SKILL FREE TELE-OPERATION OF TERRAIN HUGGING UAV USING AN ADVANCE TECHNIQUE OF SUPERVISORY COMMAND OPTIMIZATION

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ABSTRACT

In this paper we will discuss about power enhancement, the design, development, command modification and flight of helicopter at fix altitude of highly cost effective, semi-autonomous reconnaissance UAV, suitable for safe flights in close environments. The design and development is based on the modifications/up gradations, (predicated on the results of several small experiments), at a very low cost, small sized helicopter. The command modifications are achieved with the help of microcontroller and sensors. The developed UAV helicopter has successfully test-flown with in congested indoor and outdoor environment, with heavier payload for longer period as compared to similar helicopters developed at much higher cost.

KEYWORDS: *Helicopter, Pay load, Wrong command rejection, Generation of modified commands, Cost effective UAV use simple of DC motors, flight at fix altitude*

I. INTRODUCTION

This in the world of today, Unmanned Aerial Vehicles (UAVs) have become a necessary part of a country's strategic technology. It can serve as a platform for many applications and for pure academic research [1], [2]. "A huge market is currently emerging from the potential applications and services offered by unmanned aircrafts. If we consider civil applications, a wide range of scenarios appear. For instance remote environmental research, fire-fighting management, security e.g. surveillance, defence, border monitoring, agricultural applications, oceanography, communication relays for wide-band applications. In general, all of these applications can be divided into four large groups: environmental applications, emergency-security applications, communication applications, and monitoring applications" [3].

"Diverse methods such as approximated linearization [4], neural network [5], [6] and learning control [7], have been used to design flight control laws for the UAV helicopters to improve performances of automatic landing, hovering and automatic flights [8].

A typical UAV should consist of the following essential components:

1) A physical aircraft with engines or motors to perform some basic flight functions.

2) A simple avionic system to implement flight control systems. Such a system should include:

a) An airborne computer system to collect data, to execute flight control laws, to drive actuators and to communicate with a ground supporting system

b) Necessary sensors to measure signals and actuators used to drive the control surfaces

c) A communications system to provide wireless communication, which contains two duplex transceivers, one is airborne and the other is on the ground

d) An airborne power supply system

e) An automatic flight control system

3) A ground supporting system, which includes:

a) A full duplex transceiver to provide wireless communication with the aircraft [1].
b) A computer system to pre-schedule flight courses and collects in-flight data.

It is noted that the Military UAVs use specific control designs specially designed for the particular surveillance mission that they will implement [3]. However, a civil UAV should be able to put into practice for large variety of missions with little reconfiguration of time and overhead, if it is economically feasible [9].

II. DVELOPMENT OF THE DESIGN

First of all we used a double rotor coaxial helicopter (2KD design with horizontal Tail Rotor) in the project because it is inherently highly stable during flight at both low as well as high altitude, ability of hovering and provides a good basis for research. The design has Double Rotor Blade configuration that ensures small size and good thrust as shown in Fig. 1. More importantly, it is a very cheap design (see table IV), which makes it easier for us to upgrade the RC helicopter into an application specific high cost UAV helicopter system. It is ideal for serving as the basic aircraft in a UAV helicopter. The size of the helicopter is listed in Table I. Functions and capabilities of helicopter after modification as listed in table III.

