Design and Fabrication of Tilt-Hexacopter with Image Processing for Critical Applications

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Abstract—In recent times, the deployment of unmanned aerial vehicles (UAVs) for practical applications is an emerging one. In order to build an UAV for critical application, the designers should reduce the general drawbacks of UAVs. The fixed wing UAV needs a long runway and it is not sufficiently expert in vertical take-off and landing (VTOL), which makes it unapproachable for certain applications. Another perspective, the rotary wing aircraft will have the VTOL ability but the disadvantages are its slow operational speed, greater the consumption of energy. Here, the proposed Tilt-Hexacopter would be capable of VTOL feature and provide more stability with high maneuvering capability during the critical surveillance. The main purpose of this copter is to provide wealthy surveillance with image processing techniques and gives updated information to the ground controller by taking necessary action at any critical environment. The CAD diagram of Tilt-Hexacopter has been modeled in CATIA with calculated parameters. The image processing techniques for critical applications have been simulated using MATLAB.

Keywords—Crack; Image processing; Surveillance; Tilt Rotor.

I. INTRODUCTION

UAV is a very broad term because this can vary from any small size aircraft to big one which can able to fly without on-board pilot. Implementation of UAVs in the critical application is the one emerging areas in the aerospace engineering. Interest in UAVs for many critical applications including crack detection on the buildings, disaster monitoring, detection of wildfires and animals, border surveillance have been emerged recently especially UAVs provides momentous role to the military. In military reconnaissance, intelligence, surveillance, and target acquisition are the premier missions of UAVs, they also provide substantial support to the intelligence preparation of the battlefield, situation development, battle management, battle damage assessment, and rear area security, but there are criticalities in the design and development of UAVs because of the varied and non-intuitive nature of the configurations and missions which can be executed. Therefore the designer must provides an UAV, which have the high lifetime, high operational speed, more secure on-flight and low maintenance cost in order to survive at critical applications. One of such main issues is difficult to estimate an accurate data on/in the development of UAVs on existing situations but which can be efficiently managed by advanced technologies such as GPS waypoints, integrational approaches and machine vision, etc [1].

A. UAV Configurations

UAVs are advanced aircraft in technologies used, flexible for operations and cost effective which can perform a massive amount of inherently hazardous missions. In general, UAVs are divided into three groups based on its configurations which are fixed wing UAV, rotary wing UAV and multirotor UAV. In this paper, hexarotor has been selected as basic platform, which has been comes under multirotor UAV. A multirotor UAV is lifted and propelled by more than one rotor such as tricopter [three propellers], quadcopter [four propellers], pentacopter [five propellers], hexacopter [six propellers], octocopter [eight propellers], etc. Here, the design methodologies, the real time manufacturing criticalities and the generation of object detection/crack detection algorithms have been focused for advanced multirotor UAV (Tilt-Hexacopter) in order to employ for critical applications [2].
B. Basic Platform of Tilt-Hexacopter

Basic platform of this paper is hexarotor, which is the next step up from a quadcopter. It has six rotors, which are attached with individual arms all are connected symmetrically to the central hub. In which, more number of rotors are adds to the high stability of an aircraft this can suit more image processing applications by stable camera sensor platform. Probability of mission failures due to rotor working nature is low because of one motor can die while the rest pick up the slack [3]. Each rotor is driven by an individual electric motor, in which four rotors have fixed pitch blades and other two rotor blades are able to do tilt. The electronics used for communication and control are located on the main hub associate with battery. With the help of the rotors thrust, the maneuvering have been executed efficiently in the Tilt-Hexacopter. In which, differential thrust can be used to execute the maneuvering of the Tilt-Hexacopter because the source of the thrust is located outside the center of gravity. The rotation of rotors also produces a reaction torque opposite to the direction of the rotation. Since half of the propellers are spinning in one direction, the net torque is zero when all rotors have equal speed [4].

