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Self-Navigating Quadcopter

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Abstract: **This paper presents an approach for a self-navigating quadcopter stabilization using PID controller and sonar sensor for obstacle and collision avoidance. In this work, a quadcopter is designed and constructed from the scratch. A closed loop control feedback mechanism used in PID controller is implemented to maintain stability and steadiness. An ultrasonic sensor device is used in the sensor module to overcome the obstacle and collision avoidance issue.**

Keywords:* *Self Navigation, Command Centre GUI, Return to Origin, Sonar based Altitude hold, obstacle detection, failsafe via remote controller.

I. INTRODUCTION

Quadcopter also usually known as drone or Unmanned Aerial Vehicle (UAV) is either an autonomous or remote controlled state-of-the-art aerial flying vehicle without a human on board. Quadcopters have the VTOL (Vertical Take Off landing) characteristic unlike the other conventional flying objects or the Unmanned Aerial Vehicles which allows to hover at a particular point. They are highly suitable for environments (i.e. indoor or congested environment) where human access is at difficult situation. Due to their portability in size, there is an ease of usability in accomplishing tasks or missions such as commercial applications like package delivery from one building to another, search and rescue work, research and developmental works in agricultural, geographical, surveying and military areas, etc. It consists of four rotors which makes the vehicle mechanically simpler than an ordinary helicopter as it does not need to have variable pitch for the rotors (propellers) and it is the most popular multi-rotor rotorcraft. During the recent years, small scale quadcopters are increasingly gaining attention due to the fact that they are highly agile, capable and manoeuvrable apart from being cheap and can be constructed using easily available parts. Hobbyists and researchers use them as an advanced and a versatile platform to implement and test new ideas in a number of different fields. They have reached exceptional levels of growth in several fields say military and civilian applications. The conventional flying vehicles are sometimes prone to failure either due to lack of delivering the desired service or constant requirement of maintenance. Due to limited controls and system integrations in the early designs of 1920s and 1930s the results were of poor performance and lack of stability. But with the recent advance and development in electronics, accurate sensors and control system technology these limitations are now receding.

The paper is divided into several sections. Section II presents the related works done regarding quadcopters, section III describes about a quadcopter, section IV gives the concept of flight dynamics and its control system. Section V demonstrates about the PID controller and ultrasonic sensor altitude hold. Section VI presents the experiment and results obtained and finally the conclusion and future work is given in Section VII.

II. RELATED WORKS

The quadcopter concept started as early as the 20th century and the earliest work were started by George DeBothezat and Etienne Oemichen [1]. Their work failed due to lack of proper lifting power, instability, unresponsive and susceptibility to reliability issues. After putting efforts in recalculations and redesigning, the mentioned issues were overcome. Until the mid-1950s the quad copter designs done by Marc Adam [2] got into its true shape and structure which was also the first quadcopter designed to have flown forward successfully.

Several types of quadcopters are being built by many research individuals, groups or hobbyists according to the desired purposes. Some of the successful work found are Arducopter, Pixhawk, KK Multicopter, MultiWii, Parrot ARDrone, Microkopter, DJI Wookong and other various Open Source Projects [3]. It is obvious a UAV is sure to face obstacles either in indoor or outdoor environment or both and thus the avoidance of obstacles namely collision avoidance becomes a crucial task to overcome as cited by the United States Department of Defence [4]. Meister et.al [5] and Moses et.al [6] investigated collision detection and avoidance using multiple sensors. Sensors like RADAR, LIDAR, ultrasonic sensors, laser range finders, infrared sensor, etc. are used for ranging and detection of obstacles and hindrances in the flight trajectory for the UAV system [7]. Small size UAVs are subject to normal rotorcraft aerodynamics i.e. causing loss of lift due to wind turbulence either generated by itself or by external environment factors. There is a need to overcome such situations by continuously observing and balancing via the closed loop control feedback system. This can be achieved by Proportional Integral Derivative (PID) controller which calculates an error value determining the difference between the set point and the desired output [8]. An efficient quadcopter can be achieved by using an efficient stabilizing control system like PD controller, PID controller, back stepping, Kalman Filter and so on [9], out of which PID is most commonly and widely used [10 &11]. Some of the quadcopters are capable of altitude hold feature, in which it maintains a consistent altitude while allowing roll, pitch, and yaw to be controlled normally via the remote controller by a human [12].