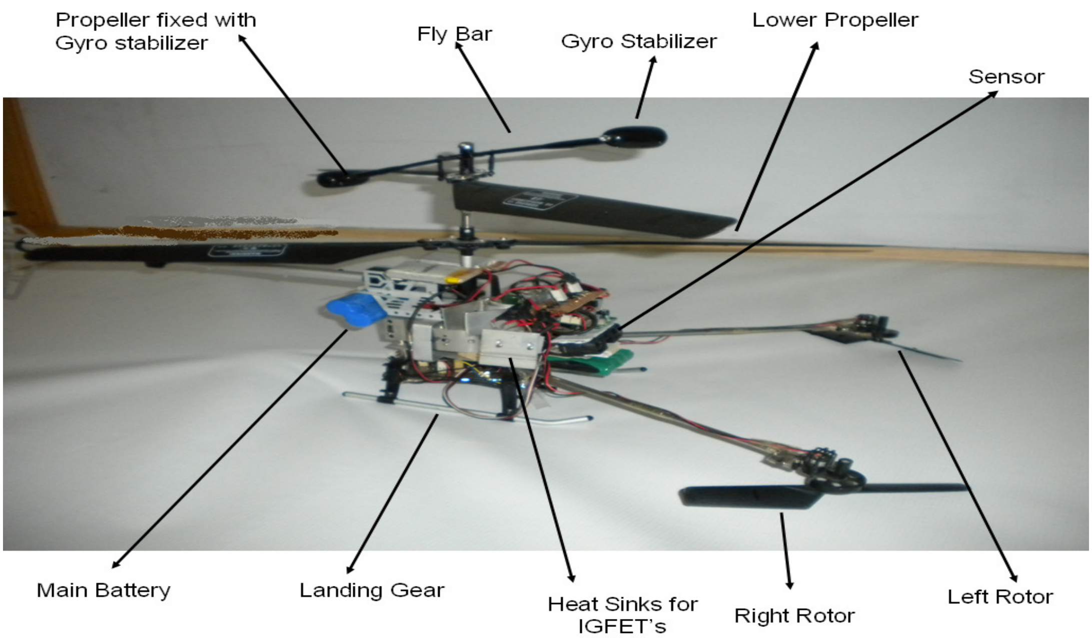

Fig. 1 Final Design

TABLE I: SIZE OF HELICOPTER

Full length	1980mm
Main Rotor Diameter	617mm
Total Height	556mm
Tail Rotor Diameter	210mm

2.1. Design Experimentation:

A number of experiments based on effects like weight shifting technique, quad copter design, forward looking propellers design, tail rotor positioning and tripod (Y-shape) design were designed and performed on the above described initial design, in order to find the best possible modifications for optimum results.

2.1.1. Tail Rotor Positioning:

In this experiment we tried to reduce the size of helicopter. We removed the tail rotor along with tail boom and test the flight, this was interesting experiment to fly helicopter without tail. It was working successfully but at that time there was no mechanism to move it in forward or backward direction so we design a separate quad copter and place this helicopter without tail so that, that quad copter help it to perform its manoeuvres.

2.1.2. Quad copter Design:

For this experiment we design an X shape structure of quad copter having four motors along with propellers at each end of quad copter and test its flight. We control these motors with the help of microcontroller. But unfortunately those motors were not providing much thrust to lift that weight. Then we place helicopter without tail on this structure and again test the flight but again result of this experiment was not fruitful for us so we move on the next experiment which was weight shifting technique. A hardware arrangement is shown in fig 2 below.

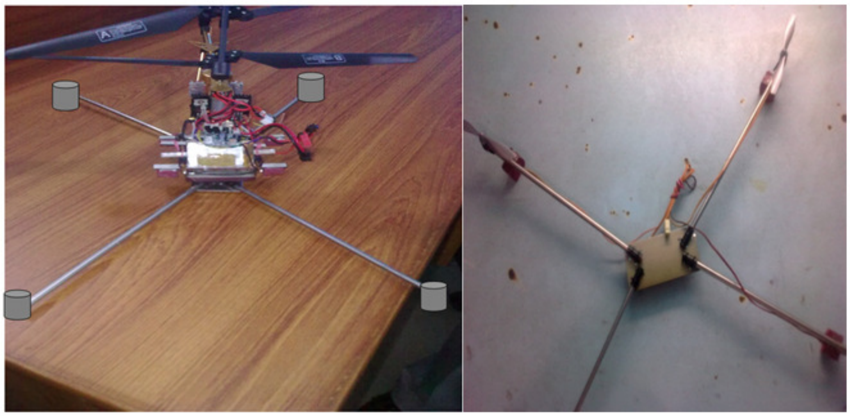

Fig. 2 Quad Copter Design

2.1.3. Weight shifting technique:

In this experiment, we removed the quad copter from helicopter, now again helicopter was only able to move in upward or downward direction. We then designed a special battery compartment to replace the Li-poli battery in it. Basic idea behind this technique was that when we shift the weight away from centre position, helicopter should drift in that direction. So we control the movement of weight (battery) with the help of servo motor and observe the drift as shown in figure below. This technique was giving us drift but the response was not fast enough to change the direction or to provide drift in any other direction, that is why we had to find any other solution and we had to change our design, another problem was that all time helicopter had to carry weight and its motors will operate at maximum speed.

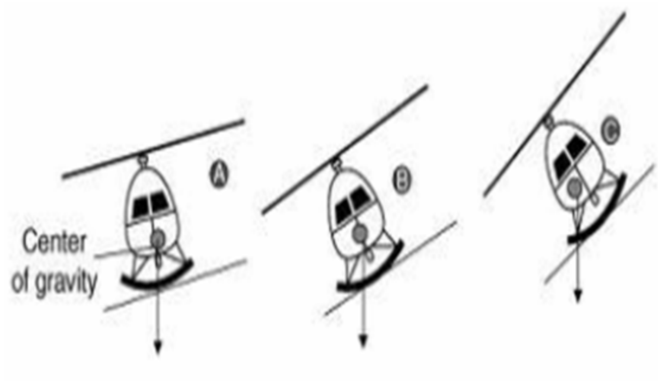

Fig. 3 Effect of shift of weight from centre position

2.1.4. Forward looking Propellers

This time we adopted another technique and were looking forward to see some result oriented experiment. We completed the helicopter by adjusting its tail back, tested its flight and started a new experiment.

