Development Of Obstacle Detection And Collision Avoidance For Micro-Aerial-Vehicle Using Multi-Ultrasonic Sensor

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Abstract

An obstacle detection and collision avoidance system are needed to detect obstacles in the Quadcopter's flight path. An obstacle detection and collision avoidance system based on a multi-ultrasonic sensor design is proposed in this paper. An effective collision avoidance algorithm was developed using Arduino programming to detect and avoid obstacles using a multi-ultrasonic sensor, as well as to track vehicle motion in the vicinity of a possible collision zone. To avoid collisions with obstacles, the algorithm was implemented on an Arduino board, and the control signal will be transmitted from the Arduino board to the flight controller board. The proposed obstacle detection algorithm is appropriate for quadcopter real-time collision avoidance systems.

Key words: Introduction, mechanics of the drone, proposed methodology, hardware used, software used, experiment, results & discussion

Introduction

Unmanned Aerial Vehicles (UAVs) have many main advantages of modern technology, the most important of which is the ability to operate in difficult-to-access or dangerous environments without endangering human lives. Drones come in a variety of shapes and sizes, including Hexa-copters, Octa-copters, Quadcopters, and more. For our drone, we've chosen the quadcopter orientation.

Quad-rotor UAVs are an aircraft that can be vertically takeoff and landing which are powered by four electric machineries. Due to its low-cost implementation, high flexibility and simple structure quad-rotor are widely used in Surveillance, aerial photography, environmental monitoring, agriculture drones etc. As the number of applications in the usage of quad-rotors are increased, there is a need to ensure the safety of the drone or UAV to prevent itself to get damaged or destroyed during the usage time. So that, we have to implement the collision avoidance system to the drone to safe-guard the drone from the obstacles.

1. Mechanics of the Drone

A force equal to or greater than the force of gravity is needed to lift a quadcopter into the air. The basic principle of aircraft lift is the regulation of upward and downward force.

Quadcopters now rely on motor design, motor specifications, the number of blades available at the propeller, propeller direction, and propeller dimensions to generate the required force/power to counteract gravity's pull on the quadcopter.

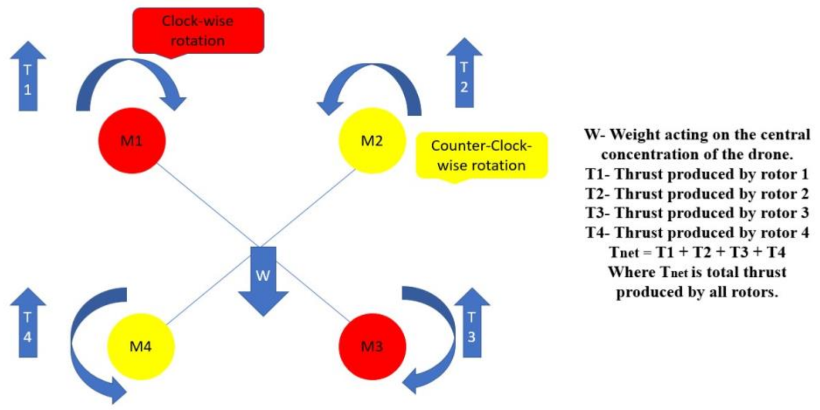

Fig 1: Mechanics of Drone

As it turns, the rotor (propeller + motor) generates a downward force. According to Newton's Third Law of Motion, there is an equal and opposite reaction force for every action force. As a consequence of the above-mentioned theory, the rotor pushes down the air, allowing a reaction upward force to act on the rotor. Therefore, faster the rotor spins, greater the lift produced by the rotor.

Two rotors spin clockwise while the other two motors spin counterclockwise to create a quad-X-copter hover, as shown in Fig 1. An unbalanced sideward momentum is generated when all four rotors of a drone turn in the same direction, causing the drone to rotate in the same position instead of hovering steadily.

Each rotor will produce 990g (990 grams or 9.720 Newton) of thrust and the net weight of the drone is 0.7Kg (700g or 6.86 N).

So, the net thrust (T_{net}) produced = 990 × 4 = 3960 g.

Resolving the Forces in the vertical direction (ΣV) = T_{net} - W = 3260g (31.948 N).

Thrust to Weight ratio

The thrust to weight ratio is used to evaluate the performance characteristics of any aircraft or unmanned aerial vehicle (UAV). The greater the thrust to weight ratio, the higher the efficiency of the aircraft or UAV. In general, the thrust to weight ratio for drones should be 2:1 in order to perform well.

