Experimental Study on Low-Cost Sensor Sensitivity of Inspection Quadcopter's Anti-Collision System

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Abstract: This manuscript presents the experimental study on low-cost sensor sensitivity of inspection quadcopter's anti-collision system. This inspection quadcopter is designed to be operated in aerodrome or hanger forthe inspection of wide body aircraft for lightning strikes. One of most important features that the inspection quadcopter must equipped with is anti-collision system. The anti-collision system will ensure the inspection quadcopter maintain a safe distance from the aircraft and other structures during the inspection process. As one of the project's objectives is to design and develop an anti-collision system for the inspection quadcopter, it is aimed at developing using low-cost sensors and components. Experiments were done to choose the best low-cost sensor to be used as the rangefinder in the inspection quadcopter'santi-collision system. The sensitivity of the low-cost sensors were tested by comparing the measured distance and the actual distance of obstacles. The percentage error reflects the sensitivity of the sensor under certain circumstances. The second objective of this research is integrating the best low-cost sensors the anti-collision system. The anti-collision system was programmed using Arduino IDE software. Lastly, the third object of this research, which is to experiment the performance of anti-collision system was achieved by performing the ground test on the anti-collision system of the inspection quadcopter. The performance of anti-collision was shown on the PWM correction signal generated by the anti-collision system. In conclusion, this paper shows the engineering approach on an industrial problem on developing an anti-collision system using low-cost sensors.

Keywords: low-cost sensor sensitivity, anti-collision system, drone system, quadcopter drone system.

1 Introduction

A quadcopter is a type of under-actuated unmanned aerial vehicle that only has four rotors but can still handle six degrees of freedom. Therefore, the control system of a drone must be developed in such a way that it can control the six degrees of freedom with just four rotors. This may be accomplished by combining the motions of two or more rotors to create a certain movement of the drone. For instance, to make a drone turn to the left, the control system needs to be built so that the drone rolls to the left and then uses push to restore its height after the roll. This is because drones tend to lose their altitude after they have completed a roll. Torque and lift are produced by each rotor of a quadcopter. There is also a force that acts in the opposite direction of life, and that force is called drag.[1]

When a definitive response is supplied concerning the precise location of the quadcopter, the necessity for safety systems such as an anti-collision system that makes use of sensors that measure the amount of time in flight is eliminated [2,3]. To ensure that unmanned aerial vehicles (quadcopters) can continue to operate safely, anti-collision technologies are of the utmost significance. Obstacle detection, collision prediction, and collision avoidance are the three primary functions that make up quadcopter's anti-collision technologies. In general, these are the functions that make up these technologies. quadcopters can acquire the identification and location information of objects by sensing the environment around them. This information may then be utilized for collision prediction. The sensors in the quadcopter gather environmental information, such as the position and speed of obstacles, while the obstacle detecting process is in progress. Through the wireless network that links the quadcopters together, environmental data may be sent between the quadcopters participating in a quadcopter swarm.[4,5]

Using widely available ultrasonic sensors to implement the idea of obstacle avoidance would give the quadcopter a feel of its surroundings, making it simpler and significantly safer to fly in close quarters. Therefore, empirical data will be gathered via experimental trials carried out in accordance with the suggested techniques to check the performance. Previously, the project aimed to explain and demonstrate the idea of obstacle avoidance using a quadcopter built on an Arduino platform. A quadcopter was chosen because of its great degree of mobility, as it can take off, cruise, hover, and land in confined spaces. This made it simple to conduct our tests indoors, thereby reducing certain variables.[6,7]

Using low-cost ultrasonic and infrared range finders, which are much cheaper though noisier than more expensive sensors such as laser scanners, is an innovative and straightforward solution for detecting obstacles and avoiding collisions with unmanned aerial vehicles (UAVs) optimized for and evaluated with quadrotors. This method was found to be effective in both testing and evaluation. To achieve superior data fusion, inertial and optical flow sensors are employed as a reference for the distance derivative Because of this, a UAV is capable of distance-controlled collision avoidance, which is a solution that is both more sophisticated and powerful than similar solutions that are simple. At the sametime, the solution is uncomplicated and requires a small amount of computing effort. Therefore, the memory-intensive and time-consuming process of simultaneous localization and mapping is not necessary for the avoidance of collisions.[8-12]

