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3D Drone Mapping

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Abstract

A major portion of the earth remains unexplored today. There are many reasons for this. One of them is because those places are or maybe dangerous for the explorers. Also, Nepal and many other under-developed countries buy satellite images and maps of their territory from other countries. The problem with these maps is that they are not always up-to-date and are very low-resolution images. In order to solve these problems, this research work has designed a quadcopter (four propellers) drone with HD camera. This device is capable of capturing images with colour, intensity, and depth values at each pixel so that a 3D map can be constructed. Unmanned Aerial Vehicles (UAVs) also called Drones can be designed for numerous objectives and tasks. This article intends to design a drone capable of creating its own pathway and taking flight autonomously. During the flight, the UAV is programmed to capture high-resolution images at regular intervals with 60-80% overlap. The overlap between images is highly necessary to obtain numerous data of the same point, which will be beneficial in creating a finer 3D map. The 3D map is generated by using a process called photogrammetry, which takes pictures as input and displays a 3D map as output by utilizing the data present in pictures. This drone can be used to capture pictures and create 3D maps of unexplored areas like caves, volcano craters, etc. Also, high-resolution pictures can be merged and uploaded for satellite imaging applications. Besides, the same vehicle can be used for many other applications like forest fire monitoring systems, endangered wildlife monitoring, surveying, and so on with slight alterations.

Keywords: Drones, UAV, Photogrammetry, Propellers, Pixels, QuadCopter, Digital Elevation Model (DEM)

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1. Introduction

Mapping is one of the important aspects of the modern world. Its importance reflects when it comes to surveying, tracking, disaster management, landmines mapping, and so on. Mapping techniques through remote sensing, 3D earth modeling using GIS (Widodo & Budiharto, 2021) and GPS techniques have now achieved significant progress these days. Moreover, with the implementation of complex sensors and software and accurate modeling can be achieved. However, this technology somehow depended on thematic mapping with high-resolution satellite imagery (Kotaro & Iizuka, 2018). The main obstacle in this process is the acquisition of data which is quite an expensive and tedious process especially for mapping a local area covering a small proportion of land and requiring frequent updates of the area. One alternative is to use Unmanned Aerial Vehicle (UAV), which requires low cost, is easy to operate, obtains a high-resolution image, and can be used frequently as per required. In the context of Nepal, where geographical terrain is a challenging hurdle for surveying, 3D modeling using UAV is a landmark in the field of surveying and disaster management. The main purpose of this project is to achieve 3D mapping by developing a drone, which can then be used for other purposes such as monitoring plants in agriculture, endangered species monitoring systems, and so on.

All of the projects mentioned above are dependent on how precisely we can map the surveying area. The PixHawk 4.0 flight controller controls all of the drone system's peripheral components and devices. The frame used here is holybro s500. This frame was particularly selected due to its light weight and high strength.

2. Literature Survey

Drone topic and aerial vehicles are well-established today. Many researches and projects are carried out across the globe in recent days but limited contributions have been done to enable the mapping implementation of UAVs. Recently, Kashmir Wildlife Foundations (KWF) initiated a two years project in Nepal aiming to build a 21 feet fixed-wing drone that has a flight time of 24 hours. The drone is supposed to take flight at more than 5000 feet. The project aims to enable wildlife conservation and habitat detection of snow leopards in Himalayan areas. Several types of research works have been carried out on the UAV and its applications in various areas like surveillance, security, military applications, wildlife applications, forest fire detection, film industry etc. In 2009, Burke and Axle performed their work on UAVs for their surveillance and reconnaissance applications

(Bürkle, Axel, 2009). Also, in 2020, Ayman and the team designed a quadcopter drone in the SITL simulator. The drone was a quadcopter drone that was applicable for many purposes with small modifications.

Also, in 2018, Kotaro, Iizuka, and team did some similar research on UAVs for their mapping implementation by using photogrammetry (Kotaro & Iizuka, 2018). The primary purpose of the project was for the landscape analysis and comparison with satellite data. Similarly, a team worked on the drone mapping implementation for engineering surveys in 2019. The team was led by Olympia Tziavou (Olympia Tziavou, Jock Souter, Stella, and Pytharouli, 2019). They also did the technical considerations for obtaining the optimum results. Again, in 2020, a team of Indian engineers worked on a practical approach for generating high-resolution 3D models of the open pit slopes by using UAVs (Rushikesh & Battulwar, 2020). They also implemented the ability of flight path planning and optimization of the path by using remote sensing. Another research was performed in 2021 by Widodo and Budiharto, where they performed 3D modeling of an area by using a quadrotor drone. In their project, they also implemented the GIS system implementation (Widodo & Budiharto, 2021). The implementation of the GIS system has increased the accuracy of the photogrammetry approach and the slicing and layering of the 3D map were possible. This provided a possibility of detailed analysis of the terrain.

