A Pragmatic Template for Quadcopter Development

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Abstract
This article presents a pragmatic quadcopter development template for parcel delivery in Nigeria. The quadcopter is equipped with a camera, parcel pouch and wireless telecommunication to capture live events and send them back to the control station for real-time delivery feedback. The study also discusses the design methodology adopted as a conceptual design approach vital to product development, it encompasses information gathering and identifying the problem, creating the solutions systematically and eventually evaluating and developing a concept for the drone and its attributes and presenting clear results for design calculations.

Keywords
Drone, Unmanned Aerial Vehicles, Quadcopter, Drone Development, Flight

1. Introduction
Drones are also regarded as unmanned aerial vehicles (UAV) these machines are self-propelled robots, and quadcopters are four-rotor UAVs with easy controllability and simple design [1] [2]. They possess a distinct ability to manoeuvre in congested zones, and vertical take-off and landing capabilities [1] [3]. Quadcopters are equipment with some mechanisms to grasp objects and deliver them to the required destination [4]. The capability makes the quadcopter suitable for various applications and tasks such as search and rescue, delivery and other industrial applications [5]. The interest in autonomous robotic platforms in recent decades offers several advantages such as reduced costs, and flight performance improvements [6]. There are essential features to autonomous systems; these include but are not limited to efficient energy sources, structural hardware, computing hardware, sensors and actuators, and autonomous software which are
generally divided into remotely piloted and autonomous vehicles [7]. This trend has led to less human supervision and more intelligence of the machines to effectively perform tasks and execute timely decision-making [7] [8] [9].

Quadcopters are part of the future drone industries with so much potential for applications, their popularity is also due to their relative cost, more torque, higher topographical advantage and more convenience [5] [10] for blades fixed on a frame with two blades having clockwise and the two having counter-clockwise rotor motions [1] [11], it is a lightweight and high thrust generating capacity motors, which increase its weight lifting capability. The copter is controlled by altering the speed of one or more rotors [2] [4], the upward and downward motion is achieved by increasing/decreasing the rotor’s speed, and forward/backward, left/right movement is achieved by different control strategies by the rotor speed.

The rapid design and development of UAVs of different sizes, shapes and capabilities with improved functionalities was due to the advancement of flight control and integrated circuit (IC) technologies [9] [12]. The use of UAVs was initially for military applications [13], recently, civilian applications are on the rise with use in search and rescue, agriculture, shipping and delivery of packages, image collection and mapping, monitoring of large infrastructures and giving feedback to ensure quality decision-making [6] [8] [14]. For example, quadcopters are used in agriculture to spray pesticides, monitor livestock on the farm to improve farm security, ship and deliver parcels to required destinations, monitoring of large projects such as oil and gas, pipelines, roads, bridges, power grids and many more [6] [15] [16] [17] [18].

The Design concept for the quadcopter was based on [1], with some modifications [19] [20], the quadcopter propellers are attached to the brushless DC motors which are mounted on the ends of the frame [21]. Because of its characteristics, there’s so much research on quadcopters to cater for several applications [22]. A study was conducted to design and fabricate a solar quadcopter, the design adopted the use of finite element analysis to understand the morphology of the structure of the frame upon the addition of load to the copter [3], while it highlighted the component of the copter. Some authors developed a lightweight quadcopter for transporting goods while recording flight time which increases as weight is increased [20] [23].

Despite the attributes mentioned about UAVs, implementation, testing and operating such machines has been challenging, achieving such requires effective coordination, control mechanisms, reliable communication systems, and intelligence to navigate through various terrains. As such this paper presents a pragmatic template for developing a quadcopter to perform one of the attributed tasks of UAVs for the shipping and delivery of parcels using a conceptual design approach.

2. Materials and Methods

The components used in the design consist of the frame, brushless DC motors, electronic speed controller, four propellers, video camera, sensors and flight
controllers (Table 1) [4] [22] [23].

Table 1. Material Selection Process.

