Design and Implementation of an Arena for Testing and Evaluating Quadcopter

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Abstract - **Quadcopter technology has been an emerging field of interest among many science enthusiasts due to its vast applications in various fields. In their initial stage it is very frequent that quadcopters crash due to difficulty in controlling by the users which is challenging for any application purpose. In this paper we propose the design and implementation of an arena suitable for testing quadcopters to train the users so that they gain proper control over them. The arena consists of different types of paths that a quadcopter can travel. Testing the quadcopter in such different paths and conditions will give an idea about how to judge the performance and the stability of the quadcopter in different conditions for any application purpose and how the entire system responds to those conditions.**

Keywords—quadcopter, stability, training, control

I. INTRODUCTION

Quadcopter is an unmanned aerial vehicle (UAV) but unlike UAVs it is controlled by four rotors. The concept of UAVs initially started at Australian war in 1858 and even after in World War-1. The first model of the quadcopter was developed in 1920 to solve the problems of helicopter pilots that they were facing in vertical flights. Unmanned quadcopters of certain size used in aerial surveillance, imaging, environmental study etc. are cheap and are available in different sized models with its simple mechanical design. They find exhaustive applications in humanitarian aid during natural disasters like earth quake, flood etc.

Recently it is found that there is a huge increase in the drone sale by 63% in the year 2014-15[12]. Many countries like America, China, Russia, India etc. are showing interest to invest in this field of drones because of its vast application in this modern technical world. The United States is planning to invest 17.5 billion dollars in the FY 2017-21[13]. Quadcopter is a basic stage to start researching in the drones. But it is frequent that beginners will face problem in handling that quadcopter and as a result it gets crashed. To avoid this, the user has to be trained in testing the quadcopter in different environments. Training and testing is the most important and crucial process to avoid crashing as one can learn to control the quadcopter for its safe flight, landing and to judge the mechanical condition of the quadcopter in different types of motion. This would make the quadcopter to be stable and efficient. To test the quadcopter, we have to create a different testing environments. Using Remote Controlled (RC) transmitters, we can control the quadcopters in a step by step process in different paths. By doing so we can ensure that

Quadcopter can work in any conditions and can be effectively controlled.

II. MOTIVATION and PROBLEM STATEMENT

Many of users start their research from a basic quadcopter, which is challenging to control where stability is a major issue. Stability can be achieved by integrating the system with stabilizers like IMU sensors. If a fresher is going to use quadcopter for a particular application without knowing its full behaviour such as battery status, controlling etc., it will be disastrous to the copter. A fresher requires proper training and skills to control the copter without crashing. To achieve this, a good training arena with variety of setups for manoeuvring would be a good option. Choosing the different manoeuvring setups which will make the fresher a trained user is not a simple task. In this paper we present design and implementation of an arena with variety of manoeuvring setups for any fresher to practice and train. We also discuss about the basic implementation of a quadcopter used in this arena.

III. RELATED WORKS

In recent years much research has been carried out on quadcopter performances. The research paper [1], discusses about the design, implementation of the quadcopter and gives a clear idea on dynamic mechanical implementation which helps for future applications. The kinematics and dynamics of the quadcopter in mathematical modelling is presented in [2]. Paper [16] focussed on the implementation of Inertial Measurement Unit sensors in Gesture application. Paper [3] presents the work on enhancement of pixhawk for its efficient performance based on some factors in real time scenario. Research papers [4],[15] focuses on the stability of the quadcopter with the help of PID control algorithm. In research paper [5] trials are being done in different conditions, using proposed PID algorithm and final stability performance was observed. Simulation of altitude stability using different controllers, which is essential in efficient performance of quadcopter, is discussed in research paper [6]. Quadcopter has been tested in indoor environment, which is integrated with different sensors such as IMU, laser etc. as explained in [7]. The system control, system dynamics, translational and rotational behaviour of the quadcopter when it is tested in a light wind are well

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explained in [8]. The authors of [9] explain how to adapt the modelling errors and the changes in the testing platform. Semi-autonomous quadcopter using arm gesture for navigating, which is somewhat sensitive is elaborated in [10]. Paper [11] explains about the quadcopter being tested in a simulated environment with Gazebo and ROS. Even though there are several research papers detailing several aspects of quadcopter, the test environment for training novice users proposed in this paper is not to be found in any prior research work.

