Modelling, Analysis and Fabrication of a Single Propeller Multi-Terrain Spherical Drone

Kaushik Balasundar, Aby J Kottoor, Edwin Easo Mathew, Akash S Nambiar, Abhishek S.A.

Abstract— **This paper demonstrates a working configuration for a single propeller spherical multi-terrain aerial vehicle designed primarily for search and rescue operations and military applications. The drone is housed inside a carbon-fiber 2-v geodesic sphere, making it collision tolerant and allowing it to land anywhere without the need for extensive pilot training. The inner and outer rings constitute a gimbal mechanism which is decoupled from the motor and electronics embedded on the central frame. This allows the drone to remain stable after experiencing collisions. The drone is stabilized using an MPU 6050 6 DOF IMU sensor coupled to an Arduino flight controller and servo motors that actuate the control vanes to achieve the desired attitude control. We also discuss the possible applications such as in the military, constrained space surveillance, search & rescue and in pipeline inspection to detect gas leakage.**

I. INTRODUCTION

Traditional search and rescue drones have exposed propellers which impose limits on the terrain in which they can function. These drones cannot fly near humans due to the risk of injury from the high-speed rotating propellers. Conventional autonomous drones have vision integrated control algorithms targeted at anticipation and negotiation of obstacles in real time. This process is computationally intensive which in turns increases the cost of the drone. Furthermore, the pilot operating the drone will need to be highly skilled and experienced to effectively maneuver the drone in the desired path. These are some of the major limitations that traditional drones are facing in the current scenario. Our primary goal is to build a robust drone which overcomes these disadvantages.

Inspired by the Japanese Ball drone, the limitations mentioned above can be solved by housing the propeller in a completely enclosed meshed 2-v geodesic meshed sphere such that it is not exposed to the surroundings and becomes collision tolerant. Therefore, there is a need to ensure that the propeller that provides the necessary thrust is always oriented in the same direction before and after collision. This necessity is satisfied by housing the motor, propeller and electronics within a gimbal stabilized mechanism. The two rings that comprise the frame of the spherical drone are decoupled from the central member housing the motor and electronics. Hence, the orientation of the central member of the drone is independent of the orientation of the external meshed spherical sphere. This means that the drone's exterior will be able to roll on the ground and on walls while the direction of thrust provided by propeller will be constant before and after collisions.

As a result, there is no need for any real time obstacle-avoiding control. In other words, rather than trying to avoid obstacles, the drone can use the obstacles to maneuver along narrow spaces and uneven terrain. This will greatly increase the scope of application of drones in terrains which are currently inaccessible to humans such as in pipelines and manholes. The following sections elucidate the design of the frame, 2-v geodesic meshed sphere and primary hardware components required to realize a working prototype of the single propeller multi-terrain spherical drone.

II. MODELLING AND DEVELOPMENT

The Body

The 3-D model of the drone was developed using Fusion 360. This model was then used to 3D print the body of the drone. Due to dimensional constraints of the bed of the 3D printer used, the inner and outer rings were printed as four independent quarters and joined together during assembly. The inner and outer rings can pivot freely about the central axis and is decoupled from the central frame that houses the motor, propeller and electronics. The weight of the motor, propellers and battery is symmetrically distributed on the central frame such that it remains upright even if the decoupled inner and outer rings are at different orientations, thus forming a gimbal mechanism. The joints that integrate the four quarters of the rings are fastened by nuts and bolts and further reinforced with glue.

2-v Geodesic Meshed Sphere and Control Vanes

The outer 2-v geodesic meshed sphere used for collision tolerance is made using 1.8mm diameter

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carbon fiber rods. The pentagonal and hexagonal hubs for assembly of the meshed sphere was also 3D printed and appropriate lengths of carbon fiber members were used to construct the outer mesh. The control vanes were also printed using PLA and coupled to the frame underneath the propeller for attitude control. Figure 1 shows the 3-D assembled and rendered view of the spherical drone.

