Initial Design of Flight Data Acquisition Unit (FDAU)

Try Kusuma Wardana[1, a)], Fuad Surastyo Pranoto[1, b)], Sayr Bahri[1, c)], Prasetyo Ardi Probo Suseno[1, d)] and Atik Bintoro[1, e)]

[1]*National Institute of Aeronautics and Space (LAPAN), Indonesia.*

[a)]try.kusuma@lapan.go.id
[b)]fuad.surastyo@lapan.go.id
[c)]sayr.bahri@lapan.go.id
[d)]prasetyo.ardi@lapan.go.id
[e)]atik.bintoro@lapan.go.id

Abstract. Flight investigations of aerodynamics and flight dynamics for a small unmanned aerial vehicle (UAV) demand the usage of automatic data acquisition system to support valid estimation of UAV aerodynamics and flight performance. All subsystems consist of commercial hardware component and popular component in the market. The system is low weight, low power, small in dimension, and low cost. The feature of this FDAU is nine degrees of freedom (9-DOF) inertial measurement unit (IMU) with 3-axis accelerometer, 3-axis gyroscope, and 3-axis magnetometer, global navigation satellite system (GNSS) and storage device. FDAU combines a large variety of sensor streams into a unified state data stream that is recorded for later aerodynamic analysis. This FDAU works by taking data from IMU sensor and GNSS, converts the signal to the correct level and filters the signal analog using signal conditioning, and then the data is switch-selected, connecting one channel at a time by multiplexer. The data is converted using converter (analog to digital or digital to analog signal), before it is processed by central processing unit (CPU) to generate become values who indicated a many flight parameter also to process with Kalman Filter, and then data is recorded by storage device. The results of this research show that the initial design of FDAU can record 13 different flight parameters. Not only that by using Kalman Filter concept, but the quality of resulting data is also better than the raw sensor data, from there the data has been successfully stored in the storage device with spreadsheet format.

INTRODUCTION

Data Acquisition (DAQ) is a term known for a branch of engineering related to gathering information from a number of digital and analog sources to be transmitted to a data processor. DAQ reads electrical signals from sensors, these signals represent a physical process *i.e.* position and orientation.[1] The data acquisition system considers several general principles so that the units can be combined together to form a system for a particular purpose, including how the data is transferred to the processor, displayed, analyzed, and recorded for processing.

Flight investigations of aerodynamics and flight dynamics for small UAVs demand the usage of automatic data acquisition systems to support valid estimation of UAV aerodynamics and flight performances.[2] Generally, manufacturers might want to know the device used and want to use the data to understand how their vehicles are performing.[3] There exist many kinds of microprocessor-based data acquisition systems but all of them do not satisfy specific requirements of UAV flight tests.

Investigation of aerodynamic and flight performances for small UAVs is a rather complicated problem because of severe dimensions, mass and power restrictions for a Flight Data Acquisition Unit (FDAU) needed to support flight data gathering and registration. Data collected from FDAU would be used for aerodynamics research.[4] Another difficult problem is selection of composition and placement for FDAU sensors.

The objectives of this paper are as follows: 1) to make an instrument design for recording flight data parameter, 2) to produce better data quality than sensor raw data, and 3) convert raw sensor data into other flight data parameter.

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A Flight Data Acquisition Unit (FDAU) is suggested to provide support for flight data gathering and registration processes. These recording systems highly vary in weight, size, and power consumption, sometimes standalone but are often part of a processing unit.[4] The data stored separately in a spreadsheet can be later used for analyzing and processing.[5] This FDAU consists of a microcontroller-based on flight data recorder equipped with a memory card to store experimental data, a set of sensors to measure UAV flight parameters, and software utility providing visualizations of the recorded data. In information systems, data acquisition, logging, and analysis are an all-important aspect and an indispensable tool.[6]

FLIGHT PARAMETER & SENSOR REQUIREMENTS

In this initial design of flight data acquisition unit (FDAU) there are several flight parameters to be retrieved. In a flight, there are many flight parameters available, but in this research, 13 flight parameters were taken, which are listed in Table 1 below.

TABLE 1. Initial design of FDAU's flight parameter and sensor requirement.