IV. QUADCOPTER DYNAMICS

A. *Thrust to Weight Ratio (TWR)*

The minimum thrust required to hover the quadcopter is equal to the weight of the quadcopter. Therefore, TWR value is always greater than one. The value varies based on the application because the ratio depends on the hovering speed. Racing quads hover at high speed, so the TWR value is greater than or equal to 5. For practical purpose, the value is 2 or 3 based on the weight of the quadcopter. So the thrust and weight of the quadcopter are related as shown below. The total thrust is produced as the sum of the motor thrusts equally produced by each of the four brushless motors.

*Total Thrust = (TWR) * (Weight of the quadcopter)*

Motor thrust = (Total thrust)/4

The below calculations are for the minimum thrust for throttling the quadcopter off the ground.

In our case, weight of the quadcopter, W = 998gm

Since the research is for application purpose, TWR = 2:1

Required thrust, Tmin = W*TWR = 998*2 = 1996gm

Number of motors, N=4

Thrust produced by each motor = T/N = 1996/4 = 499gm.

B. *Motor Propeller relation*

Motor speed and the propeller length are inversely related. Higher rpm motors need short propellers used for the racing quads which lacks the stability due to its high speed. The medium range rpm motors need long propellers for the practical applications which require the stability. As the most of the applications need the stability of the quadcopter, the combination of medium rpm motor with long propellers is the apt. In this research, we used the motor of 1000 rpm/volt with the 10 inch propellers.

C. *Equilibrium*

While building the quadcopter the weight distribution is very important. The Center of Gravity (CG) should exactly be at the center of the quadcopter for an effective motion. We have achieved the CG by measuring the weights of all the components which are to be fixed on the quadcopter and then integrated them on the frame symmetrical about the center. However weight distribution depends on the type of frame we use. We have used an X-shaped frame, symmetric about its center. Stability of the quadcopter always depends on the symmetry of the quadcopter.

V. QUADROTOR DYNAMICS

There are four basic motions that a quadcopter can hover around. They are throttle, pitch, roll and yaw as shown in Fig. 3. Before going to the motion of the quad, we should know about the propeller dynamics. One of the diagonally related propellers should be of clockwise direction while the other propellers should be of counter clockwise direction as shown in Fig. 1. The red or the short arrow and the blue or the long arrow represents the low and the high speeds of rotation respectively. For every motion the Center of Thrust (CT) changes depending on the direction of motion of the quadcopter. For each revolution the quad moves a distance equal to the pitch of the propeller provided there is required thrust.

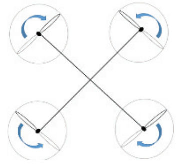

Fig. 1 Propellers direction

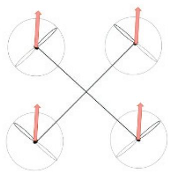

Fig. 2 Throttle motion

A. *Throttle*

Throttling is moving the quadcopter up and down in the same vertical line. For this, all the propellers need to give same thrust as shown in Fig. 2. So the maximum thrust from each brushless motor will take the quadcopter to reach its maximum height. For an efficient throttling, CT and CG should coincide at the centre.

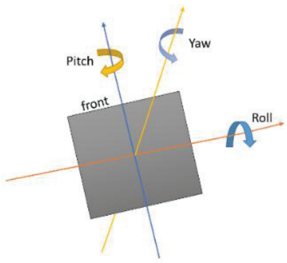

Fig. 3. Throttle, pitch, roll and yaw in quadcopter

B. *Pitch and Roll*

Pitch means to lean forward or backward. For the forward motion the quad should lean forward and it is the negative pitch. For the backward motion the quad should lean backward and it is the positive pitch. These are shown in Fig. 4 and Fig. 5. For forward motion the CT should be in forward direction and in backward direction for backward motion. Roll means drifting right and left for which CT should be towards the right and left directions respectively in Fig. 6 and Fig. 7.

