will be in motion. Since the sensor's polling frequency and drone's acceleration are currently unknown, we will have to combine the sensor's latest reading with the drone's latest velocity in that direction in order to accurately prevent a collision. In designing the software and hardware that add autonomous capability to the drone, I suppose it would be more efficient to combine the localization, mapping, and collision detection systems on one microcontroller. A report by the NHTSA that analyzed automotive collision avoidance displays a model titled "Collision Warning Vehicle Mechanization", and the design includes a separate Collision Avoidance Processor specifically tasked to process the sensor data and modulate speed and steering accordingly [5]. Although a separate microprocessor for the collision avoidance system could be possible for our quadcopter project, I think it would be more efficient to embed the logic of each feature on a single microprocessor since they will be using the same sensors for input data. If it proves difficult, we can easily attach a separate microprocessor; however, its best to start with less hardware since weight and space are important considerations we must make.

Requirements

Choosing the sensor is a seemingly straightforward process for the quadcopter, but the decision is made more complex by the different tradeoffs of each technology. On top of that, component choices must me made such that the sensors are appropriate for not only the collision detection aspect of the project, but also the autonomous navigation and mapping aspect. For collision detection, you would use a shorter-range sensor, but for navigation and mapping you may find a long-range sensor more suitable. A site studying remote sensing technologies in self-driving cars compared the three most popular sensors for applications such as collisions detection: LiDAR, sonar, and radar. The overall conclusion of the analysis was that LiDAR was the most accurate and expensive, radar was fast and long-range, and sonar was short-range and most compact [6]. For our purposes, sonar seemed the most appropriate because of its ideal size, cost, and accuracy. We will also try to extrapolate the drone's velocity from the sonar data. I found a patent titled "Visual collision avoidance system for unmanned aerial vehicles" that made use of "a forward-looking TV camera which senses visual obstacles in the direction of flight" [7]. This would have been a feasible option for us, however the direction of flight for a quadcopter is occasionally different from the front face of the drone, e.g., when the drone pans left. Therefore, we would require a camera on each side just like the sonar modules. Since the camera module is slightly more expensive than a sonar sensor, the cost benefit of the camera module is diminished. Depending on the starter drone that we initially decide to modify, we may also have to add a separate microcontroller and power supply. We can easily equip a drone with a small microcontroller and battery housing if the default hardware of the quadcopter is unmodifiable. However, getting the microcontroller to properly execute the collision detection features and interface with the drone's rotors will require some work and reading of the appropriate documentation. The programming language will also be decided once we choose a microcontroller, but it will most likely be C or Python.

Conclusion

All in all, I feel more confident in our ability to equip the drone with collision detection and avoidance because there are proven concepts already on the market. The project will very much be a trial and error type as we refine the capabilities of the drone and make certain software and hardware adjustments. Our goal is to simply increase the functionality of quadcopters at a low cost. To implement collision detection and avoidance, we will pair affordable sensors with a microcontroller to make the drone travel in the optimal direction whenever it foresees an upcoming collision or obstacle.

References

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