Flight Parameter	Sensor
Position in x-axis (x_g)	GPS/Accelerometer
Position in y-axis (y_g)	GPS/Accelerometer
Position in z-axis (z_g)	GPS/Accelerometer
Altitude (h)	GPS/Altimeter
Bank/Roll Angle (Φ)	Gyroscope
Inclination/Pitch Angle (Θ)	Gyroscope
Azimuth/Yaw Angle (Ψ)	Magnetometer
Roll rate (p)	Gyroscope
Pitch rate (q)	Gyroscope
Yaw rate (r)	Gyroscope
Translation acceleration in x axis (b_x)	Accelerometer
Translation acceleration in y axis (b_y)	Accelerometer
Translation acceleration in y axis (b_z)	Accelerometer

From the 13 flight parameters that were measured in this study, after doing analysis, there are several main sensors that were used, like the accelerometer, gyroscope, magnetometer and satellite navigation.

SYSTEM DESIGN

Data acquisition (DAQ) uses a central processing unit to the process of measuring an electrical or physical phenomenon. Complete data acquisition system consists of sensors, DAQ hardware and a central processing unit with programmable software.[7] A system that is widely used may have many input channels. Typically, the systems take fewer than ten samples per second.[8]

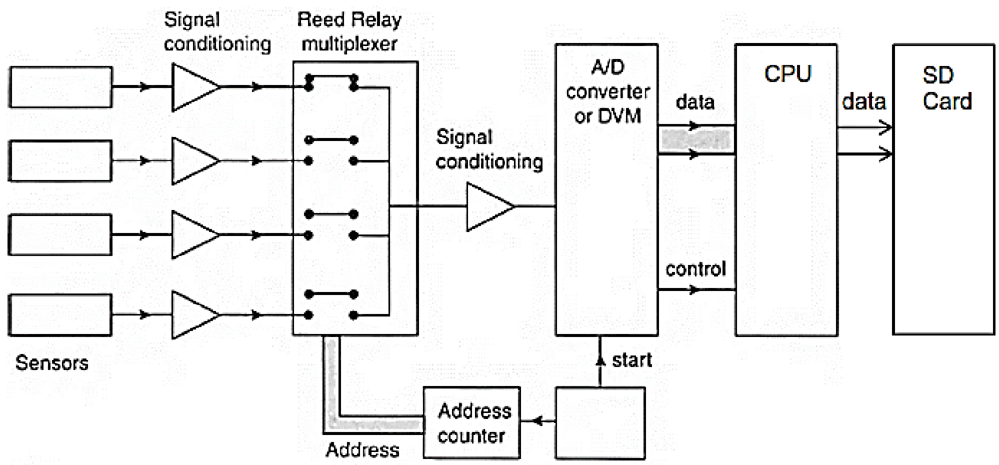

FIGURE 1. General architecture of FDAU's initial design

The following elements commonly found in data acquisition systems are sensors and/or transducers. They are devices which convert the quantity which is to be measured into a proportional electrical signal. Signal conditioning includes all the devices which convert the signal from the sensor to the correct level for the ADC (analog to digital converter) and filter the analog signal. Anti-aliasing filters are used to remove high-frequency signals which cannot be accurately converted. A sample and hold circuit is used before the multiplexer to sample several signal channels simultaneously or before the ADC to prevent the input to it changing while conversion is taking place. The multiplexer (MUX) is a selector switch connecting one channel at a time to the ADC. Central Processing Unit (CPU) is used to process raw data into the values of several flight parameters used. SD Card is used to storing CPU processed data.

KALMAN FILTER

Kalman Filter (KF) is an iterative algorithm which relies on a series of measurement observed over time.[9] The applications of KF encompass many fields, but its use as a tool is almost exclusively for two purposes: estimation and performance analysis of estimators.[10] KF is a complex filter algorithm that takes measurements that still have noise. KF has two steps, namely updating and predicting. First, in the step of predicting data, the filter gives an estimation. The second step is updating. In this step, before the filter retrieves the latest data, the filter compares the results of the updated data with the results of the forecasted data with the Kalman gain. Figure 2 shows the working principle of the KF.

