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Modeling of a high-speed and cost-effective FPV quadcopter for surveillance

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***Abstract*—Despite the admirable improvements in Unmanned Aerial Vehicle (UAV) technology, high-speed but cost-effective trajectories with six degrees of freedom motion remains challenging in terms of developing considerable models. This paper describes the design of a quadcopter with a mounted First-person View (FPV) mini-camera generating live video feed to the pilot alongside various parametric information on the display. We introduced a quadrotor helicopter based on the Mamba flight controller stack hardware bind with 32-bit Betaflight configurator software, a control system of which was simulated in MATLAB Simulink and validated by performance evaluation algorithms – offering a flexible and large control range. The developed drone is much more affordable and has the ability to fly with a maximum speed of 53.3ms^{-1}, weighing less than 1kg that can hover for more than 16.4 minutes. By integrating an action camera this aircraft also can be used for aerial photography besides drone racing or package delivery; however, intelligent surveillance would be the foremost suitable application.**

***Keywords*—unmanned aerial vehicle, first person view, integral performance, flight controller, quadcopter**

I. Introduction

The recent advances in aeronautics came up with the need for vehicles to fly in air medium. The term Unmanned Aerial Vehicle (UAV) also known as a drone, referrers to an aerial vehicle that flies without the presence of an onboard pilot [1]. There are various sorts of UAVs available nowadays, named after the number of rotors they use to fly with regard to their applications. The quadcopter is among the foremost famous of all that employs 4 rotors positioned equidistant from one another from the middle of the mass of the drone to get lift and control flight [2]. These quadrotor-based drones are a sort of a helicopter, which has more dynamic stability than a single rotorcraft and mostly utilized in the defense sector. The fashionable development of quadcopters connected with the First-person View (FPV) goggles also helps to capture and report every minute details because a camera integrated with it moves as per the given direction [3].

French engineer, Etienne Oehmichen designed and utilized the first quadcopter in 1924 [4]. Researches are persistently trying to develop compact drones to forestall the menace posed by large-sized aircraft in complex environments. UAVs are designed in such a fashion that it utilizes a closed-loop control to take care of an outlined trajectory, have automatic hovering capabilities, and rotates as guided [5]. The dimensions of a UAV can vary from the size of an insect to the immensity of an aerial vehicle counting on the sort of application [6]. Recently designed drones are usually deployed for surveillance in terms of border patrol, mining detection, and agricultural monitoring. The planning configuration of quadcopters is often in plus (+) or cross (×) formation, where the later can handle more payload [7].

In this research, we aimed toward developing an FPV quadrotor-based helicopter drone by considering the subsequent objectives,

- Design a high-speed remote-controlled aircraft.
- Deploy a robust model with the extended flight time.
- A cost-effective camera-associated surveillance system.

The forthcoming sections of this paper describe the literature review, system design, and drone architecture of our developed project.

II. Literature Review

The author Gordon Ononiwu (2016) [2] described a UAV mechanism for search and rescue applications employing Nirvaino multi-rotor control board, speed controllers, brushless motors, Mobius camera, Lithium cell battery, SkyZone FPV wireless receiver, and 4mm heat shrink tube. The frame was made from very light optical fiber to make sure stability while flying with an approximate weight of 1.5kg, flight altitude of 7ft, and control range of 1km. The estimated flight time of the quadcopter was 15minutes, thus faced limitations concerning the specifications of greater mass, less altitude, and little coverage.

Author Vibha Kishor (2017) [8] proposed an Arduino Uno based flight controller for economical, efficient, and smaller appliances, which was integrated with a camera and Global Positioning System (GPS) tracker. The designed helicopter had a lifting capacity of 3.5kg and was ready to supply a payload to an in-depth destination of quadcopter's frequency transmission range. This technology generated problems due to structural fragility and critical control.

Nathaniel Kingry (2018) [9] presented an experimental test set of a solar-powered quadcopter for enduring missions, that both flight dynamics and aerodynamics models were developed. The PID controllers for stability control under wind disturbances were verified through MATLAB/Simulink simulations. For a mean weight of 7kg with payload, the flight time ranged from 1hr to 2hr, which is why the difficulty was in terms of the speed of the drone.