3. System Design

3.1 Block Diagram

The figure is the basic block diagram that depicts the reference connections for the system. the crucial part of the system is the pixhawk 4 flight controller. The controller is provided with a 12 V dc power supply using a lipo battery via a power distribution board inbuilt into the UAV’s frame. The controller is responsible for all the control activities of the UAV. The controller directly controls the activities of the electronic speed controllers i.e., the ESC which in turns controls the rotation of the motor. The ESCs also adjust the speed of the motors. The controller also controls the activities of the camera used in the system. the pictures captured by the camera are stored in the memory and given to the PC for further processing and generation of the 3D map. The processing of the images is done in the drone deploy or Pix4D software and a 3D map is generated. The commanding of the UAV is done using a software named mission planner that acts as a ground station.

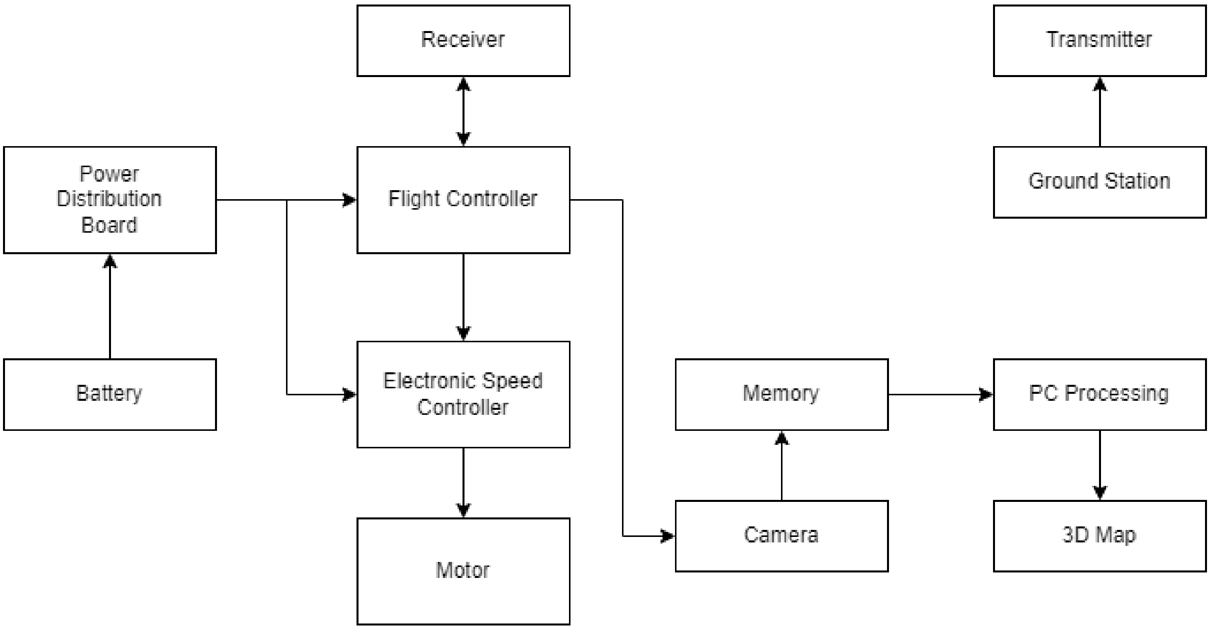

Figure 1. Block Diagram for the UAV 3D Mapping System

3.2 System Architecture

3.2.1 System Manual Architecture

Figure 2 shows a system in manual mode. In this mode, it has two inputs. The first one is the radio signal from the RC transmitter and the second is the power from the battery. The radio signal receiver receives the signal and transmits it to the CPU where the algorithm adjusts the vehicle dynamics. The adjusted value is then transmitted to the ESC which controls the speed and direction of the engine. Power Distribution Board (PDB) takes the power from the battery and distributes it to the other parts of the system.

