Obstacle Avoidance System for a Quadrotor UAV

Thirupathi Srinivasan
Aerospace Engineering
Mentor: Dr. Subodh Bhandari
Kellogg Honors College Capstone Project

INTRODUCTION/BACKGROUND:

There exists growing interest in the use of Unmanned Aerial Vehicles (UAVs) for missions that would otherwise be dangerous or tiresome for human pilots. Such UAVs require obstacle avoidance or Sense and Avoid (S&A) capabilities for autonomous operation. However, small UAVs do not possess the power or structure to handle heavy, expensive, and energy-consuming sensors or computers. The purpose of this research was to develop and demonstrate an inexpensive obstacle avoidance capability on a quadrotor UAV using commercial-off-the-shelf (COTS) components. The research was constrained to indoors testing, where GPS signals are inaccessible and the UAV must rely on its inertial measurement unit (IMU) for navigation.

APPROACH:

HARDWARE:

The primary hardware on the quadrotor consisted of six MaxBotix LV-EZ0 ultrasonic rangefinders and the APM 2.6 autopilot as shown in Figures 1 and 2 below.

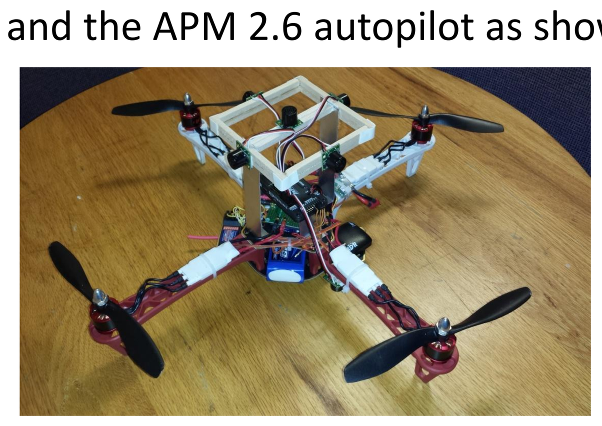

Figure 1. Quadrotor

Figure 2. Maxbotix LV-EZ0 Ultrasonic sensor

ALGORITHMS:

The implementation of the S&C capability was based on the Rapidly-Exploring Random Tree (RRT) and optimal path algorithms. Both of these algorithms required that a map of the surroundings be known prior to navigating between two or more designated waypoints. The location of the quadrotor was determined using IMU data and quadrotor dynamics. The RRT algorithm makes use of a randomly growing space-filling tree that expands to cover unexplored regions of the environment. Each node in this tree is represented as an intermediate waypoint. The optimal path algorithm chooses the shortest route from the starting location and a target waypoint, which is manually specified in the code. The final result of the optimal path algorithm is shown for a sample case, where the quadrotor must navigate between two rooms that is connected by an open doorway.

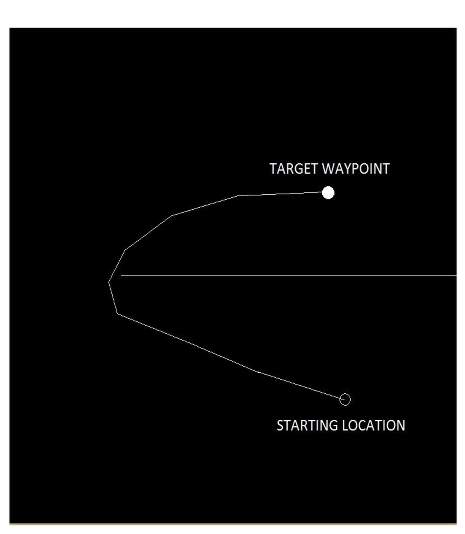

Figure 3. Simple Room Navigation

SYSTEM ARCHITECTURE & BEHAVIOR:

The functional behavior of the individual components are shown in Figure 4 below. The autopilot provides IMU data which are used to obtain the quadrotor's position relative to its starting location. This is calculated from the dynamics equations of the quadrotor. The quadrotor then computes the distance to the next waypoint, changes its heading, and flies there using the built-in PID control system. This process is continued until the target waypoint is reached. The sonars assist in altitude maintenance and in keeping the quadrotor at a safe distance from walls or obstacles.