Therefore, amidst all the challenges listed above, this research is intended to design, implement, and validate a quadcopter [10] for surveillance operations with a weight close to 1kg, maximum flight speed around 50ms^{-1}, hovering time greater than a quarter-hour, affordable cost less than 350US$, and video transmission coverage of 3-5km; that also need to have the structural strength, high altitude flight, smooth control with payload carrying capacity.

III. System Design

The working methodology of quadcopters is sort of simple but implementing the architecture considering proper

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functionality is challenging because of the freedom, control, and model difficulty that lies within the subsystems.

A. *Degrees of freedom*

In a 3 Dimensional (D) space, there are 6 Degrees of Freedom (DOF) for an aircraft to control flight; 3 translational directions (up/down, left/right, forward/backward), and three rotational directions (roll φ, pitch θ, yaw ψ), as illustrated in Fig. 1 [11]. Since a quadcopter is an under-actuated system with 4 actuators, by developing a system that couples rotations and thrust (z), the general goal for motions (roll, pitch, yaw, and throttle) are accomplished. To regulate the yaw of the craft properly, the spin direction of the two opposing motors of the same bar is needed to be set clockwise. On the other hand, the spin direction of the rest of the two opposing motors of the other bar is needed to be set counter-clockwise to balance out the torque. By increasing and decreasing the rotational speed of the respective motors, the flight path of the craft is controlled smoothly.

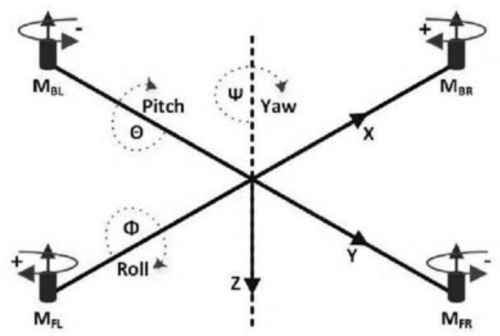

Fig. 1. Different motions of a quadcopter.

B. *Control system architecture*

The flight of the aircraft is controlled by employing a radio transmitter as the feedback system to the loop, operated by a human – usually referred to as a drone pilot. To supply autonomous functions to the quadcopter, Proportional Integral Derivative (PID) controllers are used for generalizing the position and altitude errors. If the craft took off slightly from the given coordinates due to wind gust or other environmental issues, the PID controllers would adjust the reference frame [12]. Here, the ascending, descending, and motions are designed for an X-configured frame structure to create a model with maximum payload lifting capability. Therefore, the motors (M) of the automated control software are modified independently (F/B=front/back, L/R=left/right) to provide flight commands, where equations for the motor mixing algorithm of a quadcopter are applied as follows,

$$M_{FR} = z + \varphi + \theta + \psi \quad (1)$$

$$M_{FL} = z - \varphi + \theta - \psi \quad (2)$$

$$M_{BR} = z + \varphi - \theta - \psi \quad (3)$$

$$M_{BL} = z - \varphi - \theta + \psi \quad (4)$$

C. *Flight code model*

After completing the theoretical analysis, the aircraft is simulated in MATLAB Simulink as depicted in Fig. 2. The parameters in terms of x, y, and z axes coordinates are defined for the specified direction of the quadcopter through path command to set points. Then the position controller compared the feedback – current position of the craft, with the given line points to correct the error by data computation within the body frame. The information is then mapped to the specified velocity and thrust to generalize the trail command. Likewise, the altitude controller took feedback from the system and site as inputs, containing the PID to make sure the parametric values of the reference frame by correcting altitude [13].

The control mixing block corrected its parameters along the 3D plane and provided command as needed by actuating the motors via control dynamics, which is then visualized [14].

