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Low-Cost Data Acquisition System with LabVIEW GUI for Real-Time Flight Data Transmission in UAVs

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***Abstract*— Every aircraft has certain flight data which are very important for the safe operation of an aircraft. The parameters like flight altitude from sea level, ambient pressure, ambient temperature, aircraft's pitch, roll and yaw angles are among the major flight data which are to be continuously recorded and monitored. Data acquisition system (DAS) built for this project comprises sensors, microprocessors, storage, transmitter and receiver modules to sense, process, store and transmit the signals of aforementioned flight data. The signals are received, processed and displayed on a graphical user interface.**

***Keywords*—DAS; Flight data; Arduino; Sensors; LabVIEW; GUI.**

I. INTRODUCTION

The data acquisition system is an important instrumentation system employed in aircraft. Data acquisition system abbreviated as DAS is a system used to acquire information or data from the desired domain. DAS is majorly equipped in the aircraft industry sector to gather all the important flight data in real-time. The gathered information is either transmitted to the ground station from the on-board system or simply stored in the storage device in the aircraft itself which can be later deprived. The data collected in real-time includes important technical parameters like deflections of control surfaces, airspeed, altitude, the density of air, absolute pressure, engine RPM, Engine thrust and other required parameters. Also, it records non-technical data like cockpit voices which is helpful for post-flight analysis. **Fig.1** gives a clear picture of this project's DAS.

II. LITERATURE SURVEY

The swift growth in UAVs and their wide range of applications raise the demand for improved data acquisition systems for their safe operation [1]. A pre-programmed automatic data acquisition system [2] was used to remotely operate the DAS which was on-board with a graphical user interface. The unique GUI was designed and written in LabVIEW software to operate the DAS. It was written in such a way that it controls and operates all the sensors and also acquires, processes, displays, and stores the data [2, 5].

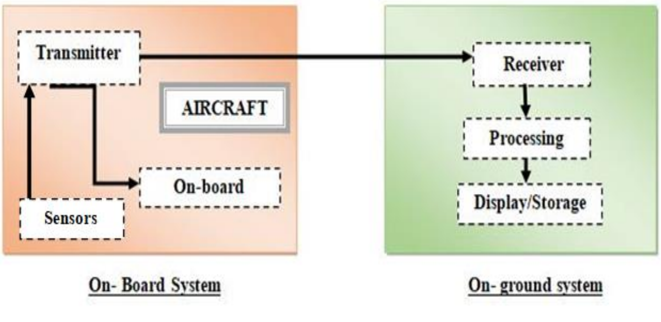

Fig.1: General block diagram of DAS

M. Sri-Jayantha [3] says that the sensors of DAS required to provide useful information about the aircraft dynamics are classified into three groups: inertial, air data, and control displacement. The inertial sensors are 3 linear accelerometers, 3 angular rate gyros, and 3 angular accelerometers which are rigidly and orthogonally mounted.

Ankan and Ashish [4] made a wireless Flight Data Recorder (FDR) in which the flight Parameters were measured and stored in real-time. Later on, the same data was also transferred to Personal Computer (PC) which was at the ground. The XBEE-RF Module was used to transfer data from plane to ground station. The plane sends the information via ZIGBEE to the ground station which could track hundreds of planes at the same instant of time. For the development and testing of the instrumentation system used to acquire flight data [5], the LabVIEW software was used to convert data of each test run from hexadecimal format into base-ten text files and later data was used in a MATLAB for data analysis program.

MPU6050 triple-axis accelerometer and gyro sensor are used for the calculation of aircraft pitch, roll and yaw angles because it not only produces values with less noise but also the sensor has good dynamic response [6]. However, the sensor itself did not have a magnetometer in it. So, the yaw angle values were inaccurate. This problem was solved by using a three-axis magnetometer. In this project, we have used HMC5883L as a triple-axis magnetometer.