A major problem for a GVI method that is safe to perform automatically is the detection and avoidance of barriers in the inspection region. The ultrasonic sensor was purchased off the market and used as the foundation for the system. The trigger pin of the sensor requires a strong pulse of at least 5V for at least 10 microseconds for measurements to begin. This pulse starts the sensor. When the sensor determines that an ultrasonic echo has been received, it sets the Echo pin to High and transmits eight cycles of an ultrasonic burst at a frequency of forty kilohertz. The amount of time that passes between the Trig pulse and the Echo pulse increases in direct proportion to the distance between themselves and the

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reflecting object. To overcome the limitation of low-cost ultrasound sensors, a total pf 12 sensors have been used for 6 degrees of freedom. those low-cost sensors together with the situation analysis software that has been designed works well since it has the weighted filter, where the software intelligently accepts the output which is important from the sensor. Hence, proper filtering control must be added to obtain a better detection of obstacles.[13,14]

2 Methodology

This section explains the overall methodology of this project, which focuses on the development of the anti-collision system of the inspection quadcopter and the experiments that have been carried out to evaluate the performance of distance sensing sensors. Fig 1 shows that flow chart of this research paper

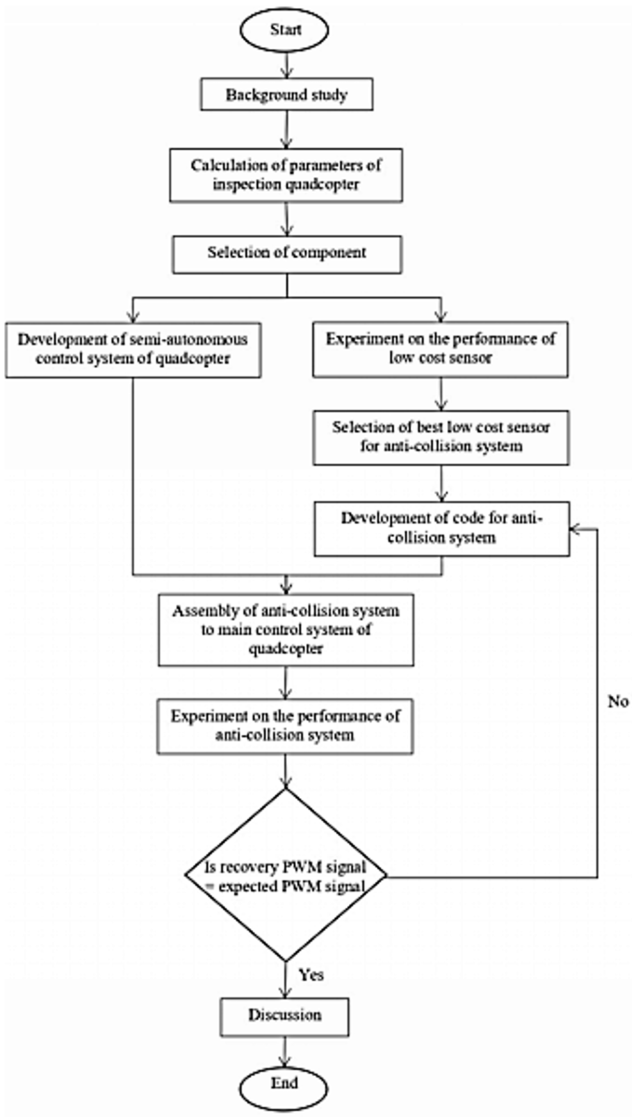

Fig. 1. shows the flowchart of the overall

The research and development of the control system of inspection quadcopters began with background study on the previous studies on the control system and the anti-collision system in quadcopters. Then, the calculation of parameters of the inspection quadcopter was prepared. The parameters of the inspection quadcopter, like thrust generated by each motor, the propeller size required and the battery capacity. These parameters were essential for selecting the components for the inspection quadcopter, as the components selected must fulfill the requirement of the inspection quadcopter's structure. Once the parameters are set, the components for the control system are chosen and assembly is done.[15]
An experiment was designed and carried out to test the performance of low-cost sensors, which are HC SR04 ultrasonic sensor and sharp IR sensor, under certain circumstances. One of the experiments is tomeasure the performance of HC SR04 ultrasonic sensor and sharp IR sensor under different colored obstacles and the second experiment was to test the performance of both sensors under obstacles made up of different type of materials. The experiment was carried out in a controlled environment. The result of this experiment determines the best low-cost sensor to be used in an anti-collision system. The best low-cost sensor which has been determined using the experiment is then used in the anti-collision systemof inspection quadcopter as rangefinder. The anti-collision system was programmed using Arduino IDE software.[16-18]
