DESIGNING AN AUTOMATIC FORMAT GENERATOR FOR A NETWORK DATA ACQUISITION SYSTEM

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ABSTRACT

In most current PCM based telemetry systems, an instrumentation engineer manually creates the sampling format. This time consuming and tedious process typically involves manually placing each measurement into the format at the proper sampling rate. The telemetry industry is now moving towards Ethernet-based systems comprised of multiple autonomous data acquisition units, which share a single global time source. The architecture of these network systems greatly simplifies the task of implementing an automatic format generator. Automatic format generation eliminates much of the effort required to create a sampling format because the instrumentation engineer only has to specify the desired sampling rate for each measurement. The system handles the task of organizing the format to comply with the specified sampling rates. This paper examines the issues involved in designing an automatic format generator for a network data acquisition system.

KEYWORDS

Automatic Format Generation, Network Data Acquisition

INTRODUCTION

Current PCM-based distributed data acquisition systems that are used on many active test programs use either the CAIS bus or an alternative proprietary data bus for communication between the various units in the acquisition system. These systems typically use either a single format to acquire data from all of the units in the system or multiple distributed formats operating on each unit. In either case, a single master format collects the data that is acquired by all of the units in the system.

For a flight test engineer, the process of creating all of these data acquisition formats is one of the most time consuming and error prone aspects of configuring a data acquisition system. Many attempts have been made in the past to automate the process of creating a format. These attempts have typically met with limited success. The most common issue with these systems is that they do not fully encapsulate the rules of the data acquisition system. As a result, the intervention of an instrumentation engineer is required in order to complete the process.

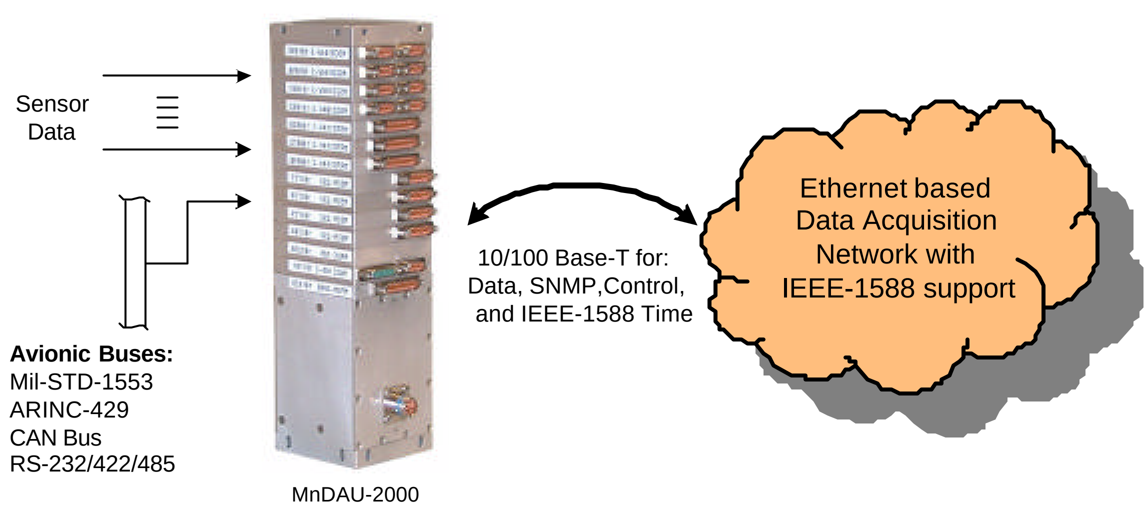
The development of new network-based distributed data acquisition systems provides both users and vendors with an opportunity to reevaluate the use of automatic format generation. Network data acquisition units operate as autonomous systems while receiving time information from a single global time source. In most applications, a network data acquisition system does not need a master format. Another important aspect of the design of a network system is that the configuration of one unit on the network does not effect the configuration of any other unit. This greatly simplifies the process of creating a data acquisition format.

This paper describes the hardware architecture of a network data acquisition unit and the functions that simplify the creation of an automatic format generator. The advantages of automatic format generation and the major software design issues that are involved with creating an automatic format generator will also be discussed.

