Understanding the Sense and Avoid Challenge

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Fares El Tin

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Introduction

One research aspect of the Property Drone Consortium focuses on the use of Unmanned Aerial Systems (UAS) to inspect roofs for damages from severe weather. The process is ideally fully autonomous, with a flight plan developed prior to arriving at the property. However, even the most meticulous and organized plans sometimes fail to note changes at the imaging site. These modifications may be needed due to landscaping, tree branches, electric or telephone wires that could obstruct the UAS's path. The objective of this research is to develop and understand a system which can detect and avoid collisions while simplifying operations.

Sense and Avoid Systems

With the increase in UAV uses in the industry, the need for a UAV sense and avoid system is also increasing. Several companies, such as Parrot and DJI, are actively researching and developing collision avoidance technology for UAV integration. SenseFly, a subsidiary of Parrot, has developed the eXom system with "advanced situational awareness," using multidirectional ultrasonic sensors to scan its environment[1]. The DJI Matrice 100, a development platform released by DJI, includes an expansion known as Guidance, which is a "visual sensing system" that "includes five sensor modules and one central processor."[2] In addition to DJI and Parrot, Intel, in collaboration with Ascending Technologies, has come up with a device that uses Intel's RealSense 3D technology to map out the area ahead of the UAS, and commands it, using computer algorithms to avoid any collisions.[3] The limitations of an aerial system, such as weight and power, provide many challenges to develop a complete and comprehensive solution. This paper discusses some of the possible setups of a sense and avoid system, their advantages and their limitations.

Setting up a Sense and Avoid System

The flight controller used in this research is the Pixhawk, which is an open source autopilot readily available from 3D Robotics® among others. This flight controller is the hardware of choice due to its many capabilities, such as autonomous flight, and its open source environment that allows for further development. The Pixhawk module interfaces between the off-board, user-controlled computer and the onboard computer that combines user input with its onboard sensors and commands the motors. The basic framework behind a sense and avoid system includes a sensing device, essentially a rangefinder such as SONAR, an Infrared Proximity sensor or LiDAR, and a communication link between the device and the flight controller.

In order to avoid the complications of reprogramming the Pixhawk, an external microprocessor was used as an interface between the sensors and the flight controller. In this case, the platform of choice was the Pro Micro – 5V/16MHz, which is an Arduino-compatible microcontroller developed by Sparkfun Electronics®, and features an ATmega32U4 processor.[4] Due to its small size and light weight, it was the perfect candidate for UAV integration and still provides all of the powerful features of an Arduino. The most effective and simplest sensor to implement is the SONAR sensor. SONAR sensors work by transmitting sound waves and receiving the pulses back as they bounce off of an object. Some simple math is then performed, using the speed of sound, to determine the distance between the sensor and the object. This work utilized Maxbotix's LV/XL-MaxSonar®-EZ™ Sensor Line, which provided a range of low-cost ultrasonic distance sensors that offered an easy-to-use output, calibrated beam patterns, stable range readings and low power demands, all in a small lightweight package.[5]

