ON-BOARD DATA PROCESSING AND FILTERING

Marc Faber

Zodiac Data Systems GmbH

Friedrich Ebert Strasse 75, D-51429 Bergisch Gladbach, Germany

ABSTRACT

One of the requirements resulting from mounting pressure on flight test schedules is the reduction of time needed for data analysis, in pursuit of shorter test cycles. This requirement has ramifications such as the demand for record and processing of not just raw measurement data but also of data converted to engineering units in real time, as well as for an optimized use of the bandwidth available for telemetry downlink and ultimately for shortening the duration of procedures intended to disseminate pre-selected recorded data among different analysis groups on ground.

A promising way to successfully address these needs consists in implementing more CPU-intelligence and processing power directly on the on-board flight test equipment. This provides the ability to process complex data in real time. For instance, data acquired at different hardware interfaces (which may be compliant with different standards) can be directly converted to more easy-to-handle engineering units. This leads to a faster extraction and analysis of the actual data contents of the on-board signals and busses.

Another central goal is the efficient use of the available bandwidth for telemetry. Real-time data reduction via intelligent filtering is one approach to achieve this challenging objective. The data filtering process should be performed simultaneously on an all-data-capture recording and the user should be able to easily select the interesting data without building PCM formats on board nor to carry out decommutation on ground. This data selection should be as easy as possible for the user, and the on-board FTI devices should generate a seamless and transparent data transmission, making a quick data analysis viable.

On-board data processing and filtering has the potential to become the future main path to handle the challenge of FTI data acquisition and analysis in a more comfortable and effective way.

Keywords: On-Board Processing, Data Reduction, Telemetry Downlink, Faster Post Processing, Engineering Unit Data Conversion, Event Identification, On-Board Quick Monitoring

INTRODUCTION

On-Board Data Processing

The on-board data processing has been a well-established method in every aeronautical or space system for many decades in many ways of aircraft control or operations. In the TT&C (Telemetry, Tracking & Control) units redundant data processing systems provide:

- reception, error correction and decoding of telecommands, storing and forwarding them to the avionic components,
- measurement of discrete values such as voltages, temperatures, binary statuses, extracting them from data busses,
- reduction the amount of raw data generated by modern instruments through various signal processing and compression techniques to be able to transmit them to the ground in an efficient manner,
- real-time buffering of the measurements in a data pool, collation and encoding of pre-defined telemetry frames, storage and downlinking them to the ground,
- management and distribution of absolute time or some kind of reference time,
- substantial digital signal processing capability for controlling the communication channels,
- processing capability to achieve the aims of the mission, often using the data collected.

This article targets on-board data processing during aircraft operation such as flight testing or health and usage monitoring.

Flight Test Systems

The traditional Flight Test Instrumentation (FTI) involves acquiring measurements from various sensors and collecting data from other on-board sub-systems (e.g. data buses) with some kind of coherent time stamps. This data is typically pre-processed (filtered, compressed) in such a way, that some selected and bandwidth critical data formats can be created for telemetry downlink (e.g. PCM frames). Typically, all collected data is formatted for on-board recording (usually in some packetized data format).

Over the last decades, more advanced on-board data processing methods have been made operational – where real-time on-board test monitoring is also possible. The tests are monitored by flight test engineers on board with the help of complex flight test computers. These flight test systems are available on larger civil and military aircrafts, where the available space and weight of the flight test systems are not a constraint.

The flight test systems of smaller aircraft are often limited to a PCM system and telemetry transmitter for transmitting critical parameters to the ground for real-time monitoring, and a bulk data recorder which records all available data on board for later post-processing analysis.

As technology advances, the benefit of the on-board data processing methods can be migrated from the large installations to smaller flight test systems. This article aims at identifying on-board data processing methods that can be efficiently integrated into a compact flight test system installation.

Flight Test Data

There are different layers of data during FTI. Various classifications are used by different operations. In the following, these are grouped from a data processing point of view:

Test Parameters

For flight test engineers, some physical values are always of interest, e.g. temperature, structural load, vibration, etc.

In some cases these parameters can be determined indirectly by measuring a given signal – e.g. the measured temperature or pressure at a given location – by placing a sensor in the proper position. The sensors typically convert the measured parameters to another physical unit – mostly electrical – with some delay and inaccuracy, but these can be taken into account in the further calculation.