III. QUADCOPTER DESCRIPTION

Copters are versatile and due to manoeuvrability to execute various tasks, they possess certain complexity. In conventional copters, a main rotor and a tail are equipped together. In this project a quadcopter is used which is constructed by four equal length aluminium rod serving as the frame with four symmetrical propellers at the end of each frame rod. The stable hovering and accurate flight can be achieved by balancing the forces generated by the four propellers. Two of the motors (say M1 and M3) in the quadcopter will rotate in counter-clockwise direction and the remaining two motors (M2 and M4) in clockwise and due to rotational axis a net torque of zero will be resulted as illustrated in Figure 1.

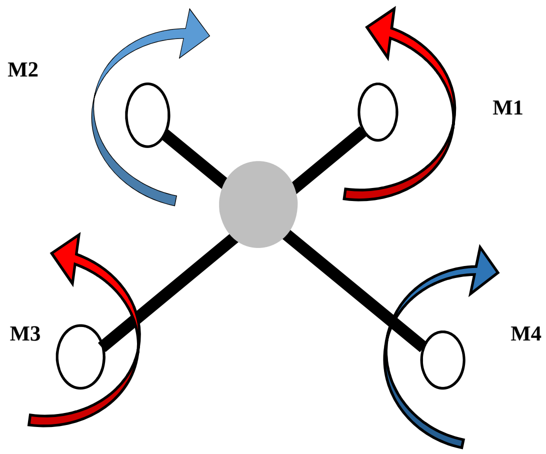

Fig. 1. Quadcopter motor configuration

To achieve the desired autonomy, first and foremost a stable flight needs to be attained. The symmetrical design of the quadcopter also allows an easy control in stabilizing the flight. To manipulate the thrust exerted by the motors, controllers are required which can be done by using a microcontroller. An electronic device called Inertial Measurement unit (IMU) is used which includes combination of the sensors– accelerometer, gyroscope and an ultrasonic sensor. An IMU is used to determine the angular rotation as well as the linear acceleration of data that are given as input to a microprocessor.

Each of these sensor devices can determine 3 axes of coordinates (x, y and z). For instance, combination of accelerometer and gyroscope will give number of different independent parameters that describe the state or configuration of the system which is called 6 Degrees of Freedom (6 DoF). A gyroscope is commonly used in quadcopter control boards as it gives the angular rate around the 3 axes of space and to get the orientation of pitch and roll, a 3-axis accelerometer can be used.

The key parameters of a flight system are the angles of rotation in three dimensions about the vehicle's centre of mass, known as roll, pitch and yaw as illustrated in figure 2.

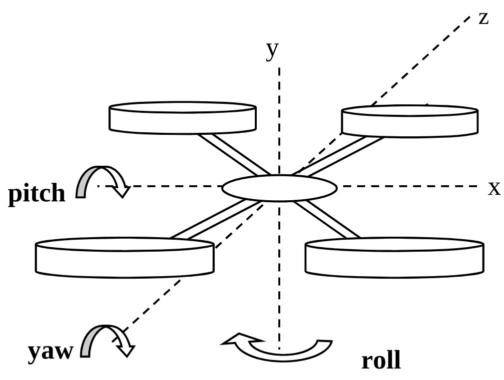

Fig. 2. Flight Dynamics

Inertial Measurement Unit (IMU) is used to determine the pitch, yaw and roll by calculating the values for the parameters of stability controller, i.e. PID controller. It measures the error value as a difference between a measured input and a desired target output which may be used in take-off, flying forward or even avoiding an obstacle. The data from the sensors – accelerometer and gyroscope is given as input to the PID controller to determine the stability, acceleration and orientation as well as it will sense any changes during the flight.