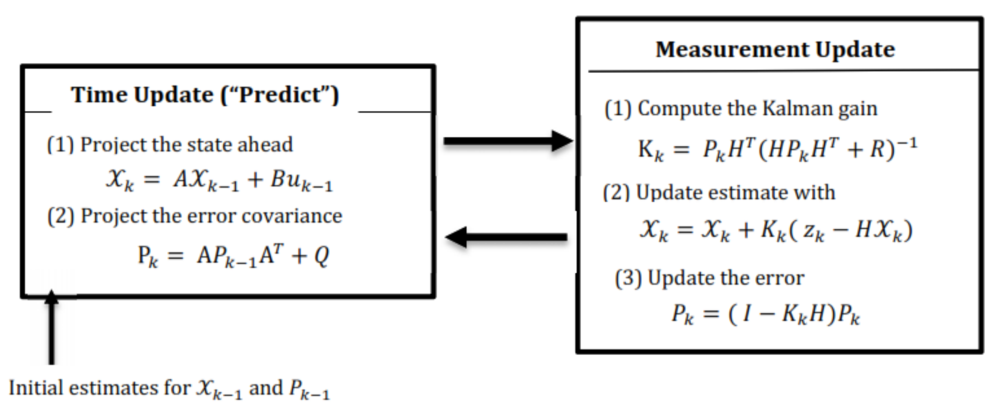

FIGURE 2. Working principle of KF

CENTRAL PROCESSING UNIT

A central processing unit (CPU) is the component in a digital computer that interprets computer program instructions and processes data. CPU provides the fundamental digital computer trait of programmability and is among the essential components in computers. It receives data input, executes instructions and process information. It communicates with input/output devices, which send and receive data to and from the CPU.

For this initial design of flight data acquisition unit (FDAU), Arduino Nano was used as the central processing unit. The specification and schematic diagram of Arduino Nano is shown and described below.

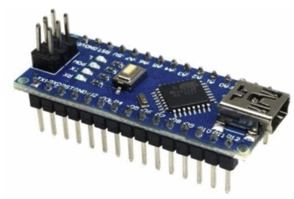

FIGURE 3. Arduino Nano

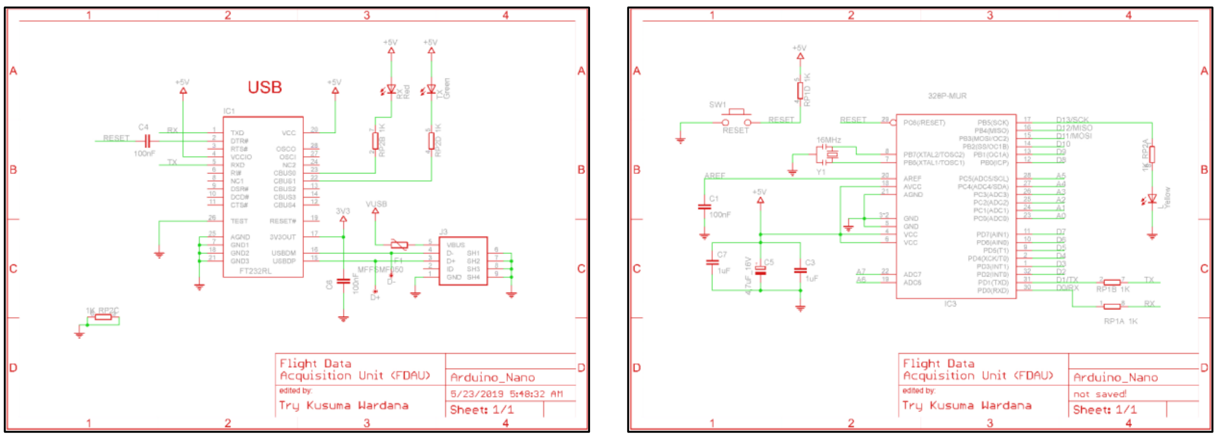

FIGURE 4. Schematic diagram of Arduino Nano

COMMON SENSOR

Inertial Measurement Unit (IMU)

An inertial measurement unit (IMU) is an electronic device that measures and reports orientation, velocity, and gravitational forces through the use of accelerometer and gyroscope and magnetometer. IMU is the main component of the inertial navigation systems used in aircraft, unmanned aerial vehicle (UAVs) and other unmanned systems, as well as missiles and even satellites. The data collected by an IMU is processed by computers to track position through dead reckoning.

For this initial design of flight data acquisition unit (FDAU), MPU-6050 was used as accelerometer and gyroscope sensors and HMC5883L was used as magnetometer sensor. The specification and diagram schematic of MPU-6050 is shown and describes below.