The ground control system is used for controlling the aircraft trajectory, attitude and heading [7, 8]. But the controlling of aircraft by ground control system depends upon the values transmitted from the on-board data acquisition system. The transmission of data is done using the Xbee Zigbee module which is simple, user friendly, reliable, quick and performs efficiently at low relative power [3, 9, 10].

III. PROPOSED METHODOLOGY AND DISCUSSION

A. Hardware

i. Battery: Orange 850mah 3s 30c Lithium Polymer (LiPo) battery is used as a source of power for DAS.

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The output voltage is 11.1V. The weight is around 75g. This battery is rechargeable. It has good performance and reliability.

ii. Microcontroller / Microprocessor: Arduino UNO R3 with ATmega328 microprocessor is used to control and coordinate all the sensors connected to it. It also processes the raw data sensed by the sensors. It supplies power from the battery to the rest of the sensors.

iii. Gyroscope / Accelerometer sensor: MPU 6050 triple-axis accelerometer and the gyro is used for sensing aircraft pitch and roll angles. It has standard I2C interface with gyroscopic range +/- 250, +/-500, +/-1000, +/-2000 degree/second and accelerometer range +/-2g, +/- 4g, +/- 8g, +/- 16g [11].

iv. Magnetometer sensor: HMC5883L triple-axis magnetometer is used for obtaining the yaw angle of aircraft. It is also used as a compass in aircraft. It has a standard I2C interface with a magnetic field range +/- 8 gauss [12].

v. Barometric pressure and Temperature sensor: BMP 180 barometric pressure sensor is used to measure barometric pressure, temperature and altitude together. It has an I2C interface with a pressure range of 30000 Pa to 110000 Pa and the corresponding altitude range of +9000m to -500m [13].

vi. Air quality sensor: MQ135 gas sensor is used for air quality monitoring. It has good sensitivity to Ammonia, Benzene, smoke, CO, CO2, NOx, Alcohol and other volatile gases.

vii. Storage module: Micro SD card module is used to store the sensed values. It is compatible with both the Arduino board and the micro SD card. It has an SPI interface module.

viii. Transmitter and receiver: Digi Xbee S2C module is used to transmit and receive signals. It is featured with UART of 250 Kbits/s and SPI of 5mb/s. the transmission frequency is 2.4GHz and its operating temperature range is -40°C to 85°C [14].

B. Cost analysis

Most of the UAVs available in the international market include data acquisition systems of higher cost. This paper aims at minimizing the cost required to develop the DAS. An estimated cost of hardware required is listed in **TABLE 1**. All the sensors selected for the DAS is available in the local market, which reduces the cost to a great extent.

TABLE 1: Estimated cost of hardware

Sl. no	Components	Price (INR)
1	850mah Lipo battery	800
2	Arduino UNO R3	1100
3	MPU6050	200
4	HMC5883L	150
5	BMP180	100
6	MQ135	250
7	SD card module	100
8	XBee Zigbee modules	1900
9	Miscellaneous	1000
	Total =	5600

TABLE 2: Cost of DAS in the international market

Sl. no	Components	Price (USD)
1	USB Flight Data Recorder	300$ - 320$
2	Eagle tree systems FDR-02 flight data recorder V2	170$

Any personal computer or laptop can be used as the display or monitoring device, so the price for no display devices is added to the table. The price of readily available complete set of data acquisition system in the international market is listed in **TABLE 2** [15, 16].

The analysis infers that the proposed DAS is cost-effective compared to the systems available in the market.

C. Software

i. Arduino IDE: This is open-source software that is used to write program codes for calibrating and functioning of all the sensors equipped. The written code is compiled and uploaded to the Arduino board.

ii. XCTU: This is also open-source software that is used to set up, configure and test XBee RF modules. The transmitting XBee is configured as a router and receiving Xbee is configured as coordinator.

iii. LabVIEW: This software is used to design and develop a unique GUI for displaying real-time values of the flight data. The received signal values are processed and real-time graphs are plotted.

iv. MS Excel: The stored data in a micro SD card is fed to MS excel for validation. The graphs of flight data against flight time are plotted.