<table>
<thead>
<tr>
<th>S/N</th>
<th>UAV Parts</th>
<th>Material Performance Requirement</th>
<th>Probable Material</th>
<th>Final Material Selection</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Frame</td>
<td>Ductility, tensile strength, toughness, cost effective, and lightweight</td>
<td>Aluminium, steel, titanium, thermoplastics</td>
<td>Thermoplastics</td>
<td>Corrosion resistance, toughness, affordability, good strength, and low density</td>
</tr>
<tr>
<td>2</td>
<td>Motors</td>
<td>Efficiency, reduction in heat generation, lightweight, and low noise</td>
<td>Magnets of iron, copper, cobalt alloys, aluminium</td>
<td>Alloy with aluminium</td>
<td>Absorbability of heat by aluminium, lightweight</td>
</tr>
<tr>
<td>4</td>
<td>Flight Controller</td>
<td>Stability, processability of commands, compatibility</td>
<td>Sensors such as gyroscope, accelerometer, barometric pressure (barometer), compasses (magnetometer)</td>
<td>Lithium polymer (Li-Po), Lithium ion (Li-ion), Lithium iron Phosphate (LiFePO4)</td>
<td>Lithium Polymer</td>
</tr>
<tr>
<td>5</td>
<td>Battery</td>
<td>Rechargeability, replaceability, low cost, availability, ability to store energy for long, lightweight, high discharge rate to power</td>
<td>Lithium polymer (Li-Po), Lithium ion (Li-ion), Lithium iron Phosphate (LiFePO4)</td>
<td>Lithium Polymer</td>
<td>High energy density</td>
</tr>
</tbody>
</table>

3. Kinematic Structure of the Quadcopter

The kinematics structure of the quadcopter refers to the air and motion that enters for movement of the quadcopter [24]. The rotors are mounted on the far ends of the frame of the quadcopter. The rotors are controlled by the motors that drive the propellers, the flight controller controls the speed and direction of the motors which are equipped with microcontrollers that receive input from ground sensors and commands from the control centre. The camera is mounted on the copter to provide smooth shorts, while the wireless communication allows the copter to send wider footage to the control centre on the ground which can be monitored and analyzed.

3.1. Conceptual Design

This methodology was adopted in the designing of the quadcopter, which is the identification of required problems through summary, establishing functional structures, selection of appropriate working principles and unifying these problems into a working structure. It answers the following question; has the prob-
lem been sufficiently clarified, is the conceptual design needed or has known solutions permit the embodiment design, to what extent should the conceptual design be developed? [25] [26] 

Figure 1 shows the steps in performing conceptual design.

3.2. Design Considerations

The design factors considered in this endeavour were based on simplicity, aesthetics, cost-effectiveness, parcel size and other engineering properties relevant to the development of a quadcopter [10] [19] [20] [25] which form part of the conceptual design process shown in Figure 1.

3.3. Design Calculations

Thrust calculations

The form normal to the propellers required to provide the motion to the quadcopter, the force is generated by the rotors which span at the certain angular velocity is given by the equation:

\[ T = \frac{\pi D^2 \rho \cdot v \cdot \Delta v}{4} \]  

Figure 1. Steps to conducting conceptual design [25].
where: $T =$ thrust (N), $D =$ Propeller diameter (m), $\rho =$ air density (kg/m$^3$), $v =$ velocity of air (m/s), $\Delta v =$ velocity of air accelerated by the propeller.

Total mass lifted by the quadcopter: the total mass ($M$) is given by the equation:

$$M = \frac{T}{\alpha}$$

where:

$M =$ total mass (kg), $T =$ thrust, $\alpha =$ acceleration due to gravity = 9.81 m/s$^2$.

Force Analysis: the forces applied on the rod are given as thrust, centrifugal forces and the movement created by the propeller [24]

$$F_c = mRw^2$$

where, $F_c =$ centrifugal force, $m =$ mass of the propeller (kg), $R =$ Radius of the Propeller (m), $w =$ angular speed = $\frac{2\pi N}{60}$.