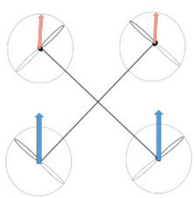

Fig. 4. Forward pitch

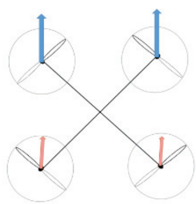

Fig. 5. Backward pitch

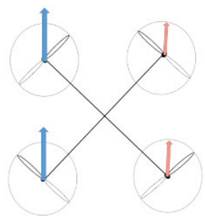

Fig. 6. Right roll

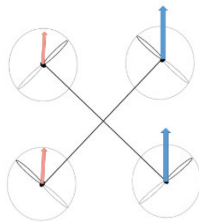

Fig. 7. Left roll

C. Yaw

Yaw is to rotate or to turn in the same horizontal plane. Fig. 8 and Fig. 9 represents the yaw motion.

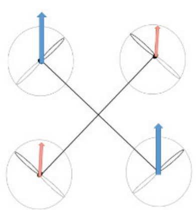

Fig. 8 Left yaw

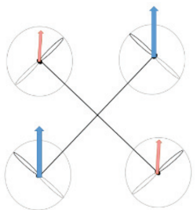

Fig. 9 Right yaw

VI. DESIGN AND IMPLEMENTATION

A. Block Diagram

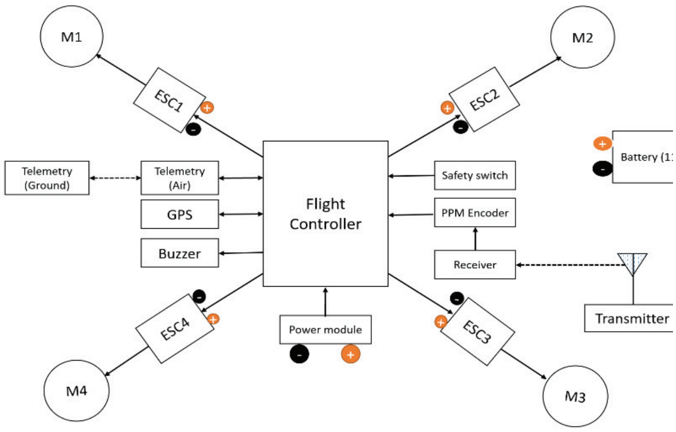

Fig. 10. System Architecture

The Fig. 10 represents the block diagram of the entire system of this research work. The controller we used was the Pixhawk 2.4.8 flight controller, a 32 bit microprocessor with 256KB of RAM. It's a small circuit board which direct the rpm of each motor according to the commands from the pilot or based on some intelligence. It has inbuilt IMU sensors namely Gyroscope, Accelerometer and Magnetometer which are responsible for stabilized flight. We used FlySky CT6B Transmitter and R6B Receiver of 2.4GHz frequency for the controlling the quadcopter and a Pulse Position Modulation (PPM) encoder to encode the signals before it feed to the flight controller. Electronic Speed Controllers (ESC) are used to control the speed of the motors according to the commands from the flight controller. We used ESCs (1, 2, 3 and 4) of 30A for brushless motors M1, M2, M3 and M4 of 1000 rpm/volt. The wide variation in power and fine rpm control over the speed of motors provide all the required motions. For power, we used 3s 11.1v LiPo Battery of 4200mAh capacity. A power module to provide the flight controller a 5v dc from 11.1v is used. We have used X-shaped f450 frame which weighs about 282gm. We have used the Mission Planner [14] software as the Ground Control Station (GCS) for calibrating the components and the entire setup on our computer. We used safety switch for enabling and disabling the entire setup and a buzzer which indicate different status of the quadcopter or any alarming signs.