The thrust to weight ratio for our drone is

Thrust to weight ratio = $T_{net} \div W$ = 5.6571:1

Rate of Climb (RoC)

The rate of climb (RoC) of an aircraft/UAVs is the vertical speed of the aircraft/UAVs with respect to time. The rate of climb for our drone is 10 m/min (0.166667 m/sec).

Range and Endurance

The endurance is the maximum amount of time that an aircraft/UAV will spend in cruising flight, or the amount of time that an aircraft/UAV can remain in the air with a single load of fuel/battery power.

The range is a measure of distance travelled, I.e the maximum total distance travelled by an aircraft/UAV between takeoff and landing for a single load of fuel/battery power.

The maximum endurance (E) of our drone = 20-25 min at the full batter power capacity.

The maximum range (R) of our drone = 150m.

Rate of discharge

The rate of discharge is defined as the constant current in amperes (A) that can be drawn from a battery of a given capacity (Ah) over a given period of time (h).

The discharge rate for our drone battery is 20 C/s.

Forces Acting on Drone

The four forces acting on the drone are lift (L), weight (W), thrust (T), and drag (D). The lift operates in the opposite direction as that of the weight. The act of thrust is the exact opposite of drag. When all the four forces are balanced, the drone can fly in a level flight. The drone will rise if the forces of lift and thrust are stronger than the forces of gravity and drag. The drone will fall if gravity and drag forces are greater than lift and thrust forces. Figure 1.2 depicts a detailed diagrammatical explanation of how the powers behave in the drone.

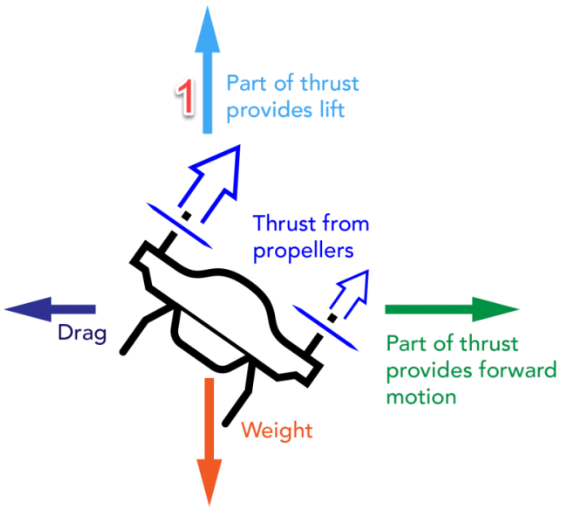

Fig 2: Forces acting on Drone

Proposed Methodology

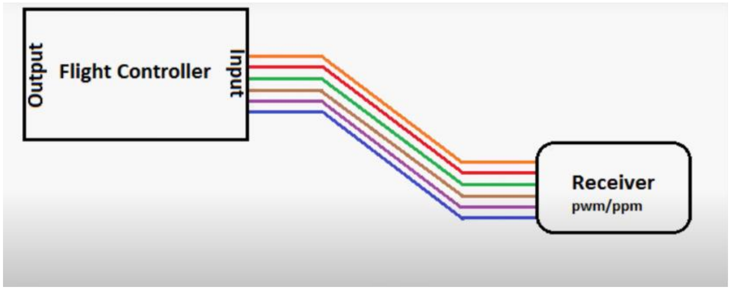

Fig 3: General Signal Transmission from Receiver to Transmitter module

Typically, PWM (Pulse Width Modulation) signals from the receiver are routed directly to the flight controller input. As a result, based on the transmitter operations, the drone will perform the required output operations.

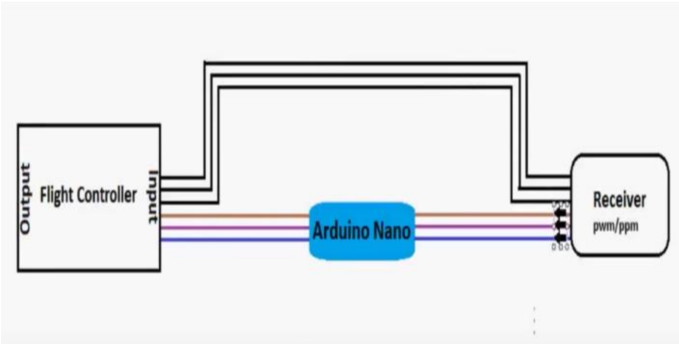

Fig 4: Arduino Interface between the Receiver and Transmitter module

In this case, however, an Arduino Interface will be installed between the Receiver and Transmitter modules. As a consequence, when a command is transmitted from the transmitter to the receiver module, the PWM signals received are sent to the Arduino Interface.