II. TILT-HEXACOPTER AND ITS SPECIFICATION

A. Structure of Tilt-Hexacopter

The proposed Tilt-Hexacopter consists of six motors, and it is an integrated maneuvering output of a fixed wing and a rotary wing aircraft. It has higher efficiency and can attain higher speeds than a normal multi-rotor UAV. The problem associated with rotary wing aircraft is that their efficiency and forward speed are on the lower side, which has to be removed. Hence, the solution to the existing problems is a hybrid aircraft, which has the advantages of both the fixed wing and the rotary wing aircraft and to a large extent should be successful in removing their individual disadvantages. As the name suggests, it houses the tilt rotor mechanism on two propellers. The purpose of the mechanism is to enable two modes of flying. The first one is the VTOL feature, in which all six rotors would be in the horizontal position. The second mode would be the Horizontal Take-Off and Landing (HTOL) operation in which the aircraft would execute the forward speed like conventional fixed wing aircraft with the help of two forward propellers tilt [5]. When in transition from one mode to the other mode, the rotors would “tilt” 90 degrees which facilitate the hybrid use of the proposed aircraft. Rotational directions of rotors are different in VTOL and HTOL actions, for VTOL all the rotors are kept horizontally, then for forward motion, in rearward of copter two rotors are tilting vertically and other four rotors are kept horizontally. For right side movement, tilting two rotors vertically and other one rotor is kept horizontally in left side of copter. For left side movement, tilting two rotors vertically and one rotor is kept horizontally in right side of copter. In this paper, quarter turn mechanism is used for propellers tilt, which has been achieved by DKJZ type quarter turn actuating mechanism [6].

B. Special Characteristics of Tilt-Hexacopter

The various special characteristics of Tilt-Hexacopter are high maneuverability, energy efficient, high operational speed, and greater speed control. The comparisons of parameters of multirotor UAVs are listed in table 1. In general, the design methodologies of UAVs are based on fixed speed and/or fixed speed approach. In this case, the designed forward speed range of Tilt-Hexacopter is 40–50 ms and designed weight of the Tilt-Hexacopter is 1–1.25 kg, which provides the right path to the mission completion.

<table>
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<tr>
<th>Comparison of Ground speed</th>
<th>Table 1. Parameter comparisons of multirotor UAVs</th>
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<td>15 m/s</td>
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C. Problem Summary on Tilt-Hexacopter from literatures

Major problems in the multirotor UAVs are low speed while in the forward motion, poor stability during maneuvering, unable to land in uneven parts and do not have proper landing methodologies. To overcome such issues, the Tilt-Hexacopter has been proposed and having the advantages of greater overall power, speed, and elevation compared to the quadcopter. Safety has been provided through additional motors and can carry more amount of payload. This Tilt-Hexacopter is best suitable for any critical environment operation such as border surveillance, forest surveillance, etc. A few of the drawbacks with Tilt-Hexacopter compared to a base multirotor UAVs such as cost and size, making the copter harder to fly in tight spaces, motor parts are more expensive if they need to be replaced [7]. Figure 1 provides the development process of Tilt-Hexacopter.

![Fig. 1. Development process for Tilt-Hexacopter](image-url)
III. THEORETICAL APPROACH

A. Components Selection – Basic Criteria

Selection of components for Tilt-Hexacopter is a difficult task, even though which can be completed here with the help of literature survey and theoretical calculations. In general, the components selection has been finalized in two ways: top-down approach and bottom-up approach. Top-down approach is achieved by fixing the weight and/or speed of the Tilt-Hexacopter, and choosing the component in that weight/speed range. Bottom-up approach is attained by without fixing the weight of the components of a Tilt-Hexacopter, the individual component will be finalized based on critical applications and thereby the weight could be estimated. Here, the selection components are based on top-down method, which means fixing the weight of Tilt-Hexacopter ranging between 1–1.5 kg. After the approach finalization, factor of safety plays a vital role which deals the input of component selection.

B. Basic Components

The Basic components selected for the Tilt-Hexacopter are sensors, battery, motor, propeller, frame, flight controller board. Figure 2 shows the overall block diagram of Tilt-Hexacopter, which comprises of all components derived from the standard theoretical approaches. Also figure 2 gives an idea about the location of components and its usages.

![Fig. 2. Block Diagram of Tilt-Hexacopter](image)

C. Justification for components selection

1) Motor selection

The maximum weight of this proposed Tilt-Hexacopter has been fixed as 1.5 kg and factor of safety as 2. Therefore the thrust required should be double the weight of the Tilt-Hexacopter, which is 3 kg thrust overall. The Tilt-Hexacopter has totally six motors, so each motor should contribute 500 g thrust based on thrust and weight combination. 2300KV high power motor has been perfectly matched with this paper requirement, thus it has been selected. The consolidated weight of the motors is determined as 201 g (6*33.5=201) [8].