This time we placed two propellers on helicopter side by side and the direction of both propellers was forward looking and the position was exactly under the main propellers as shown in fig 4. We did not extend them away from centre because this produces unbalancing and also increase size of helicopter along x-axis. So we kept them close to the centre point. We tested this design i.e. the purpose of these propellers was to perform command modification which was our main task. Result of this experiment was not as fruitful as much we were expecting because these propellers were exactly under the influence of main propellers and their thrust was almost negligible as compare to original propellers. So again we had to change our design.

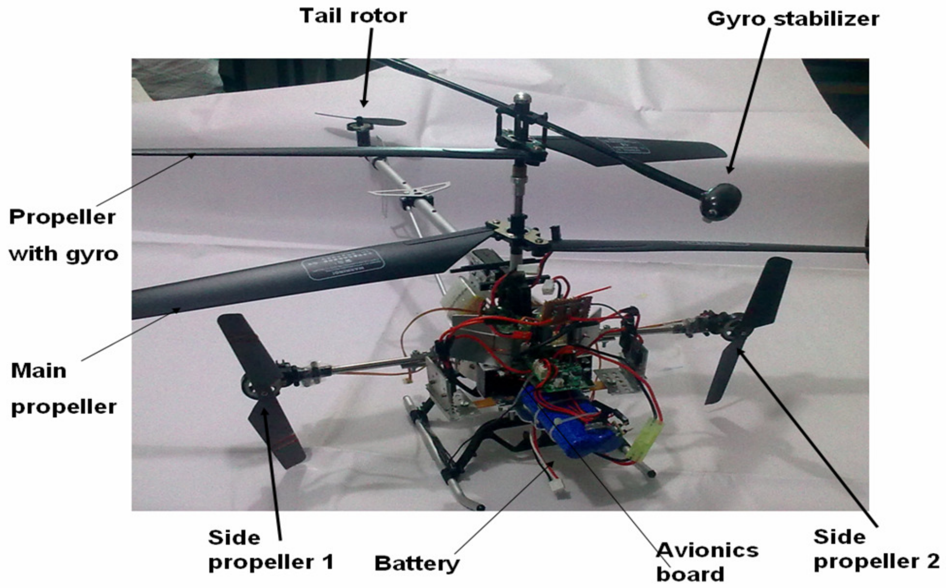

Fig. 4 Forward looking Propellers Design

2.1.5. Y-shape tripod Design:

In this experiment we arranged two extra propellers along with tail in Y-shape; these three motors now work with the help of microcontroller and were completely automatic and added a decision making power in helicopter in the sense of rejecting wrong commands and generation of new modified commands with the help of microcontroller. This was our final design and the complete detail is explained in next section i.e. design modification.

2.2. Design Modifications:

Based on the findings of the above experiments we decided to introduce the following modifications in the toy helicopter to achieve the desired functionalities.

2.2.1. Modified Assembly:

Following are the components and systems we added in our design. A carbon fibre rod and specially designed small mechanical parts to incorporate several modules on the helicopter's body, Special heat sinks for motors of the main rotors, IR Range Finder that serve as the basic sensing units, simple small DC motors to reject wrong commands and generation of new commands, An ATMEL based embedded board that serves as the main controlling unit, Payload capability enhancing module, height fixing module to fly it at fix altitude.