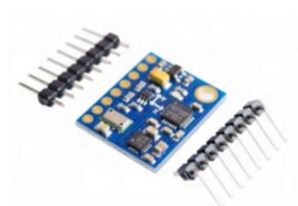

FIGURE 5. IMU MPU-6050

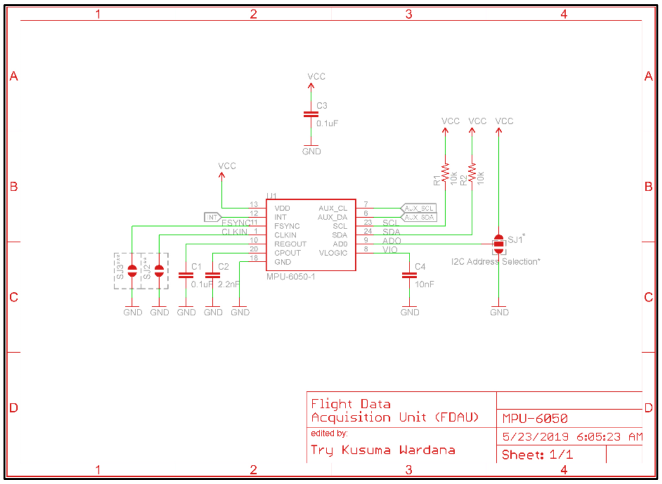

FIGURE 6. Schematic diagram of IMU MPU-6050

Satellite Navigation

A system that uses satellites to provide autonomous geospatial positioning allows small electronic receivers to determine their location to high precision (within a few centimeters to meters) using time signals transmitted along a line of sight by radio from satellites. The system can be used for providing position, navigating, or for tracking the position of something fitted with a receiver.

For this initial design of flight data acquisition unit (FDAU), U-Blox Neo M8N was used for satellite navigation. The specification and diagram schematic of U-Blox Neo M8N is described and shown below.

FIGURE 7. U-Blox Neo M8N

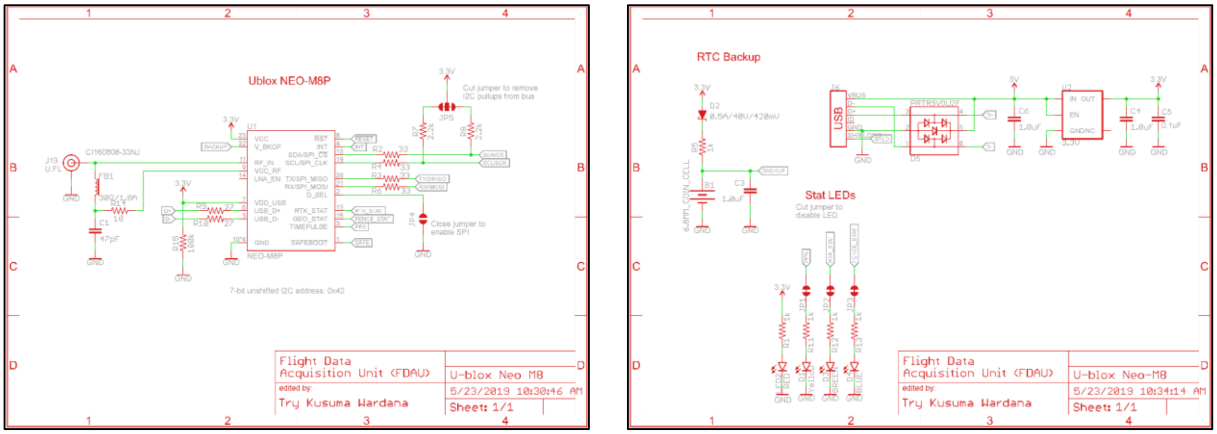

FIGURE 8. Schematic diagram of U-Blox Neo M8N

SOFTWARE DESIGN

The overall system software design is shown in Fig. 9. It consists of processing system input data and calculations to obtain the values of various flight parameters derived from sensor raw data. Data input system processing includes processing input data from IMU.

