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Development of an Avionics System for Flight Data Collection of an UAV Helicopter

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Abstract**—**In this present work, the development of an avionics system for flight data collection of a Raptor 30 V2 is carried out. For the data acquisition both onground and onboard avionics systems are developed for testing of a small-scale Unmanned Aerial Vehicle (UAV) helicopter. The onboard avionics record the helicopter state outputs namely accelerations, angular rates and Euler angles, in real time, and the on ground avionics system record the inputs given to the radio controlled helicopter through a transmitter, in real time. The avionic systems are designed and developed taking into consideration low weight, small size, anti-vibration, low power consumption, and easy interfacing. To mitigate the medium frequency vibrations embedded on the UAV helicopter during flight, a damper is designed and its performance is evaluated. A number of flight tests are carried out and the data obtained is then analyzed for accuracy and repeatability and conclusions are inferred.

Keywords**—**Data collection, Flight Testing, Onground and Onboard Avionics, UAV helicopter

I. INTRODUCTION

IN the last two decades research on UAV's (unmanned aerial vehicles) have gained popularity due to their applications in both military and civil domains. They are indispensible in military operations like seek and destroy and ship borne operations which include automatic take off and recovery [1]. UAV's are much used in civilian applications namely reconnaissance[2], search and rescue operations along coast lines[3], forest fire surveillance [4], traffic monitoring and their use in dealing with emergency situations such as natural disasters make them imperative[5].

Among the various UAV's , small scale R/C (remote controlled) helicopters are especially attractive due to their small size, high payload capability , unique flight capability namely vertical takeoff and landing and hovering, due to this various researchers have indigenously developed their own UAV helicopters[6-8] for their study on helicopters. Advancements in design of small scale UAV helicopters and integration of hardware and software designs for automatic flight have also been reported in National University of Singapore (NUS) [9]. The design of a simple avionic system and assembly of an UAV was also elucidated by Cia et al. [10]. For the development of an autonomous flight of an UAV helicopter various steps namely software and hardware design and integration, system identification and control law design and implementation are essential [11]. In the early part of the last decade conventional such as Maximum Likelihood Estimation Method (MMLE) which involved linearizing the helicopter dynamics about some operating conditions throughout the flight envelope, such as hover were used. Unfortunately these conventional methods of system identification require the structure of the mathematical model (differential equation) to be known a priori. Helicopters are open-loop unstable and most mathematical models contain a moderate-high degree of uncertainty associated with neglected dynamics Since helicopters are a difficult type of aircraft to control which generically exhibit a complex, nonlinear dynamic behavior and are subject to a high degree of inter-axis coupling the proposed conventional techniques may not be possible to come up with a structured mathematical model of a highly coupled nonlinear system like UAV helicopter. Hence nonconventional methods like Fuzzy Logic and Neural Network, which do not explicitly require a mathematical model of a system, have gained popularity in recent times. The methods elucidated above require flight data for system identification.

One of the most important steps in system identification is the collection of flight data during flight experiments. The practical flight test data is then utilized to identify the mathematical model of UAV helicopter and implement an automatic control. This necessitates the need for the development of an avionics system to collect the flight data, with this in view we develop an on ground and on board avionics system for the collection of flight parameters and input signals of the Raptor 30 V2 helicopter. Among all the states of the helicopter the hover is most difficult and it is dynamically unstable when it flies at hover mode with nearly zero forward speed. Moreover hovering performance of unmanned helicopter is of key importance in flight [12]. Therefore a number of in-flight tests are carried out for data collection at hover. During tests, the onboard avionics system records, in real time, all helicopter state outputs namely accelerations, angular rates and Euler angles and similarly the on ground avionics system captures the entire R/C pilot's inputs (stick inputs in transmitter), simultaneously along with the onboard avionics, which include the signals to command the lateral flapping, longitudinal flapping, heave and yaw of the helicopter. Unlike in earlier studies [11] where the data collection of inputs and output states of the helicopter took place onboard, the advantage of using an onground avionics system is that it eliminates any possibility of an erroneous signal being sent to the receiver on board which causes

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glitches in the R/C helicopter and is completely isolated from risks that is disastrous to the UAV helicopter.