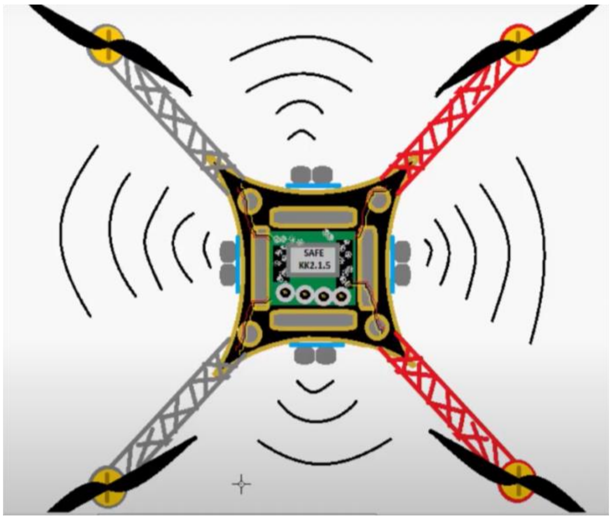

Fig 5: Sensor placements at the Drone

Since the Ultrasonic Sensors are linked to the Arduino Module, it can detect the presence of obstacles. If an obstacle is detected at any direction, the drone can move to a safer position to avoid it. If no obstacles are detected, it works in compliance with the transmitter's command.

Designing of the Sensor Tower:

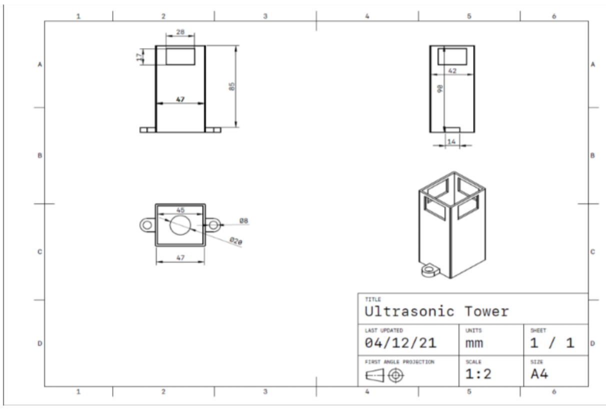

Fig 6: Sketch of Sensor Tower

The sensor tower is designed to hold all the four ultrasonic sensors and the Arduino Nano board. This tower is designed and fabricated to avoid the complications like avoiding the detection of the propeller blades as an obstacle by the distance sensors and also to reduce the complexity in wiring of the circuit.

Fig 7: 3-D Printed Sensor Tower

Working principle of Ultrasonic Sensor:

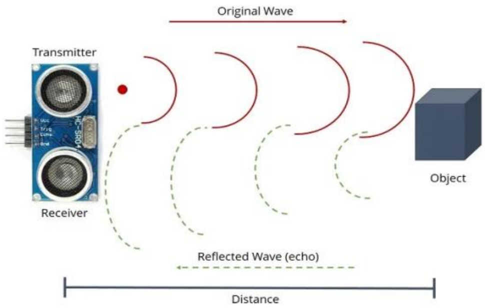

Fig 8: Working principle of Ultrasonic Sensor

Ultrasonic sensors operate by emitting a sound wave at a frequency that is beyond the range of human hearing. To receive and transmit ultrasonic sound, the sensor's transducer serves as a microphone. The ultrasonic transmitter emits a sound wave with a frequency of 40 kHz; if the transmitted ultrasonic waves strike the target, they are reflected back and detected by the receiver. Like many others, the ultrasonic sensors use a single transducer to transmit a pulse and receive the echo. The sensor calculates the distance to a target by calculating the time elapsed between transmitting and receiving the ultrasonic pulse.

Distance = $c * t / 2$.

Hardwares Used

3.1 F450 Frame with Integrated PCB board.

The F450 Quadcopter Frame with an Integrated PCB Board was used. The frame's dimensions are approximately 450mm from one end to the other, and it is made of high-quality materials. Glass fiber is used to make the integrated PCB Board. We can directly solder the ESCs and battery power connections to the PCB circuit board due to the integrated PCB connections. This removes the need for a separate power distribution board or complicated wiring in order to give the electronics a more professional appearance. This board is made of thicker molded materials, which eliminates the possibility of the frame breaking during a hard landing.