B. Telemetry

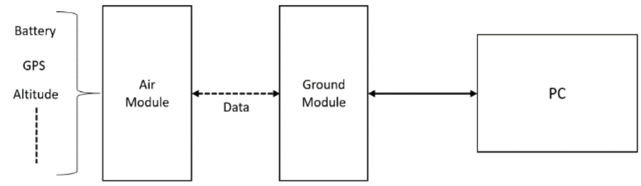

Fig. 11. Telemetry system

As shown in the block diagram in Fig. 11, we have used the telemetry setup with air and ground modules of 915MHz. Telemetry is the process of recording and transmitting the information or readings of a particular system or an instrument. Here we require some data from the quadcopter which needs a continue observation like battery levels, altitude, tracing the location by using GPS, etc. Air module was setup in the quadcopter to record the above data and transmit to the ground module which was connected to the PC or smartphone running with the GCS software. Telemetry is also used to set the way points for the quadcopter by GPS technology and making it autopilot. We have used a NEO M8N GPS module with internal compass. Adding GPS with internal compass in turn increases the stability of the quadcopter.

C. Working Procedure

a) Signal flowchart

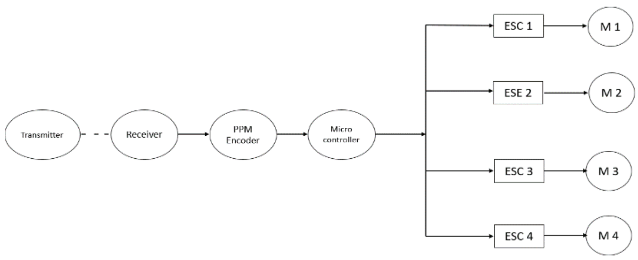

Fig. 11. Flow of signals from Transmitter to motors

Wireless radio wave communication is one of the important aspects of this system. As shown in the above Fig. 11, the Receiver receives the Pulse Width Modulation (PWM) signals from the Transmitter and send them to the PPM Encoder which encodes those PWM signals into a single PPM signal and fed it to the flight controller. The necessity of this encoding is that the power remains constant in PPM signals compared to that in PWM signals. Once the flight controller gets the signal from the encoder, it performs the required action by commanding and directing a small current flow to the ESCs based on the transmitted signal. The controller continuously vary the current it sends to the ESCs based on the signal intensity it gets from the Transmitter. ESC control the speed of motors based on the amount of current received from controller and by varying the power it send to the motors. Hence there is change in motor speed for every small change in the transmitted signal.

b) *Self-balancing algorithm*

While hovering, the quadcopter experiences the errors in pitch, roll and yaw irrespective of the transmitted signal which causes the imbalance in quadcopter. The difference between desired and obtained output gives the error. These error values are detected by the IMU sensors within the flight controller with respect to the mean values which are usually zero in all directions. These sensors follow the closed loop system algorithm to minimize the error values as shown in the Fig. 12. The self-balancing system contains the IMU sensors namely Gyroscope, Accelerometer and Magnetometer which measures the angular velocity, acceleration and the magnetic field respectively in 3 Degrees of Freedom each. Hence the quadcopter is being stabilized in 9 Degrees of Freedom.

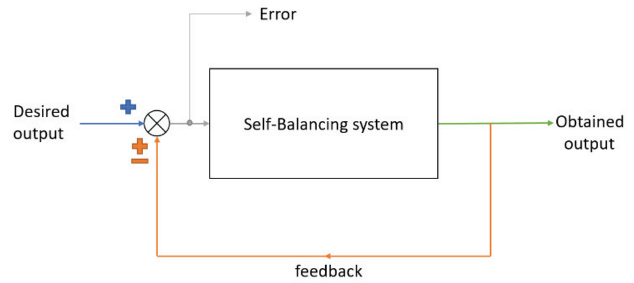

Fig. 12. Self-balancing system

VII. Testing

The arena was setup to train the users to control the quadcopter and study motion errors and altitude stability. The whole arena was structured with simple things like rope and winding wire to make different hurdles like circle and square at different altitudes and locations. Plastic ropes were used for making horizontal bar like setup. We have also used the crossbars under the roof in the corridors for hanging the different hurdles. There are certain precautions to be taken care before the first flight.