D. Methodology

All sensors are procured, calibrated and tested individually. MPU 6050 sensor is initially calibrated to produce proper values. MPU 6050 is placed in parallel with the center of gravity of aircraft so that the sensor gives accurate values when aircraft perform pitch and roll motions. HMC5883L sensor is used to obtain the yaw angle because the values that were obtained from MPU 6050 had an error in it. HMC5883L sensor is also initially calibrated and tested. Similarly, BMP 180, MQ 135 sensors and SD card module are also calibrated and tested. The connections of all sensors are shown in **Fig.2**.

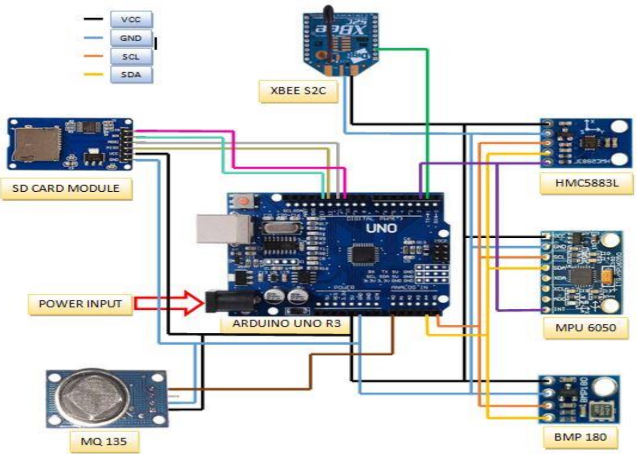

Fig.2: Onboard transmitting end of DAS

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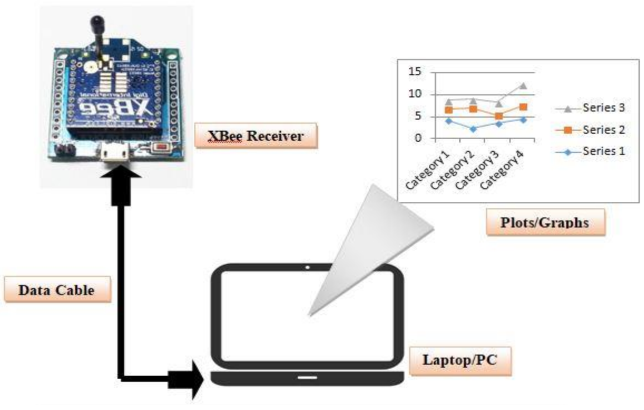

Fig.3: On-ground receiving end of DAS

Xbee S2C modules are also configured into router and coordinator respectively. A router is configured as API2 to transmit the flight data which are temporarily stored in Arduino. A coordinator is configured as API1 to receive the signals transmitted [17]. Therefore, the router is on-board and the coordinator is on-ground. To have a secured connection between XBee modules secret pin is set at the time of configurations. The pin can be set in the combination of 4 digits. So, we have secured transmission of data. The receiving end of DAS is shown in **Fig.3**.

Later full-length code is written taking all sensors and modules into consideration. When the full-length program was executed successfully, the positions of all the sensors on aircraft were planned. The sensors are placed and connected accordingly to the Arduino pins. The connections are properly soldered to prevent misalignment and lose connections.

Finally, the full-length programming code is uploaded to the Arduino UNO R3 board. The onboard setup is mounted on the aircraft at a specific location. The specific location is chosen where the value of the sensor drift is very small. The drift in values is due to vibrations incurred in the aircraft.

The transmitted signal will be in the form of a string. This string needs to be split accordingly to obtain the flight data values using LabVIEW. A data flow program is developed using LabVIEW's back end workspace to process the received signal. Also, a unique GUI is developed in front end workspace. Hence, the flight data values from the processed signal are displayed on the GUI.