The performance of the anti-collision of the inspection quadcopter was tested and analyzed by performing an experiment. The performance of the anti-collision system was tested by measuring the correction PWM (Pulse Width Modulation) signal generated by performing a ground test. The experimentwas performed on ground, where in a controlled environment. The inspection quadcopter, which is equipped with the anti-collision system is tied to remain in a fixed position. The motors of the quadcopterwere armed and allowed to spin at a RPM, which is close enough to make the quadcopter hover. Then, obstacles were brought near to the quadcopter to observe the correction PWM signal generated by the anti-collision system of the quadcopter. If the correction PWM signal is same as the expected PWM signal, then the experiment success. The results obtained were tabulated and plotted.[19]

2.1 Low-cost Distance Sensing Sensors

HC SR04 ultrasonic sensor is a piece of component that utilizes ultrasonic sound waves to determine the distance between itself and an object [20]. The transmission of a sound wave at a frequency that is inaudible to humans is essential to the operation of ultrasonic sensors. The ultrasonic sound may be received and sent thanks to the transducer of the sensor, which functions as a microphone. The anti-collision system that has been added to the inspection drone consists of four ultrasonic sensors, which powered by Arduino Uno microcontroller. Each ultrasonic sensor is fixed at each side of the quadcopter. Figure 2 shows HC SR04 ultrasonic sensor which has been used for the anti-collision system of inspection quadcopter.

Fig. 2. HC SR04 Ultrasonic Sensor

Other than ultrasonic sensor, Sharp Infrared (IR) sensor also being used in this research. The Sharp IR sensor is a gadget that measures distance and may be utilized by robots for the purpose of obstacle detection. The measured distance is reflected in the sensor's output voltage, which is proportionate to the distance. Since the sensor utilizes the triangulation approach, it is not easily impacted by the varied reflectivity of the item or the temperature of the environment and hence produces accurate measurements. Sharp IR sensor mainly used to perform a comparison between the ultrasonic sensor and sharp IR sensor on the suitable sensor to be used in anti-collision system of the inspection quadcopter. Figure 3 shows sharp IR sensor which has been used for the anti-collision system of inspection quadcopter.

Fig. 3. Sharp IR Sensors

2.2 Anti-collision System

The anti-collision system of the quadcopter serves as a safety feature where it allows the quadcopter to maintain a safe distance from any object around it. The anti-collision system consists of four HC SR04 low-cost ultrasonic sensors, and an Arduino Uno board. Arduino Uno works as a microcontroller where it receives the input PWM signal from the ultrasonic sensor and process them to determine the distance of the obstacles from the ultrasonic sensors. Then, the microcontroller sends maneuver PWM signal to the Pixhawk flight controller to make correction on the pitch or roll angle.[21]