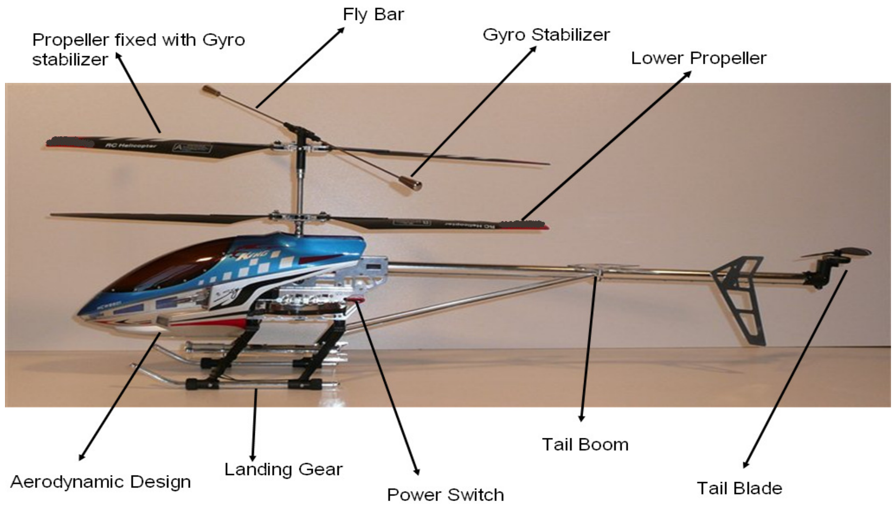

Fig. 5 Initial Design

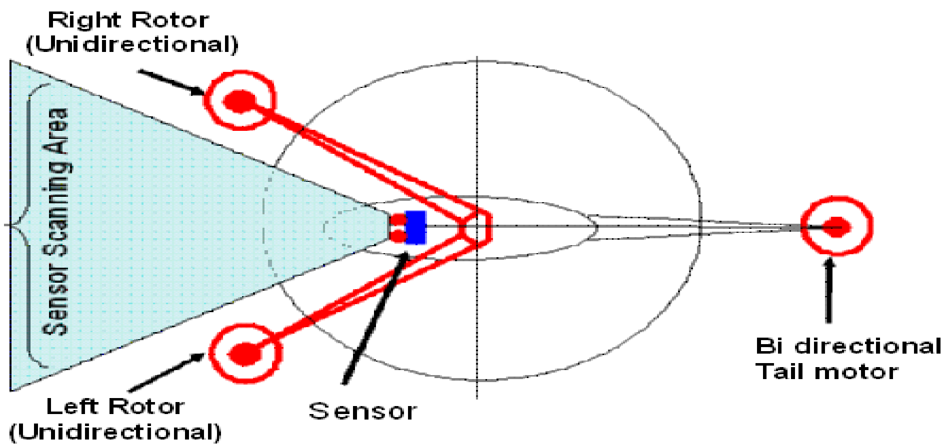

Fig. 6 Proposed Design

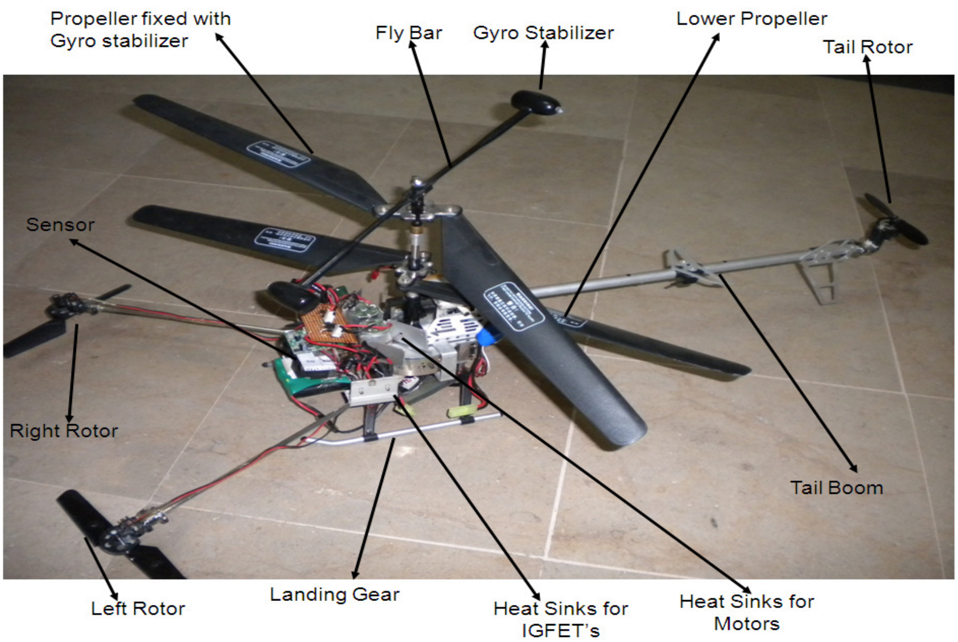

Fig. 7 Final Design

One major problem we encountered during experiments was that the motors started to get heated up after sometime during the flight. We incorporated our specially designed heat sinks inside the body to overcome this problem. We identified the empty spaces inside the helicopter's body near the main motors and placed the heat sinks there, so that they get connected with the body and whole body becomes a heat sink i.e. effectively increasing the heat dissipation.
The desired final result was to ensure safe flights and crash avoidance. To achieve this purpose we decided to use IR range finder sensor communicating with microcontroller and small DC motors. The challenge was to place them on the helicopter's body so that they monitor a good effective area around the helicopter. For this purpose a Carbon Fibre rod of Y-shape was design and place exactly under the centre of main propellers so that we will not face any balancing issue. A sensor was placed at fount on servo, the task of the servo was to keep on rotating and sensor will keep on scanning its front area. Initial and final designs are shown in figures below.
Then we designed our embedded board for computational purpose using AT89C2051 microcontroller. Sensor was attached with this microcontroller to translate external environment with the helicopter and then three motors were also connected with the same microcontroller for rejection and generation of new modified commands.
After incorporating all the changes; the final design gave a very stable flight and because small DC motors were placed out of the wing span of the main rotors, a very small time operation of these motors provided a sufficient thrust to stop the helicopter to move forward towards obstacle. The weight of all the extra parts was properly propagated throughout the system to ensure proper manoeuvring during flight.