II. R/C HELICOPTER

The UAV helicopter system consists of the following parts: (a)a R/C hobby helicopter, (b) an onboard avionics system, and (c) an on ground avionics system. The avionics are developed with the R/C helicopter as the base of the construction. The onboard avionics play an important role in collecting flight data which include accelerations, angular rates and angles in all three axes. The on ground system collects the input commands of the transmitter of all five channels namely; throttle, aileron, collective, elevator and rudder/gyro. Fig. 1 shows an overview of the UAV helicopter system. It is observed that the working of the on board avionics does not interfere with the working of the R/C helicopter. This method employed eliminates any remote possibility of a random signal being transmitted to the on board receiver by the electronic circuit which causes glitches and hence eliminates the risk of the helicopter going out of control during the flight tests..

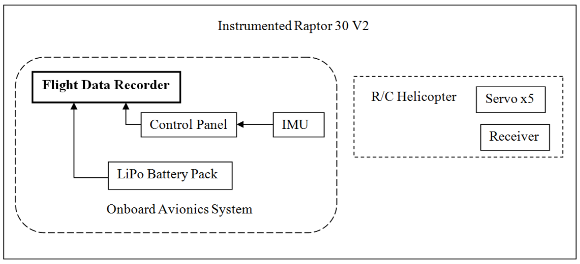


Fig. 1 Overview of the helicopter system

The UAV helicopter, shown in Fig. 2, is developed based on a high quality engineered R/C helicopter, Raptor 30 V2. It has a large payload capability and great maneuverability, and can be easily upgraded to a UAV helicopter with an autopilot system, sensors and communication devices. The Raptor 30 V2 helicopter has an optimized rotor head for precision flying. In addition, the main frame has a proper center of gravity which makes the helicopter very stable when performing hover, agile flight and very sharp 3D flying even in high wind conditions. Some key parameters of the helicopter are listed in Table 1. It is equipped with a 293g ‘‘OS Max-37 SZ-H” engine, which is capable of producing approximate 1.044 kW at 18,000 rpm in the speed range of 2000–21,000 rpm. Its maximum takeoff weight is up to 6 kg while the gross weight is around 3.1 kg. Therefore, a total of about 3 kg payload can be carried into the sky. It is big enough to install the avionics box and other onboard devices. A fuel tank of 300 cc provides capability of a longer flying time.

The actuation of the helicopter is performed by five onboard servo actuators and the swash plate is controlled by three servos namely elevator, aileron and collective working independently. This method of controlling the swash plate of the helicopter has an advantage over CCPM (wherein all servos work together to control the swash plate) as it would be easy to identify individual commands and link the movement of the helicopter to the particular input, which will help during the development of system identification. Among the five servos, one servo is linked to control the engine power and another servo control the inputs to the tail rotor. In detail, the elevator servo moves the swash plate forward and backward to implement the pitching motion of helicopter and the aileron servo moves it right and left to implement the rolling motion of helicopter. The collective moves the swash plate up or down so as to increase or decrease the lift generated in the helicopter. It is essential to note that the single channel movement of the transmitter controls both the throttle and the collective; this mixing of the controls is employed so as to reduce the load on the rotor head at the same time maintaining the rpm of the main rotor at a desired value for a comfortable hover. The last servo is employed to control the yaw motion along with a yaw rate gyro. The servo is a High Speed Futaba 9253 model, the servo used is different from the other four servos’ so as to ensure that the gyro sends necessary signals without delay to keep the helicopter from yawing.