IV. FLIGHT SYSTEM AND FLIGHT CONTROL SYSTEM

Specially designed propellers of various dimensions and materials to generate required thrust can be used based on the quadcopter configuration. Each propeller is attached to the motors. The motors are chosen depending on the weight of the quadcopter, also known as all up weight (AUW). The thrust that each motor will exert can be determined by the following rule.

General rule of thumb is

Required Thrust per motor = (AUW x 2) / 4 (1)

Power is supplied by a high capacity lightweight battery. Li-Po batteries are best suited for this purpose. They can deliver high amount of current at short time which is required by the motors for the lift and have very small footprint.

A microcontroller with at least 4 digital IO/PWM (pulse-width modulation) to signal the motors via the electronic speed controllers (ESCs). The microcontroller should also have an interface like Inter-Integrated Circuit (I^2C) to connect to the IMU device so that the number of ports necessary to attach multiple sensor devices are reduced. As stated previously, accelerometer is required to sense the orientation, position and velocity without the need for external reference. With an accelerometer alone, either a really "noisy" data output that is responsive, or a "clean" output that is sluggish is obtained. But when the 3-axis accelerometer is combined with a 3-axis gyroscope, an output that is both clean and responsive at the same time can be acquired. Gyroscope utilizes angular momentum to determine orientation and change of direction. In order to understand the arrangement of the hardware components, the schematic wiring block diagram is represented as follows:

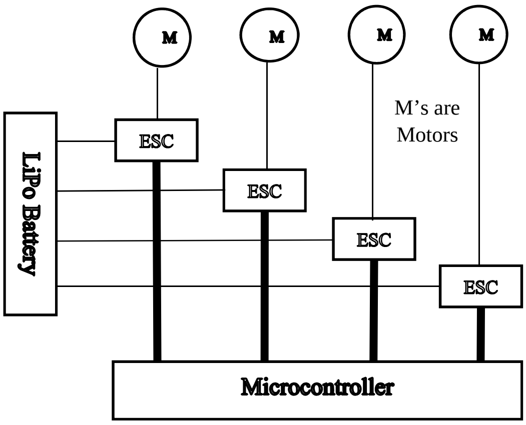

Fig. 3. Schematic Wiring Block Diagram

The hardware component consists of a frame, microcontroller, electronic speed controllers (ESCs), a battery, gyroscope, accelerometer and brushless motors.

V. PID CONTROLLER FOR STABILIZATION

The stability of a quadcopter flight is induced by using PID controller which enables a feedback loop mechanism. This mechanism gives back the resulted output as input causing a loop. It can help in overcoming disturbances, uncertainties in model, reducing sensitivity to parameter variations and hence improve stability.

The beneficial factors of closed loop control system are:

- Disturbance rejection
- Guaranteed performance even with model uncertainties
- Stabilization of noisy processes
- Sensitivity mitigation of varying parameter

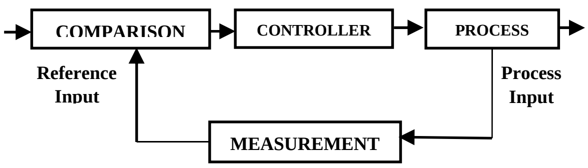

Fig. 4. Closed Loop Feedback mechanism

To generate the lift, each of the four motors need to exert the same thrust simultaneously which also depends on the external factors such as wind in order to attain the stability of the lift. The IMU obtains the values acquired by the sensors – accelerometer and gyroscope and thus in turn provide the feedback to the PID. To obtain the process equilibrium of the lift and then maintain the balance, the weighted sum of these three Proportional, Integral and Differential values is used to minimize the error. Based on measured process variable which is the measured error in this case and the set point defined (target output value), the control algorithm works in a loop to provide the desired set point. To achieve autonomous flights of predefined waypoints, a computer is used to set the way points which defines the paths and points to travel. The three parameters of P, I and D when obtained can be applied to the error and get the result of the next outputs for the motors assigned to rectify the error. The function of the three parameters of PID is summarized in the following:

A. *P Parameter*

P is the backbone parameter which can make the quadcopter fly quite stable without depending on the other parameters. It determines the optimal value out of the values measured by the gyroscope or determined by the human control. The sensitivity and spontaneity of the quadcopter to an angular change depends on the higher value of P. If P value is low then the performance of quadcopter will be slow and poor. So P is high, the quadcopter oscillates with a high frequency.

