DESIGN AND IMPLEMENTATION OF A LOW-COST OBSTACLE AVOIDING UAV

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Abstract

The quadcopter is a device which works like a four-rotor helicopter with fixed rotor blades. It comes under the category of a drone. This paper explains how the quadcopter avoids the obstacle autonomously. For this, the ultrasonic sensors are used around the drone which senses the objects from distance and gives the signal to the Arduino controller board. It generates the signal which controls the quadcopter autonomously.

Keywords : Drone, Quadcopter, Unmanned Aerial Vehicle, Obstacle Avoidance, Electronic Speed Controller(ESC).

I. Introduction

A Quadcopter is an unmanned aerial vehicle which can fly without the need of a pilot. They are also known as Drones. A conventional helicopter differs from Quadcopter in rotors. These rotors can change the pitch of their blades dynamically when they move around the rotor. Whereas in multi-copters the rotor blades are fixed, and the speed of the rotors vary according to the directional movement. In the earlier days, quadcopters are the possible solutions for accurate, controlled and autonomous systems. The vertical flight torque-induced control issues can be reduced by anti-clockwise rotation and the relatively small blades construction is easier. Due to their mechanical simplicity, Small size drones are more durable and cheaper than conventional helicopters. They had the ability to cause less damage because their smaller blades possess less kinetic energy. For small-scale drones, this makes the vehicles safer for close interaction.
Nowadays the microelectronic industry is increasing day by day and more micro electromechanical sensors (MEMS) are available in the market which makes the drones work like a robot.

In the last decade, the unmanned aerial vehicles (UAV) were used widely for military purpose, agriculture purpose as well as for the wide range of commercial applications. From the Fig. 2 the two pairs of diagonal propellers spin in two directions one in clockwise and the other in anticlockwise allowing the craft to ascend vertically [X], soar in the air and fly in the controlled direction. The circular arrows indicate the rotor spinning directions and orange colored arrows represent the direction movement of the quadcopter.

The movement of the quadcopter is divided into following types

Roll: Rolling of the quadcopter is done by right and left rotors’ speed.

Pitch: Pitching is done by front and back rotors’ speed.

Yaw: It’s done by changing the speeds of diagonal rotors.

Vertical: Simultaneous and similar change in rotors’ speed can move the quadcopter in the vertical direction.

The design of Quadcopter is very simple and contains less moving parts and can be operated simply with the remote control. The frame of quadcopter made with lightweight materials like carbon fiber or fiberglass. It has four limbs, each carries a BLDC motor and a propeller. ESCs work as a mediator between controller board, battery, and motors. It changes the speed of the motor according to the instructions of the controller board. The control board can be connected to the remote control, gyro, accelerometer, barometer, GPS, telemetry etc. for stabilization and controlled operation.

The operation of both helicopter and a quadcopter/multi-copter is similar. Another feature of this quadcopter is that it can move in its 360° radius [III],[I]. But the quadcopter has no tail boom like the helicopter. And so, irrespective of its head and tail the quadcopter can easily fly in any direction. Thus, unlike any other flying machine, the direction of flight of the quadcopter can be changed more rapidly.
The concept of multi-rotor has been around for a long time. But as its design is inherently unstable, it wasn't practical till now. It is not possible for an average person to control the multiple rotors, and to maintain steady flight as it is extremely difficult. But the technical advances like gyroscope attitude sensing technology made everything possible even to a common man. With this new technology very small, low power sensor have developed. These can easily be fitted into the computer logic to balance the quadcopter automatically. Thus, the pilot can completely focus on his flying skills without any distractions. In addition to control of quadcopter obstacle avoidance [VI] concept is also included in this paper.

II. Technical Work Preparation

For obstacle avoidance, primarily, we need to know the distance between the obstacle and the ultrasonic sensors which are attached to the quadcopter. These sensors receive the distance of the obstacle and send it to the Arduino controller board. With the preloaded program provided on the Arduino board, it always checks the obstacle distance with reference distance. If the obstacle is within the range it generates PWM signal which controls motors.

![Block diagram of Obstacle Avoidance Quadcopter](Fig.3)

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The major components of obstacle avoidance of a quadcopter are given in below subsections.

II.i. Ultrasonic Sensors (HC-SR04)

There is a wide range of sensors such as infrared ray sensors, LIDAR (light detection and ranging), and ultrasonic sensors for the detection of the obstacle. The ultrasonic sensors are chosen for its lower price, high accuracy up to 3mm, less weight, range up to 400cms and efficient when compared to other sensors.

HC-SR04 is an ultrasonic sensor. It provides a non-contact measurement range from 2 cm to 400 cm. Its accuracy range is 3mm and the effectual angle is < 15°. It can be powered from a 5V power supply.

ultrasonic sensor has two hollow cylindrical shaped openings on its front. One opening transmits ultrasonic waves, the other receives them. So the first opening acts as a speaker and the other as a microphone. It calculates the distance according to the span of a sound wave and then sends it to the Arduino in the form of an analog signal. If the setpoint is 10cms from the sonar sensor and if it reaches 10cms then the PID algorithm in the Arduino will start work by sending out the correction value to the stabilizing board.

The normal range for Roll, Pitch, and Yaw is up to 400cm in the center or neutral value. Since there is no need to flip the quad, the reference range can be up to 100cm to 400cm. The quadcopter moves away from the obstacle when it goes nearby any vehicle according to Arduino commands.