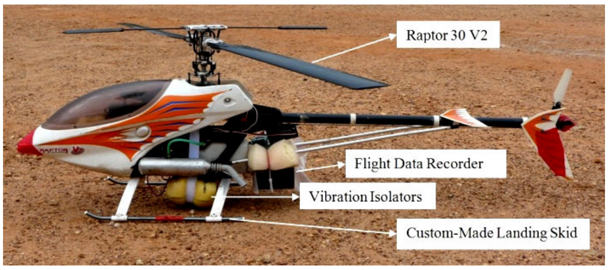


Fig. 2 Construction of the UAV helicopter

TABLE I
SPECIFICATIONS OF RAPTOR 30 V2

Length of fuselage	1150 mm
Width of fuselage	140 mm
Height of fuselage	400 mm
Main rotor diameter	1245 mm
Tail rotor diameter	260 mm
Gear ratio (main: engine :tail)	1 :9.56:4.57

All the servos are controlled by pulse width modulation (PWM) signals generated by the R/C receiver. The R/C receiver receives the signal commands from the transmitter and sends the PWM signals to actuate the servo motors. During flight tests, the deflections of every servo motor are recorded. To obtain the deflections, the PWM signals generated in the R/C receiver need to be captured. This is elucidated in the next section on on-ground avionics.

III. ONGROUND AVIONICS

To record the inputs given to the helicopter without interfering with the integrity of the RF (radio frequency) transmitter, the inputs are recorded from a receiver placed on the ground. This method has an added advantage over recording data from the transmitter through a receiver on board such as; not occupying space on the helicopter and not adding extra weight, which may bring about a change in flight characteristics of the helicopter.A microcontroller board is connected to the receiver on ground and the data is converted and sent to a computer via serial communication. This eliminates the need for a microcontroller with high memory capacity or a development of a GPS system. In this present work two receivers are bound to a single transmitter. A receiver is placed onboard and another on the ground. The two receivers receive signals simultaneously from the transmitter. Fig. 3 illustrates the working principle of the dual- receiver method.

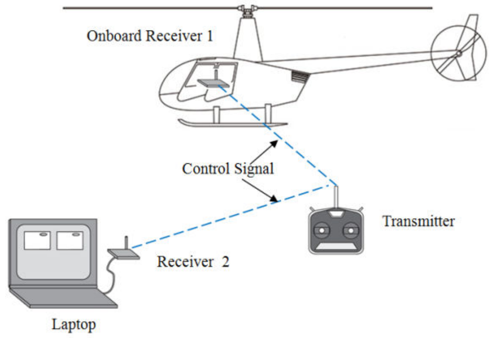


Fig. 3 **N**Principle of the Dual-Receiver method

To measure the PWM signals from the receiver a simple microcontroller board having Atmega 32 as microcontroller is used. All the components are powered by a 4 cell AA battery, with a total voltage of 6 V.The output of the receiver is a PWM signal of 50Hz frequency. The width of the pulse varies between 0.8ms to 2.1 ms and the signal from subsequent channels is cascading in nature. Fig. 4 shows the processing sequence for the five channels of the receiver on ground. Channel 1, Channel 2, Channel 3, Channel 4, Channel 5 receives inputs from the throttle, aileron, collective, elevator and rudder/gyro respectively. It is essential for system identification that the commands by the gyro to the rudder servo is also collected because most of the time the gyro sends signals to the rudder servo and is rarely controlled by the R/C pilot, hence in this present work the PWM signals of the gyro is also measured along with the rudder commands by the pilot. There are four Ports namely Port A, Port B, Port C and Port D on the microcontroller and each port has eight pins. Each channel of the receiver is connected to a pin on Port A of the Atmega32 microcontroller. An external clock of 16 MHz is connected to maintain accuracy and support high speeds of data transfer without errors. Data is not stored on board but immediately transferred using the built in USART (universal synchronous/asynchronous receiver/transmitter communicate synchronously), to the computer to MTTY software, which allows for real time serial communication. The Algorithm of the program developed in C programming language. Initially the program waits for a falling edge on the first channel and enters a while loop, the time taken for the rise and fall for a signal of a single channel is recorded and then the timer is reset. These steps are repeated for all five consecutive channels and upon the exit of the while loop the recorded data is sent via an USART and the entire cycle is repeated again.