B. *I Parameter*

I has the ability to raise the precision of the angular position. For instance, consider the situation where the angle value is changed by 30 degrees. Theoretically the value of angle will be returned as 30 degrees but in actual when a quadcopter flying forward is made to go to left or right side, it will not instantly react but it will take a few seconds to counteract the action. So I is useful while encountering windy conditions or turbulence situations from the motors. When I value is large the quadcopter will slow down and consequently the P parameter is affected.

C. *D Parameter*

This parameter helps in getting the desired value speedily, and so it is like an accelerator parameter. The user input set to control for stability is amplified by D. When the error gets reduced quickly, it lowers the control action in a short period of time. The response of a quadcopter is also increased by D parameter.

In figure 5, the illustrated work of the PID structure is given.

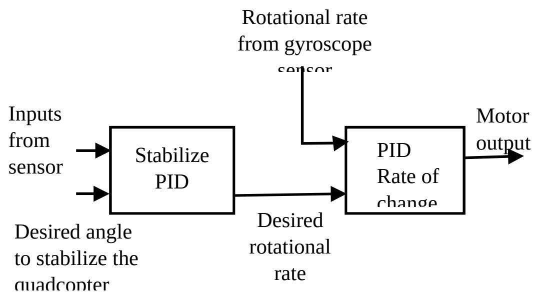

Fig. 5. Per Axis PID structure

The sensor module (Gyroscope, Accelerometer and Ultrasonic sensor) passes the inputs to the microcontroller and the output is passed to the motors through the ESCs in the form of Pulse Width Modulation (PWM). The speed of the motors are controlled by the manipulation of the forces exerted by each motor and movement of the flight is done by controlling the yaw, pitch and roll. The effectiveness of stability changes when each of these parameters are varied. There will be three PID loops each with the three parameters one per axis and so the values of P, I and D for each axis (yaw, roll and pitch) have to be set. The sensors and the PID controller are sensitive to vibrations released by the motors and so for this there may be an inaccuracy in sensing and reading the values. This is not much of a problem but it can be overcome by using a dampening method in the setup which will free the accelerometer from the vibrations and thereby prevent changes in an output. The ultrasonic sensor determines the distance range between the quadcopter and the ground and pass this distance value as an input to microcontroller and the PID controller will maintain a stable altitude motion according to the input received.

VI. EXPERIMENTS AND RESULTS

Initial experiments to determine hardware selection was done. The right selection of hardware are the key to a proper construction of a quadcopter. The first experiment was done on the motors to find out the features like weight and thrust it can generate with different types of propellers varied by its length.

A. *Motor*

Using weighing scale to measure thrust of each motor with the different types of propellers (10, 8 inch and variable pitch for each) attached. The test measures thrust at low, med and high capacity of the motor including the duration of draining the battery from full charge to min charge. Note that four motors have to be connected during actual flight, so the battery drain duration will actually 4 times less than this test.

TABLE I MOTOR SELECTION

Propeller		Thrust (g)		
Length	Pitch	Low (<1100 ms PWM)	Mid (~1500 ms PWM)	High (>1800 ms PWM)
10	4.5	330	517	748
8	4.5	257	582	703

Flight time using all four motors are represented in the following table:

TABLE II FLIGHT TIME CALCULATION

Propeller Type	Discharge time (mins)		
	Low PWM	Mid PWM	High PWM
10 x 4.5	30	22	2
8 x 4.5	27	18	3

B. *Microcontroller and Sensor Module*

For this project, Arduino Nano 328 also known as Arduino ATMega 328 microcontroller is used. Unlike the other available Arduino based microcontroller (only relevant ones) for instance Arduino UNO and Arduino Pro, Arduino Nano 328 has its own USB plug in whereas in Arduino UNO an extra board is needed for USB plug in which adds extra weight above its own bulky size and heavy weight. Arduino Nano has the USB to serial chip and connector on-board with 8 analog pins and 14 digital pins. The ultrasonic sensor used in the quadcopter can measure accurately from 2 centimetres to 5 meters which was tested with different surfaces like cemented ground, grass, water, plastic, wood, metal etc. Water did not yield correct distance between the source and the surface so care needs to be taken so that quadcopter does not fly over water bodies and result in intended consequences.