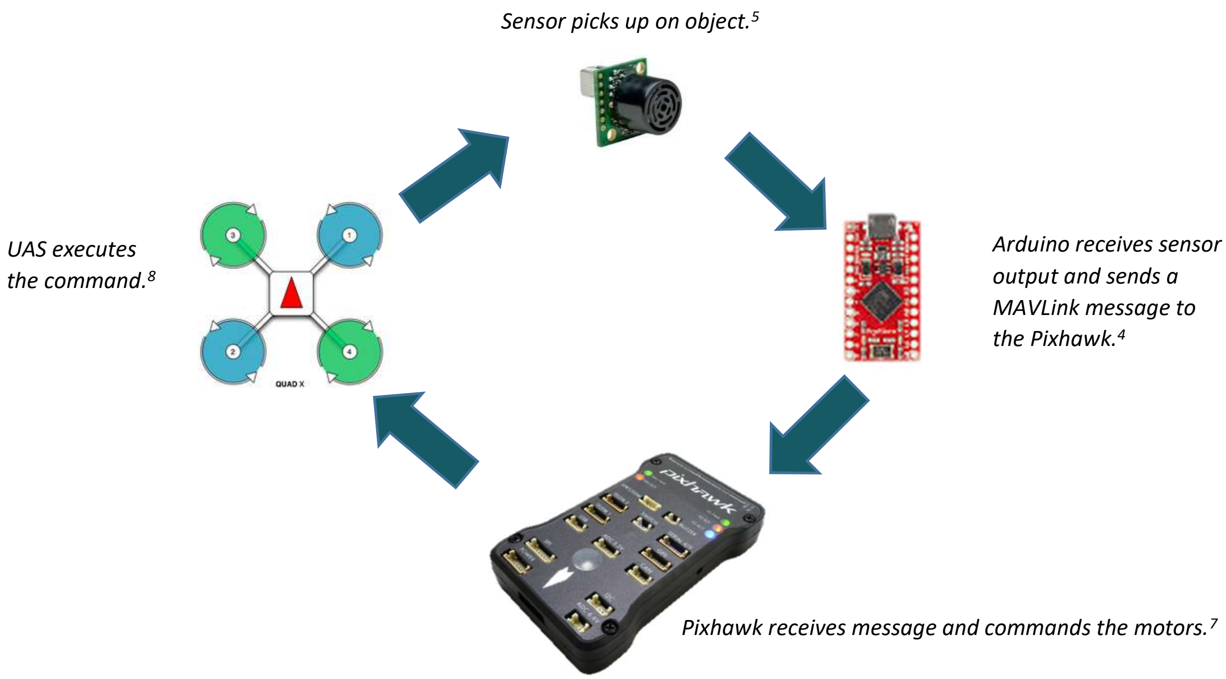

Figure 1: The cycle of sense and avoid as the signal travels from the sensor to the UAS.

SONAR Sensor Experimentation

The first phase of experimentation took place indoors and was performed with only a single sensor placed on the front side of the UAS, as opposed to sensors on all sides, in order to avoid debugging a more complicated system. The Arduino was programmed to receive the distance output from the sensor, compare it to a preset distance in the code, and then send a command to the Pixhawk. MAVLink, a micro air vehicle communication protocol, was used to communicate with the Pixhawk.

During the initial flights, it was discovered that the UAS was receiving erroneous commands which caused the platform to unexpectedly pitch. After some debugging and review, it was determined the issue originated from the sensor's harsh environment. An article by Maxbotix discussed the issues in operating on a multicopter.[6] Air turbulence produced by the propellers influences the air around the sensors and therefore, disturbs the acoustic waves in erratic ways. Propeller acoustic noise also changed the amount of energy the sensor actually detects, which added additional outside acoustic energy to the sensor.

In addition, there are other sources of noise to consider such as conducted electrical noise, grounding, power issues and frame vibrations. Sensor placement is a major concern when designing a SONAR-based sense and avoid platform. However, it is not the only variable which can be altered to minimize erroneous signals. Beam width and noise tolerance of the SONAR sensor can be changed to optimize the performance of the system. Altering the placement of the sensor, its noise tolerance, and the beam width, provided the optimal case for the SONAR sense and avoid system.

These changes yielded a much-improved output signal with a more stable flight. The UAS successfully responded every time it was approached by an object. Further testing was done using the optimal sensor setup in four directions horizontal to the UAS.