Precautions:

- Know the rules and regulations for operating the quadcopter in your region.
- Ensure the batteries are fully charged.
- Inspect the entire setup physically regarding integration, wiring and make sure that every part is held tightly.
- Have a latest firmware installed on your PC or smartphone and keep the device fully charged.
- Make sure all the parts are working properly and test the motors without fixing the propellers.
- While fixing the propellers the direction of spin is important.
- Have landing gears or some other smooth stuff fitted at the bottom to avoid any damage during crashes.
- In the initial trials choose an outdoor environment which is clear without buildings and trees. Later one may try in indoor environment.
- Make sure the weather is also clear without any signs of rain.
  Test at low altitudes and make sure you always take-off the copter from the ground.

Arena 1:

This arena was setup to test and train in takeoff and landing of the quad, both indoor and outdoor. Fig. 13 shows the top view of 15 feet landing distance from the takeoff spot and Fig. 14 shows its practical implementation. The quadcopter will take off from the spot X and will land on the specific spot marked H within the rectangular area of dimension 2 x 1.25 feet.

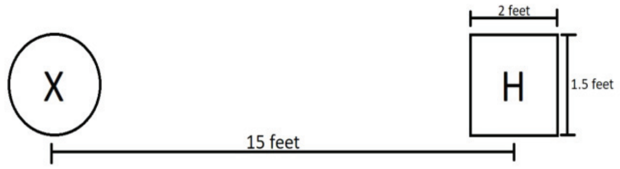

Fig. 13: Top view of arena 1.

Fig. 14: Practical implementation of Arena 1.

TABLE I: OBSERVATION OF ARENA 1

Trial	Time (s)
1	9
2	12
3	8
4	8
5	9

Table I shows the number of trails performed and time measured from the time of take off to the landing point. This testing was done to test quadcopter takeoff, landing in a straight line motion. The best result we obtained was in 8s when the quad took 2.5s and 3.0s for takeoff and landing respectively. When the takeoff and landing modes activated it is taking more flight time but with greater accuracy.

Arena 2:
Fig. 15 shows the side view of the arena and Fig. 16 shows the practical implementation of arena 2. In this arena the quad was tested for the horizontal zigzag motion along the row of pillars and to test the response when the control instructions changes instantaneously. This arena has three pillars in a row with each pillar of a circumference of 119.65 cm and 365.76 cm apart.

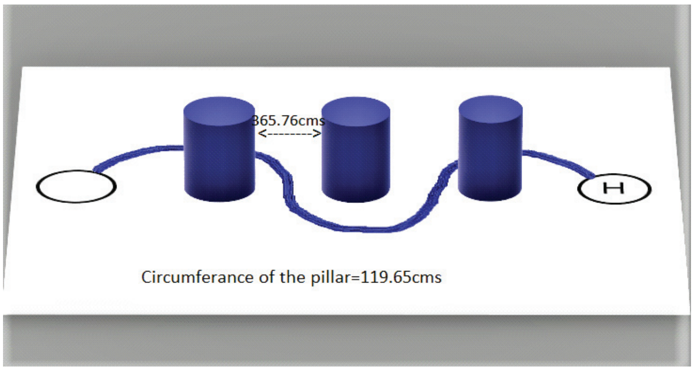

Fig. 15: Side view of arena 2.