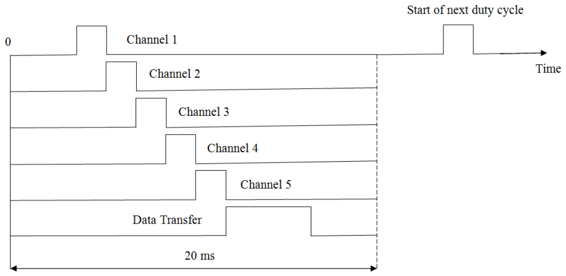
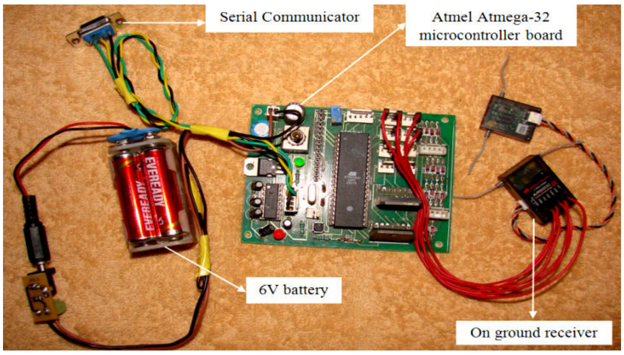


Fig. 4 Processing sequence for the Receiver on Ground

Data transfer rate is selected such that all the recorded data is transmitted during the time period available between the transmission from the last channel and the start of the next cycle. Serial data transfer is used as it is an inbuilt feature on the Atmega32 and can support high data transfer rates as required by the user. Additionally an appropriate data rate is selected so that the transmission error from the microcontroller with the 16Mhz clock source is minimal. Considering all the above factors a baud rate of 11400 bps(bits per second) is used. The data is transmitted in the form of ASCII characters (one byte of data) . This format is used as it requires minimal extra characters (tab spaces/ newline) and it allows for easy data manipulation and interpretation. This format also allows data analysis using a simple standard spreadsheet application like MS Excel.

Fig. 5 Complete assembly of onground avionics



The complete assembly of the onground avionics, comprising of an Atmel ATmega 32 microcontroller board, 6 V power supply, serial communicator and a AR6200 receiver is shown in Fig. 5.

Apart from the measuring the inputs the flight parameters namely accelerations, angular rates and angles in all three axes are essential for system identification of an UAV helicopter, the development of an onboard avionics for the measurement of these parameters is explained in detail in the next section.

IV. ONBOARD AVIONICS

The onboard components are chosen primarily based on low weight, small size, high vibration sensitivity, low power consumption, and ease in interfacing with a computer, in that respective order. In this present work, the employed on board avionics system together with the battery packs lasted for around forty five minutes, which is sufficient to complete most missions. Due to the presence of high frequency vibrations caused by the main rotor, tail rotor and the engine, which has a detrimental effect on the on board avionics, a damper is placed to protect the system. A low density sponge material is used to attenuate the vibrations on board. The block diagram representation of the working principle of the on board avionics is shown in Fig. 1.

The Flight Data Recorder is commercially developed and is made available at the Aerospace Engineering Department, Indian Institute of Science (IISc). The dimensions of the system is 42mm x 113mm x 35mm and the total weight is 450 grams. It has 10 Analog signal channels which are single ended (+/- 10 V), 4 Potentiometer channels with onboard 5 V reference and a temperature channel. A 12.6 V Lithium Polymer (LiPo) battery powers all the components of the on board avionics system. A 16 bit ADC is used and a sampling rate of 50 Hertz is achieved. The recorded values are stored on board by a 4 megabyte flash memory. A user friendly control panel is provided along with the FDR black box, which has a start and stop button to begin and end the recording of the flight data. A toggle switch enables the FDR data to be transmitted serially to a computer through a RS-232 bus. On completion of a particular flight test the data from the FDR is downloaded using the software Flight Data Recorder Ver 3.0. The data downloaded is embedded with noise due to the vibrations of R/C helicopter and needs to be filtered, in this present work Adjacent Averaging smoothing algorithm recommended and available in the commercially available software package OriginPro-8 is used.