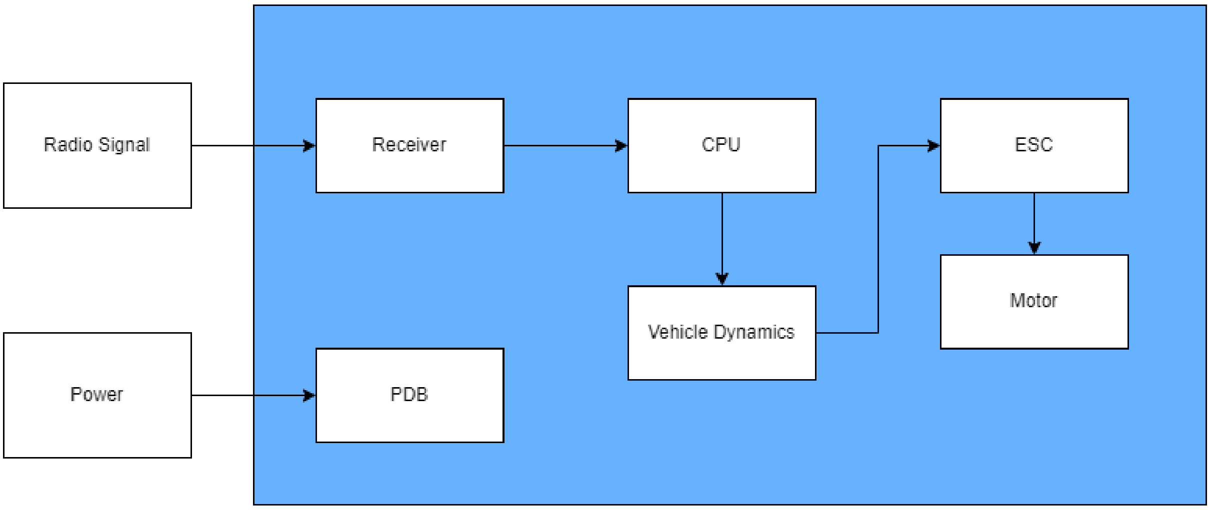

Figure 2. System Architecture for Manual Mode

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3.2.2 Autopilot Mode

Fig 3 shows the internal architecture of the autopilot system. It shows multiple components work together to perform the tasks. The entire system will have two basic inputs. The first one is the mission targets that will be fed via mission planner software and the second will be the power input from a 12v battery. The power Distribution board supplies control voltage to the entire autopilot system as well the other hardware like BLDC motors and sensors modules. Accelerometers control the speed of the drone in a controlled manner whereas the internal compass along with gyroscope altitude sensors controls Yaw and Pitch.

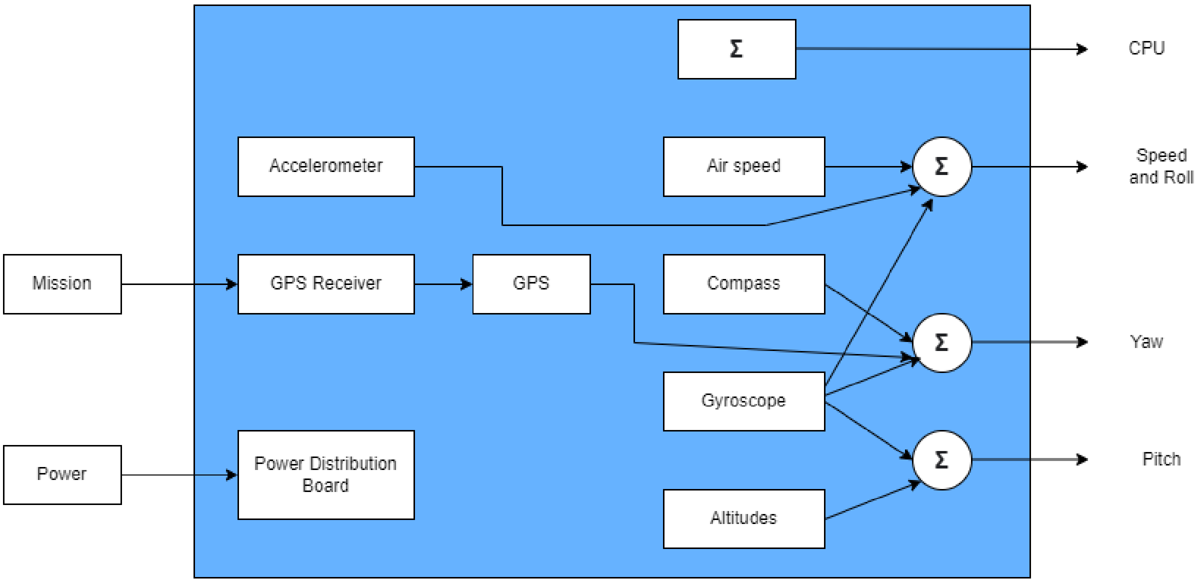

Figure 3. System Architecture for Auto Pilot Mode

3.2.3 Pixhawk Control System

Pixhawk is a powerful integrated hardware standard for open-source autopilot. It is to designed and programmed to accomplish a high level of stability. However, for most end users it’s not necessary to know the internal control architecture details that are ongoing inside Pixhawk, according to the author Anton Erasmus in his lecture stated that Pixhawk has two sets of control systems inside it. The first one is the Inner Controller followed by the Outer Controller. Figure 4 shows the cascaded control architecture of the Pixhawk flight controller.