III. ELECTRONIC MODIFICATIONS

Power Enhancement to increase Payload Carrying Capability:
One of our main objectives was to increase the payload carrying capability of our design. Because initially it was not able to lift any kind of weight .In order to lift weight of extra propellers and motors we had to increase payload capacity to carry our embedded computational boards, motors and sensor. To achieve this functionality a 'payload carrying capability enhancing' module was specially designed that incorporated power MOSFETs (IGFET's). Circuit diagram is shown in fig 10. To avoid overheating of these MOSFETs we decided to attach them on heat sink and place then on helicopter in such a way that they have no contact with body because body of helicopter is conducting.
This was one of our main achievements. Normally these small helicopters are designed to carry only their own weight. To make the helicopter capable of carrying the extra load of added modules; we increased the operating battery voltages from 7.4V to 11.1V, 1.8A. These motors had a maximum rating of 15V and we were operating in a safe range. To achieve this task we had to go through a series of experiments with various Power MOSFETs incorporated in place of original FETs i.e. D150 used in the original helicopter.

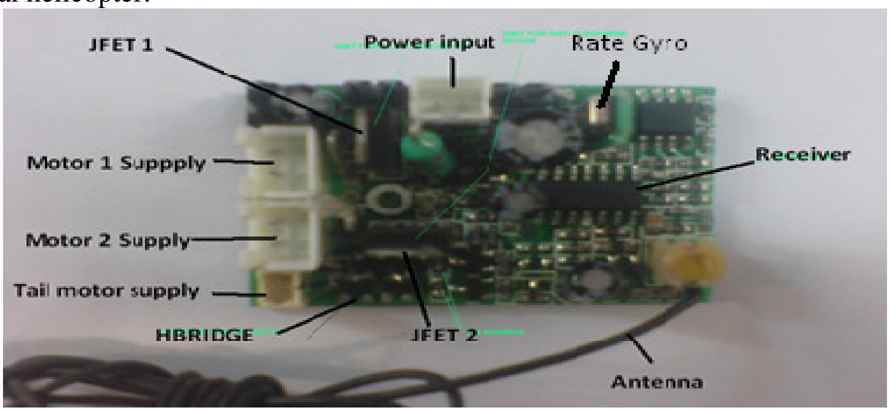

Fig. 8 Receiver Circuit

The problem we encountered in achieving this feature was that there was not enough voltage for the gate drive available at the receiver circuit's original FETs. To overcome that problem we conducted a complete study of the receiver circuit, did reverse engineering on it and extracted signals at different points as shown in Fig 8. There are two power ports for the two motors of the main rotors being powered through the JFETs as numbered. Then there was a small port for the tail rotor we replaced their main motors supply with our new power enhancing module and used tail connection in command modification module.

To overcome the problem of handling extra current from the higher voltage battery, we needed a high current handling Power MOSFET to replace the original FETs i.e. D150. A Power MOSFET IRL3705 (2 MOSFET parallel with each other for each main motor) appeared as the best choice to handle extra current at increased battery voltage and had sufficient switching speed to handle the incoming signal. Motors power arrangement before power enhancing and after power enhancing is shown in fig 9 and 10 respectively.