In most cases though, the test parameters cannot be directly measured – they have to be calculated from the measureable signal. They may need to be calculated from a single signal: e.g. minimum or maximum value of a given time period, a mean or RMS value of the signal, or some values in the frequency domain. But often the test parameters have to be computed from multiple measured signals. For these calculations the measured signals may have to be filtered, interpolated in time, up/down sampled, etc. before using them in simple or complex mathematical calculations: e.g. power calculated from voltage and current, frequency or phase difference calculated by FFT.

The FTI engineer defines which signals shall be measured to be able to calculate all necessary test parameters, and how this calculation will be carried out.

Measured Signals in Engineering Units

Numeric values in engineering units are the results of directly measurable signals. This is the format a flight test engineer can directly understand and interpret.

On the other hand, the measurements themselves are carried out by sensors, which typically output some electrical signals as the physical value changes. These electrical signals are converted to digital counts in order to be able to transmit, store or process them in a straightforward fashion and with higher transmission fidelity.

The sensors and the measurement systems are not ideal. Therefore, sensor or system calibration corrections may need to be taken into account in order to finally arrive at measurement values with the required accuracy. This calibration process uses sensor calibration data bases.

Raw data

The raw data is the output of the electrical signal digitalization process by a data acquisition unit (DAU), or an output of another sub-system (e.g. data bus). This data is coded in different formats – including fix or floating point representation, bit numbers, signed / unsigned coding, lookup tables and non-linear coding. Sometimes the values are divided into separate fields, and field concatenation is needed to gain them back. One goal of these methods is to get the information coded by the lowest number of bits possible.

The raw data is typically represented by one or more integer values (even if the format is a floating point number).

The Interface Control Documents (ICDs) of the DAUs and sub-systems define the relationship in engineering units between raw data and measurement signals.

BENEFITS OF ON-BOARD DATA PROCESSING

Wherever sizeable digital signal processing is involved to collect high-quality raw data, we consider a system as having on-board processing capability when data handling goes beyond creating, transmitting and storing raw data.

There are systems targeting on-board data processing already available on the market. However, they are typically dedicated to one special test [1].

Data Reduction for Telemetry Downlink

Data transmitted from air to ground via telemetry shall be carefully selected. Typically all data is recorded on board, but only test critical raw data is selected for transmission due to telemetry bandwidth limitations.

On the other hand the raw data acquired from single measurements are not always the most adequate for evaluating the results of the test, but the actual test parameters instead. If data processing allows to calculate the values of the actual test quantities, the amount of information delivered by telemetry can be dramatically increased while using the same bandwidth.

For further data reduction the results can be converted again back to raw data format to minimize the demand for telemetry bandwidth.

Data processing also allows the possibility to use data compression algorithms (e.g. transmitting only the difference of slowly changing values). Compressed data can be used to improve the usage of the limited bandwidth of the telemetry downlink.

Telemetry Downlink Contents Reconfiguration

Data processing provides the ability to change the contents of the telemetry downlink data stream ”on the fly”. This can be triggered by events, configurable measurements or data analysis parameters like user definable threshold values.

In the case of analyzed problems like fast vibration changes or unexpected bus messages, the processing unit is able to automatically insert predefined data into the telemetry downlink data stream in a as-needed basis. This can be for example data of adjacent sensors or changes between different video sources.

The identification of the changed data contents can be realized by PCM format change, or by changing the channel or message Ids in case of advanced telemetry downlink methods (e.g. using iNET or IRIG106 Chapter 7).

Faster Post Processing Results

The amount of data recorded on-board is continuously growing. Even with the media download speed increasing and the processing computer’s performance improving, the time needed to download and post process remains significant.

The first target of post processing concentrates in many cases on finding only sections of interest of the whole flight test time – it may include calculation of minimum / maximum values, frequency domain analysis, etc. The goal is to be able to make quick decisions, or localizing the proper area for further analysis.

The on-board processing may help finding these time sections by creating the values of interest already on-board and storing them into a separate file. The download and analysis of these files can be done relatively quickly; the results can be obtained almost instantaneously after a test flight.