NETWORK-BASED ACQUISITION UNIT ARCHITECTURE

A network acquisition unit is a system that conditions and acquires multiple input sensor channels with similar or dissimilar data types. The data acquisition unit combines these input channels into data packets for transmission over the network fabric. The network interface also provides the unit with a gateway for setup and configuration, SNMP status and control, and time synchronization using the IEEE-1588 time standard. The unit acquires data from accelerometers, strain gages, various temperature sensors, pressure sensors, synchro/resolver sensors, LVDT, discrete signals, video, and many different types of avionics buses. Acquired IEEE-1588 time is distributed within the acquisition unit for time tagging sensor data and avionics bus data. Time can also be used to trigger time dependent events, such as simultaneous sampling, within the acquisition unit or across multiple acquisition units in the network.

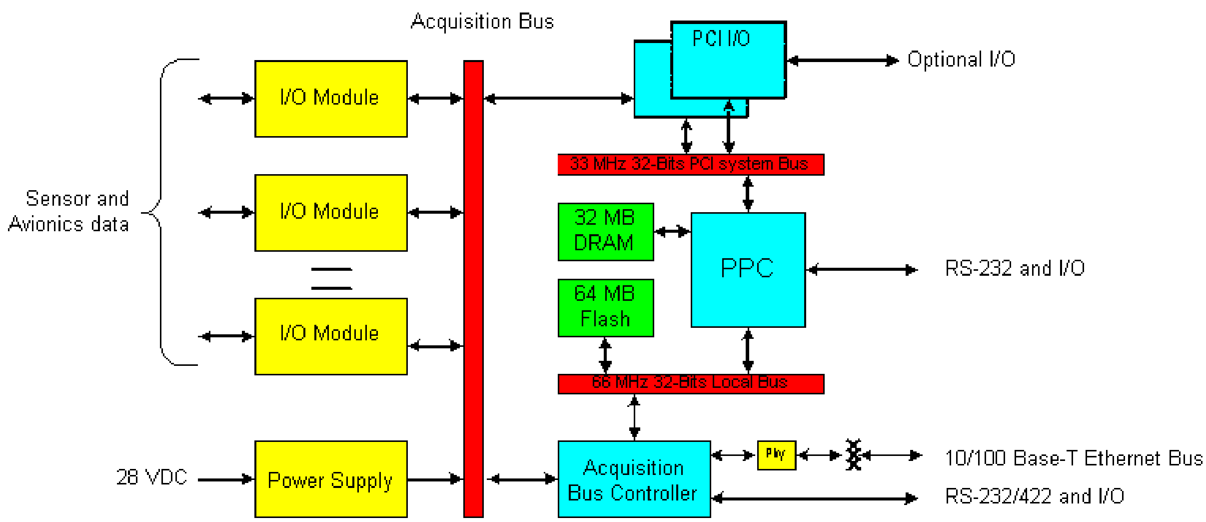
Figure 1. Network Acquisition Unit



The heart of the network acquisition unit is its built-in Power PC processor and its peripherals. The design approach was to devise an architecture that allows for maximum flexibility and capabilities that would have been unimaginable just a few years ago. The architecture shown in Figure 2 includes four core functions to enable data acquisition and automatic format generation:

- The Backplane
- The Processor / Peripherals
- Operating System
- Acquisition I/O modules

Figure 2. Acquisition Unit Architecture



Backplane: Two backplanes were selected as the backbone of the acquisition unit. The first backplane is the 32-Bit / 33 MHz PCI bus. This bus is used with optional modules that require the PCI interface. The second backplane is the Acquisition Bus. This bus is derived from the processor's Local Bus via the acquisition bus controller. The acquisition bus can interface with hundreds of off the shelf acquisition modules that are currently available for TTC's MCDAU system. The Acquisition Bus can also be easily modified to accommodate highly specialized acquisition modules.

Processor / Peripherals: The processor is based on a PowerPC core and includes a 32-Bit PCI controller, DRAM controller, one Fast Ethernet MAC, two UARTs, two IIC Bus Controllers, a Local Bus controller, and other functions. The DRAM controller interfaces with an on-board 32 Mbytes DRAM with a peak data rate of 533 Mbytes per second. The on-board 64 Mbytes Flash includes the operating system, drivers, and applications. The flash memory can also host a web server with programmable and downloadable web pages. The 10/100 base-T Ethernet bus passes through the acquisition controller to the PowerPC's MAC to trap IEEE-1588 time packets. The processor has ample processing power to deliver packetized data to the Ethernet–based network in various packet formats, and to provide customized on-board EU (Engineering Units) processing capability.

Operating System: The network acquisition unit uses a customized Linux 2.4.18 operating system that provides a preemptive kernel with real time scheduling. It provides very good support for the processor and many potential device interfaces.