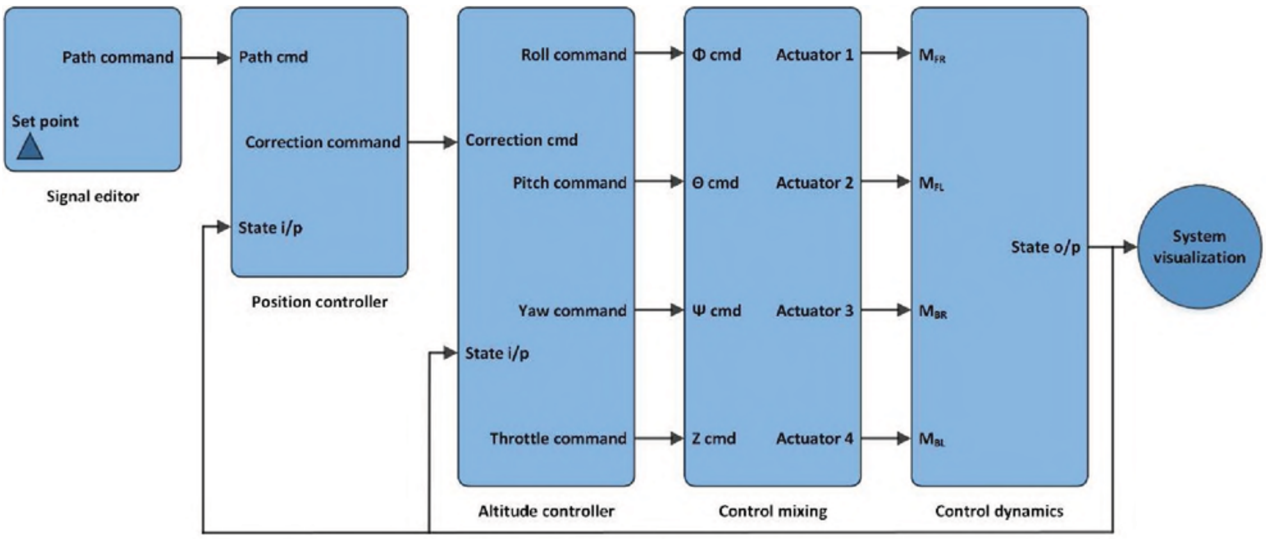

Fig. 2. Simulink model of a quadcopter.

IV. Drone Architecture

The 1st phase of the developed quadcopter was about effective component selection while the 2nd phase addressed the productive system implementation.

A. *Hardware design*

For completing the drone architecture, the components are listed in Table I.

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TABLE I. IDENTIFIED DRONE MATERIALS

Equipment (name)	Item (model)	Size (mm)	Weight (g)	Price ($)
Frame kit	HSKRC TWE210	210(s)×40.5(h)	114	15
Propeller pairs	Emax Avan Scimitar 5030	127(d)×13(h)	5.4×4=21.6	3
Mini camera	Foxeer Arrow Pro FPV HS1207	21.8(s)×30(h)	8.7	20
Video transmitter	Eachine Switchable FPV TX5258	31(l)×21(w)×5(h)	8.3	14
Flight controller	Mamba F405 Betaflight FC	38(l)×35(w)×7(h)	6	44
Speed controller	Mamba F40 HV ESC	45(l)×41(w)×6.5(h)	10	
Brushless motors	DYS Samguk Series Wei 2207	27.7(d)×32.2(h)	34.7×4=138.8	40
Rechargeable battery	ZOP Power Li-Po	135(l)×43(w)×28(h)	313	26
Portable radio	FrSky Transmitter Taranis X9 Lite	184(l)×170(w)×101(h)	505	98
FPV goggle	Hawkeye Little Pilot AR Monitor	128.5(l)×83.5(w)×14(h)	265	80
Other equipment	nuts, bolts, heat shrink tubes, zip ties, hot glue	different in size	379.6	10
Total	weight w/o #8 and #9	337(s)×68.5(h)	1000	350

[a] l: length of rectangle, w: width of rectangle, h: height of cuboid, d: diameter of circle, s: side of square

1) Frame kit

One of the primary equipment for the quadcopter that acts as the body – is the frame kit, carrying all the other components as integrated with it. The chosen frame is formed of carbon fiber material with a wheelbase structure, providing lightweight and stiffness to the model. Additionally, this frame is suitable for resisting vibrations and weather hazards as well as equipped with landing gears and camera holder.