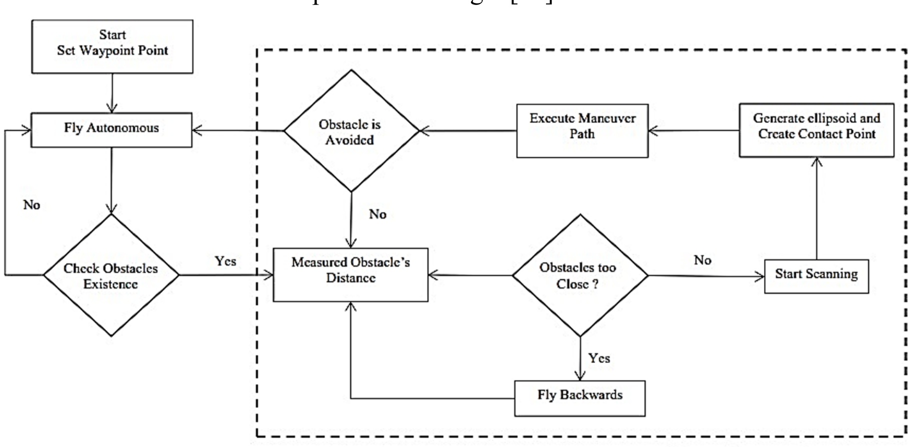

Fig. 4. Block diagram representing the anti-collision system of the inspection quadcopter

As shown in figure 4, the anti-collision system is designed to perform in both manual and autonomous flight mode of the quadcopter. During autonomous flight mode, which is when the quadcopter was set inloiter mode, when any obstacles is near the quadcopter, where the distance is less than the safe distance, the microcontroller will transmit correction PWM signal on the pitch or roll angle (depending on the direction of obstacle), to the flight controller. During the autonomous flight mode of the inspection quadcopter, there is a flaw in the anti-collision system that did not response as the was expected. The direction in which the lift force acts change whenever the vehicle spins around the roll or pitch angle. This causes the quadcopter to lose its altitude as the quadcopter tilt in the roll or pitch angle. However, in manual stabilized mode, the thrust can be increased by the pilot to regain the altitude. Hence, to overcome this problem during the autonomous mode, the mode should switch to stabilized mode, and the pilot should manually control the thrust to compensate the altitude.

2.3 Implementation of Anti-collision System

This section mainly focuses on the assembly of the anti-collision system of the inspection quadcopter. The primary components of the anti-collision system are HC SR04 ultrasonic sensor and Arduino Uno board. This session shows the building procedure and explains the connections between the anti-collision system and flight controller. The Arduino IDE is a piece of software that consists of a text editor for writing code, a message area, a text terminal, a toolbar with buttons for common operations, and a series of menus. The program for anti-collision system was written in Arduino IDE and uploaded to Arduino Uno of the anti-collision system model. The program is designed to collect the input from each sensor and generate correction signal to be transmitted to flight controller in order to deploy collision avoiding maneuver [22,23].

The radio receiver sends six different PWM signals to the PPM encoder, one for each channel in operation. The PWM signals on each channel have a range that is anywhere from 1000 to 2000, and they have a relation that is linear with the commanded variable that is dependent on them. The PWM signal for pitch and roll channel was calibrated to be at 1500 without any input from the transmitter. When the anti- collision system detects any obstacles, the value of PWM signal at pitch or roll will increase or decrease, depending on the direction of obstacle in order to make obstacle avoiding maneuver. Figure 5 Shows Position of anti-collision system model on inspection quadcopter.

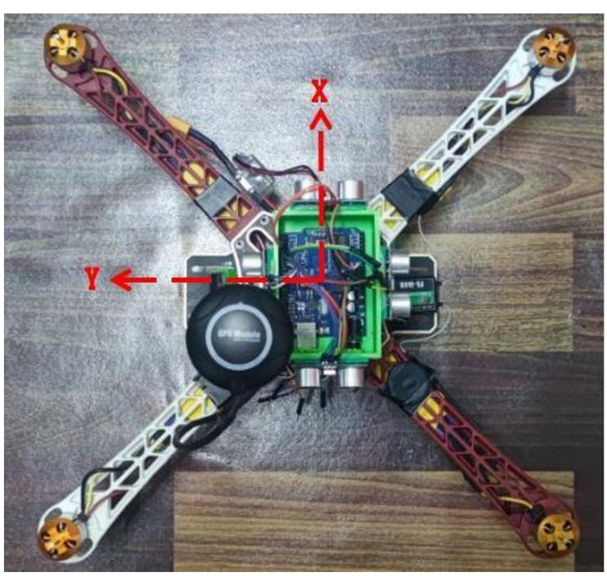

Fig. 5. Position of anti-collision system model on inspection quadcopter

3 Results and Discussion

3.1 Experiment on Performance of HC SR04 Ultrasound Sensor and Sharp IR Sensor against Obstacles with Different Color Surface