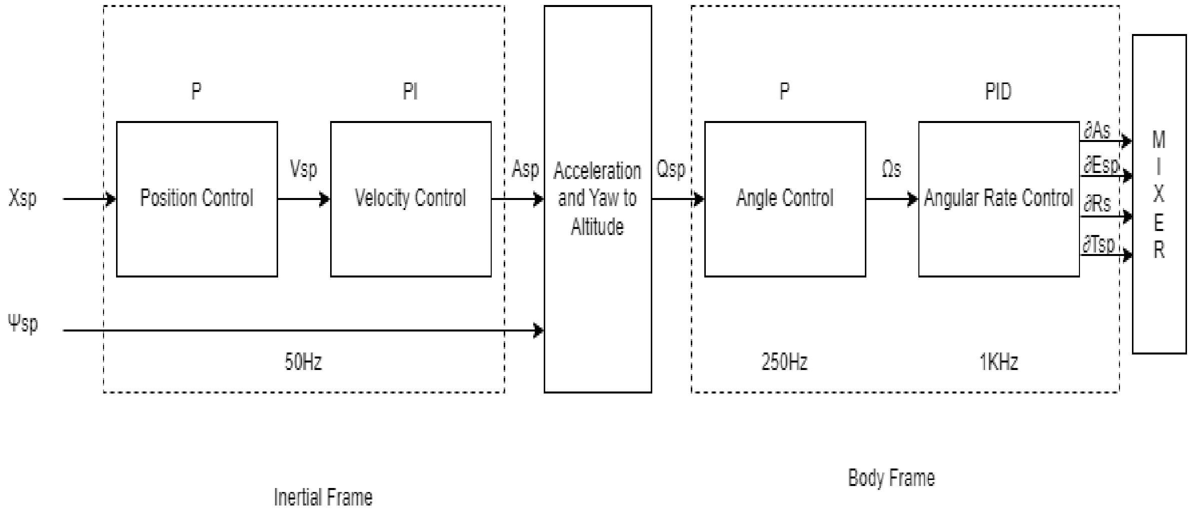

Figure 4. Pixhawk Cascade Control System Architecture

Here, Outer Controller receives a set point and generate command which serves as a set point for the inner controller. The inner controller then produces the actuator command. As shown in the figure 4 the innermost controller is an Angular Rate Controller that receives a set point from Angle Controller and produce actuator commands that control the vertical velocity along with the aileron, elevator, and rudder set points. These points are later transferred to the Mixer, which produces the thrust set point for each motor. The control mechanism used here is the Proportional, Integration, and Derivative (PID) control mechanism. In the cascaded control architecture, the angle controller receives the angular set point (Qsp) and command angular rate controller which is handled by the rate controller. Outside the angle controller here is a Velocity Controller that receives velocity set point and command Acceleration. This acceleration along with desired yaw angle is first converted to the attitude to send to the angle controller and a thrust to the mixture. The outermost part is the position controller that receives the position set point and commands a velocity. These all-control part works at a specific control rate and has a specific gain constant as shown in the figure above.

3.3 Design Calculations

3.3.1 Battery Capacity

The battery capacity C is directly linked to the total flight time of the UAV. The flight time of the vehicle is calculated using the expression below:

$$Flight\ time\ in\ minutes = \frac{battery\ Amp\ hour(Ah)}{System\ current\ required(A)} \times 60 \tag{1}$$

The calculated is the ideal time up to which the battery can supply the power to the drone. The battery mustn't get totally discharged. If the battery is completely discharged, the battery cannot be charged again. Hence, only 78% of the total battery capacity must be used. This reduces the practical flight time by 22%.

Hence, the effective battery capacity is calculated as:

$$Effective\ battery\ capacity(EAh) = \frac{3.3}{4.2} \times 100\% = 78.57\% \quad (2)$$

Thus, by replacing the battery Amp hour from equ (1) with effective battery Amp hour (EAh) our final relation reduces to as represented in equation (3).

$$Flight\ time\ in\ minutes = \frac{EAh}{System\ current\ required(A)} \times 60 \quad (3)$$

3.3.2. Thrust Analysis

To create enough thrust such that the drone can take a flight, it is necessary that the thrust generated by the propellers must be twice or more than the weight of the drone. Creating, deriving, finding or relaying on a high accurate two blades propeller thrust equation applicable to all two blade propellers application isn't easy. One may perform a bench test to analyze the thrust. However, there is an equation given by Gabrid Staples to calculate the thrust by two blades propellers (Written, 2014) (Scythian, 2017). Equation (5) shows the Gabrid Staples equation.

$$F = 0.00000004392399 \times RPM \times \frac{D^{3.5}}{\sqrt{P}} \times [0.000423333 \times RPM \times P - V_O] \quad (5)$$

Where,

F = Thrust in Newton's

RPM = Rotation per minute

D = Diameter of a propeller in inches

P = Pitch of a propeller in inches

V_o = Forward flight speed in m/s

S500 Pixhawk holybro kit has a BLDC motor with 980 KV rating along with a propellor rating as 1045 i.e., 10 inches in diameter and 4.5 inches as a pitch. Say a total weight of a drone is 2 kg, operating at 12V battery and acceleration due to gravity is 9.8 m/s^2.