2) Propeller pairs

By considering the 210mm frame size for adjustment, the propeller pairs of the quadcopter were adopted for maximizing the rotational performance while producing lift. These 2 pairs of propellers with 63.5mm radius (r) and 3 blades each - mounted on the respective motors are appropriate for the planning workload with 3-4 cell (S) pack batteries. The pitch (distance covered in one revolution) of a propeller is 76.2mm, calculated by the given formula, pitch=0.75×2πr×blade (height/width) ratio, where a higher pitch value indicates a better speed.

3) Mini camera

This Charge-coupled Device (CCD) mini camera was specified for its good 2dB wide Dynamic Range (DNR), connected to the FC, and attached to the front of the frame of the quadcopter to provide a visual experience to the pilot. With the opted 2.5mm (140° FOV) lens and 976(H)×494(V) PAL TV system, the camera can produce High Definition (HD) video for the system in terms of 600TVL (color) resolution. Whereas, the specifications for input voltage-current is 5-40V/0.166-0.075A and minimum illumination is 0.01 lux.

4) Video transmitter

For supporting the transmission of the mini camera to the FPV google of the quadcopter, the Video Transmitter (VTX) was preferred for its 4km omnidirectional range and 5.8GHz frequency with 72 channels and it was connected as well as attached to the FC. With a 3dBi antenna gain and PAL video format for the architecture, the VTX has an input and output voltage-current rating range of 7-24V/0.55-0.16A and 5V/0.3A, respectively. It also includes a sensible audio transmitter, button controller, Light Emitting Diode (LED) flash display, Reverse Polarity (RP)-SMA connector, and a right Circular Polarized (RHCP) antenna.

5) Controller stack

To reduce weight and complexity, a combined Flight Controller (FC) and Electronic Speed Controller (ESC) board were elected as the heart of the quadcopter – attached in the middle of the bottom plate of the frame using soft mountings. This 0.168GHz STM32-based F4 series Micro-controller Unit (MCU) with a 16MB non-volatile storage consists of a gyro stabilization technology; making the Inertial Measurement Units (IMU) or Micro-processor Unit (MPU) of 6 DOF to sense the present and desired positions of the structure. The high-performance FC includes a camera, audio, LED, and Received Signal Strength Indication (RSSI) control alongside an On-screen Display (OSD) and three Universal Asynchronous Receiver/Transmitter (UART) communication ports.

The connection between ESC and FC is predicated on a Digital (D) Shot protocol, where the ESC sends signals to each of the motors to regulate the flight path and therefore the operation is monitored by the Betaflight controller firmware. With an input voltage range of 12.6-25V for the controller stack, the ESC can provide a high (burst) current of 50A for about 10 seconds following a cool-down process. Henceforth, the Battery Eliminated Circuit (BEC) output of the FC is 5V/2.5A or 9V/2A as needed, whereas, the ESC is capable of supplying a continuous current of 40A (I) to all of the 4 motors.

6) Brushless motors

The 2600Kv of 4 brushless motors were accounted for the quadcopter after assessing the entire weight for a balanced thrust and proper control, which were connected to the ESC and attached to the respective arms of the frame. As recorded with various formations, the utmost voltage, current, power (P_{Max}), pull, and revolutions per minute (rpm) of each of the motors are 16V, 44A, 704W, 1140g, and 41,600rpm, respectively. With an estimated total weight (w) of 1000g – considering equal specifications of the motors, the subsequent calculations were made,

For a 4S battery with S=3.7V, the maximum rpm with no load for a motor is,

$$rpm = 4S \times Kv = (4 \times 3.7) \times 2600 = 38{,}480\ turns \quad (5)$$

For a standard 2:1 thrust/weight ratio by eliminating gravity (g) the required thrust,

$$T_R = \frac{2w}{4} \times g = \frac{2 \times 1000}{4} \times 9.8 = 4.9N \quad (6)$$

For r = propeller's radius, ρ = air density, and p = shaft's power = V×I; the static thrust,

$$T_S = \frac{2\pi r^2 \rho (0.75p)^2}{3} = \frac{2\pi \times 0.0635^2 \times 1.2 \times (0.75 \times 14.8 \times 40)^2}{3} = 20.7N \quad (7)$$

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From the above determination – considering a typical 75% efficient brushless motor, a 4S battery of 14.8V (V) supply, and a seamless 40A current flow; it can be inferred that the static thrust which will be created by a motor is around 4 times quite the specified thrust, referring a sure lift of the quadcopter.