Acquisition I/O Modules: Acquisition I/O modules interface via the acquisition bus with the processor overhead. The most common bus used by the acquisition unit, is the MCDAU R-Bus, which is used for interfacing with hundreds of TTC's off the shelf data acquisition modules. These modules are currently used in most test flights in the US and around the world. A wide variety of I/O modules exist to interface with analog/digital sensors and avionics bus data sources.

CONFIGURING A NETWORK ACQUISITION UNIT

A network data acquisition unit typically contains an overhead module that provides basic system functionality and one or more I/O modules for collecting data from sensors or avionic buses. Each module in the data acquisition unit is highly customizable. The user can change the behavior of the module to match a desired application by programming the unit with an appropriate configuration. The user can also create measurements to sample data from the I/O modules. For each measurement, the user must specify which channel to sample.

After creating measurements to sample data from channels on the data acquisition system, the measurements must be placed into a sampling format. There are two ways to create a sampling format. The standard approach is to have the user manually assign locations within the format to the measurements. The number of samples and their relative positions in the format determine the measurement's sampling rate and periodicity. The alternative approach is for the user to specify the desired sampling rate for each measurement in terms of samples per second. The automatic format generator can then use the desired sampling rates to create the sampling format without user intervention.

ADVANTAGES OF USING AUTOMATIC FORMAT GENERATION

The primary goal of an automatic format generator is to reduce the amount of information that the user must manually enter for each data acquisition measurement. The automatic format generator accomplishes this goal by eliminating the need for the user to manually place the measurements into the sampling format. The user only needs to enter a desired sampling rate for each measurement. This is much easier than having to explicitly place the measurement into the format at the correct locations to achieve a desired sampling rate. Another major benefit of automatic format generation is that the user does not have to worry about complying with the data acquisition system's rules. The system will only create valid formats. If it is not possible to create a format with the specified set of sampling rates then the system will simply alert the user that the rates are invalid.

When configuring a data acquisition system that contains thousands of measurements, the amount of time that can be saved by using automatic format generation instead of manually creating the format is significant. The user can spend less time preparing to create a new data acquisition system configuration because they do not need to manually analyze the list of required sampling rates before creating the measurements in the system setup software. The user also does not have to determine the system's bit rate or the size of the format before setting up the first measurement. Also, the time spent setting up each measurement can be reduced substantially because the user does not need worry about placing the measurements in the sampling format.

One of the biggest advantages of automatic format generation is that it facilitates the reuse of hardware configurations with different sets of sampling rates and correspondingly different sampling formats. This makes it possible to easily prepare multiple test flights with the same data acquisition hardware but different mission specifications. The ability of automatic format generation to rapidly create a complete and valid sampling format gives the instrumentation engineer several new capabilities. In a manually created format, it is usually not possible to increase the sampling rate of a measurement. Increasing the sampling rate of even a single measurement would force the user to manually redesign a large portion of the format. Since automatic format generation can dynamically recreate the entire format, sampling rates can be changed quickly. New measurements can also be rapidly added to the system configuration without worrying about running out of space in the format. Another benefit is that measurements can be removed without creating wasteful gaps in the format. This reduces unnecessary data bandwidth usage. Conceivably, automatic format generation could even make it possible to make changes to a measurement's sampling rate while in flight.

Automatic format generation reduces the potential for human error during the creation of the sampling format. As long as the user properly specifies all of the desired sampling rates, the software will guarantee that all measurements are sampled at the proper rates. The software can also enforce periodicity requirements and make sure that all of the system's rules are satisfied. During the format generation process, an error log can be easily created if there are any problems. The instrumentation engineer can check this log after the format is created to make sure that the format was generated correctly.

Setting up an automatic format generator in the system setup software is much easier than manually specifying a sampling format. The desired sampling rate for each measurement can be entered while the user is creating the measurement. The user does not need to go to a different screen in the software to place the measurement in the format. Instead, the user can simply wait until all of the measurements have been created and can then run the automatic format generator to create the format.

Increasingly, many users store their system configurations in central corporate databases and use a data interchange format like XML to import the configuration into the system setup software. These users can also benefit from automatic format generation. They can specify the desired sampling rates in the XML file that they generate. By importing this XML file into the setup software, the user can save time by eliminating the need to manually enter sampling rate information. After importing the sampling rate information into the setup software, the automatic format generator can be run to create the format. The XML file can then be updated to include all of the format information. This file can be used to populate sampling information in the central database for use by a ground station or other data analysis software.