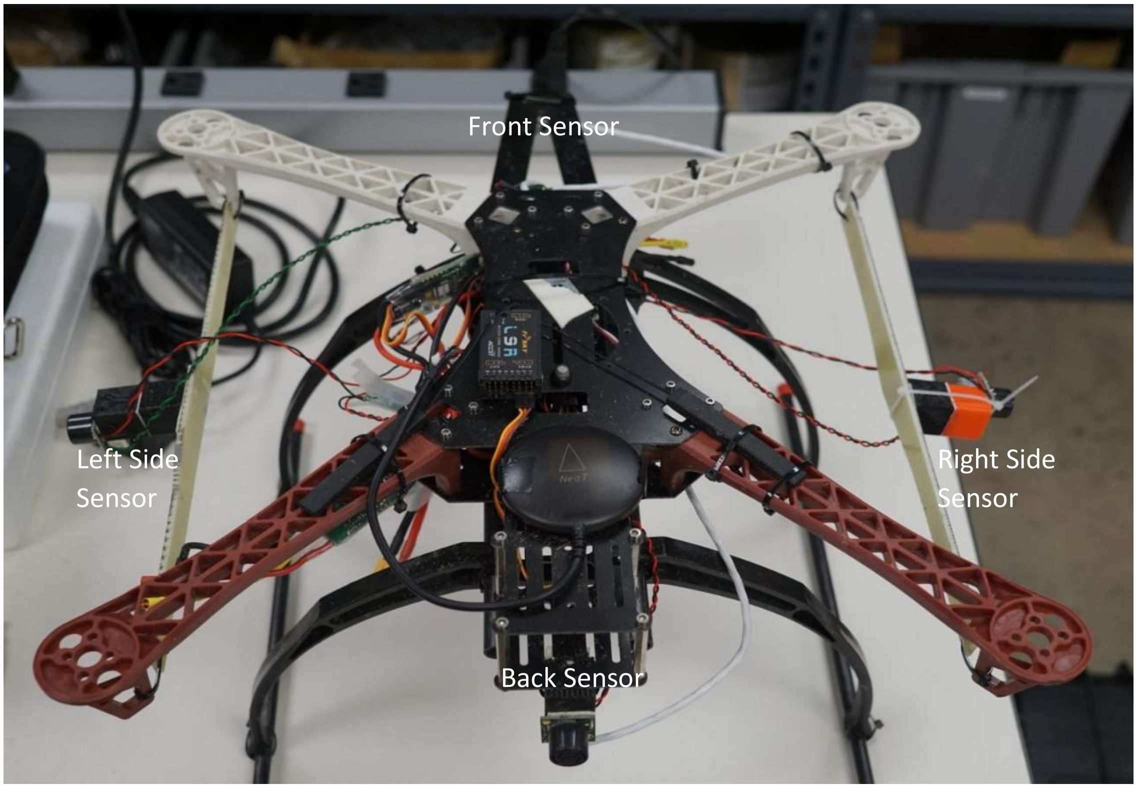

Figure 2: The Pixhawk-based UAS with four-directional sonar sensing. The sensors used were the MB1240 XL-MaxSonar®-EZ4™.

The second phase of testing took place in an outdoor arena, where the sensors were pushed to their limits with the change in environment and surroundings. Wind, ambient noise, brick walls, fences, cars, wires, trees and plants are all factors that came into play and needed to be accounted for. The advanced noise reduction system implemented in the sensors was effective enough to handle the effects of wind and background noise, but other factors still needed to be considered.

The ideal surface to receive the best ultrasonic signal is a flat one, perpendicular to the sensing element. In most cases, different motor vehicles provided enough surface to reflect a clean wave back into the sensor. Walls were also perfect in this case, as they were usually flat and upright. However, inclined roofs proved more challenging and significantly affected the distance at which the quadcopter was set to avoid. Due to the low intensity of the reflected sound the craft had to get close enough for the sensor to receive a clear signal, to the point where at higher approach speeds, a crash was inevitable. As plants and fences become more involved in testing, the speed of the craft played a bigger role on the system's performance.

There is a lot of variety when it comes to vegetation and fences. Some trees are denser and closely packed, while others are wide and sparse. Some fences are more solid and tightly meshed, others may be a couple of wires forming a very wide mesh. The main issue, when it comes to SONAR sensors, is having enough surface area for a sound wave to bounce off. In most cases, there was too little surface area, especially around the outer peripherals of trees. In order to help increase the chances of spotting loose leaves or branches, the speed of the approach was cut down significantly. Often, a crash was almost always imminent, as the sensors did not detect them in time.