The major sensor is a small, light and low power consumption Microstrain 3DM-GX1 IMU [13] which is employed to output the states of the helicopter, such as accelerations, angular rates and Euler angles. It is compactly designed using micro electro mechanical system (MEMS) technology. The unit combines a triaxial gyro, triaxial accelerometer, triaxial magnetometer, temperature sensors and an embedded microprocessor with which to output its orientation in dynamic and static environments. The output data is fully calibrated, temperature compensated and corrected for sensor misalignment. The output is presented in an easy-to-use digital format and a rate of transmission up to 350 Hz. The complete assembly of the onboard avionics, consisting of an Inertial Measurement Unit(IMU), Control Panel, LiPo battery and a FDR black box is shown in Fig. 6.

V. Experiments And Results

A. Vibration and Attenuation Tests

Due to the inherent nature of vibration in a R/C helicopter it is essential to attenuate it to permissible levels so as to prevent it from causing serious damage or destruction of the model in a short period of time. The vibrations on the Raptor 30V2 model used are reduced by employing the following methods a) balancing of the main rotor blades b) ensuring that the flybars are equal in weight and c) ensuring the main rotor shaft and feathering shafts are bend free which can otherwise load the rotor head and create high stresses during operation. Despite these preventive measures there exists considerable vibrations on board which can have an adverse affect on the functioning of the on board avionics hence the entire on board avionics system is wrapped in a low density sponge, which acts as a damper.

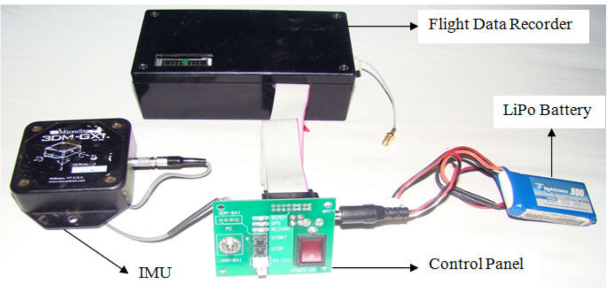


Fig. 6 Complete assembly of onground avionics

To evaluate the performance of sponge as damper the vibrations expected from a Raptor 30 V2 is simulated on a high frequency servo hydraulic Universal Testing Machine (UTM) , (BISS Pvt Ltd India), and tested by placing a 3 axis accelerometer on the UTM. The machine has an actuator capacity of 5 KN and stroke of +/- 30 mm. It is known from previous experiments, that medium frequency vibrations occur in the R/C helicopter [14] which is 4 times that of the main rotor rpm. For a comfortable hover the rpm used in the flight tests conducted is around 1500 rpm, which is verified using a tachometer, thus the frequency of vibration developed on board is approximately 100Hz. For estimating the frequency of vibrations from the engine the expression; rpm/ (2*number of cylinders) is used. From the mentioned expression the frequency is estimated to be 119.25 Hz. Thus the overall vibration on the UAV is around 100Hz. The operating conditions of the machine are adjusted to the level of frequency and amplitude expected on board.

The accelerometer data of acceleration along x, y, and z body axes is recorded during the tests. To better analyze the vibration, the acceleration responses are converted to the frequency domain by using Fast Fourier Transform (FFT). One sample plot relating to z axis acceleration for both with and without damper is shown in Figure 7. From the results, it can be seen that the vibration transferred to the onboard system is greatly decreased with the damper as compared to vibrations in the absence of the damper. The level of reduction is up to 87.5%, which indicates the vibration isolation system can effectively mitigate the vibration to an acceptable level for sensor operations. The residual 12.5% vibration is further eliminated with filters as explained in the Onboard avionics section. Similar results are also achieved for the acceleration in x and y axes.