HOW AUTOMATIC FORMAT GENERATION WORKS

An automatic format generator must convert a set of desired sampling rates into a valid sampling format. The most commonly used method for executing this conversion is called the power-of-two rule. The power-of-two rule reduces the complexity of this task by restricting the set of sampling rates that are actually used in the format. The key to the power-of-two rule is that all of the measurements are sampled at rates that are related to a dynamically selected base rate by a power of two. For example, if the base rate is 25 samples per second then measurements in the system can be sampled at any rate that is a power of two times 25 (some examples are 25, 50, 100, 200, and 400 samples per second).

The power-of-two rule simplifies the problem of creating a sampling format by reducing the number of different sampling rates that are used in a single format. Since the set of sampling rates that are used in the format is restricted, some or all of the measurements in the system will be over-sampled. The system must select the base rate in order to limit the amount of over-sampling.

Before the automatic format generator can create a format, it must map all of the user specified sampling rates on to the calculated set of sampling rates that are created by the power-of-two rule. For example, if we have a data acquisition system with five measurements, the user might want to sample the measurements at the following rates: 7, 16, 30, 55 and 117 samples per second. These rates have no obvious mathematical relationship with each other, which means that it is probably not possible to automatically create a format that efficiently samples all five of these measurements at these exact rates. The power-of-two rule makes it possible to easily create a format that samples these five measurements at slightly higher rates. To create the sampling format, the automatic format generator must analyze the user specified rates to determine the best base sampling rate. In this case, the best base sampling rate would probably be 8 samples per second. Using multiples of 8 samples per second, the system could map the user specified rates on to the following set of sampling rates: 8, 16, 32, 64 and 128 samples per second. This makes the format easy to create while limiting the amount of over-sampling.

After converting the sampling rates using the power-of-two rule, the format generator must place the measurements into the format at the calculated sampling rates. Before placing any samples into the format, the system must select the appropriate format geometry in terms of words per minor frame and minor frames per major frame. After the format geometry has been calculated, the format generator can place the measurements into the format. The format generator begins by placing the measurements that must be periodic and have the highest desired sampling rate into the format. The generator can then place all of the other periodic measurements into the format in descending sampling rate order. Next, the non-periodic measurements can be added to any available locations in the format. Finally, the system must calculate the format's bit rate in order to achieve the required sampling rates for all measurements.

AUTOMATIC FORMAT GENERATOR DESIGN ISSUES

Implementing an automatic format generator requires the instrumentation vendor to consider many important software design issues. Most of these issues are related to handling the rules that are imposed by the data acquisition hardware. Other issues arise from specialized requirements for sampling data from certain types of sensors. Another important design issue is that the automatically generated format must make an efficient use of the system's limited bandwidth. This last point is crucial because a format can be created which complies with all of the system's rules but makes inefficient use of the network's bandwidth.

A network data acquisition system imposes several basic rules on the sampling format. If the system is designed to transmit one minor frame of data per network packet then we must ensure that each minor frame contains a reasonable amount of data. If a minor frame is too short, then the system will waste a large percentage of its bandwidth transmitting packet overhead information. We must also keep in mind that there are limitations on the speed that data can be transmitted over the network fabric. This can limit the maximum rate that measurements can be sampled at in a data acquisition unit.

A data acquisition unit typically consists of one or more data acquisition modules. Each module can sample one or more channels of data. Some data acquisition modules have rules that affect their sampling rates. One of the most common rules is a requirement that a fixed minimum amount of time pass between any two samples from a module. This limitation has several causes. Some types of sensors that use AC current excitation require settling time before they can take a valid measurement. Other modules require a fixed amount of time to complete filter calculations. It is also possible for a module to have a single data pathway for all channels. This can make it impossible to rapidly sample data from different channels on the module. Some data acquisition modules that perform digital filtering or other post-data acquisition processing on sampled data have a maximum sampling rate for each channel. An automatic format generator must enforce all of these rules.

When determining the base sampling rates to use for the power-of-two rule, the automatic format generator must take into account several things. Generally, measurements cannot be under-sampled. The user specified desired sampling rate must be treated as a minimum sampling rate for each measurement. Some modules also have rules that limit over-sampling. For example, some FIFO based I/O modules can require that their data not be over-sampled.

An automatic format generator must be able to sample measurements periodically. Some measurements require periodicity because they use a digital filter to process the data before it is output to the format. The digital filter will produce invalid results if the input samples are not periodic. The user may also want to sample other types of data periodically so that it will be possible to perform a Fast Fourier Transform during data analysis. In order to place measurements into the format periodically, it is essential for the automatic format generator to determine the format geometry before placing any measurements in the format.