Lift and Weight analysis: the focus is to reduce the weight by increasing the lifting capability of the flight system given by [1]:

$$W = \text{required RPM} \times \text{reference weight}$$

Propeller Length to Weight Ratio is given by [4]:

$$y = \text{required weight} \times \text{reference weight}$$

$$\text{Lift (kg)} = \frac{W \times D^4 \times N^2}{29.9 \times c_f}$$

where $c_f =$ lift coefficient.

Duration of Flight: Duration of flight is given by [1] as

$$\text{Duration} = \frac{\text{capacity of battery}}{\text{max. current drawn by motor}}$$

Power required is given by,

$$\text{Power} (W) = K_p \times d^4 \times P \times N^3$$

where, $K_p =$ propeller constant = 1.11, $P =$ pitch of the propeller.

4. Results and Discussions

4.1. Design Calculations

Table 2. Design specification and assumptions.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Item Names</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Source of Power</td>
<td>Battery (1800 MAh)</td>
</tr>
<tr>
<td>2</td>
<td>Type of motor used</td>
<td>Brushless DC (BLDC)</td>
</tr>
<tr>
<td>3</td>
<td>Mass of the Quadcopter</td>
<td>1.5 Kg</td>
</tr>
<tr>
<td>4</td>
<td>Battery Voltage</td>
<td>11.1 V</td>
</tr>
</tbody>
</table>
**Table 3.** Design calculations.

<table>
<thead>
<tr>
<th>Initial Data Calculations and Sketches</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of the quadcopter</td>
<td></td>
</tr>
<tr>
<td>$M = 1.5$ kg</td>
<td></td>
</tr>
<tr>
<td>$g = 9.81$ m/s</td>
<td></td>
</tr>
<tr>
<td>From Equation 3.1b</td>
<td></td>
</tr>
<tr>
<td>$W = mg = F_p$</td>
<td></td>
</tr>
<tr>
<td>$W = 1.5 \times 9.81 = F_p$</td>
<td></td>
</tr>
<tr>
<td>$W = 14.715$ N = $F_p$</td>
<td></td>
</tr>
<tr>
<td>Total weight of the quadcopter, $W = 14.715$ N</td>
<td></td>
</tr>
</tbody>
</table>

1. Thrust of the propeller

- Number of propellers = 4
- $M = 1.5$ kg
- Number of the motors = 4

| From the Equations 3.2. and. 3.3         |         |
| Thrust = $\frac{4}{1} \times m$         |         |
| Thrust = $\frac{4}{1} \times 1.5$       |         |
| Thrust = 6 N                             |         |
| Thrust per motor = $\frac{m}{4} \frac{1.5}{4} = 0.375$ N |         |

2. Torque required to drive the propeller

| From Equation 3.9                         |         |
| $T = F_p \times r$                       |         |
| $T = 14.715 \times 0.13$                 |         |
| $T = 1.91$ Nm                            |         |

2. Centrifugal force required for propellers

| From Equation 3.10                         |         |
| $F_c = \frac{Mv^2}{r}$                    |         |
| $v = \frac{2\pi N}{60} r$                  |         |
| $v = 2\pi \frac{11000}{60} \times 0.13$   |         |
| $v = 8984.95$                             |         |
| $v = 0.13$                                |         |
| $v = 149.7$ rev/sec                      |         |
| $F_c = \frac{Mv^2}{r}$                    |         |
| $F_c = \frac{1.5 \times 149.7}{0.13}$     |         |
| $F_c = 25.87481$ N                       |         |
| $F_c = 25.87481$ N                       |         |
3. Power required for the propellers

\[ \pi = 3.142 \]
\[ N = 11000 \text{ RPM} \]
\[ T = 0.868 \text{ Nm} \]

From the Equation 3.12

\[ P = \frac{2\pi TN}{60} \]
\[ P = \frac{2 \times 3.142 \times 868.12 \times 11000}{60} \]
\[ P = 100000 \text{ 2.45 W} \]
\[ P = 1000 \text{ KW} \]