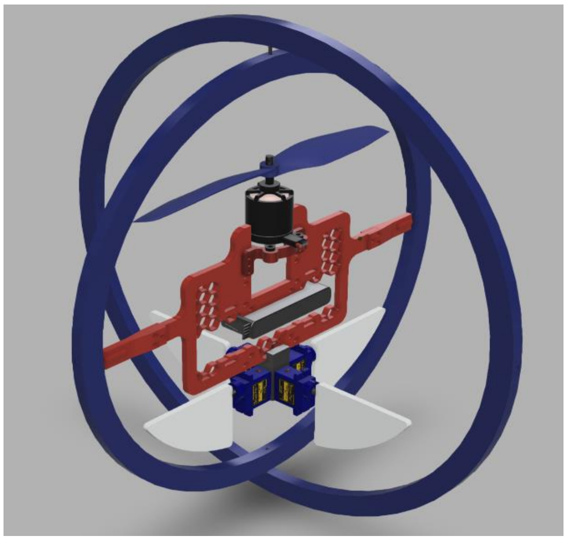

Figure 1: Assembled & Rendered View on Fusion 360

III. HARDWARE

Motor

The prototype was tested using an GT2210-13 1270 KV Brushless motor. This motor was selected as it provided 740g of thrust. It was also light enough for the PLA frame to remain structurally stable and provided a good climb rate. The model can take off at 73% throttle. We are using an 8x6 propeller as recommended by the manufacturer in the data sheet.

Model	GT2210/13
Mass	55g
No. Of cells	2-3xLi-Poly
Stator Dimensions	22x10mm
Shaft Diameter	4mm
Recommended prop	8x6, 9x4.7
Recommended model weight	600-800g
RPM	12000
Max current(<60S)	17A
Thrust	0.740 kg

Table 1: Motor Specifications

Electronic Speed Controller (ESC)

The ESC used in this prototype is FlightLine 20A Brushless programmable ESC. Its small size, low mass, smooth start-up and throttle linearity suit our requirements perfectly.

Propeller

The propeller chosen is an 8x6 slow fly as recommended by the datasheet for achieving maximum power output without heating. The propeller was balanced to eliminate vibrations.

Servos

Four digital servos 10g/1.4kg/0.09s were used to actuate the control vanes based on feedback from MPU 6050 IMU sensor.

Control Board & Communication

An Arduino control board was used for real time processing of IMU sensor data and provide actuating signals to the servos coupled to the control vanes to maintain stability of the drone and achieve attitude control. In addition, the radio communication was achieved using a FS-CT6B 2.4 Hz transmitter-receiver system.

Drone frame

The inner outer rings have been designed to form a gimbal mechanism such that the central frame is decoupled and hence independent of the motion of the rings.

Width	0.015 m
Thickness	0.004 m
Outer diameter of outer ring	0.341 m
Outer diameter of inner ring	0.300 m

Table 2: Design Parameters of Inner and Outer Rings:

The 2v geodesic sphere was chosen over a truncated icosahedron because it has a larger number of faces with each face having lesser cross-sectional area. As a result, it allows the drone to negotiate obstacles more efficiently.

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IV. ANALYSIS

The choice of material used was to be evaluated to ensure that it could withstand the load of the functional components embedded on the frame. This process was carried out using Finite Element Analysis (FEM) to ensure that the circular frame did not undergo major deformations. The results were then used to decide an appropriate cross-section of the inner and outer rings that form the gimbal mechanism. The analysis was developed considering the properties of PLA as given in the table 2. The analysis was carried out using Ansys and the results are as shown in figure 2.

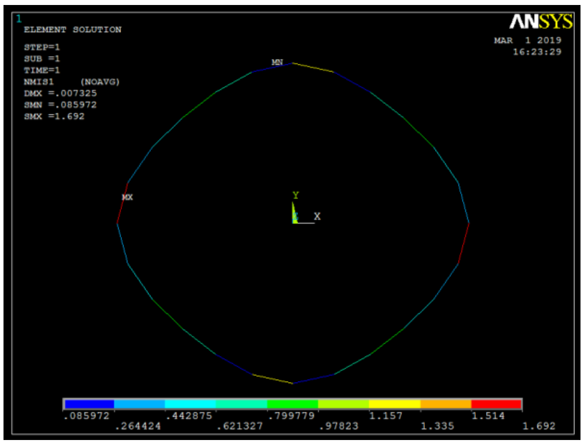

Figure 2: Ansys Analysis Results of the Inner Ring

Density (Mg/m^3)	1.25
Young's Modulus (E, GPa)	3.5
Poisson's Ratio	0.35
Elongation at Break (%)	6
Melting/softening temperature (°C)	160
Tensile Stress (MPa)	36-55
Ultimate Tensile Strength (UTS) (MPa)	35
Strength to weight ratio (kN-m/kg)	40