7) Rechargeable battery

According to the specifications of all the components, a 4S Lithium-Polymer (Li-Po) rechargeable battery (adaptive with a Li-Po balance charger) with an output of 3.2A and 75C is the most fitted for the quadcopter to provide the required electricity, which was connected to the FC by an XT60 plug and attached on the top plate of the frame by a holder strap. The amperage rating of the battery must exceed all the motors' amperage rating combined (44×4=226A) to supply the specified continuous current for the configuration. So, using the capacity (c) and continuous discharge rate (d), the utmost amperage of the battery is often calculated as follows,

$$Amperage = c \times d = 3.2 \times 75 = 240A \tag{8}$$

As the maximum amperage surpasses the amperage of the motors, the rated Li-Po battery is proved to be compatible.

Else ways, the flight time can be estimated by determining the battery run time (t), for which the required motor power (P_{Req}) and current (I_{Req}) were measured as below,

$$P_{Req} = P_{Max} \times \frac{T_R}{T_S} = 704 \times \frac{4.9}{20.7} = 166.5W \tag{9}$$

$$I_{Req} = \frac{P_{Req}}{V} = \frac{166.5}{14.8} = 11.3A \tag{10}$$

$$t = \frac{c}{4I_{Req}} \times 60 = \frac{3.2}{4 \times 11.3} \times 60 = 4.3\ minutes \tag{11}$$

The nominal flight time of a quadcopter is typically more than triple because the motors would not operate at 100% continuously.

8) Portable radio

Here, the portable radio was sorted upon the R-XSR receiver compatibility with the FC of the quadcopter that operates at 2.4GHz and 24 channels (7.4V/0.19A), reducing interference and providing flexibility. This remote transmitter is adaptive with 2 replaceable 3.7V/2.6A button top Lithium-Ion (Li-Ion) batteries to control the network. The default Operating System (OS) Open TX firmware is highly customizable alongside the navigation menu for the simplest user experience.

9) FPV goggle

Finally, the FPV goggle was favored on the idea of the VTX specifications for the quadcopter with 5.8GHz and 48 channels, adaptive with a 7.4V/1.5A rechargeable Li-Po battery. The PAL color and an RHCP omnidirectional antenna were chosen for the monitor and RP-SMA connector of the framework, respectively. This foldable goggle is extremely comfortable and removes eye-straining issues completely – providing a view of the surroundings also.

10) Other equipment

Among the other equipment for the quadcopter; heat shrink tubes, zip ties, and hot glue were applied as needed to avoid damages due to weather, fragility, and vibrational issues. The wire connections were soldered carefully and all the additional wires were cut at length to scale back the load and complexity of the vehicle. All the required attachments of the respective components were done using nuts and bolts.

B. Software specifications

The Betaflight 4.2.0 (10.6.0) configurator (STM32 VCD) was selected as the brain of the quadcopter, which functions the FC by binding FrSky transmitters and directing DShot ESCs as well as allows to regulate the VTX and camera [15], that was set up through Microsoft Windows (64-bit) OS platform. Additionally, the OSD supports a drone pilot to put values through the video feed, change settings by stick command, and implements safety features to prevent dangers if misconfigured. These flight dynamics also provide fine-tuning option supported analysis, whereas all the configuration was uploaded to the FC in bootloader mode to flash it by a USB cable connection to COM3 port and saved backup file using command tab. Here, the motions of the sticks (roll, pitch, yaw) of the remote controller were adjusted by selecting endpoints (low 1000, center 1500, high 2000) and an arming switch was employed using an auxiliary channel (CH5) for starting the motors, which were also calibrated for throttle and spin direction. Some functions like arco trainer and air mode were turned on to stabilize flight, where 8kHz gain of the PID was chosen for a freestyle control after checking the fail-safe by arming the motors and switching off the radio to watch if the motors shut down within a second.