Considering V_O = 0 m/s,

Thrust needed by a drone to operate = 2*(2*9.8) = 39.2 N

RPM of a single motor = 11760 rev/min.

Using, equation (5)

Thrust by a motor = 17.2506 N

Since there are four operating motors in a quadcopter (drone) so,

Total Thrust generated = 17.2506 *4 = 69.0024 N

Since total thrust generated is greater than the required needed thrust, therefore theoretically, drone is capable of lifting up at stationary.

3.3.3 Weight Analysis

Considering the system flies at maximum speed i.e., at 9 m/s. At this speed the thrust generated by a single motor will be,

Using Equation (5),

Thrust by a single motor at 9 m/s =10.320 N

Total Thrust generated =10.320 *4 = 41.2817 N

Minimum Thrust Required = 39.2 N

Extra thrust generated = 41.2817-39.2 = 2.0817 N

Mass of extra Payload can be lift up = $\frac{2.0817}{9.8}$ =0.21241 kg=212.21 g

This shows that with 12 V power supply, it is not suitable to add an extra payload.

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3.3.4 PID Controllers

3.3.4.1 Angular Rate Controller

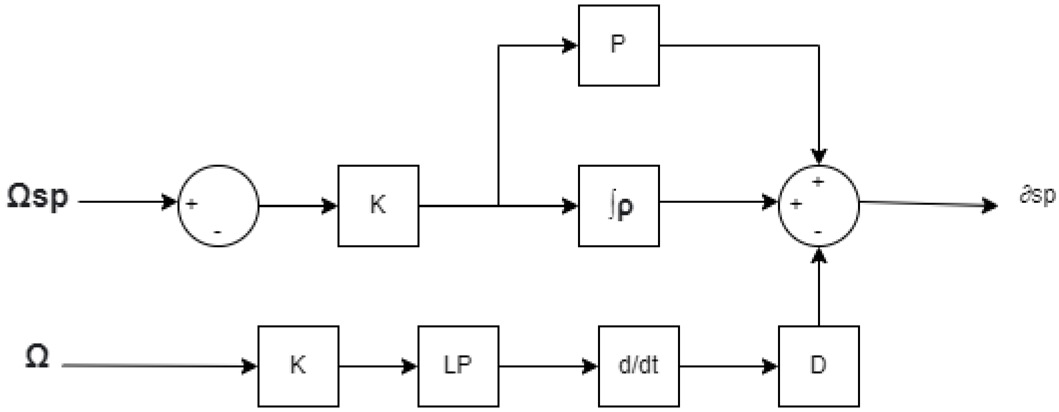

Figure 5. Angular rate controller

Figure 5 shows the architecture of the angular rate controller. In the figure it is shown that the angular rate controller receives the angular set point and subtracted it with the angular velocity measurement to produce an error. The error further propagates through series of PID command to produce a command. This command is first saturated and finally virtual actuator command are obtained i.e., allerion, elevator, and rudder. It has for gain control i.e., KPID. This is because there are two different implementations of PID control. First is the standard where P gain is set to 1 and K gain is known as the proportional constant while the second is the parallel form where K gain is set to 1 and P is known as the proportional constant. Here, the Integral form has a limit to avoid the integral windup and also to limit the control authority of the integration. Integral windup refers to the situation in the PID feedback control where a large change in set point occurs and the integral term accumulates a significant error during the rise (windup), thus overshooting and continuing to increase as this accumulated error is unwound. The derivative term is computed from measurement and not the error. This is to eliminate the phenomenon called derivative kick. Derivative kicks occur because the value of the error changes suddenly whenever the set point is adjusted. The derivative of a sudden jump in the error causes the derivative of the error to be instantaneously large and causes the controller output to saturate for one cycle at either an upper or lower bound.

3.3.4.2 Angle Controller

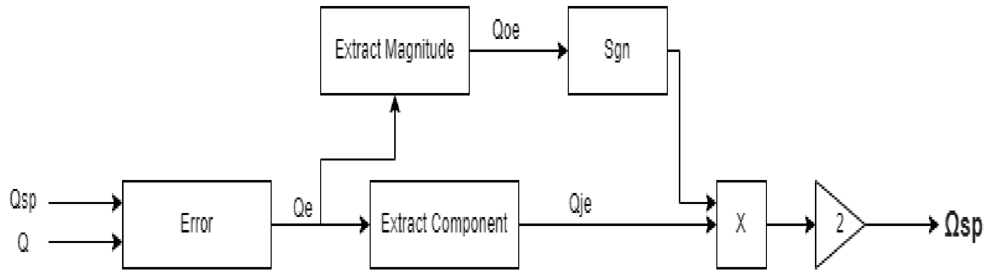

Figure 6. Angle Controller

Pixhawk uses a Quaternion attitude representation rather than Euler angle representation. An attitude representation is defined as a set of coordinates that describe the orientation of a given reference frame with respect to a second reference frame. This is done because of the singularity that exists at 90° pitch angle of the 3,2,1 euler representation which estimates the euler angle. Angle controller utilizes only proportional gain however it does have some non-linear parameter.