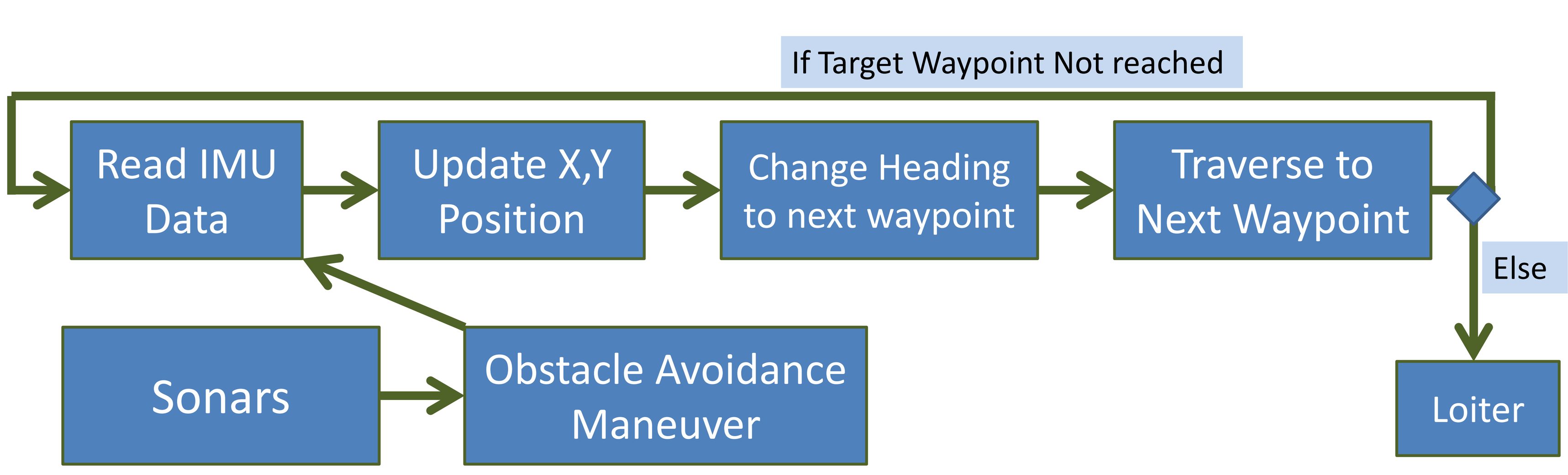

Figure 4. High Level System Behavior

RESULTS & ANALYSIS:

The algorithm and functionality of the quadrotor was tested as follows. The algorithm was regression tested to check for bugs. Meanwhile, the quadrotor was bench-tested to see its response to nearby obstacles. The algorithms were then implemented onto the autopilot and several flight tests were done in the hallways of the apartments at Cal Poly Pomona's Village residential area.

Overall, adequate results have not been obtained to gauge the success of the obstacle avoidance capability and testing is still ongoing. The following issues were detected. The quadrotor was found to drift in autonomous mode and could not maintain a steady position. This is due to the sensitivity of the sonar, as shown in Figure 5. Drifting was also due to the quadrotor's propeller wash when in close proximity to the ground. In addition, the quadrotor position measurements were not accurate. The position was inaccurate by a few centimeters. This caused the quadrotor to miss its intermediate and target waypoints. Finally, the quadrotor only responded to static obstacles (i.e. obstacles that were already known to exist on the environment map). Unknown obstacles that were detected during navigation (pop-up obstacles) caused the quadrotor to stop and fail to pursue its target waypoint.

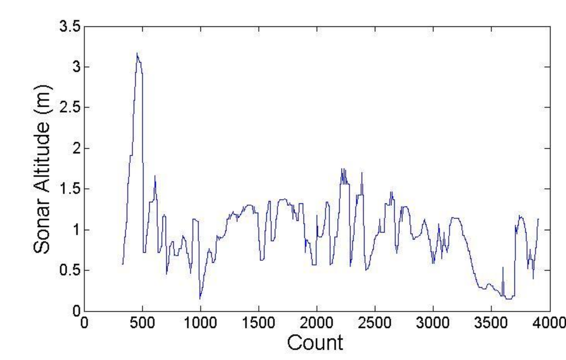

Figure 5. Variation in Sonar Altitude Reading

CONCLUSIONS & FUTURE WORK:

Several issues were detected with the quadrotor flight including inaccuracies in positioning, drifting, and inability to respond to static obstacles. More bench and flight testing is necessary to have the quadrotor properly follow the optimal path. In addition, a more robust algorithm and code is required to be able to avoid pop-up obstacles

Recommended future work include increasing the autonomy of the quadrotor and three dimensional navigation. The quadrotor UAV can be made more autonomous through automatic take-off and landing. This requires the use of obstacle detection and avoidance since the quadrotor must ensure that it does not land on an unstable object. More importantly, the S&C capability must be applied to its full extent through 3-D navigation. Currently the quadrotor is only given a two dimensional map of its surrounding environment, from which it calculates the optimal path to the target location. However, three-dimensional navigation is necessary in the case of finding objects at different elevations. This especially pertains to an indoor search-and-rescue operation, where the UAV must be able to climb building floors without the use of GPS and also be able to pass through narrow constrictions, like windows, which cannot be resembled by two dimensional mappings.

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