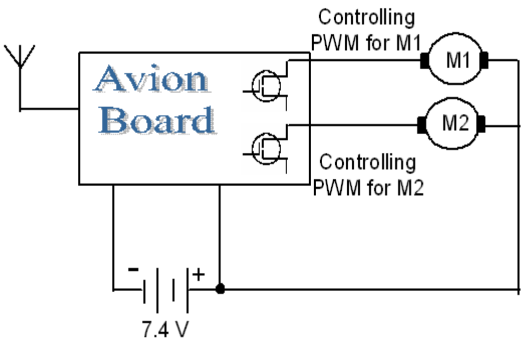

Fig. 9 Initially motors operate at 7.4V

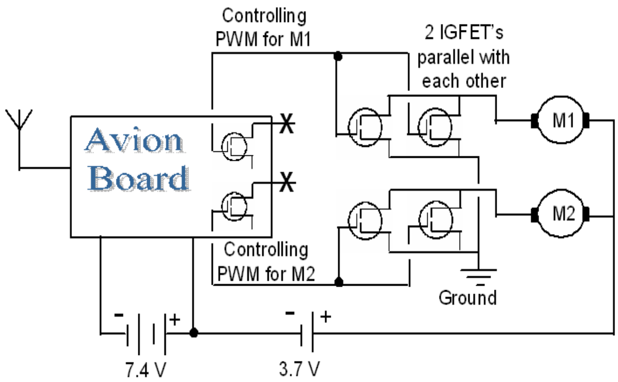

Fig. 10 After power enhancement motors operating at 11.1V

IV. Computational Boards

4.1. The Sensing System

The sensing system comprised of Sharp GP2Y0A710YK0F Package IR RANGERS. This sensor takes a continuous distance reading and returns a corresponding analogue voltage with a range of 100cm (40") to 550cm (~216"). The output of these sensors is non-linear and to use it properly we linearized it by using a straight line approximation of the voltage from 0.8m-5.5m as shown in Fig.11. We took voltage readings for every 1" distance variation from the sensor in the specified range. In this way we were able to better visualize the voltage variations in accordance with the range and it was easier to take decisions based on range.

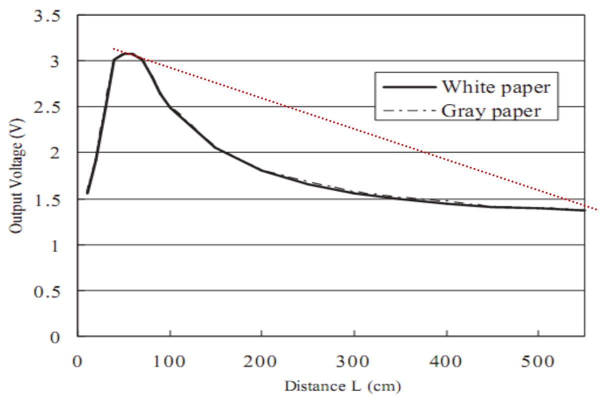

Fig. 11 IR Range Finder's original and linearized voltage curve

4.1.2. Embedded System for Wrong Command Rejection

The core component of a UAV model was a central control system. A special AT89C2051 based generic board was designed and fabricated to serve as the main control unit for the system i.e. for the installation of sensors to monitor the surrounding, then rejection of wrong commands and motors for

generation of modified new commands. The generic board acts as the brain of the system that receives the signals from the receiver circuit and the IR sensor, interprets it and generates more precise command when necessary. This module operates at a frequency of 11.0592 MHz, as shown in fig 5.
This flow control has been implemented using IR Range Finder of 5.5m range. The specified safe range of 2m has been preset in the programming which is easily changeable. Whenever an obstacle comes in this range the IR Range Finders it detects its presence and reports it to the generic board. The generic board circuit receives the sensor readings and the input commands generated by user and makes decision accordingly. There are four different situations in which obstacle can come intact of the helicopter. These four situations have been discussed in the figure 14