3.3.4.3 Acceleration and Yaw to Attitude

Here acceleration set point is converted to thrust in acceleration control function which later converted to attitude in getAttitudeSetpoint () function. Converted attitude set point is then transferred to the angle control.

3.3.4.5 Velocity Controller

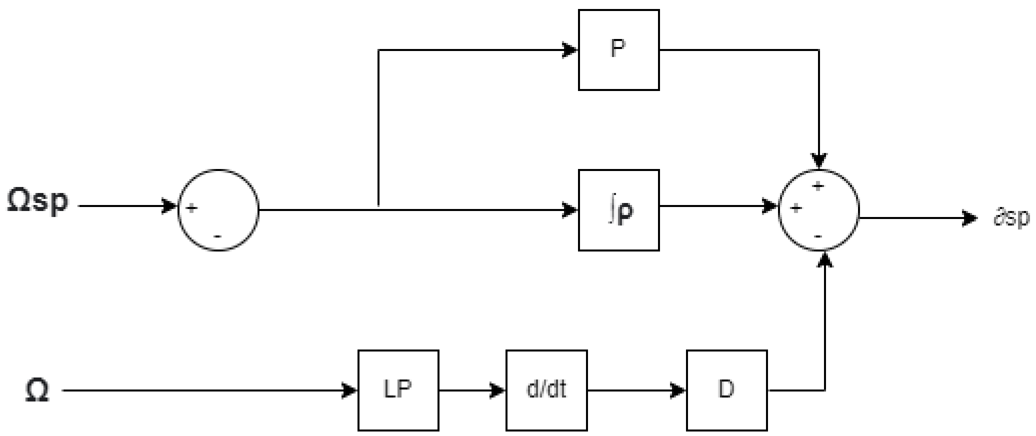

Figure 7. Velocity Controller

Figure 7 shows the control architecture of the velocity controller. It is the implementation of the simple PID control. It prioritizes the vertical velocity rather than the

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horizontal velocity as tracking anti-wind mechanism is more important for stability. Other control mechanism is similar to that of angular rate controller.

3.3.4.6 Position Controller

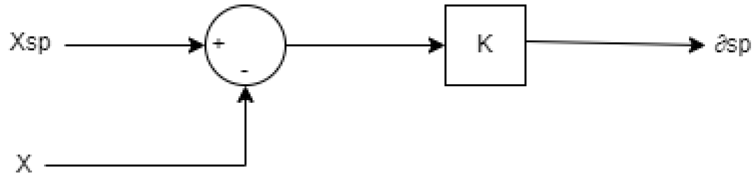

Figure 8. Position Controller

It is the simple proportional controller that limits the commanded velocity set point. Figure 8 shows the control architecture of the position controller.

3.3.5 Safety Factors

The UAV constructed has many safety measures implemented in it. The UAV tries to maintain its odometry but if it fails to do so or if the posture of the drone is impossible to maintain (i.e. crash is inevitable), the drone turns off the propellers rotation. Doing this, it is ensured that during the crash, no man or other being is harmed. Similarly, the drone stops the rotation of the propellers after it senses the ground. Likewise, many other safety measures have been taken in the UAV. Also, it is necessary for the surveyors they maintain a minimum of 6-meter distance when the drone takes off or lands. It is better to maintain more than this distance during landing. Also, the surveyor must not try to touch the drone when the battery is connected or the drone is on. It is always good to take out the propellers when the drone is not in use. The propellers can easily be applied to the motors when needed.

4. Requirement Analysis

4.1 Hardware Requirements

The list of hardware and devices that are required for the project are as listed below:

1. PixHawk 4 Flight Controller
2. Electronic Switch Controller
3. Brushless DC Motor (BLDC motor)
4. Remote Controller (Radio Link ATS9S Pro)
5. Lipo Battery

6. Propellers
7. S500 Frame
8. GPS Modem
9. Transmitter Receiver Pair
10. Camera (GoPro Hero 5 or above)
11. 3D Axis Gimbal

4.2 Software Requirements

The list of software used in the project are as listed below:

1. Mission Planner
2. Pix4D
3. Drone Deploy Cloud Software

5. Flow Chart

5.1 Flight Controller Loop

The flight controller loop is the series of sequential operations that are carried by the flight controller to make a stable flight as per planned. The process starts with gathering the IMU data. IMU stands for inertial mass unit and it is composed of three gyroscopes and three accelerometers which are mounted orthogonally on any airborne sensor designed for mapping. This measures the current acceleration and rotation of the UAV so as to determine the changes in position of the aircraft from the initial position. All of the data are fused together and then the calculations are performed in the flight controller or in the flight computer (if used). If the flight computer is not used, the flight controller takes over the process of calculation. This process includes the PID calculations, odometry determination, and position calculations with the determination of angles of yaw, pitch, roll, etc. Then, the control mixing process is conducted. This is the process by which an estimate is done taking all the calculated parameters into consideration. Then, the actuators produce an output based on the control mixed input that maintains the overall flight parameters of the UAV and the vehicle responds to the output accordingly. This process continues until the mapping/ survey is completed.