2) Propeller selection

Basically the propeller selection is based on amount of thrust produced by the individual propeller, motors specification and twist of the propellers blade. The best suitable propeller for this work is 5x4.5” propeller, which can be able to produce the 500 g thrust. The overall weight of the propellers is calculated as 22.8 g (6*3.8=22.38). The important features of 5x4.5” propellers are a set of 8 bee rotor propellers, 2 blade style with a 5 mm canter hub [9].

3) Battery selection

Generally the selection of battery plays a vital role in UAV’s design and practical simulation. The purpose of the battery in this Tilt-Hexacopter is to provide the power for overall propulsive system i.e., motors which are attached by propellers. The selection of batteries is depending upon the motors capability, the amount of weight and the specification of propellers. For this work, the best suitable battery is 3 cell LiPo battery because of its specification completely satisfy the basic requirements of Tilt-Hexacopter. The weight of the battery is 143 g.

![Fig. 3. Current vs Thrust](image)

4) Electronic speed controller (ESC) selection

The main purpose of the ESC is used to control the speed of the motors. ESC is plays a major role in Tilt-Hexacopter while the copter undergoes the primary action such as forward motion, backward motion and thrust creation. Based on the operation of ESC the speed varies in the individual propellers, which can change the Tilt-Hexacopter position by the controller requirement [11]. The individual weight of the ESC is 7.6 g, here the number of ESC requirement is 6, and hence 45.6 g (6*7.6 [with wire] is the weight contribution to the overall Tilt-Hexacopter weight on the behalf of ESC.

5) Servo selection

The work of the servo is to actuate the motor based on the mission required action which is given to the transmitter. For this work, need two servos for tilt the propeller, in which Tilt-Hexacopter attain high forward speed with the help of 90 degree tilt, so the TS-9650BB servo is suitable to actuate the motor for both motion based on our control. The TS-9650BB is an analogue plastic geared ball raced servo suitable to cyclic control on 500 size helis. The consolidated weight of the servo is 50 g, which has been determined based on individual servo weight and its requirements [12].
6) Stabilization processor board
Stabilization processor board is the main part of the Tilt-Hexacopter. The connection between battery and motor are linked through it, through which the signals are transmitted from receiver to motor. The stabilization board includes several components such as gyro, accelerometer, signal transmitter, bluetooth device, display etc. There are six signals in the stabilization board. They are aileron signal, rudder signal, and elevator signal, throttle signal and last two signals for tilt mechanism. Aileron signal used to control rolling motion of copter, rudder signal used to control the yawing motion of copter, elevator signal used to control the pitching motion of copter. Throttle signal is used to control the speed of the copter while flying conditions. And the last two signal are used to control the tilt mechanism that means which are used to tilt the motor forward or backward in 90 degree [13].

7) Overall Weight Estimation
For overall weight estimation of a Tilt-Hexacopter, a complete literature survey of past fixed, rotary wings and hybrid aircraft have been used here to complete the weight estimation process. The parameters considered are speed (m/s), range (km), endurance (hr), gross weight (kg) and payload (kg), from that the overall weight of the Tilt-Hexacopter would be estimated. Apart from the primary weight contribution the remaining components weight also evaluated here i.e., Payload weight has been fixed as 500g for critical application, the Tilt-Hexacopter is madeup of aluminium stick so the weight of the structure 150g. Finally the overall weight has been added and calculated as 1.2 kg.

IV. DESIGN OF TILT-HEXACOPTER
Typical designs of Tilt-Hexacopter have been modelled by CATIA with the help of calculated dimensions. Figures 4 and 5 shows the preliminary CAD diagram of a Tilt-Hexacopter for different VTOL action in order to overcome short runway problems.

A. Tilt operation mode
Figure 6 and 7 shows the high operation speed mode of a Tilt-Hexacopter to provide more stability and survives in critical regions.

Figure 8 shows the typical views of Tilt-Hexacopter, it has capable of undergoes high stable and more operation speed with the help of 6 propellers (2 propellers for operational speed purpose and remaining 4 propellers for stability purpose).