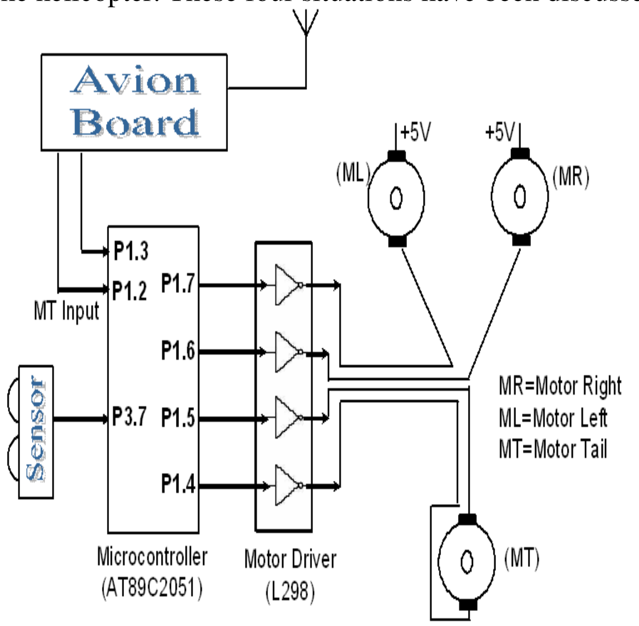

Fig. 12 Block Diagram of Obstacle Avoidance System

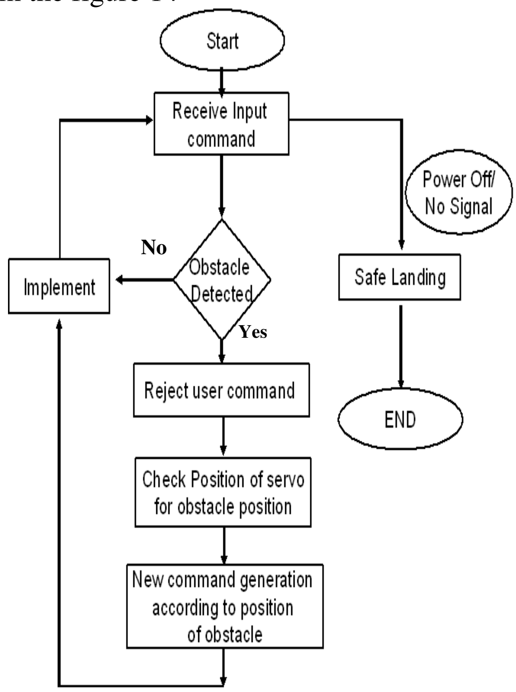

Fig. 13 Flow Block Diagram of wrong command rejection and modified command generation

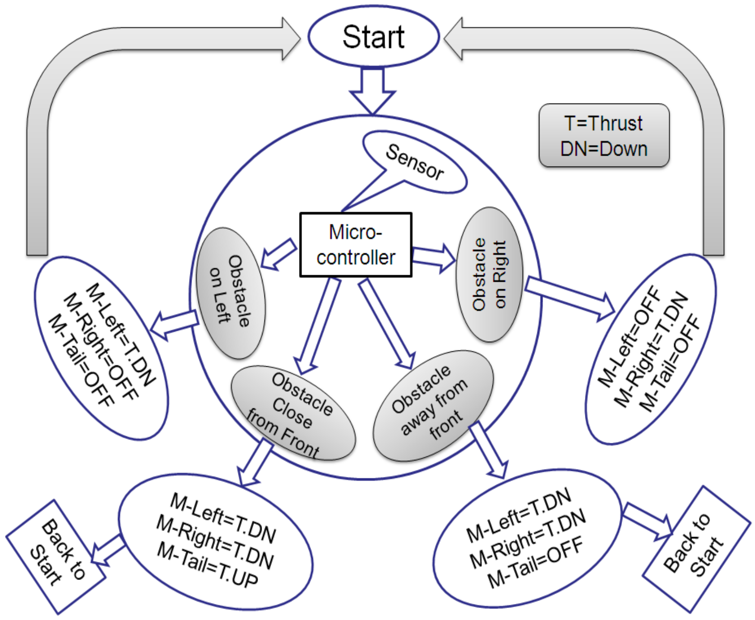

Fig.14 Response of system at time of obstacle

4.1.3. Fix Altitude

This was one of most interesting feature of helicopter to fly it at fix altitude. In this case an IR sensor was continually looking at ground ant giving us information about the height in the form of variable voltage signal. We introduced that signal in microcontroller and then with the help of PWM signal we controlled the PWM of main propellers, to keep helicopter at fix height. In our case we fixed it at height of 5.5 feet from ground level. These interesting phenomena helped us in achieving the task of terrain hugging, Fig 16 shows block diagram of circuitry and fig 17 shows control flow diagram which was stored in the form of programming inside microcontroller.