Although SONAR sensors offered reliable and accurate distance readings in a very lightweight and compact package, they failed to detect small or irregularly shaped objects. However, in an indoor environment, where walls, doors, desks and chairs form most of the objects, and the speed of the UAS remains relatively low, SONAR sensors would be perfect for the task.

LiDAR Sensor Experimentation

Due to the limitations of the SONAR-based solution, an alternative solution was desirable, and the best replacement for the SONAR sensors was a Light Detection and Ranging (LiDAR) sensor. The LiDAR sensor is a laser-based module that illuminates a target, and then analyzes the light reflected back. Knowing the speed of light and the time taken for the light to travel forth and back, the distance to the object can be calculated.

What gives this device the edge over SONAR is the very short acquisition time, less than 0.02 seconds, as opposed to an acquisition time of about 0.1 seconds when using the SONAR sensors. Even though the laser beam offers a much narrower detection zone due to the speed with which it collects data, it is able to effectively scan the area ahead and provide distance measurements. There are some drawbacks to using a LiDAR module such as the increase in weight, from about 7 grams to about 20 grams, and power consumption, from 0.015 Watts with the SONAR to about 0.5-1 Watts with the LiDAR. Even though both the added weight and power consumption are still small compared to the overall system, the time of flight is noticeably diminished, especially if multiplied by four sensors. Another disadvantage is the relatively high cost of a LiDAR module, compared to the lower price of a SONAR sensor. Therefore, given the limitations caused by both these factors, a single LiDAR module was used.

The module was placed in the front side of the UAS, mounted on a servo that rotates it from left to right in order to cover most of the 180-degree area (about 170 degrees) ahead of the copter. Due to the rapid acquisition time, the servo could be spun at a relatively high speed without any issues. This setup limited the field of view of the sense and avoid system, as opposed to full coverage with SONAR, but nevertheless provided enough coverage for testing purposes.

Figure 3: The updated Pixhawk-based UAS with the LiDAR light module from PulsedLight® mounted on a servo.

One of the issues to overcome when using a setup such as this one is the speed of the micro processing element. The lag in the time required to properly operate the servo at a higher speed causes the communication between the sensor and the flight controller to suffer. The optimal solution to this problem is to have a separate processor operate the servo, keeping the original Arduino in complete control of communications.

Another issue was that since the object could now be anywhere within the 180-degree space in front of the sensor, avoiding it would not be as simple as applying a pitch or roll command in the longitudinal or lateral direction, respectively. To avoid these complications, the Arduino was programmed to send a loiter command to the UAS which would immediately terminate the current mission, safely hold its position and await further instructions from the operator.

The LiDAR-based system performed very well. Objects were introduced at different positions around the front peripherals of the quadcopter and at a speed of about 2.5 m/s, the quadcopter came to a stop at a safe distance. As for the outdoor environment, trees and fences were successfully detected, at different positions and angles, and collisions were sensed and avoided.

Conclusions

Both the SONAR-based and the LiDAR-based systems performed reasonably well. The relatively low cost, lightweight, and low current consumption features of the SONAR sensor, with a reliable distance reading, are very alluring for UAS deployment. However, due to the physics behind SONAR technology, the sensors did not perform as expected in an open outdoor environment, where objects are random and irregularly shaped.

LiDAR, on the other hand, with its high-speed acquisition feature, was able to detect objects of different sizes and shapes. A noteworthy drawback of SONAR sensors was with respect to smaller and lower profile objects such as power lines and tree branches. Using the laser sensor however, with its rapid response features, it was able to map out an area and detect most of those objects, provided it was in a clearly visible position in the LiDAR's course. This, though, came at a higher cost and an increase in both power consumption and weight, both of which limited the number of sensors mounted on the UAS, and thus the sense and avoid field of view.

Sense and avoid technology promises a great flying experience with ease of mind, however, the reliability and portability of sensing equipment has yet to be adequate for complete trust in these systems, but as technology improves every day, we get closer to a fully integrated sense and avoid system for UASs.

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