V. RESULT AND DISCUSSION
A. Prototype of Tilt-Hexacopter
The prototype of Tilt-Hexacopter has been developed based on weight estimation and component selection. In this model, each motor is fixed in 60 degree from centre of gravity point with aluminum frame material for light weight and more strength. The components are selected based on theoretical estimation and mission requirement. Figure 9 shows the complete view of Tilt-Hexacopter with remote controller.
Figure 10 and 11 shows the top view of Tilt-Hexacopter for forward and backward motions with the help of tilt propellers.

![Prototype of Tilt-Hexacopter](image1)

Fig. 9. Prototype of Tilt-Hexacopter

![Top view of Hexacopter without tilt propeller](image2)

Fig. 10. Top view of Hexacopter without tilt propeller

![Top view of Tilt-Hexacopter](image3)

Fig. 11. Top view of Tilt-Hexacopter

B. Image processing for critical applications

The main purpose of this work is to create a Tilt-Hexacopter which can operate at any critical environment with the help of special specifications like tilt propellers, flexible landing system, etc. Here, the image processing techniques have been adopted; especially the algorithms for matching the images in order to know the status of critical environments. In order to do efficient work, there is survey of different object detection techniques and for object identification such as object matching, edge based matching, skeleton extraction etc are studied [14]. After survey the suitable methods are selected for object/crack detection. First one is intelligent video surveillance systems in which, there are basically six components such as acquisition, transmission, compression, processing, archiving, and display. Next one is moving object detection techniques in which, identifying moving objects from a video sequence is a general and critical task in many computer-vision applications. A common approach is to perform background subtraction, which identifies moving objects from the portion of a video frame that differs significantly from a background model, after this in image processing feature extraction is a special form of dimensionality reduction. And finally template matching is a technique in digital image processing for finding small parts of an image which match a template image. In this paper, two critical applications have been simulated: (1) Application based on surveillance and (2) Application based on crack detection [15].

1) Application based on surveillance

In this paper, image processing algorithm for surveillance has been derived for object detection, which has to be verified with help of internet images. Once the verification has been completed, which will be further implemented in real time application. The major surveillance applications considered here are, forest surveillance, border surveillance and cadastral survey. The flowchart of the object detection algorithm is illustrated in Figure 12.

![Flow chart of a detection algorithm](image4)

Fig. 12. Flow chart of a detection algorithm

a) Forest Surveillance

Here, standard vision features such as different animal color, natural images and animal shape have been used. The main work of this algorithm is to differentiate the animal edge from the natural image and takes the needful action when animal aerial images capture in the camera. Figures 13 and 14
have shown the reference image and aerial image of Indian tiger that has taken from internet in order to verify the surveillance algorithm, which will be suggested to implement in tiger-human interaction areas [16].

Fig. 13. Reference animal image

Fig. 14. Aerial image taken from UAV

Fig. 15. MATLAB result for animal image matching

The matching percentage of images is simulated in MATLAB, and the result comprises of the matching percentage of tiger images. The matching region in captured image compare with reference image is 92.2350, which gives assurance of tiger presence and instruct to initiate the warning system.

b) Border Surveillance

The military use of multi-rotor UAVs has grown because of their ability to operate in dangerous locations while keeping their human operators at a safe distance [17]. In this paper, standard vision features such as different intruder’s identification, enemies shape, and weapons identification have been used. The main work of this algorithm is to differentiate the intruder’s image from the own country people’s image and takes the needful action. Figures 16 and 17 are shows the reference image and aerial image which are taken from internet for verification and validation.

Fig. 16. Reference image

Fig. 17. Modified orientation of Reference image captured from UAV

The matching percentage of images is simulated in MATLAB, and the result file is the matching percentage of intruders’ detection. The matching region in captured image compare with reference image is 12.8085, which gives that absence of intruders’ in the given border.

c) Cadastral Monitoring

Another major application is cadastral monitoring, in which the boundary of land has been monitored effectively. Figure 18 and 19 shows the reference image and aerial image in order to check the boundary of the given land.

Fig. 18. Reference image for processing

Fig. 19. Reference image for processing
The matching percentage of images is simulated in MATLAB, and the result here is 100%. The result of this case instructed that there is no reduction of land boundaries in the given region.

2) Application based on crack detection

Nowadays smaller UAVs are more comfortable than larger UAVs for critical crack detection applications such as dam surface crack detection, wind turbine surface detection, structural health monitoring of an UAV and solar panel connection monitoring. In image-processing applications, the brightness of the image and template can vary due to lighting and exposure conditions [18]. A classification algorithm typically performs better using the statistics extracted using the features instead of using the original data. The crack detection algorithms developed for this paper followed the same overall step-by-step with exchangeable sub-components, which are shown in the figure 20.