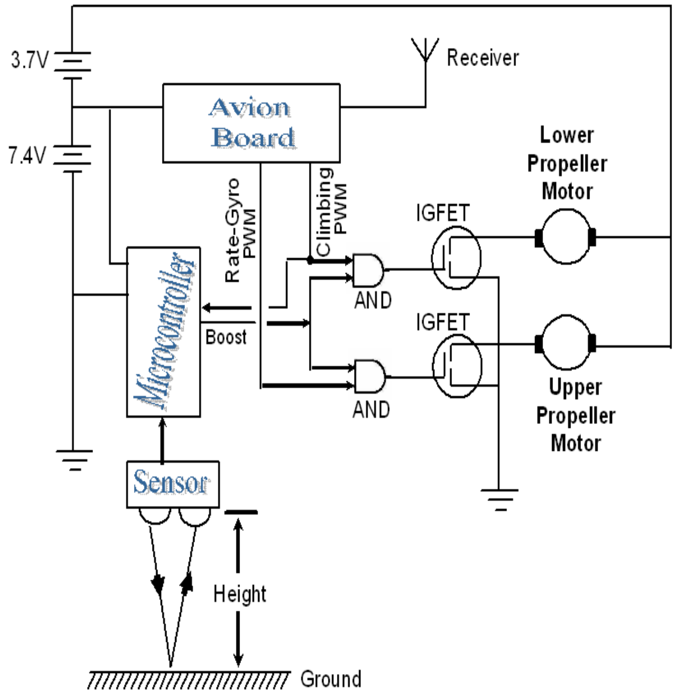

Fig. 16 Block Diagram of fix altitude System

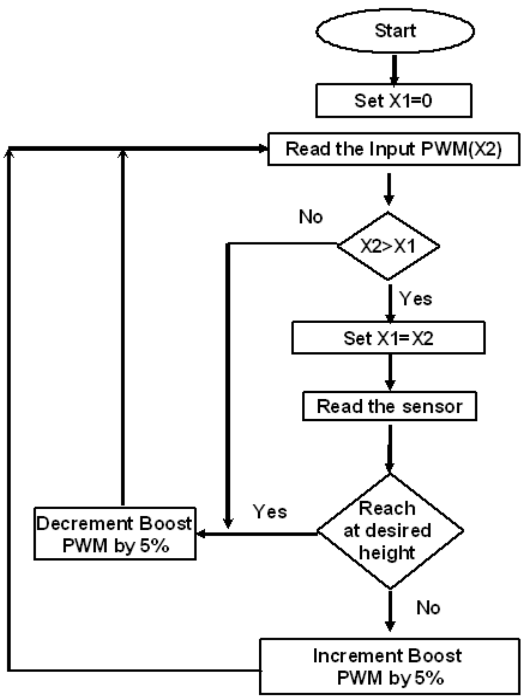

Fig. 17 Flow Block Diagram of fix altitude of Helicopter

As shown in figure 16, that to keep helicopter at fix height we had to control PWM speed of motors. As duty cycle of input signal is high then motor will operate at high speed. But if duty cycle of PWM signal is less than the motor will operate at lower speed. Same mechanism was applied in this case. We generated a PWM know as boost PWM with the help of microcontroller and passed it along with input signal coming from avion board through AND gate which allowed only to pass signal when output of microcontroller was high. In any other case the signal will not pass, so by keeping PWM signal in control we controlled the height of helicopter. We adopted the mechanism of hopping for sensing height. We continually increased and decreased the PWM to keep helicopter in small jumping mode which kept the sensors active and helped in monitoring the height.

TABLE III: FUNCTIONS & CAPABILTIES

Function	Basic Capabilities
Flight	- Safe flight in close environment - Elevation control - Inherently stable design - Searching tunnels, caves and mines - Sports and media broadcasting - Wrong command rejection & optimization
Sensors	- IR Range finders(5.5m) that can detect any object in its path and provide wrong command rejection
Communication	- Radio transmitter and Receiver operating at 40Mhz
Control Unit	- An ATMEL based embedded system that receives the user commands and the signals from IR Ranger and then generates the appropriate signals for various modules to ensure wrong command rejection and safe flight.
Fix Altitude	- Our modified UAV is capable of flying at fix height which is 5.5 feet from ground is set in programming coming from sensor. - Design is capable of performing function of terrain hugging specially in congested environment without colliding with any obstacle.

V. DESIGN COMPARISONS

A comparison of our design with similar available designs is presented in the table IV.

TABLE IV: COST, SAFETY, PAYLOAD COMAPRISON

DESIGN	COST($)	PAYLOAD
HeLion helicopter [10]	5240	12kg
MikroKopter-hexacopter UAV [11]	1550	0.8kg
Knight Quad Arduino UAV [12]	750	0.5kg
BabyLon Helicopter [13]	600	0.5kg
Our Design	270	0.75kg

Almost all the UAV helicopter's designs available are very costly and do not have proper safety mechanisms to avoid crashes. The designs that carry payloads are very expensive and are used for very specific applications. Our design presents an optimum solution providing cost effectiveness, crash avoidance surety, a moderate payload carrying capability as well as flight at low altitude. The proposed design has the capability of further payload enhancement and implementation of advance flight control techniques.

VI. CONCLUSION

The design proposed and developed modifies a small size toy helicopter into a very low cost complete UAV. The final design is capable of avoiding crashes, carrying small payloads and providing surveillance. Our novel designed algorithms using simple DC motors which are very economical as compare to powerful BLDC motors and IR Range Finder – as the major sensing units, virtually eliminate the possibilities of a crash. It also keeps intact the element of inherent stability of the original design resulting in a highly safe and stable system. We have also managed to introduce payload carrying capability and have successfully tested the design prototype

VII. FUTURE WORK

In the course of development of our model several possibilities appeared, the use of which may lead to even better and advanced flight control mechanisms in the future enhancements of our design; especially the processing of video using video camera on it can be utilized for target locking, tracking, smoke/fire detection, fog navigation etc. The choice of 8 channel microcontroller allows plenty of room for interfacing more sensors like compass sensors, 2-3D Rate Gyros etc to implement advance flight control algorithms – in the next stage of enhancements in our design and model. Our design can only detect obstacle only in one direction. But there is possibility in future someone implement 4 sensors to monitor all 4 sides. By increasing range this design can be modified for large scale as well.

ACKNOWLEDGEMENTS

We dedicate our project to our dear parents, who are sacrificing their present for our future. Without their prayers, support and efforts of teachers and parents our dream to become engineer could have never come true.

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