Quadcopter flight time

Max motor Ampere = 4.62A

From Equation 3.13

\[ \frac{1800 \text{ MAh}}{1000} = 1.8 \text{ Amp} \]
\[ t = \frac{\text{Battery Ampere} \times 60}{\text{Motor Ampere}} \]
\[ t = \frac{1.8 \times 60}{4.62} \]
\[ t = 23 \text{ minutes} \]

Factor of Safety (F.S) for the Quadcopter

\[ F.S = 1.25 \]

From Equation 3.8

\[ \sigma = \frac{\sigma_u}{F.S} \]
\[ W = A \]
\[ A = \frac{\pi d^2}{4} = \frac{3.142 \times 0.5^2}{4} \]
\[ A = 0.7854 \text{ m}^2 \]
\[ W = 14.715 \text{ 0.196} \]
\[ \sigma = \frac{75.1 \text{ N/m}^2}{\sigma_u = \sigma \times F.S} \]
\[ \sigma_u = 75.1 \times 1.25 \]
\[ \sigma_u = 93 \text{ N/m}^2 \]

Twisting moment for the propeller

\[ d = 260 \text{ mm} = 0.26 \text{ m} \]
\[ r = 130 \text{ mm} = 0.13 \text{ m} \]
\[ T = 1.91 \text{ Nm} \]
\[ \pi = 3.142 \]
\[ \tau = 22 \text{ MN/m}^2 \]
\[ F.S = 1.25 \]

From Equation 3.16

\[ \tau = \frac{\tau_u}{F.S} \]
\[ \tau_u = \tau \times F.S \]
\[ \tau_u = 22 \times 10^6 \times 1.25 \]
\[ \tau_u = 27500000 \text{ N/m}^2 \]
\[ \tau_u = 27 \text{ MN/m}^2 \]

From equation 3.18b

\[ J = \frac{\pi d^4}{32} \]
3.142 \times 0.26^4 \quad 32
\frac{J}{32} = 0.0144
J = 4.5 \times 10^{-4} \text{ M}^4

From Equation 3.18
\frac{T_m}{J} = \frac{r}{r}
T_m = \frac{Jr}{r}
T_m = \frac{4.5 \times 10^{-4} \times 22 \times 10^4}{0.13}

T_m = \frac{9900}{0.13}
T_m = 76153.8 \text{ Nm}
T_m = 76 \text{ KNm}

Bending moment for the propeller

I = \frac{\pi d^4}{64}
\frac{y}{2} = \frac{d}{2}
d = 260 \text{ mm} = 0.26 \text{ m}
r = 130 \text{ mm} = 0.13 \text{ m}
y = \frac{0.26}{2}
y = 0.13 \text{ m}
I = 2.24 \times 10^{-4} \text{ m}^4
\sigma = 75.1 \text{ N/m}^2

From Equation 3.19b
I = \frac{\pi d^4}{64}
I = \frac{0.0144}{64}
I = 2.24 \times 10^{-4} \text{ m}^4

B_m = \frac{\sigma}{I}
B_m = \frac{\frac{I\sigma}{y}}{y}
B_m = \frac{2.24 \times 10^{-4} \times 75.1}{0.13}
B_m = 0.0168
B_m = 0.13 \text{ Nm}

Equivalent twisting moment for the propeller

T_m = 76153.8 \text{ Nm}
B_m = 0.13 \text{ Nm}

From Equation 3.20
T_e = \sqrt{T_m^2 + B_m^2}
T_e = \sqrt{76153.8^2 + 0.13^2}
T_e = 7599401254
T_e = 76153.8 \text{ Nm}
T_e = 76 \text{ KNm}

Equivalent bending moment for the propeller

\frac{\pi d^4}{64} = \frac{y}{2}
d = 260 \text{ mm} = 0.26 \text{ m}
r = 130 \text{ mm} = 0.13 \text{ m}
y = \frac{0.26}{2}
y = 0.13 \text{ m}
I = 2.24 \times 10^{-4} \text{ m}^4
\sigma = 75.1 \text{ N/m}^2