In this paper, image processing has been simulated by MATLAB with the help of reference images and aerial images are taken from the internet. Image processing for crack detection is a critical operation, in which the clarity of the image and pattern able to fluctuate due to lighting and exposure conditions, the images can be first normalized [19]. Color, shape, clarification and crack detection are the fundamental attributes to symbolize and catalog the images. These abnormal features of images are extracted and implemented for a similarity check among images. Image indexing is not good in terms of space and time in traditional methods so it generated the improvement of the new technique [14].

a) Case – 1: Result for crack detection:

Case – 1 discuss the image processing results and their prediction capture of 2D surface with crack and reference 2D wind turbine image, which are taken from the internet for algorithm verification.

b) Case – 2: Result for crack accuracy:

Case – 2 is a extend level of case – 1. In practical, the image processing may provide high probability of failures results due to affect of lighting affect, gust load disturbance. Hence case – 2 provides the details about more advanced crack detection.

Fig. 20. Flow chart of a detection algorithm

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detection algorithm to solve real time crack detection with the implementation of advanced technologies.

Figure 24 is the image of the surface with crack; Figure 25 is the reference image of the surface. Figure 26 is the result image of crack detection for different surface image with and without crack input using the method grayscale in MATLAB for real time applications [19].

c) Case-3: Surface crack detection on UAV

While small UAVs undergoes the critical operation, they may affect by external sources so the designer must provide the high secure and safe flight for an UAV, which means the surface of the UAV must be monitoring in order to predict the crack on the UAV surface. This work suggests that the on-board crack images are efficiently recognized by vision based navigation system. Important component for vision based navigation is localization of perfect crack detection algorithms, sensing the crack by camera, and finally record and transfer the monitoring information. Real time videos will be captured in the surface behavior of the UAV with the help of rotating camera, which will be attached in the planned location on the UAV i.e., upper and surface of the UAV. From the videos, the frame will be formed by the video splits, which will be comparing it with reference. The collected videos from on-board camera will be collected in ground controller station and which will be image processed by Higher level image processing algorithm in MATLAB [20].

Fig. 24. Surface defect image

Fig. 25. Surface reference image

Fig. 26. Crack accuracy result
Case – 3 is a typical section of crack detection algorithm. The on-board crack and its initiations are planned to record frequently but the immediate actions such as urgent maintenance, immediate landing are need to take depending upon the percentage of crack occur on the UAV. In this health monitoring has designed for if the matching percentage is more than or equal to 50, the emergency information will be shared the details with ground controller. In this case, the input image (Fig 27) has been stored in the system (ground controller station) and the similar aerial images with crack are modeled in CATIA software for algorithm verification. Figure 29 shows the completed result of matching percentage with the help of MATLAB, in which it shows 13.9283% due to minor modification of co-axial propellers.

d) Case – 4: Result for video importing crack detection

Case – 4 is advanced section, which deals with vision based navigation technique. In this case, crack on the source object has been captured from camera, which is transmitted to the algorithm in order to detect the modification on the boundary of the UAV. All the inputs and the results are combinable shown in the figure 30.

![Fig. 30. Video importing crack detection](image)

VI. CONCLUSION

Major problems in the multirotor UAVs are stability, poor landing and limited speed are easily overcome by Tilt-Hexacopter with the help of its unique techniques. Selection of individual components of Tilt-Hexacopter is based on standard theoretical calculation and experimental verification, so this approach helps the designer to concentrate on the reduction of Tilt-Hexacopter fabrication cost. The reference model of this paper has been designed by CATIA. The targeted aim of this copeter is to monitor the critical application with the help of image processing, which is generated in the MATLAB. Theoretical object detection simulation has been simulated with the help of reference images, which are taken from internet as well as research papers. Tilt-Hexacopter has unique characters such as more comfortable flight, less vibration so it can able to reliable and capable to withstand any critical environment. With the help of six propellers Tilt-Hexacopter can able to track the moving object as well as cover the whole predefined region with an efficient manner. Hence the proposed Tilt-Hexacopter is a better solution for critical application such as animal poaching, animal – human interaction, border surveillance, cadastral survey, crack detection, etc.

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