3.2 Motors, Propellers and ESC used

Brushless motors 920KV-2212, coupled with 10inch propellers, produced 9.702 N (990g) of thrust. The Turnigy 45A high quality Electronic Speed Controller (ESC) is used. This ESC features a high-performance microprocessor with a faster sync rate and throttle response. This ESC uses less power from the battery and produces less heat. Because of the existence of a separate voltage regulator, this ESC is unique in that it has excellent anti-jamming capabilities. The ESC has a continuous 45A output that can burst to 50A for up to 10 seconds, and the maximum speed at 2 pole, 6 pole, and 12 pole is 210,000rpm, 70,000rpm, and 35,000rpm, respectively.

3.3 NAZA M LITE Flight Controller

The NAZA-M Lite flight controller was used, which is extremely reliable and stable. This flight controller is designed in such a way that it is easy to mount while still saving space and weight. Its light and compact Main Controller includes inner damping, controllers, a 3-axis gyroscope, a 3-axis accelerometer, and a barometer. When the drone is in operation, it can calculate its altitude and attitude. As a result, this system can be used as an autopilot. It has a specialized attitude stabilization algorithm, as well as excellent flight stability and maneuverability. This flight controller switches to fail safe mode in the event of a transmitter failure. Almost all 2-axis gimbal systems are compatible with the gimbal stabilization module. After the parameters are set the first time, the device will change the gimbal and camera based on the aircraft's attitude.

3.4 NAZA GPS Module

We have used the NAZA GPS module which exhibits characteristics like accurate position holding, Return-To-Home feature, and Intelligent Orientation Control functionality, and also the plug-and-play GPS module can greatly improve the performance for Aerial Photography. Even in windy weather, the multi-location rotors and altitude will be accurately locked thanks to the GPS Module. Hovering precision is around 2.5m horizontally and 0.8m vertically.

3.5 HCSR04 Sonar Sensors

We have used the HC-SR04 Ultrasonic sensor which consists of two ultrasonic transducers. The one serves as a transmitter, converting electrical signals into ultrasonic sound pulses at a frequency of 40 KHz. The transmitted pulses are detected by the receiver. If it receives them, it generates an output pulse whose width can be used to calculate the distance between the object and the sensor. The sensor is compact, simple to use, and provides excellent non-contact range detection with a 3mm accuracy between 2 cm and 500 cm. It runs on 5 volts, and we've used jumper wires to link it to the Arduino Nano board directly. We used four identical sensors to avoid the obstacle from four directions: front, back, left, and right.

3.6 Arduino NANO

Based on the ATmega328, the Arduino Nano is a lightweight, full, and breadboard-friendly board (Arduino Nano 3.x). It operates on 5 Volts. It only has a DC power socket and uses a Mini-B USB cable rather than a regular one and also can be powered by an external battery source. We have used this Arduino nano board to perform the developed collision avoidance algorithm and command the flight controller to perform obstacle avoidance process.

3.7 LIPO batteries

We used a Turnigy 2200 mAh battery, which has a 20-30 C high discharge Lithium-Polymer (LI-PO) 3-cell battery that powers approximately 11.1V.

3.8 Transmitter and Receiver

The 2.4Ghz Fly-sky FSI6 six channel digital proportional radio control system and the matching 2.4Ghz six channel digital proportional radio control receiver have the same transmitter and receiver specifications.

Software's Used

4.1 Arduino programming software

Writing code and uploading it to the Arduino board is simple with this open-source Arduino Software (IDE). It's compatible with all the platforms like Windows, iOS etc. There are many pre-coded programs are available in this software which enables us to learn this program in a very shorter period of time. We used this software to develop the program for the obstacle avoidance and upload the developed program to the Arduino Nano board.

4.2 DJI NAZA-M assistant 2.0

We used this NAZA-M ASSISTANT V2.20 app to configure our drone in quad-rotor mode, and then we used it to calibrate the GPS for our drone, which was equipped with the NAZA –M Lite flight controller.

4.3 Autodesk-Fusion 360

We used this software to design the Sensor Tower and then 3-D print the tower to hold the four distance sensors and the Arduino Nano Board, so that it will be easy to integrate the tower and the drone together.