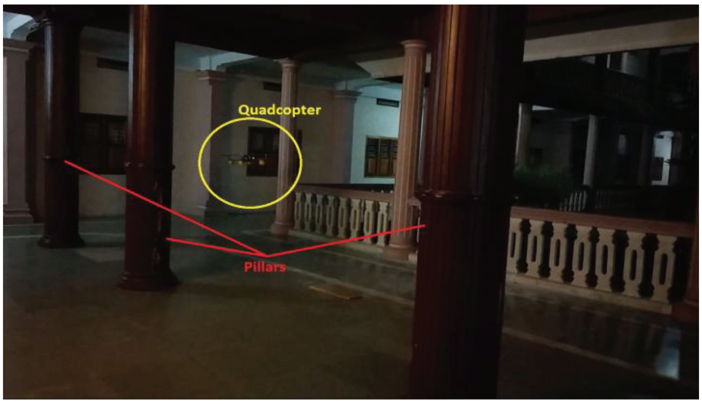

Fig. 16: Practical implementation of the arena 2.

TABLE II: OBSERVATIONS OF ARENA 2.

Trial	Time(S)
1	40
2	45
3	43
4	47
5	45

Table II shows the number of trials performed and time measured for the completion of horizontal zigzag motion. The best result obtained in this arena was in 44 sec. The Quad has good response to instantaneous changes in controls.

Arena 3:
Fig. 17 shows the top view of the arena 3 and Fig. 18 shows the practical implementation of the arena 3.The arena consists of a circle placed a height of 548.64cm from the ground. This arena was made to test the altitude stability.

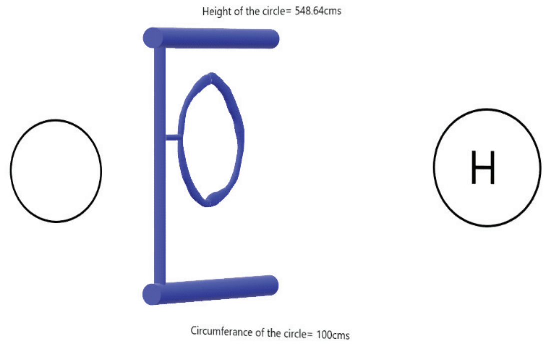

Fig. 17: Top view of the arena 3.

Fig. 18: Practical implementation of the arena 3.

TABLE III: OBSERVATION OF THE ARENA 3.

Trial	Time(S)
1	15
2	17
3	12
4	15
5	14

Table III shows the number of trials performed and time taken to complete the task. This test is performed to find quad's altitude stability, as the quad need to be in the level of the circle to pass through it. The maximum time where the quad had a stable altitude was for 5 seconds. The best flight obtained was in 12 seconds.

Arena 4:
Fig. 19 shows the top view of the arena 4 and Fig. 20 shows the practical implementation of the arena. The arena consists of two hurdles: one is circle and the other is a square. The circle if is of diameter 100cm and the square with side 100cm.The circle and the square are held at a distance of 180 cm. The hurdles were set at a height of 6 feet from the ground. Circle was the first hurdle which was tied to the roof bars of the corridors and the square hurdle was suspended from the roof bars as shown in the Fig. 19. This arena was setup to test quad's motion error while travelling in the straight path.

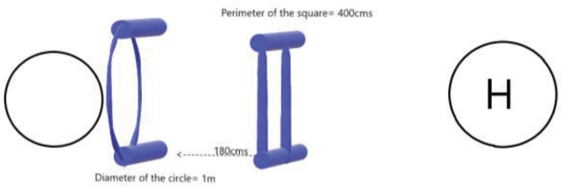

Fig. 19: Top view of the arena 4.

Fig. 20: Practical implementation of the arena 4.

TABLE IV: OBSERVATIONS OF THE ARENA 4.

Trial	Time(s)
1	25
2	31
3	30
4	33
5	28

Table IV shows the number of trials performed and time taken for completing the task. This arena was setup in such a way it will test quads stability and to find any errors in its straight line motion. The best flight in this arena was in 33sec.