Fig. 3 represents the varied connections of the quadcopter; during which case the various operations of mini camera, portable radio, and FPV goggle can be updated and bind using their respective hardware-software combination.

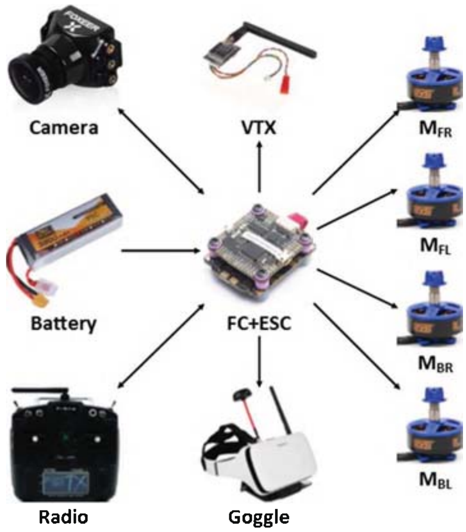

Fig. 3. Circuit diagram of the quadcopter.

C. Simulation result

Considering the above-mentioned component parameters, for a propeller area of $A=\pi r^2$, the average speed of the quadcopter is,

$$V = \sqrt{\frac{T_R}{\rho A}} = \sqrt{\frac{4.9}{1.2 \times \pi \times 0.0635^2}} = 17.9ms^{-1} \tag{12}$$

The simulation result for the approached methodology is in Table II.

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TABLE II. QUADCOPTER MATHEMATICAL MODEL

Parameters	Value
Total drone mass, M_D	1kg
Motor response time, T_M	0.003s
Motor distance from body center, D_M	0.105m
Motor-propeller moment of inertia, J_{MP}	6.9×10^{-6}kgm^2
Central principal inertia matrix, J_{XX}, J_{YY}, J_{ZZ}	1.7×10^{-6}, 1.7×10^{-6}, 2.9×10^{-6}kgm^2
Motor curve slope, $M_{S\omega}$=(steady speed-$M_{C\omega}$)/throttle	2359.6rads^{-1}
Motor curve constant, $M_{C\omega}$=steady speed-($M_{S\omega}\times$throttle)	457.8rads^{-1}
Propeller-thrust coefficient, C_{PT}=thrust/rotational speed^2	1.434×10^{-6}N/(rads^{-1})^2
Propeller-moment coefficient, C_{PM}=torque/rotational speed^2	1.121×10^{-8}Nm/(rads^{-1})^2
Aerodynamic-drag coefficient, C_{AD}=drag/linear velocity^2	1.433×10^{-2}N/(ms^{-1})^2
Aerodynamic-torque coefficient, C_{AT}=drag/angular velocity^2	1.963×10^{-3}Nm/(rads^{-1})^2

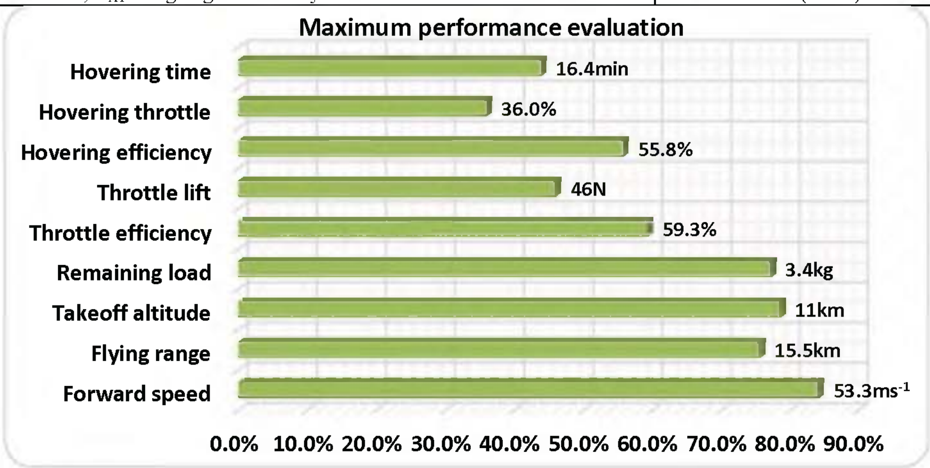

Fig. 4. Performance values of the quadcopter.