II.ii. Flight Control Board

The Naze32 is a small 32bit flight controller board. It has an STM32 processor running at 72 MHz. This board comes in two models Acro Naze32 (FunFly) and Full Naze32. The Full Naze32 has an additional barometer and compass. The Acro version would be more than enough because it provides relatively stable self-level mode. Although the Naze32 uses ported version of Multiwii, it is not exactly a Multiwii flight controller because it uses a different type of processor (STM-based).
**II.iii. System PID Control**

For controlling quadcopter or any type of multi-copters, the output of sensors (like the pitch angle) is very much needed. From the sensor data, the error can easily be estimated (how far away from the desired pitch angle). Then PID algorithms can be used for eliminating errors [IV]. To have any kind of control over the quadcopter measuring the quadcopter sensor output is primarily necessary (for example what angle the quad is on each axis).

The error can be estimated by knowing the desired angle of the quad. Then the control algorithms can be applied to the error, to get the next outputs for the motors aiming to correct the error. Each of these control algorithms would introduce some unique effects to the craft’s flight characteristics.

Fig. 6 is the flowchart for obstacle avoidance. It clearly shows the behaviour of the quadcopter when the particle comes in its path [XI].
III. Mathematical Modelling

The thrust force is proportional to the speed of propellers [VIII] such that for motor $i$ is

$$f_i = k \omega_i^2$$  \hspace{1cm} (1)

$$\tau_i = b \omega_i^2 + I_M \omega_i$$  \hspace{1cm} (2)

Where $\tau$ is the torque produced by the drag force, $k$ is lifted constant, $f$ is thrust force, $\omega$ is the angular velocity of the propeller $I_M$ is the moment of inertia of the propeller. The supply voltage and the PWM determine the motor speed. If the supply voltage is maintained constant then the speed will be depended on PWM such that

$$\omega_i = (\rho_i \times \omega_{\text{max}})/100$$  \hspace{1cm} (3)

Where $\omega_{\text{max}}$ the maximum motor speed for a rated voltage, $\rho$ is the PWM as a percentage and $\omega_i$ is the motor speed.

As the quadcopter moves in three axes, the center of the reference point for the other frame the arm of the quadcopter can be used as an obvious axis in x and y-direction, leaving the third z-axis as being orthogonal to these.
The body reference frame (B), F1, F2, F3, and F4 are the thrust forces acting on the body, \(mg\) the effect of gravity of the quadcopter and \(l\) the distance from the motors to the axis center. It can be explained by the papers [II],[VII] and [V]. By Newton’s second law of motion

\[
F_{\text{total}} = F_1 + F_2 + F_3 + F_4 - mg
\]  

(4)

The resultant acceleration of quadcopter can be determined by

\[
F_{\text{total}} = ma
\]  

(5)

\[
F_{\text{total}} = ma
\]  

(6)

Where \(m\) is the mass of the quadcopter in kg and \(a\) is an acceleration of the body in m/s².

If the speed of all the four rotors is equal the quadcopter moves upward or downward direction. If the quadcopter has non-zero roll or pitch angle then motion will occur in the x or y-direction such that

\[
F_x = F_{\text{total}} \sin \theta
\]  

(7)

\[
F_y = F_{\text{total}} \sin \phi
\]  

(8)

\[
F_z = F_{\text{total}} \cos \theta \cos \phi
\]  

(9)

Now acceleration, velocity and displacement equations can be determined, and their equations are

\[
a_i = F_i/m
\]  

(10)

\[
\dot{v}_i = a_i
\]  

(11)

\[
\ddot{s}_i = a_i
\]  

(12)
Where $a_i$, $v_i$ and $s_i$ are the acceleration, velocity and displacement along the i-axis respectively.

Fig.8 Rotation angles

The difference in speeds of all motors in a quadcopter exhibits different thrusts which cause to move in a different axes direction.

$F_Z = -(T_1 + T_2 + T_3 + T_4)$ \hspace{1cm} (13)

$M_X = (T_4 - T_2)l$ \hspace{1cm} (14)

$M_Y = (T_1 - T_2)l$ \hspace{1cm} (15)

$M_Z = (T_1 + T_3 - T_2 - T_4)K$ \hspace{1cm} (16)

Here $F_Z$ is the total thrust, $M_X$, $M_Y$ and $M_Z$ are the roll, pitch and yaw movements respectively, $l$ is the distance from the centre of gravity to propeller’s center, $K$ is the constant that relates the yaw moment to the propeller’s thrust.

The following are the responses to different obstacles placed in four directions of the quadcopter. The deflections produced because of the detection of obstacles can be clearly identified. In the graph red, violet, sky-blue, blue and green colored signals indicate the corresponding roll, pitch, throttle, yaw and auxiliary signals of the quadcopter. The up and down signals indicate corresponding roll and pitch in the direction of left, right, forward and backward movements of a quadcopter.

IV. Results

The following are the responses to different obstacles placed in four directions of the quadcopter.
The deflections produced because of the detection of obstacles can be clearly identified. In the graph red, violet, sky-blue, blue and green colored signals indicate the corresponding roll, pitch, throttle, yaw and auxiliary signals of the quadcopter. The up and down signals indicate corresponding roll and pitch in the direction of left, right, forward and backward movements of a quadcopter. The following picture illustrates the distance between the obstacle and the quadcopter found by the four ultrasonic sensors and then the PWM signals will be generated which regulates the direction of the quadcopter automatically.
V. Conclusion
In this paper, the Mathematical modeling of the quadcopter was determined. Even the number of sensors are used around it, the quadcopter stabilizes itself. The system was implemented practically and performed satisfactorily. It has the ability to avoid obstacles autonomously in any direction of the quadcopter. Thus it is a feasible design for the better way of avoiding obstacles.

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