Event Identification

Based on real-time processing of raw or calculated data warnings, error conditions or telemetry downlink data stream changes can be defined. These warning and error conditions can simplify the decision-taking during the flight test either on-board (signals to the pilots or on-board test engineers), on the ground (sent these events by telemetry to the ground) or logging them in a file to expedite the analysis during post-processing.

Start of Post-Processing During Flight

Time to getting to results is more and more critical as flight test schedule grows tighter.

To shorten the post processing time, all or a part of post processing can be done already during the flight. The results can be stored on a separate section of the storage medium – and in extreme case the results can already be transmitted during landing and taxiing via airport networks to the processing station.

Data Reduction for Recording

On-board data recording quality, security, capacity, and storage bandwidth is continuously increasing due to technology improvements and to the usage of solid state media – however the system prices for high speed recording and the storage prices remain considerable.

Several well-known data compression techniques have been used for a long time in order to reduce data amount and total recording bandwidth – e.g. lossy or lossless audio or video compression techniques. These are widely spread and already well established methods for data amount reduction. On-board data processing can be used for compression of other data types in a similar way. Typical compression methods are LZ (Lempel-ZIV) or LZX algorithms applicable for all data types, LPCM, CVSD, MPEG3 for analog data, JPEG for images, MPEG-1,-2,-4 or H.261-H.265 for video, etc.

Another standard technique for data reduction is intelligent data filtering. Filtering techniques based on selected bus message identifiers is already widely used. With the help of on-board processing this can be enhanced for advanced filtering based on more complex criteria: including data word level parameter extraction, calculations between values, etc.

On-board Engineering Unit Data Conversion

Whenever a flight test engineer is on board during flight test, his task is to supervise the reliability of the flight test system. For his decisions the measured signals in engineering units (EU) are useful. On-board data processing can provide help at monitoring these values by means of a simple EU conversion of the acquired data (single sensor, or some combination of sensors).

Another useful application is to store the EU converted data during on-board recording already into one or more separate files using another data formats, which post-processing application can directly process. There are many ground data processing systems still in operation which need ASCII text, Excel csv, or MATLAB file format as input for processing data. If processing and storage capability allows for it, the off-line post-processing data conversion of Chapter 10 data to other formats can already be made parallel with raw data recording.

However, for the values to be embedded in the telemetry downlink stream, raw data is preferred.

On-board Quick Monitoring with Low-Processing-Power Visualization Devices

On-board data must be pre-processed in order for it to be used by low-processing-power devices like smartphones and/or tablet computers. Consequently, application software tools running on these devices provide the means for having a quick and easy visual check of data of interest and high priority.

Therefore, in order to realize a comfortable (i.e. mobile) way of easy monitoring and quick data verification, it is conceivable that the requested data be filtered, converted/manipulated and sent to a low-processing-power visualization device.

Data Manipulation for Security Reasons

In many cases the recorded / transmitted information needs to be handled at different classification levels. Data processing needs to generate data streams excluding classified information to be recorded or transmitted (e.g. removing or overwriting some classified messages or only data words of bus traffic). Classified and non-classified data maybe recorded on different media.

DEFINING THE SCOPE AND TASKS OF ON-BOARD PROCESSING ALGORITHMS

Meta Data

An aspect of major relevance at defining the detailed tasks that on-board processing should involve is the language used to define the algorithms. To be able to describe the needed algorithms, the most convenient way for the test engineer is to define the required processing at the test parameter level. The implementation of the algorithm – including the setup of all the measurement system components – shall be automatic, at least as far as possible. This automatic system setup generation requires that the whole flight test instrumentation be defined in some data base – or by some system definition languages. These descriptions are called Metadata – and there is a lot of effort put into creating a metadata language which allows defining the complete FTI system to the furthest extent.

The meta-languages range from simple Excel sheets – which are still widely used in FTI, to TMATS (part of the IRIG106 standard [2] maintained by the RCC), XiDML (an open XML based definition language proposed by Curtiss-Wright), IHAL (a language defined by KBSI), and MDL (a definition language grown out from the iNET program. Currently, an MDL working group – supported by the major aircraft manufacturers – is actively developing this language).

Among all of them, MDL is the most advanced, however a standard has not been finished yet [3]. MDL allows defining mathematical or logical operation on measurements, so it is a good base for describing data processing.