Fig. 4 demonstrates the essential information regarding our developed quadcopter[1], assessed by Flight Evaluation software, whereas Fig. 5 exhibits the rendered SOLIDWORKS CAD model. The algorithm evaluated the hovering, maximum throttle, and integral performances compared to standard dataset of multi-copters [16], where the ESC operated at 2.65A and 26.6A current while in hover and maximum throttle, respectively. Henceforth, the motor speed and power for hovering and maximum throttle conditions were 12,482rpm at 25W and 27,039rpm at 254W, accordingly. Moreover, the battery voltage and current within the situations of hovering and maximum throttle were 16V/11.1A and 15V/106.2A, correspondingly. For the maximum throttle and integral performance cases, the flight time varied from 1.7-11.2 minutes approximately in normal operation.

Fig. 5. Structural design of the quadcopter.

The quadcopter denoted the performance for a maximum tilt angle of 76.8° with 12° wind resistance.

The real fabrication of the designed air vehicle gave the readings in a range of 90-95% of the simulated result with that obtained from the real-time flying. These identified metrics of the quadcopter are dependent on the component's performance to overall weight ratio; and to increase the hovering time, a battery with higher capacity is needed to be installed in which case the total mass will be increased and the remaining load to be decreased – effecting the altitude, range, and speed to be slightly higher, and vice versa. In such a scenario, the hovering throttle and throttle lift will increase along with hovering and throttle efficiency. On the other hand, a UAV will have limited altitude and range for flight due to the radio and video transmission coverage as well as ascertained drone rules and regulations for any respective airspace, where the maximum designated altitude in Bangladesh is 200 feet. Lastly, employing brushless motors with higher rpm or propellers with better pitch value will enhance throttle, lift, and efficiency but that will require more power and eventually escalating the overall mass to a small degree. For intelligent surveillance in regards to capturing images and videos for gathering information about a specific individual, group, or environment; the provided bird's-eye view technology – having the capability to survey such subjects that might be physically inaccessible, is undoubtedly useful.

Additionally, the combination of computer vision, face recognition, and tracking technology can be utilized for the

[1] Findings related to this paper are available at: create.arduino.cc/projecthub/ErtezaTawsif/overwatch-a5e575

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quadcopter to become adaptive to perform autonomous tasks like object detection for further assistance.

V. Conclusion

In this paper, a durable and light-weight quadcopter design with longer flight time is presented, which is best suited for surveillance considering surreptitious investigation as well as agricultural monitoring. This UAV costs under 350US$ to develop, which weighs less than 1kg, providing the required functions to realize high-speed (maximum $53.3ms^{-1}$) with an FPV experience. The quadrotor-based helicopter gained a mean hovering time of 16.4 minutes after proper integration of the Mamba F405 flight controller stack and 32-bit Betaflight 10.6.0 configurator. All the hardware-software implementation of the aircraft was tested and calibrated through the performance evaluation matrix to avoid damages and attain the specified goals. The general temperature of the brushless DC motors of the vehicle while in motion showed to be under the endurable condition and offered smooth control to a drone pilot with a 4km video frequency coverage.

The following factors might be considered for further improvement of the quadcopter,

1. Employing fan ducts could change the dynamics by concentrating the downwards airflow.
2. Less weighted power sources like fuel cells would enhance both flight time and forward velocity.
3. An autonomous program accounting for a damaged rotor should yield better control, accuracy, and flight.

In summary, our compact and user-friendly model is compatible with multi-purpose applications starting from digital imaging to responsive actions.