Experiment, Results & Discussion

5.1 Single Sensor Ground Level Testing

From the Serial Monitor Output available at the Arduino Programming software, we were able to determine the Minimum and maximum range of our distance sensor which is 2.7 cm and 557 cm respectively. After obtaining the sensor range, we computed a basic program for obstacle avoidance for a single, if any obstacle is detected that is if the distance between the sensor and the obstacle is less than or equal to 70cm then the output should indicate a “RED” light else it should indicate a “GREEN” light.

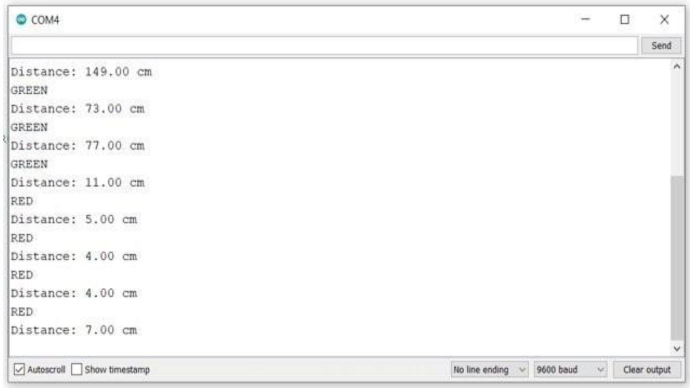

Fig 9: Serial Monitor Output

5.2 Multiple Sensor Ground level

After testing the avoidance algorithm for the single sensor, we integrated all the four sensors together in the Arduino Nano board, and developed the obstacle avoidance algorithm for the four sensors. If the distance between all the four sensors is less than or equal to 70cm it will indicate a “RED” light else it will indicate a “Green” light which depicts that no obstacles are detected.

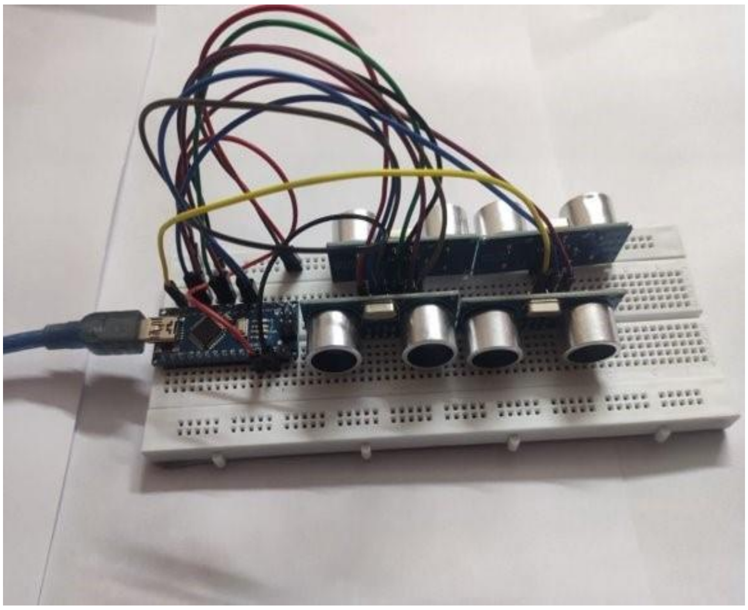

Fig 10: Circuit Connection for the Four Sensors

Fig 11: Serial Monitor Output

5.3 Final Drone Design and Testing

The fabrication of the drone is completed and the integration of the sensor tower and the drone is processed. The developed Obstacle Detection & Collision Avoidance Algorithm is tested, even if we apply the maximum throttle if any obstacle is detected the drone avoids the collision by maneuvering to the opposite direction as the Arduino interface commands the flight controller. We have also developed a channel switch for tuning ON/OFF the obstacle avoidance algorithm. If the obstacle avoidance channel is turned “OFF”, it is indicated by glowing a “WHITE” color LED, if the obstacle avoidance channel is turned “ON” and any obstacle is detected “PURPLE” color light will indicate the presence of obstacle and if no obstacles are detected a “BLUE” color LED will glow to indicate there is no presence of any obstacle.