The first experiment was set to test and compare the performance of ultrasonic sensor and IR sensor against obstacles with assorted color. The color of surface of the obstacles chosen were black, red, yellow,blue, green, and white. The parameter measured in this experiment was the distance of the obstacles with different surface colors. The range of measurement was from 10cm (about 3.94 in) to 150cm (about
4.92 ft). The ultrasonic sensor and sharp IR sensors were connected to a simple circuit of Arduino. The data of the distance of obstacles from each sensor was extracted from the serial monitor of Arduino IDE software. Figures 6 and 7 show the percentage error of measured distance by ultrasonic sensor and sharp IR sensor for each color surface of obstacles.

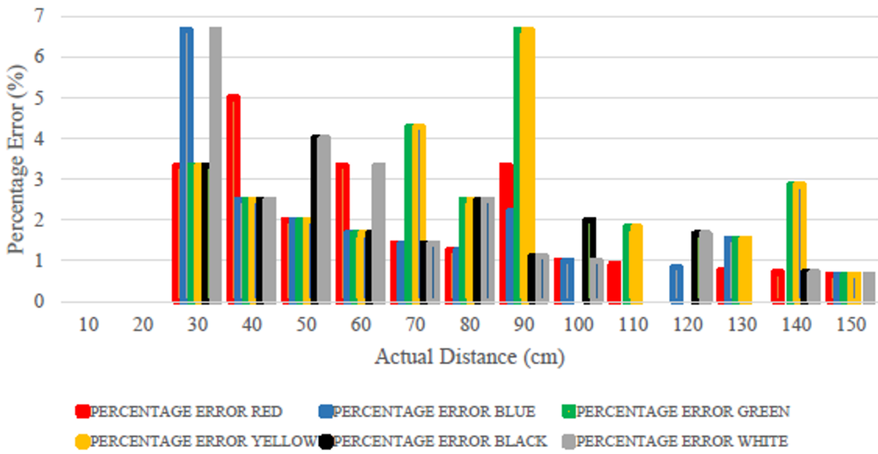

Fig. 6. Percentage error of the measured distance by the ultrasonic sensor for each surface color ofthe obstacles

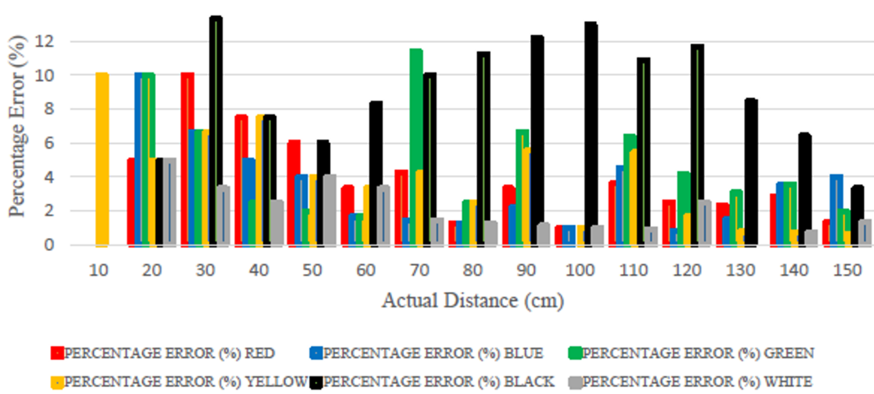

Fig. 7. Percentage error of the measured distance by the infrared sensor for each surface color of the obstacles

Based on the result in figure 6, the percentage error remained below 10 percent throughout the experiment, however it does increase gradually as the distance increases, especially from 40 cm (about 1.31 ft) to 150 cm (about 4.92 ft). However, as the maximum percentage error is 6.7 percent, which is below 10 percent, ultrasound sensor is quite accurate for low-cost sensor segment. Accuracy of the ultrasonic sensor varies from 93.3 to 99.33 percent for all color surface of obstacles. This proves the performance of ultrasonic sensor is not affected by color of the obstacles.