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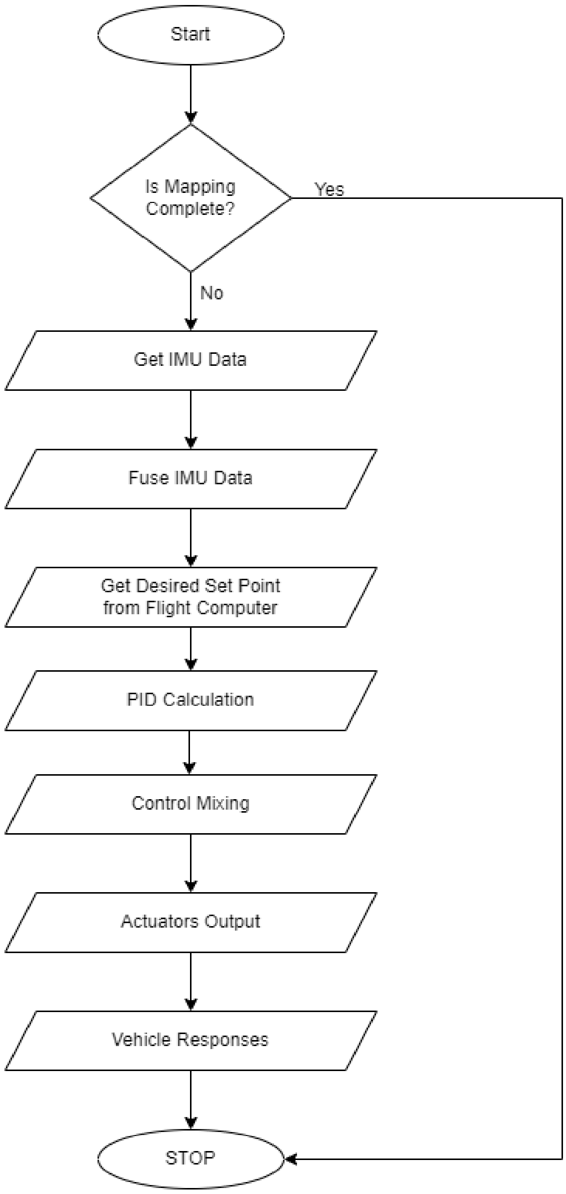

Figure 9. Flight Controller Loop

5.2 Pix4D Approach for 3D Map Generation

The generation of 3D map of any arena using images is a very complicated process including various operations as shown in below flowchart. First the original images are processed and the data contained in the images are extracted. The data in each pixel of the images are RGB value, intensity value, and the depth value. Then, the points are placed in a 3D space as directed by the extracted data. This forms the point cloud. Now, the next process is aerial triangulation. In this process, a series of three adjacent pixels are taken randomly and a triangular mesh is created. The area between the triangular mesh created is filled with the mean RGB and intensity value to create finer images. This gives rise to the ortho mosaic pattern and finally, a digital elevation model is applied to create layers of the points, and hence 3D map is generated.

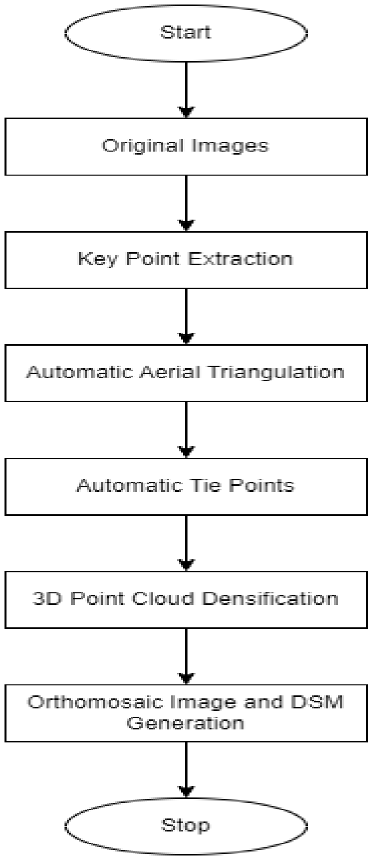

Figure 10. 3D Map Generation in Drone Deploy or Pix4D Software

6. Methodology

The system initiates after a power is given to the power distribution board of the drone’s frame. The overall methodology of the system can be divided into 3 different steps which are explained below.