From Equation 3.19
I = \frac{\pi d^4}{64}
I = \frac{0.0144}{64}
I = 2.24 \times 10^{-4} \text{ m}^4

B_m = \frac{\sigma}{I}
B_m = \frac{\frac{I\sigma}{y}}{y}
B_m = \frac{2.24 \times 10^{-4} \times 75.1}{0.13}
B_m = 0.0168
B_m = 0.13 \text{ Nm}

\frac{\pi d^4}{64} = \frac{y}{2}
d = 260 \text{ mm} = 0.26 \text{ m}
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y = \frac{0.26}{2}
y = 0.13 \text{ m}
I = 2.24 \times 10^{-4} \text{ m}^4
\sigma = 75.1 \text{ N/m}^2

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I = \frac{\pi d^4}{64}
I = \frac{0.0144}{64}
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B_m = \frac{\sigma}{I}
B_m = \frac{\frac{I\sigma}{y}}{y}
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B_m = 0.13 \text{ Nm}

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From Equation 3.19
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I = 2.24 \times 10^{-4} \text{ m}^4

B_m = \frac{\sigma}{I}
B_m = \frac{\frac{I\sigma}{y}}{y}
B_m = \frac{2.24 \times 10^{-4} \times 75.1}{0.13}
B_m = 0.0168
B_m = 0.13 \text{ Nm}
Continued

\[ T_m = 76153.8 \text{ Nm} \]
\[ B_m = 0.13 \text{ Nm} \]
\[ T_e = \sqrt{T_m^2 + B_m^2} = 76153.8 \text{ N} \cdot \text{m} \]

From Equation 3.21
\[ M_e = \frac{1}{2} \left( B_m + \sqrt{T_m^2 + B_m^2} \right) \]
\[ M_e = \frac{1}{2} \left( 0.13 + 76153.8 \right) \]
\[ M_e = \frac{1}{2} \left( 76153.93 \right) \]
\[ M_e = 38077 \text{ Nm} \]
\[ M_e = 38 \text{ KNm} \]

Lift required for the Drone

\[ v = 2 \text{ to } 9.5 \text{ m/s} \text{ (speed of air from meteorological data)} \]
\[ \rho = 1.293 \text{kg/m}^3 \]

\[ q = \frac{1.293 \times 344^2}{2} = \frac{153008.4}{2} \]
\[ q = 76504.2 \text{ N/m}^2 \]

\[ A = L \times B \]
\[ A = 0.5 \times 0.5 \]
\[ A = 0.25 \text{ m}^2 \]

\[ C_L = \frac{F}{Aq} \]
\[ q = \frac{1}{2} \rho \times v^2 \]

At 0° angle of attack
\[ C_L = 0.4096 \]

\[ L = \frac{0.4096 \times 1.293 \times 344 \times 0.25}{2} \]
\[ L = 7834.03 \text{ N} \]
\[ L = 7.834 \text{ KN} \]

Lift required for the drone

\[ \rho = 1.293 \text{kg/m}^3 \]

Drag required for the Drone

\[ D = \frac{1}{2} \rho V^2 AC_D \]
\[ \rho = 1.293 \text{kg/m}^3 \]
\[ V = 2 \text{ to } 9.5 \text{ m/s} \text{ (from meteorological data)} \]
\[ A = L \times B \]
\[ A = 0.5 \times 0.5 \]
\[ A = 0.25 \text{ m}^2 \]
\[ C_D = 1.0 \text{ to } 1.5 \text{ (for squared quadcopter depending on angle of attack, Reynolds number and other aerodynamic characteristics)} \]

\[ D = \frac{1}{2} \times 1.293 \times 9.5^2 \times 0.25 \times 1.5 \]
\[ D = 43.76 \]
\[ L = 21.88 \text{ N} \]
Continued

Thrust generated by the rotors

\[ T = [(\eta W)^2 \times 2\pi R^2 \times \rho]^{1/3} \]

where \( \eta = 0.8 \) (is taken as the efficiency)