Fig 12: Final Drone Design

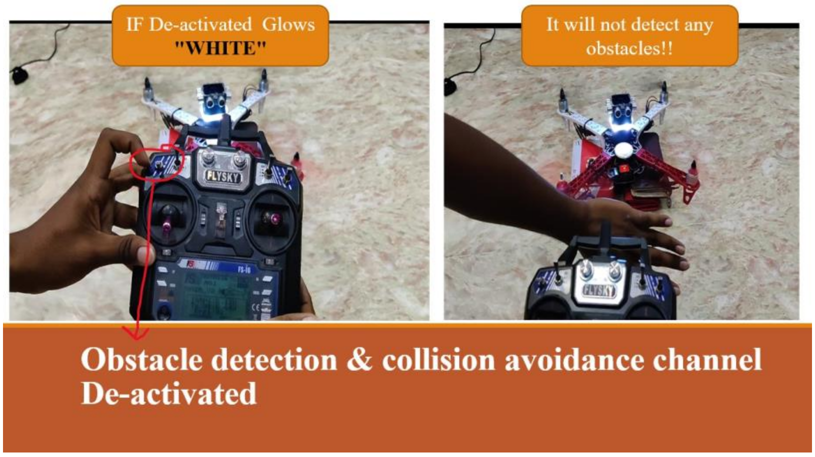

Fig 13: Final Serial Monitor Output

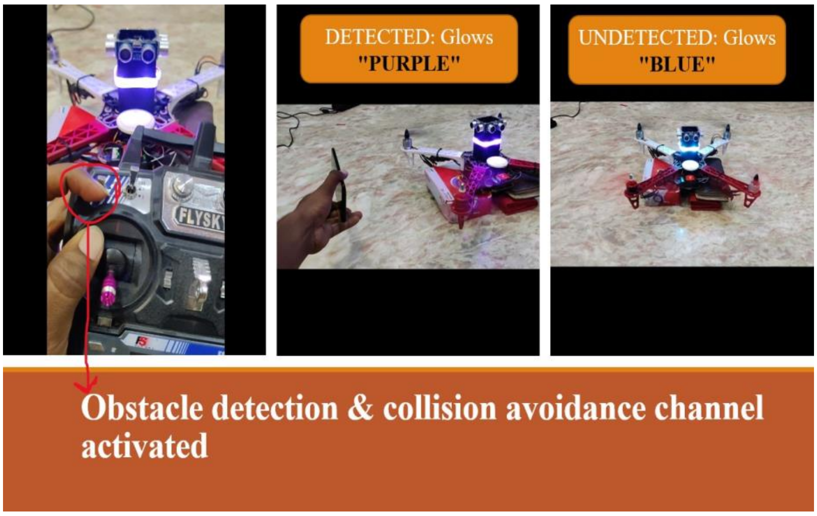

Fig 14: Final Serial Monitor Output

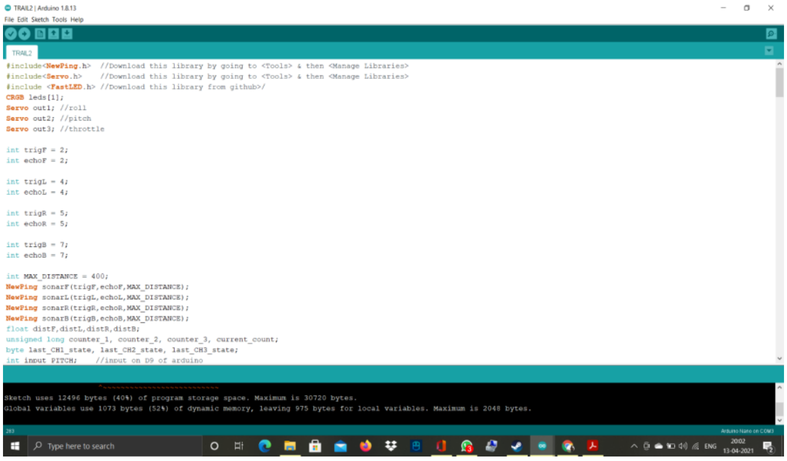

Fig 15: Outlook of Final Obstacle Detection & Collision Avoidance Coding

Fig 16: Final Serial Monitor Output

Conclusion

An obstacle detection and collision avoidance algorithm for quadcopter navigation in indoor and outdoor environments has been proposed. The experimental results show that the proposed obstacle detection and collision avoidance algorithm can detect and avoid obstacles in the MAV's flight path. After the multi configuration ultrasonic sensors measure the distance between the MAV and the obstacle, the control signal (PWM signal) will be sent to the flight controller's pitch channel to pitch the MAV backwards to avoid collision with the obstacles. If we attach a camera to this drone, it can be used for rescue missions since it transmits live recording data to the transmitter and also helps in avoiding human interference to search for any life support at unintended fire zones or any construction site.

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