Arena 5:
Fig. 21 shows the top view of the arena 5 and Fig. 22 shows the practical implementation of the arena. This arena is mixed one, through which we were able to test quads stability, motion errors. The arena consists of three horizontal bar hurdles at a distance of 100cm from each other. This is accompanied by a square of perimeter 400cm and a circle of diameter 100cm suspended from the cross bar.

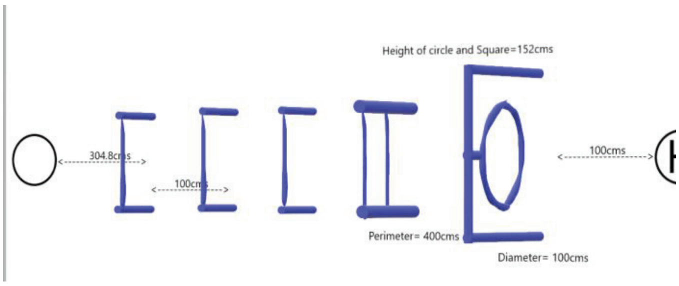

Fig. 21: Top view of the arena 5

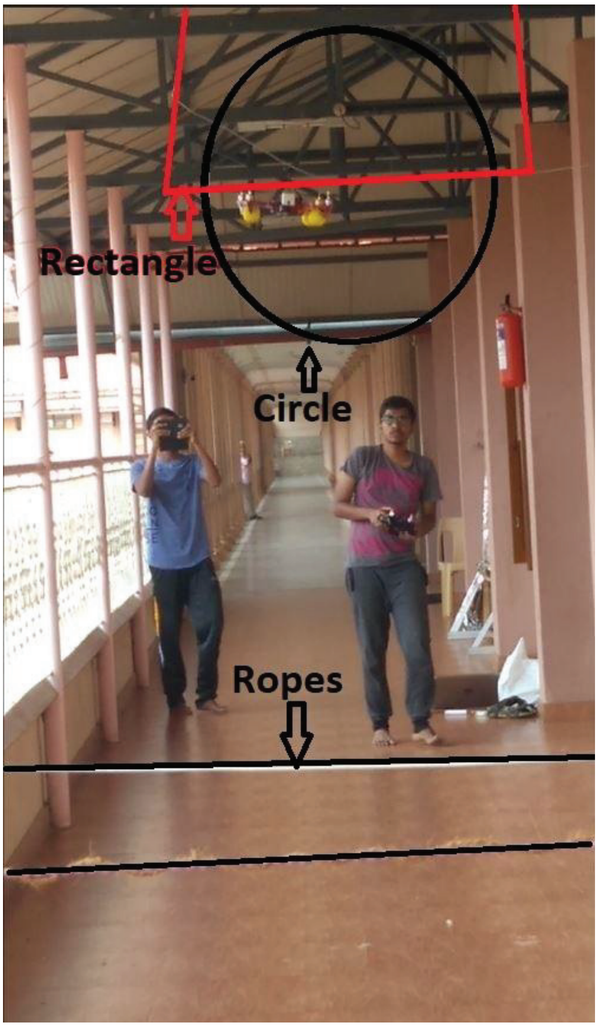

Fig. 22: Practical implementation of the arena 5.

TABLE V: OBSERVATIONS OF THE ARENA 5.

Trial	Time(S)
1	55
2	65
3	64
4	54
5	62

Table V shows the number of trials performed and time taken for completing the task. This arena is a tough one, it constantly kept in track every movement from takeoff to the landing. The best flight obtained was in 54 seconds.

VIII. Conclusion

In this paper we presented the need for setting up proper testing environment for testing the quadcopters for novice learners to train themselves to control the copter at the introductory part. Then we presented our own design of the quadcopter that we built for this purpose which was followed by the detailed description of setting up of different test environments for getting trained and controlling the copter. The quadcopter we designed was tested in different arena setup and the results were tabulated.

Though much work is still going on to evaluate the arena, we feel that the results point to a solid beginning.

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