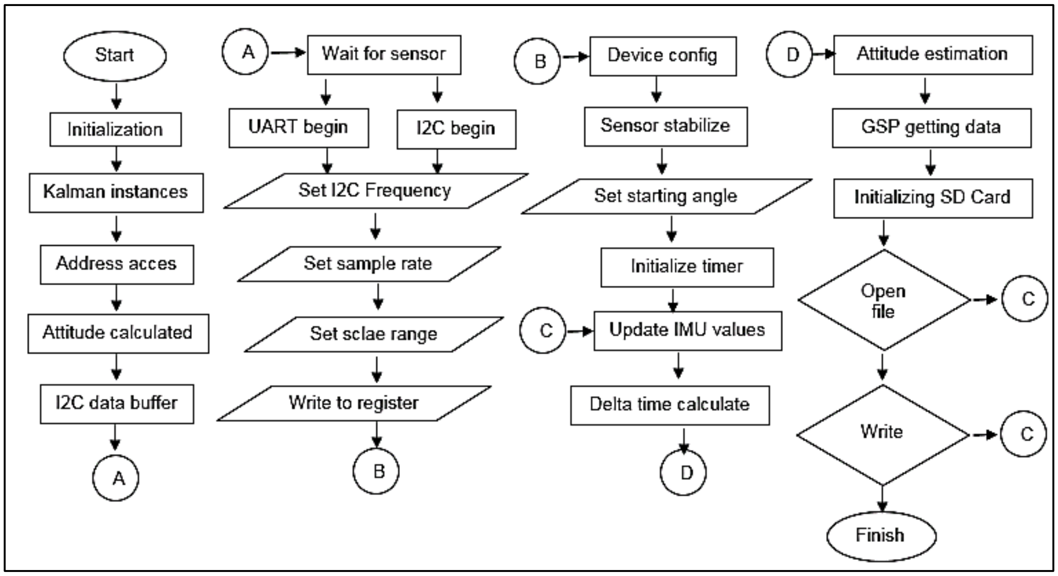

FIGURE 9. Data flow diagram of FDAU's initial design

The processing of the IMU input data; the reading data from the instruments in it, such as the accelerometer, gyroscope, and magnetometer was processed in such a way that it can be obtained from the plane's attitude angles, such as roll, pitch, and yaw. IMU input data processing was done by entering the sensor data readings to the IMU as shown the algorithm (Fig. 9) and perfected with the Kalman Filter that was made before.

In the Kalman calculation process, there are 3 inputs, which are the angle of the accelerometer, the gyroscope angular velocity, and the sampling time used and the noise found on the known sensor based on reference Q_angle, Q_bias, and R. On the first process state estimation was done, the angle used came from the accelerometer sensor reading and the rate used came from the gyroscope sensor reading. The second process is a noise prediction calculation process, where a bias value used, which was reduced by a bias value based on time, so that the reduced bias was obtained. And then, it was added to the accelerometer noise so that the prediction error was known at state K-1. The third process is a process where error prediction was performed to measure error predictions. The measurements here were used to determine how big is the calculation value of Kalman gain, where Kalman gain was used to update the angle value and the bias value of the state by multiplying the Kalman gain with innovation. Innovation itself is a process of calculating the difference between the reading of the measurement angle and the reading of the previous angle.

EXPERIMENTAL SETUP

IMU sensors used in this study were accelerometer and gyroscope sensors type MPU6050 and magnetometer type HMCL5883L. The IMU sensor read the attitude and the heading of the plane, for the situation 2 axis were used, x-axis and y-axis, while for the flight direction the z-axis was used. The movement of the plane on the x-axis was rolled, the movement on the y-axis was the pitch, and movement in the z-axis was yaw. IMU calculated the angle of movement of the aircraft against the three-axis to be able to know the state of the aircraft during flight.

TABLE 2. Raw data vs Kalman filter data.

Raw Data	Kalman Filter
-0.96	-0.77
-0.75	-0.77
-0.88	-0.77
-0.6	-0.78
-0.64	-0.78
-1.16	-0.79
-0.89	-0.79
-1.03	-0.8
-0.83	-0.8
-0.42	-0.8
-0.79	-0.81
-1.07	-0.82
-0.95	-0.82
-0.83	-0.82
-0.87	-0.83
-0.54	-0.83
-0.45	-0.84
-0.62	-0.84
-0.68	-0.84
-0.96	-0.85
-1.04	-0.85
-0.7	-0.86
-0.77	-0.86
-0.73	-0.86
-0.55	-0.87

Raw sensor data were processed in the central processing unit (CPU) using Kalman Filter concept, the results showed that Kalman Filter data has better quality than raw sensor data.