Based on the figure 7, the percentage error of measured distance differs from 0.67 to 13.33 percent. The percentage error of the measured distance when the obstacle's surface color is high, where the maximum percentage error of measured distance was 13.3 percent when the obstacle's surface color wasblack. This is because each surface color has its own reflectivity coefficient. The relative IR reflectivity of black cardboard is the lowest compared to other colored cardboard surfaces. This proves black colored surface has the lowest reflectivity coefficient compared to other colored surfaces. The brighter the obstacles are the better the object detection by the IR sensor. Hence, since the black cardboard is not bright as it has less reflectivity coefficient, the IR sensor could not detect the distance of the obstacle accurately. Hence, this concludes the color of the surface of obstacles majorly affects the performance ofIR sensor in measuring the obstacle's distance.

Thus, at the end of this experiment, it can be concluded that ultrasonic sensor is better compared to sharp IR in detecting obstacles with various color surfaces. So, ultrasonic sensor is the best option to be used in the anti-collision system as it enables the quadcopter to maintain a safe distance from aircraft tobe inspected, which has assorted color surfaces.

3.2 Performance of Ultrasonic Sensor and Sharp IR Sensor based on the Type of Material of the Obstacles

The performance of ultrasonic and sharp sensors is tested with obstacles made up of diverse types of materials such as mirror, aluminum, concrete, plastic, plywood, carbon fiber and lastly natural fiber composite. This experiment was carried out to represent the large obstacles that made up diverse types of material. The experiment was set up but placing the ultrasonic and IR sensor in fixed position. Obstacles made up of varied materials are placed 100 cm (about 3.28 ft) from the sensors.

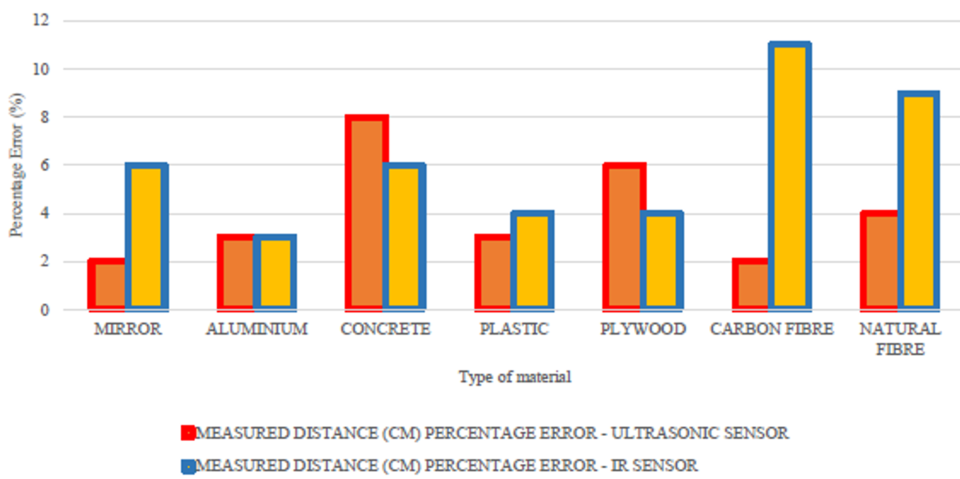

Fig. 8. Percentage error for different type of materials using ultrasonic and sharp IR sensors