The data string received from the Xbee module has a specific number of characters. The string gets updated as new data is received. **Fig.4** represents the block diagram for the processing of the string. The data string received is in the form 'X000Y111Z222A333T44P55555', where the characters 000,111, 222, 333, 44 and 55555 represent pitch angle, roll angle, yaw angle, altitude, temperature and pressure respectively.

Match string function is used to identify the characters and subset function is used to extract the adjacent numerical string. For example, in the above-mentioned string to extract pitch angle the match string function is specified to identify 'X' character and the subset function extracts the adjacent numerical string '000'. Later a conversion function is used to convert the numerical string to actual numerical values. These numerical values are displayed on the GUI using plot function and also stored in an array for further references.

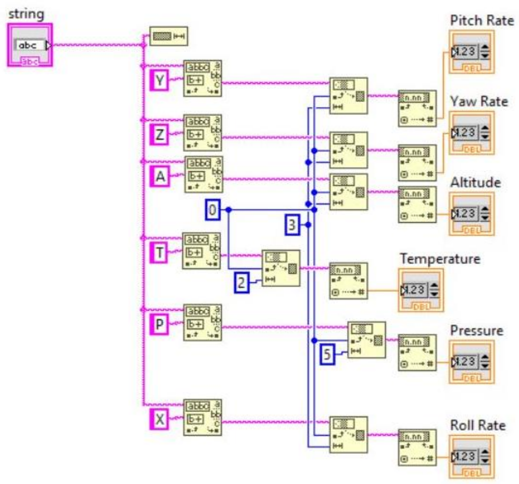

Fig.4: LabVIEW block diagram

IV. RESULTS WITH GRAPHS

The sensors continuously sense the data and stores temporarily in Arduino. This temporarily stored data is transmitted through the onboard XBee router and is received by the ground station XBee coordinator. The signal is processed and displayed on the LabVIEW GUI with real-time graphs. Also, the sensed data are stored in a micro SD card using the SD card module in .csv format. SD card can be deprived after completion of the flight. The .csv file is used to analyze the flight data and plot the graphs of pitch, roll, yaw, pressure, temperature, and altitude with respect to the flight time in MS Excel. Also, the quality of air is monitored and its data is stored in the SD card. **Fig.5** shows the front end GUI for displaying flight data.

As the aircraft performs different maneuvers its corresponding pitch, roll, and yaw angles are recorded. **Fig.6** shows the variation of these angles against flight time. The values of flight data are obtained every $1/10^{th}$ of a second. Therefore, the aircraft's behavior which includes variation in pitch, roll and yaw is recorded and plotted precisely. Similarly, other flight data like altitude, temperature, pressure are also recorded and plotted against flight time as shown in **Fig.7**, **Fig.8** and **Fig.9** respectively. The ambient pressure is found to be acceptable for the corresponding range of altitude and temperature values mentioned in **TABLE 3**. This infers that the flight data in **Fig.7**, **Fig.8** and **Fig.9** are in acceptable accuracy.

MQ135 air quality sensor has SnO_2 as the sensing material. This material's conductivity varies with air quality. Its conductivity is less in clean air and is high in polluted air. Therefore based on this property sensor records the air quality as GOOD / TOLERABLE / BAD / WORST accordingly. This information is stored in the SD card.

TABLE 3: Flight data values

Sl. no	Flight data	Range with units
1	Altitude from sea level	737 m to 761 m
2	Temperature	29°C to 30°C
3	Ambient pressure	92745 Pa to 92795 Pa