\( W = \) Propeller power = 260.94W

\( D = 10'' = 0.254m \)

\( R = 0.127m \)

\( \rho = 1.22kg/m^3 \) (density of air)

\[ T = [(0.8 \times 260.94)^2 \times 2\pi(0.127)^2 \times 1.22]^{1/3} \]

\[ T = 17.531N \]

\[ T = 17.531N \]

Power of the rotor

\( \text{Power required } W = K \times N^3 \times D^4 \times P \times \eta \times \text{where } K \) is propeller constant, it depends on the design of the propeller blade thickness, width, aerofoil profile etc.

\( K = 5.3 \times 10^{-15} \)

\( N = \) Speed of the rotor in rpm \( \eta = 0.8 \) (efficiency)

\( D = \) Propeller diameter in inch \( = 10'' \)

\( P = \) Pitch of the propeller \( = 4.5'' \)

\( W = 5.3 \times 10^{-15} \times 11100^3 \times 10^4 \times 4.5 \times 0.8 \)

\[ W = 260.94 \text{ watts} \]

\[ W = 260.94 \text{ watts} \]

Maximum current drawn at full throttle

\[ I = \frac{w}{v} \]

\[ I_{\text{max}} = \frac{260.94}{11.1} = 23.508 \text{ A} \]

\[ I_{\text{max}} = 23.508 \text{ A} \]

Velocity of air accelerated downward

\( V_d = \frac{(2 W \eta)}{T} \)

\[ V_d = \frac{(2 \times 260.94 \times 0.8)}{17.531} \]

\[ V_d = 23.82 \text{ m/s} \]

\[ V_d = 23.82 \text{ m/s} \]

Flight of speed or Aircraft speed

\( V_s = \frac{1}{2} \times V_d \)

\[ V_s = \frac{1}{2} \times 23.82 \]

\[ V_s = 11.91 \text{ m/s} \]

\[ V_s = 11.91 \text{ m/s} \]

4.2. Discussions

The developed quadcopter presented in this study was designed to cater for cost-effectiveness, simplicity and mechanical design (See Appendix 1) done using Solid Works and specifications with a brief description of the quadcopter components used in the development of drones for parcel delivery and other tasks shown in Table 2, while Table 3 displayed the mathematical equations used in the design and development of the quadcopter. The design was tested and proved to be effective and demonstrated stability and energy efficiency as per design calculations.

4.3. Recommendations

The following recommendations were proposed for further enhancement of the performance reliability and aesthetics.

The quadcopter should be equipped with weatherproofing to make it have multifunctional capabilities over varied weather conditions and also another design alternative should be considered to reduce the noise of the quadcopter.
Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References


https://doi.org/10.1109/mwc.2018.1800023

https://doi.org/10.1016/j.micpro.2018.05.002

https://doi.org/10.1016/j.compag.2022.107017

https://doi.org/10.1109/ines.2018.8523943


https://doi.org/10.1016/j.petrol.2021.109633


https://doi.org/10.1109/ic3a48958.2020.233296


https://doi.org/10.1016/j.procs.2021.01.003

https://doi.org/10.17756/nwjl.2023-s4-011

https://doi.org/10.1007/978-3-319-19839-2

https://doi.org/10.1016/s0010-4485(01)00157-9
Appendix 1: Design Drawings

[Diagram of a drone with labeled parts]

<table>
<thead>
<tr>
<th>PART NUMBER</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Motor</td>
</tr>
<tr>
<td>2</td>
<td>Servo</td>
</tr>
<tr>
<td>3</td>
<td>Flight Control Box</td>
</tr>
<tr>
<td>4</td>
<td>Battery</td>
</tr>
</tbody>
</table>

[Table of parts with quantities]

<table>
<thead>
<tr>
<th>Drawing Title</th>
<th>Designed by</th>
<th>Drawn by</th>
<th>Supervisor</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Diagram of drone components]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[Diagram of drone components with measurements]

[Diagram of drone assembly]