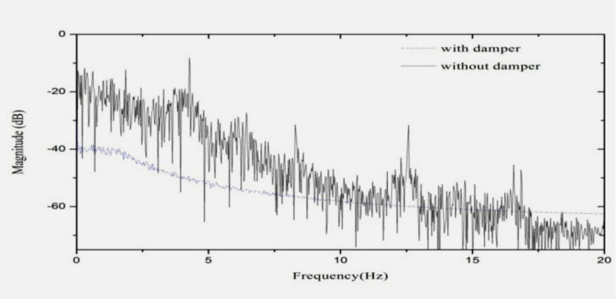


Fig. 7 Magnitude of z axis acceleration in frequency domain for with and without damper

B. Field Flight Tests

A number of flight tests are conducted for hover by a trained R/C pilot. The tests begin by initially placing the helicopter in an open air field. To power the electronic devices such as laptop on the air field, a 12 V battery along with an inverter is used , this ensures an additional 1 hour of flight test if the need arises. The on board and on ground avionics systems are switched on simultaneously even while the helicopter is still on the ground. Video of the R/C helicopter is captured in two axes for correlating the movement of the UAV, flight parameters recorded and the input commands by the pilot, this would be very helpful especially in determining the mathematical model of the helicopter.

Once the electronic devices have started recording data, the pilot gradually increases lift to hover the helicopter at a height, which is safe from the effects of in ground effect which would otherwise reduce the induced power. After each flight test the data of the on board avionics is downloaded onto a laptop It takes around 2 minutes for each flight test and the same experiment is repeated for more than 4 times.

Fig. 8–11 shows the results in hovering flight test. The results consist of pilot input signals and the helicopter outputs namely and accelerations, angular rates and Euler angles, The pilot input signals are the PWM signals generated by R/C receiver. The horizontal axis in each graph represents the flight time and the values of the first 30 s are plotted for analysis. Fig. 12 illustrates the duty cycle of the PWM signals in percentage varies over time in the hovering condition. The PWM signal in each plot is used to drive the corresponding servo actuator. It is observed from the graphs that until about 1.5 s the helicopter is idling. After this time period the helicopter starts gain rpm of the main rotor and severe vibrations occurs before the helicopter take-off. This is due to the effect of ground resonance [15]. Ground resonance is a type of vibration that is the most destructive and dangerous of all the type of helicopter vibrations and can destroy it within a short span of time. Ground resonance never occurs during flight and only affects grounded helicopters with turning rotors. Ground resonance is often the result of unbalanced forces in a rotor system that causes an aircraft to rock on the landing gear when the helicopter is at or near its natural frequency. The vibration is drastically decreased once the helicopter takes off and during hovering, which ensures the accuracy and dependability of the collected data. At this point a type of vibration called medium frequency vibration acts on the system. Medium frequency vibration is a common rotor system vibration that occurs due to loose components of the R/C helicopter.