6.1 Arena Design in Mission Planner (Survey Grid Formation)

Mission planner is an open software that is mostly used for ground station communication and control of small aircraft. The software is easily accessible. Also, the grid design in the software is easy. The firmware is available in the software for unicopters, bicopters, tricopters, quadcopters, hexacopters, and octocopters. The firmware is installed and the field or area that needs to be scanned is chosen. Then, survey grids are made in the selected arena. The altitudes, speed, and other parameters required for the drone flight are set. This area data is then fed to the quadcopter’s flight controller with all necessary supporting parameters. To feed this data, a transmitter-receiver pair is required. An example of the grid that is prepared in the mission planner software is as shown below.

Figure 11. Survey Grid Made in the Mission Planner Software

6.2 Image Capture

The UAV takes its flight and while it is flying in the survey grid as prescribed, the camera mounted on the UAV takes pictures at regular intervals. The images are captured such that at each pixel, three data are taken. These include intensity, depth, and RGB value. These pictures are taken such that the adjacent images have an overlapping of at least 60-80%. These images are stored in the memory card which is plugged out after the drone lands for further processing.

6.3 Image Processing/ Photogrammetry

The collected images are processed so as to obtain a 3D map of the area. The pictures as discussed before contain three pieces of information. These are the depth, intensity, and RGB values. These images are then given to the drone deploy software that processes the data and calculates the average of these parameters and assigns the average value to each pixel. Hence, it is necessary to have an overlap between the adjacent images so that more data will be present and hence the statistical calculation will be more accurate. The values assigned to the pixels when displayed are not quite recognizable and are seen as color dots on a black background. This is known as point cloud estimation. Then, the neighboring pixels are formulated and the 3D map of the area is generated.

Figure 12. Point Cloud Estimation of Data from the Images

7. Results and Discussion

The 3D map of the selected area is the expected result. Fig 13 shows the 3D map of the Advanced College of Engineering and Management situated in Nepal. The drone collected a total of 120 overlapped images that are processed together in the drone deploy cloud software. for the flight plan, mission planner software is chosen. These photos are processed and key points are evaluated. The key points calculated from the point cloud of the mapped area. Then the triangulation of the point cloud gives the contours and surfaces. The intensity, RGB values, and depth of the missing points or area between the point clouds are statistically calculated the average values are placed in the missing spaces. This results in the 3D output of the scanned area. Figure 14 also shows the end result i.e. the 3D map of an Engineering college situated at Kalanki, Nepal. The 2nd 3D map is constructed by using 98 pictures of the college taken making 80% overlap. The flight plan for the 2nd picture is done in the Pix4D software.

Figure 13. 3D Map of the Selected Area

Figure 14. 3D Map of an Engineering College

8. Conclusion

The proposed research work is completed successfully and a drone capable to scan an area autonomously is designed. Also, the pictures are processed in one of the two software Pix4D or Drone Deploy to obtain the 3D map of the scanned area. The UAV is designed using the holybro drone set with its main component Pixhawk flight controller version 4.0. Along with it, four brushless motors and 10-inch propellers are utilized in the project to give the necessary thrust for the UAV flight. The drone is designed in such a way that it can be manually controlled by the user using a Remote Controller or can be set to autopilot mode when required. For the UAV to function in autopilot mode, it is necessary that the arena data along with the grids and other pieces of information like the UAV’s speed, height, etc. are given. These data are fed to the flight controller and processed to carry out the flight and scanning process. The scanning process is implemented in the system using the GoPro hero 5. The selection of the camera is done such that it is able to not only capture the images with RGB value, but can also take the depth, latitude, and longitude data. This depth data is necessary while forming the 3D map. Also, the latitude and longitude data taken are beneficial to upload the images to satellite for satellite imagery or 3D earth views.

8.1 Future Scope

The research drone that has been constructed is capable of surveying, picture intake, automation, 3D mapping, pile measurement, etc. Besides these, the drone can be used for various other purposes like forest fire detection, in film industry, wild life conservation, forest fire detection, delivery systems, and thermal sensing. To utilize the drone for these purposes, few modifications need to be done. Also, no safety mechanisms have been taken for safe landing at some unfavorable conditions like high winds, battery run down, etc. So, some approaches like emergency parachutes can be applied in the drone for a safe landing. Also, the drone can be used for delivery purposes. Since, the drone is a quadrotor drone, the lift created by its four propellers is limited. Hence, to increase the lift, the frame of the drone can be changed to a hexacopter or octa-copter frame. This will increase the lift by a huge amount but consume more battery. Hence, research on the perfect balance between the number of propellers and battery consumption.

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