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References

[1] A. L. Salih, M. Moghavvemi, H. A. F. Mohamed, and K. S. Gaeid, "Flight PID controller design for a UAV quadrotor," *Sci. Res. Essays*, vol. 5, no. 23, pp. 3660–3667, 2010, Accessed: Jun. 1, 2020. [Online]. Available: http://www.academicjournals.org/SRE.

[2] G. Ononiwu, A. Okoye, J. Onojo, and N. Onuekwusi, "Design and Implementation of a Real Time Wireless Quadcopter for Rescue Operations," *Am. J. Eng. Res.*, no. 59, pp. 2320–847, 2016, [Online]. Available: www.ajer.org.

[3] A. Saha, A. Kumar, and A. K. Sahu, "FPV drone with GPS used for surveillance in remote areas," *Proc. - 2017 3rd IEEE Int. Conf. Res. Comput. Intell. Commun. Networks, ICRCICN 2017*, vol. 2017-December, pp. 62–67, 2017, doi: 10.1109/ICRCICN.2017.8234482.

[4] R. D'Angelo, R. Levin, D. Cyganski, and R. J. Duckworth, "Design of an Autonomous Quadrotor UAV for Urban Search and Rescue A Major Qualifying Project Report," 2011.

[5] J.-B. Devaud, S. Najko, P. Le Nahédic, C. Maussire, E. Zante, and J. Marzat, "Full design of a low-cost quadrotor UAV by student team," 2012. Accessed: Jun. 1, 2020. [Online]. Available: https://hal.archives-ouvertes.fr/hal-00732845.

[6] G. Ostojić, S. Stankovski, B. Tejić, N. Dukić, and S. Tegeltija, "Design, control and application of quadcopter," *Int. J. Ind. Eng. Manag.*, vol. 6, no. 1, pp. 43–48, 2015.

[7] S. G. Pawar, K. Dongare, M. Dalvi, S. Doshi, and K. Das, "Automated Quadcopter Using Android Controlling System," *Int. J. Eng. Sci. Manag.*, vol. 5, no. 4, pp. 3–7, 2015.

[8] V. Kishor and M. S. Singh, "Design and Development of Arduino Uno based Quadcopter," *Int. J. Eng. Manuf. Sci.*, vol. 7, no. 1, pp. 14–19, 2017.

[9] N. Kingry *et al.*, "Design, Modeling and Control of a Solar-Powered Quadcopter," pp. 1251–1258, 2018.

[10] A. Christian *et al.*, "Initial Development of a Quadcopter Simulation Environment for Auralization," May 2016.

[11] "Drone Simulation and Control - Video Series - MATLAB & Simulink." https://www.mathworks.com/videos/series/drone-simulation-and-control.html (accessed Jun. 1, 2020).

[12] J. Delmerico, T. Cieslewski, H. Rebecq, M. Faessler, and D. Scaramuzza, "Are we ready for autonomous drone racing? the UZH-FPV drone racing dataset," *Proc. - IEEE Int. Conf. Robot. Autom.*, vol. 2019-May, pp. 6713–6719, 2019, doi: 10.1109/ICRA.2019.8793887.

[13] "Design, Build and Improve a Quadcopter : 34 Steps (with Pictures) - Instructables." https://www.instructables.com/id/Design-Build-and-Improve-a-Quadcopter/ (accessed Jun. 1, 2020).

[14] E. T. Efaz, A. Al Mamun, K. Salman, F. Kabir, S. N. Sakib, and I. Khan, "Design of an indicative featured and speed controlled obstacle avoiding robot," in *2019 International Conference on Sustainable Technologies for Industry 4.0, STI 2019*, Dec. 2019, doi: 10.1109/STI47673.2019.9068018.

[15] "Home · betaflight/betaflight Wiki." https://github.com/betaflight/betaflight/wiki (accessed Jun. 1, 2020).

[16] D. Shi, X. Dai, X. Zhang, and Q. Quan, "A practical performance evaluation method for electric multicopters," *IEEE/ASME Trans. Mechatronics*, vol. 22, no. 3, pp. 1337–1348, Jun. 2017, doi: 10.1109/TMECH.2017.2675913.

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