Algorithms

The definition of the on-board processing algorithms typically include standard mathematical calculations – simple equations or more complex function calls (e.g. RMS calculation, FFT, etc) – which can be described by simple mathematical equations. The temporary or final results of the calculations are considered to be new "signals" – which can be used for further calculation, for creating an on-board display, to be used in telemetry downlink, or be added to an on-board recording along with the raw data or be written into a separate file.

A more complicated task is to offer free programmable algorithms to the user. This is usually done by providing to the user some library function for data acquisition, transmission and storage hardware access. The algorithms can be written in a standard programming language (commonly C, C++ or C#) by using its pre-defined library routines. Before the setup of the hardware, the user algorithms are compiled to machine code, and together with the library the code is downloaded to the hardware. These methods need otherwise deeper understanding of the acquisition hardware for the user – and the system designer needs to take precautions to avoid system crash or performance loss in case of programming errors or processing overloads in the user algorithms.

Meta Data Editors

Entering meta data is a complex task for the user. Each metadata definition system has dedicated editors, typically implemented in form of graphical user interfaces (GUIs). Currently, MDL can be edited by the "Configuration Manager" tool – which is not yet fully developed as a GUI.

Meta Language Compilers

The on-board processing algorithms defined in any meta-language shall be translated to some machine understandable code. The kind of code lies within a wide spectrum of variants starting from binary compiled code machine code, processing definition tables, macro code, or even high level symbolic textual definition of mathematical functions.

DATA STORAGE

Data storage and retrieval is a key component in on-board data processing. Chapter 10 aims to store the data optimized for storage space and speed, while on-board processing calls for quick access of data – possibly already time correlated, as raw data is not necessarily sampled simultaneously at different sources. An iNET type network telemetry concept would really require to store the data into a well indexed real-time data base.

Article [4] analyses these questions in details and tries to find a method by means of which the investments into Chapter 10 technology (hardware and software) shall not be discarded by introduction of network telemetry or on-board processing.

Two ways seem to be workable for handling “big data” for storage and processing by keeping Chapter 10 records available and the same time allowing the new functions:

The first method is to store the data still speed and space optimized according to the Chapter 10 standard, but an additional indexing method allows quick access to the stored data on-board in real-time.

The other is to store all raw data in Chapter 10 format, and an additional, already pre-selected “critical” data set is stored in a real-time data base, which can be easily accessed from the ground, or stored as separate data set even on the recording media.

The first method needs probably less storage and does not required pre-selection of data, but the indexing information is either lost after the system is switched off, or it has to be stored along with the data – which would need a standardization process for how this indexing shall be done.

The second method does need a separate pre-selection, secondary data base handling, but the results of the on-board calculations could be stored also as Chapter 10 data along with the raw data.

HARDWARE IMPLEMENTATION OF DATA PROCESSING

Distributed Processing Architecture

Most of the DAUs, Encoders and on-board recorders are already incorporating powerful data processing capabilities. The internal architecture of these systems is prepared for complex signal processing, calibration, filtering, data formatting and precise time stamping, sometimes supporting various network protocols as well.

This architecture typically reflects an and/or combination of field programmable gate arrays (FPGAs) and general purpose central processors (CPUs) or digital signal processors (DSPs).

Depending on the architecture details, the on-board processing tasks can be divided into sub-tasks: the single signal measurement specific tasks can be carried out by the above mentioned

FPGAs, CPUs or DSPs – while the system-wide processing tasks shall be implemented by the central processing unit of the system, or by dedicated on-board data processor.

This distributed architecture has a lot benefits: all single measurement specific tasks can be handled more efficiently in the processing unit built specifically to handle that specific data type. The data can be prepared and sent to the central processing unit in a unified format (including representation and maybe also unified timing) - simplifying the description of the cross-signal calculations.

CONCLUSION

The time is ripe for introducing on-board processing into smaller flight test installations to help the test engineers take quicker decisions during flight and speed up the post processing as well.

As of today, data acquisition boxes and on-board recorders are featuring sufficient computer power to quickly carry out a relatively high amount of calculations. Even without a powerful on-board computer, distributed on-board processing can be implemented in these devices.

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