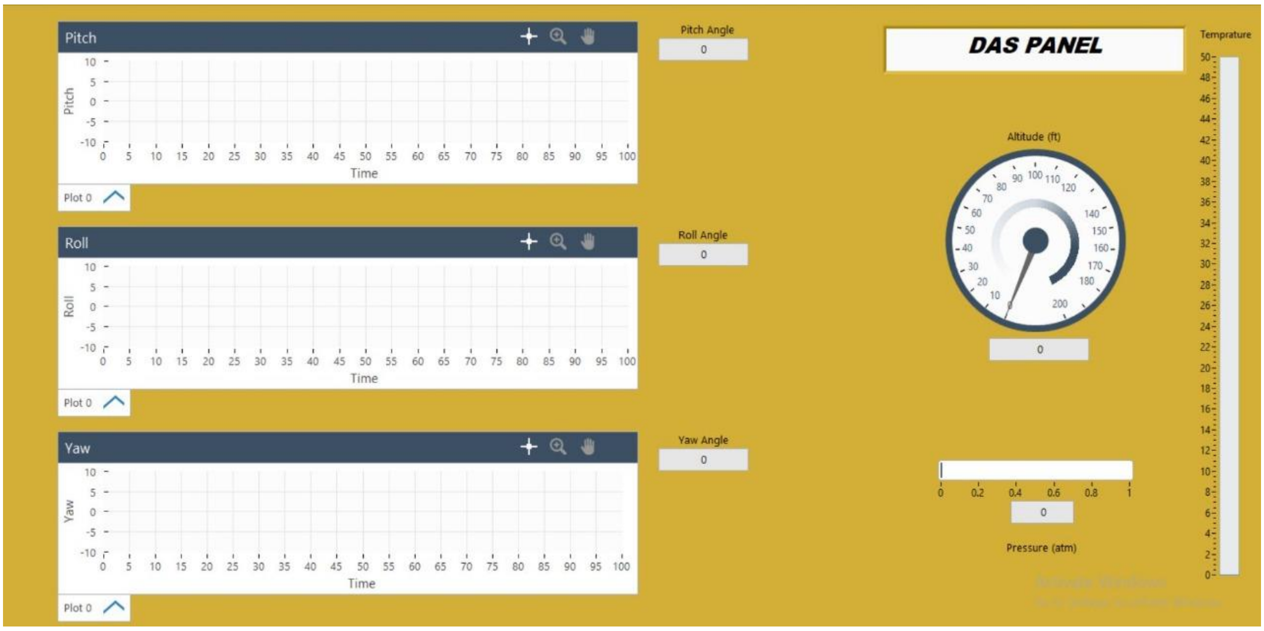

Fig.5: Front End GUI

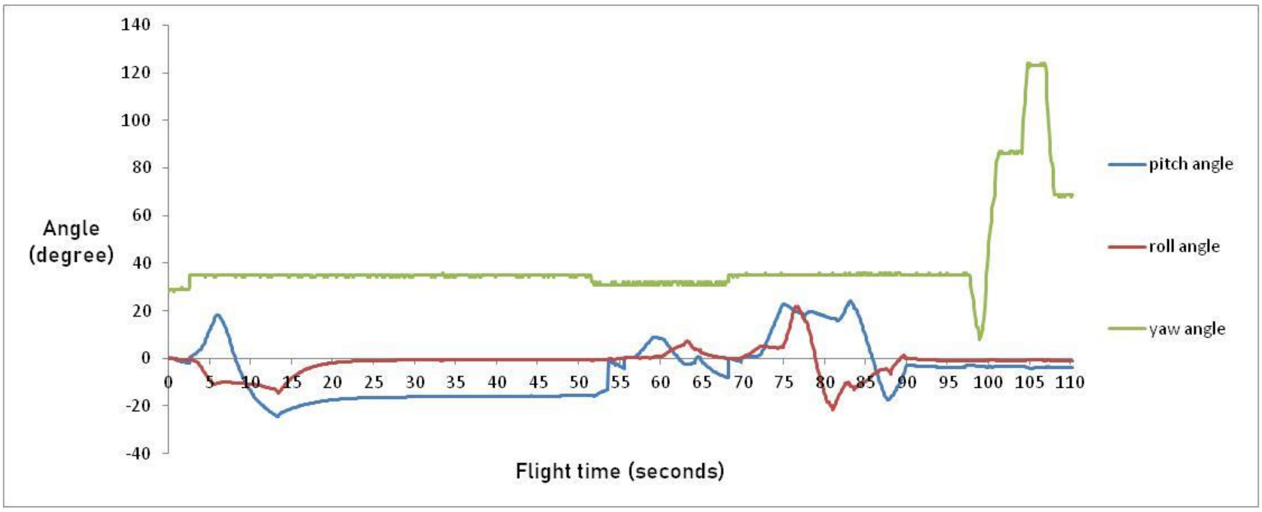

Fig.6: Pitch, Roll and Yaw angles versus flight time

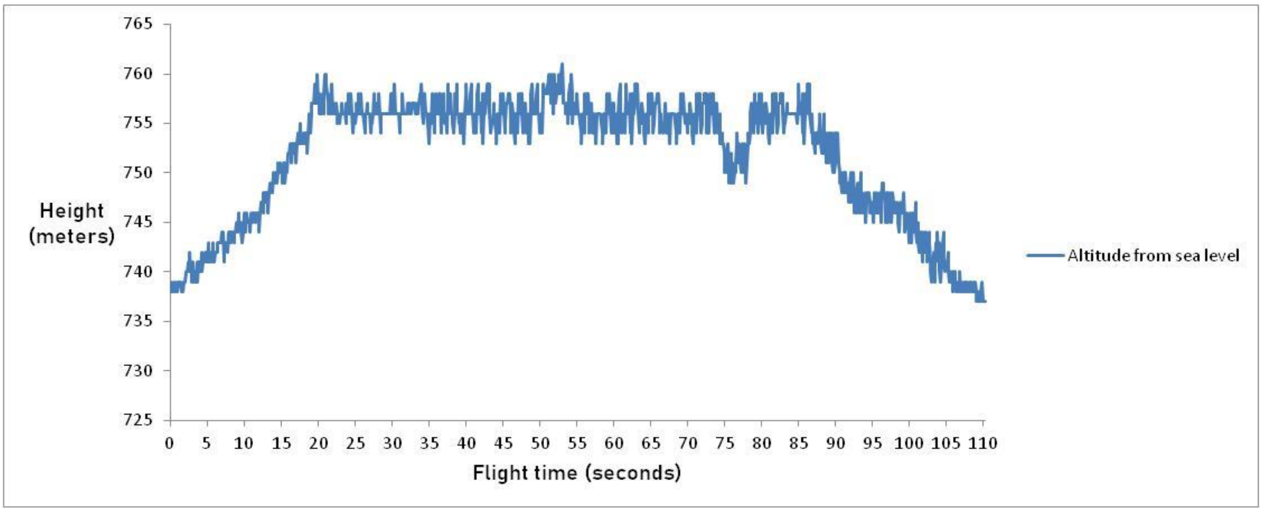

Fig.7: Altitude from sea level versus flight time

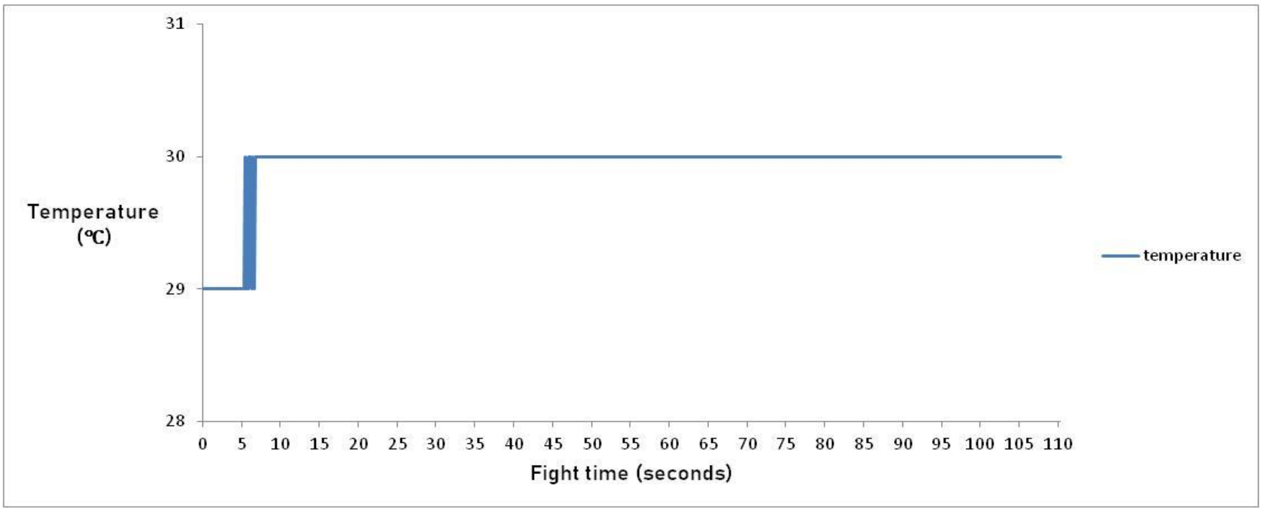

Fig.8: Temperature versus flight time

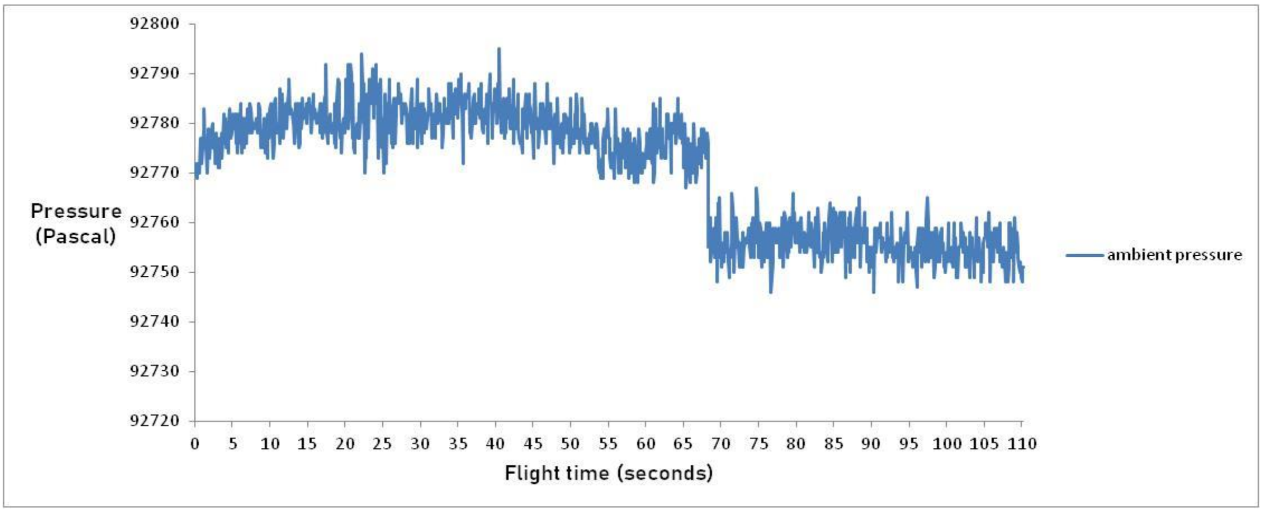

Fig.9: Ambient pressure versus flight time

V. CONCLUSION

The flight data of aircraft are recorded effectively using sensors in a short period with acceptable accuracy. The DAS developed is reliable as it shows real-time values and also stores data for further analysis. As the data is updated and stored for the entire flight time the flight parameters are available at any instance. The sensors are accurate and the values are sensed, stored and transmitted every 1/10th of a second making this DAS swift and reliable. The maintenance and cost of operation of this DAS are low as the hardware is readily available at a reasonable price. It has a major application in measuring air pollution at different altitudes as air quality monitoring is performed. The system developed is also flexible to other sensors which can be included based on the requirement. DAS developed is small and lightweight which can be used in a wide range of UAVs.

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