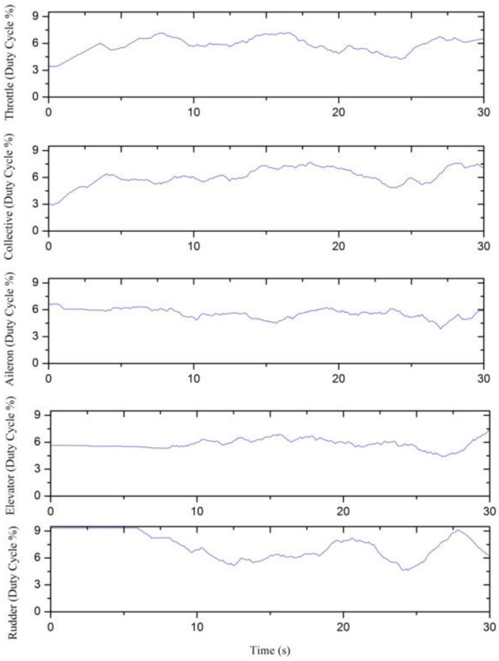


Fig. 8 Input signals in hovering flight test

Due to wind gusts or the spontaneous aerodynamic characteristics of the small-scale helicopter, it is quite difficult to keep the helicopter steady in hover and the helicopter sweeps itself in a relatively wide range. For each in flight test the motion of the helicopter is compared with respect to input signals, it is observed that the helicopter does not deviate from the motion anticipated. The input signals namely the throttle and collective dip at around 25 seconds, this change is observed in the video where there is a drop in altitude of the helicopter. Along with the improvement of the pilot skills, the hovering helicopter can be maintained in a smaller space and the deflections in throttle and collective are reduced. Since the vibrations are considerably reduced after takeoff, as is evident from Fig.9-11, the accuracy and dependability of the collected data is ensured.

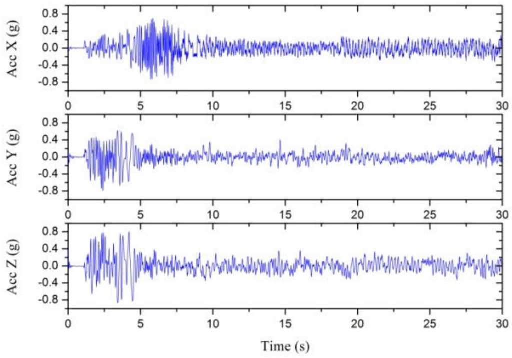


Fig. 9 Accelerations in hovering flight test

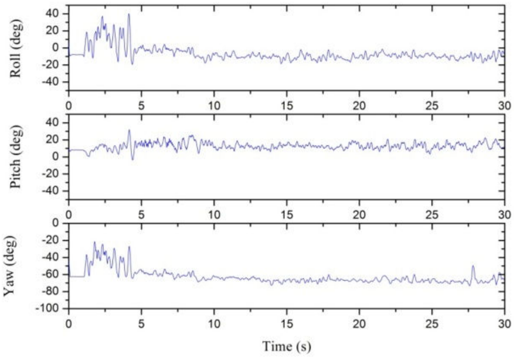


Fig. 10 Angular rates in hovering flight test

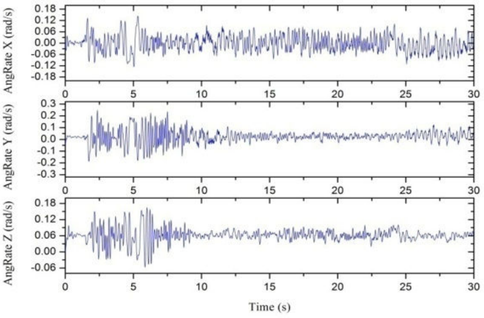


Fig 11 Euler angles in hover flight test

VI. CONCLUSION

In this present work, the development of an avionics system for the flight data collection of a Raptor 30 V2 R/C helicopter is carried out. The hardware and software parts of the onboard system and on ground system are designed and have been successfully implemented. The onboard avionics system comprises of a Flight Data Recorder, an Inertial Measurement Unit (IMU) and a user friendly control panel. The onground avionics system comprises of a Atmel Atmega 32 microcontroller board, a serial communicator and a receiver. A number of components are selected separately for these systems to equip the onboard system with the attributes of compact, light weight and low power consumption.The onboard and on ground hardware and software have been thoroughly tested in actual flight tests, and their reliability and feasibility are evaluated. The results are plotted and show that the collected data is logical and sufficiently accurate for finding the mathematical model of the helicopter. This designed onboard system may be applied to all types of model aircrafts actuated by servo motors. Both hardware and software design can be readily expanded. The onboard system is employed to collect flight data but the methods such as the manipulation of hardware components, task scheduling, can be utilized straightforward on autonomous flight development of the helicopter.

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