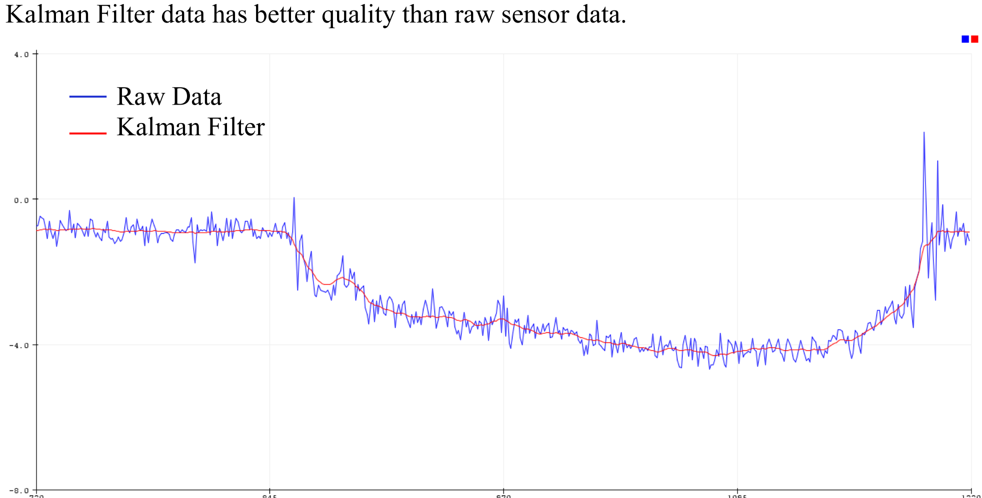

FIGURE 10. Graph of raw data and Kalman filter data

Satellite navigation position in x-, y-, and z-axis (x_g, y_g, z_g) and altitude (h) data were obtained from satellite navigation sensor/global positioning system (U-Blox Neo M8N). Those were raw data from satellite navigation sensor. Bank/roll angle (Φ), inclination/pitch angle (Θ), azimuth/yaw angle (Ψ), roll rate (p), pitch rate (q), and yaw rate (r) data were obtained from gyroscope sensor. Roll, pitch, and yaw angle data were obtained by integrating the gyroscope data (raw data) once, while for roll, pitch, and yaw rate data was obtained from raw data of the gyroscope sensor. Translational acceleration in x-axis (b_x), y-axis (b_y), and y-axis (b_z) data are obtained from the accelerometer sensor. Those data are raw data from the accelerometer sensor and no processing required.

	A	B	C	D	E	F	G	H	I
1	roll angle x	roll angle y	roll angle z	roll rate x	roll rate y	roll rate z	accel in x	accel in y	accel in z
2	-1.94	-2.72	-36.26	3.46	-2.00	0.31	660.00	-564.00	14484.00
3	-1.81	-2.79	-36.26	3.66	-1.79	0.14	728.00	-460.00	14420.00
4	-1.80	-2.84	-36.27	0.04	-1.79	0.01	860.00	-432.00	14392.00
5	-1.80	-2.90	-36.28	0.24	-1.72	0.12	728.00	-492.00	14504.00
6	-1.68	-2.96	-36.29	3.76	-1.79	0.22	772.00	-624.00	14476.00
7	-1.56	-3.01	-36.30	3.80	-1.79	0.13	824.00	-572.00	14520.00
8	-1.57	-3.07	-36.32	0.00	-1.85	0.05	696.00	-672.00	14372.00
9	-1.47	-3.13	-36.23	3.44	-1.76	3.89	756.00	-664.00	14576.00
10	-1.37	-3.18	-36.25	3.50	-1.82	0.11	656.00	-544.00	14516.00
11	-1.25	-3.23	-36.30	3.77	-1.50	0.18	772.00	-620.00	14624.00
12	-1.16	-3.28	-36.34	3.57	-1.71	0.37	812.00	-764.00	14416.00
13	-1.05	-3.33	-36.37	3.80	-1.80	0.13	736.00	-504.00	14428.00

Sheet1

FIGURE 11. Data record format

CONCLUSION

The initial design of the flight data acquisition unit was completely fabricated from a popular component on the market, which reduced both system cost and implementation time. FDAU has better data produced than raw data produced by the sensor. This FDAU can also get some flight parameters that are not obtained from the raw sensor data but through processing. The FDAU combines a large variety of sensor streams into a unified state data stream which recorded for later aerodynamics analysis while simultaneously forward the data to a separate processing unit.

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