C. *Graphical User Interface Implementation*

A Graphical User Interface (GUI) controller is integrated with the implemented parts which allows to display the manipulation of the quadcopter movement. It has the basic movements (MoveForward, TurnLeft, TurnRight and Return To Origin) of quadcopter displayed on its screen which is manipulated by using the commands as the input of the quadcopter controller.

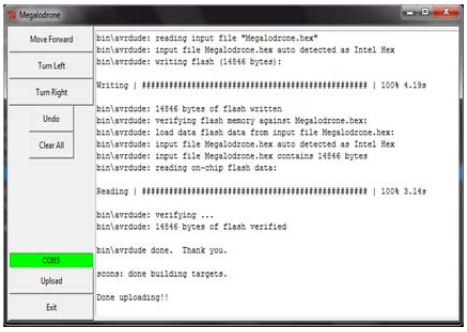

Fig. 6. Implementation of the Command Centre GUI

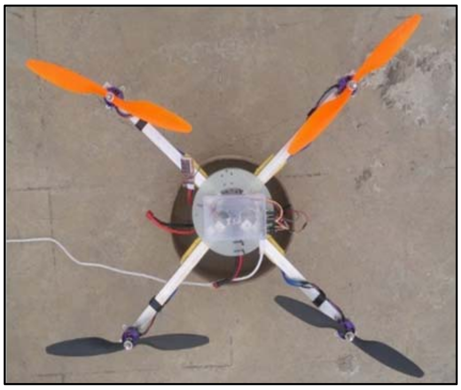
Fig. 7. The self-navigating quadcopter

D. *Quadcopter assemble and flight*

The quadcopter constructed using four equal aluminium rods, four motors, propellers, microcontroller and sensors on board is shown in figure 7.

The work of quadcopter carries certain risk and so needs a lot of care while working on it. The Li-Po battery used needs frequent checking while charging as well using as an overload may lead to an explosion of the battery and could be the reason for fire. To avoid danger and damage to anyone and to the quadcopter the flight test was done in an open space.

CONCLUSION

The objective of this work is to give an autonomous quadcopter with a stabilised and efficient performance using PID controller. The three parameters P, I and D are the key for stabilization of the quadcopter. Sonar technique is used for implementing an enhanced system of obstacle and collision avoidance.


Fig. 8. Quadcopter in flight

The work of quadcopter carries certain risk and so needs a lot of care while working on it and so certain limitations had to be faced while carrying out the work like air turbulence during take-off and landing, inconsistencies in quadcopter material, rigidity of the quadcopter structure and unsteady wobbly nature of rigid propellers. Sustainable materials of hardware were used so that more work and application can be expanded in future like addition of vision to the quadcopter for localization and navigation. With the vision support surveillance applications in the field of traffic, agriculture, animal observation and various research study can be extended. Further works on it with neural network techniques can help in achieving an artificially intelligent quadcopter. Working on the failsafe to be an inbuilt will help in detecting crashes automatically as well as implementation of a reliable Dead Reckoning technique. The usage and application of a quadcopter are dynamic and so it can be extended and expanded to many varying degrees of changes and development.

ACKNOWLEDGEMENT

The research and development on quadcopter design and model optimization, stabilization control, autonomous navigation and localization are on-going and actively carried out by hobbyists, individuals and research organisations. This work has been done as part of my M.Tech final year project which has not yet been completed and approved by the college authority. Only the progress work of the project has been represented in this paper.

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