Table 2: Mechanical Properties of PLA

Mass	0.540 kg
Payload	0.180 kg
Diameter	0.341 m
Motor	EMAX GT2210/13
Propeller	GWS SF 8x4.5
Battery	Lithium Polymer 11.1V 2200mAh 25C
Electronics Speed Controller	Flightline 20A
IMU	MPU 6050
Flight Controller	Arduino Nano

Table 3: Technical Specifications

Spherical radius	175 mm
Spherical diameter	350 mm
Height	175 mm
60x Strut A	95.643mm, 15.86°
60x Strut B	108.155 mm, 18°
Hexagonal Hubs	30
Pentagonal Hubs	12

Table 4: 2v Geodesic Sphere Specifications

V. APPLICATION

Thousands of professionals risk their lives every day in dangerous missions such as fire fighters entering unstable structures, workers inspecting mines, pipelines and powerlines, or rescuers trying to save victims trapped in collapsed buildings. We can potentially save thousands of lives by allowing robots to carry out tasks in hazardous environments. To deploy a drone to inspect these hazardous environments, it must be collision tolerant. There is an immediate requirement for drones that don't require large open spaces and skilled pilot training for operation. By equipping HD cameras and thermal imaging cameras to the spherical drone, it is possible to carry out surveillance in collision prone hostile environments. It can also operate in conditions where there is a high chance of human interaction, as the guarded propeller is unlikely to cause arm when near humans. In addition, many industries require inspection of pipelines where there may be noxious gas leakages. It is an immense challenge to get visual feedback about the nature and location of the damage occurring on the pipelines. The spherical drone will solve these issues because it uses the constant collisions with the pipeline wall to navigate down the pipeline. In this regard, the following gas sensors will be used based on the nature of the gas being detected:

MQ-2	General Combustible gases
MQ-4	Methane
MQ-7	Carbon Monoxide
MQ-8	Hydrogen
MQ-9	LPG
MQ-135	Carbon Dioxide
MQ 137	Ammonia

Table 5: Gas Sensors

These sensors are ideal for this application as they are light-weight, low cost and can also be calibrated to measure the gas concentrations in ppm. The drone can also be dropped from a height as the carbon fiber material will be able to sustain impact loading. This is specifically useful in military and defense applications as the drone can be airdropped for surveillance.

VI. Photographs

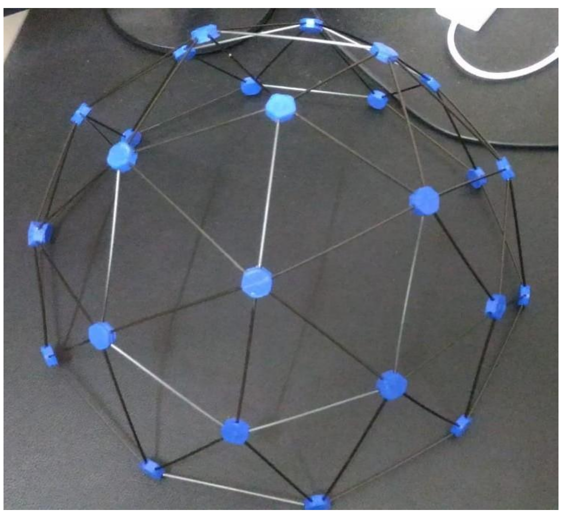

Figure 2: 2-v Geodesic Sphere Construction

Figure 3: Sectional View of Drone

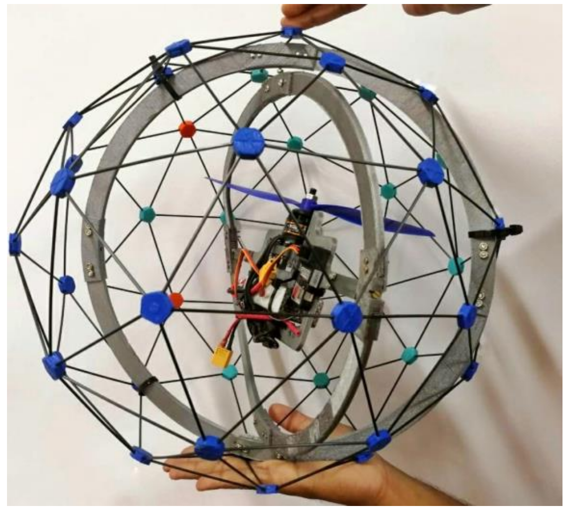

Figure 4: Assembled Prototype

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