Figure 8 shows the percentage error of measured distance of obstacles made up of several types of material using ultrasonic and IR sensors, respectively. The percentage error of measured distance by ultrasonic sensor is highest in plywood and concrete. Concrete and plywood can absorb the ultrasonic sound wave and reflect less wave to the receiver. This affects the distance detection of ultrasonic sensors. The percentage error of distance measured by IR sensor is high in carbon fiber and fiber composite. The performance of IR

sensor is affected by the brightness of the obstacles or object. The brighter the object the better the reflection of light ray sent from the IR sensor. However, carbon fiber composite and natural fiber composite are dull in color. Due to low reflectivity coefficient of these objects, performance of IR sensor in detecting the obstacle drop, eventually causing high percentage error.
The type of materials of the obstacles chosen for this experiment represents the common objects found around the inspection quadcopter. Besides the type of materials used in this experiment represents the different level of hardness and materials with different characteristic. Hence, from this experiment it can be concluded that ultrasonic sensor can perform better than sharp IR sensor in detecting obstacles made up of hard materials, like mirror, aluminum, plastic, carbon fiber and natural fiber. An aircraft is majorly made up of aluminum, and composite materials, which are hard materials. Since the inspection drone will be operating around aircraft for the inspection for lightning strikes, ultrasonic sensor is suitable to be used in anti-collision.

3.3 Anti-collision System Ground Test

The performance of the anti-collision system and the response of the inspection quadcopter to avoid obstacles, in aspect roll and pitch rotation, were tested on ground. At first the quadcopter was disarmed, and the battery was disconnected, and the anti-collision system was tested. An obstacle was brought near to the quadcopter, which was less than the safe distance set (60cm) at each side of the quadcopter. The response of the quadcopter was observed by reading the Pulse Width Modulation (PWM) signal input from the microcontroller to the flight controller using Mission Planner software.
Once the PWM signal input is observed, the quadcopter was set to be tested on the response on the anti-collision system. The quadcopter was tied to poles to be in fixed position and armed. The throttle was set at PWM value of 1350 and let the quadcopter hover at fixed position without any input in pitch angle and roll angle by the pilot. Then, the PWM signal correction made by the anti-collision system in pitch and roll axis as the obstacles brought near the quadcopter in each side of the quadcopter respectively was recorded and tabulated.

Table 1. Experimental value of ground test of anti-collision system

Axis of rotation	**Ultrasonic Sensor**	**Obstacle distance >60cm**		**Obstacle Distance <60cm**	
		PWM value	Angle	PWM value	Angle
PITCH	1 - FRONT	1500	0	1250	-22
	2 -BACK	1500	0	1750	22.5
ROLL	3 - RIGHT	1499	0	1249	-22
	4 - LEFT	1499	0	1751	21.5

Table 1 shows the PWM correction values made by the anti-collision system as the obstacle brought near quadcopter at less than 60cm (about 1.97 ft). The PWM correction values generated by the anti- collision system are the same as the expected PWM correction values. The PWM correction signal causes the inspection quadcopter to take proper maneuver to avoid any obstacles around the quadcopter. The maneuver along the pitch and roll axis of the quadcopter is also recorded in the table. Hence, this experiment concludes that the anti-collision system performs its task in generating the correction PWM signal and generate proper maneuver in avoiding the obstacles during flight.

4 Conclusion

This manuscript shows the experimental results of the sensitivity of two low-cost sensors, which are HC SR04 ultrasonic sensor and sharp IR sensor. According to the experimental result obtained from this research, the HC SR04 sensor was chosen to be the best low-cost sensor to be used in the anti-collision system as it has the lowest percentage error in the measured distance of obstacles compared to sharp IRsensor. The implementation of the HC SR04 ultrasonic sensors in the anti-collision system was explained and shown in this paper. The anti-collision system of the inspection quadcopter is made to ensure the quadcopter does not collide with any obstacles during the inspection. In this paper, the working mechanism of the anti-collision system was shown and explained. The ground test on the anti-collision system shows the response of the anti-collision system towards the obstacles. The response of the anti- collision system of inspection quadcopter was presented in terms of PWM signal and pitch and roll tilt angle. The result of the test shows the anti-collision system works well towards the obstacles and the communication between the anti-collision system and the flight controller of the quadcopter is well. At the end of the research, all the objectives have been achieved through experiments and prototype development.

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