Another issue that factors into the design of an automatic format generator is the ability to handle formats that contain both very high data rate measurements, like embedded video, and very low rate measurements, like system status words. Since the total number of words in a major frame is limited by the data acquisition hardware and the need to transmit the minor frames over the network, it is sometimes not possible to create a format that accommodates both high and low rate measurements. To overcome this limitation, the designer of the format generator will need to consider several possible solutions. One solution would be to make the format large enough so that the lowest rate measurement takes exactly one word per major frame. Another solution would be to over-sample the low rate measurements so that they can fit into a reasonably sized format that also accommodates the high rate measurements. A third solution would be to sample the high rate measurements non-periodically. This allows the system to place more samples of the high rate measurements into the format without increasing the format size.

One of the most difficult issues to address is the need to place groups of related measurements in sequential order within the format. The most common case where this issue occurs is in measurements that contain more bits of data than a single data word. Most data acquisition systems place the most significant bits of the output into the original data word and require the user to sample a special extended read instruction to read the remaining bits. This special extended read instruction typically has to be sampled immediately after the original data word in the format. Some other examples of measurements that are related are messages from a MIL-STD-1553 or ARINC-429 bus. The user might want to sample a set of messages from one of these buses in sequential order in order to simplify data analysis. Another case where the user might want to sample measurements from a module in a sequential block is reading data from an embedded PCM Format created by a legacy data acquisition system. If the data is sampled as a contiguous block, it is easy to extract the embedded minor frames. When assigning sampling rates, the automatic format generator must treat these linked measurements in a special manner. The rate for the first measurement in each group must be used as the sampling rate for the entire block. This rate should be over-sampled if required and then assigned to each measurement in the block. In order to guarantee that there is enough unassigned space in the format; linked measurements must be the first thing that is added to the format. Using linked measurements may result in wasted space in the format because the format will need to be made larger in order to accommodate periodic measurements, which have to be placed around the linked blocks. This should not be a major problem unless the block length of the linked measurements is quite large.

Several additional factors can be considered in order to optimize the sampling format. In terms of optimization potential, the two most critical aspects of the format generation process are the selection of the base rate for over-sampling and the calculation of the format geometry. The base rate must be selected in a manner that limits unnecessary over-sampling. It is important to remember that data bandwidth is wasted every time a measurement is over-sampled. When calculating the format geometry it is necessary to consider the fact that every minor frame that is transmitted contains overhead data that is required for the data acquisition system but is not necessary for the user to complete their flight test. Despite this fact, it is important to break the data into reasonably sized minor frames because of network rules that limit the length of each packet.

CONCLUSION

Designing an automatic format generator is a complex task that requires a careful analysis of the many issues involved in creating a sampling format. In order to be practical, the automatic format generator must require the user to enter as little information as possible. The format generator must create a format that is reasonably optimized without excessively over-sampling any measurements. This format must also comply with all of the system's rules and sample every measurement at or above its user-specified desired sampling rate.

Network data acquisition systems are a new technology for the telemetry industry. Initially, many network data acquisition will be designed to be backwards compatible with existing PCM-based telemetry equipment. This means that while the data-encoding and transmission schemes are different, the basic concept of a sampling format is largely unchanged. Future systems can eliminate many of the issues that interfere with the design of a simple automatic format generator by fundamentally changing the way that the system functions. Since data is transmitted over an Ethernet-based network in data packets, there really is no reason why the data has to be placed into a periodically sampled fixed-length sampling format. Future systems could create different packets for measurements that need to be sampled at different rates. Each packet would contain all of the samples from the data acquisition unit that are sampled at a specific rate. The system could simply generate and send the packet at the appropriate rate. Alternatively, each data acquisition module could buffer a set of measurements from a sensor and package them with a starting time stamp and a time-delta measurement into a data packet. If the user wanted to analyze data from a particular sensor, they would simply have to listen on the network for packets that identify themselves as coming from the sensor. Processing these packets would be easy because the packets contain sensor specific time information.

The development of new network data acquisition systems offers the telemetry industry a unique opportunity to transition from manually created sampling formats to automatically generated formats. The many advantages of automatic format generation and it's potential for reducing the amount of time that is spent configuring data acquisition hardware make this transition an essential step in the technological development of the telemetry industry.

REFERENCES

1. Portnoy Michael. "An Implementation of a Complete XML System for Telemetry System Configuration", Proceedings of the 41st Annual International Telemetry Conference (ITC 2005), USA, October 24-27, 2005.
2. Berdugo Albert, and Roach John, "Migrating from PCM to Network Data Acquisition System", Proceedings of the 26th European Telemetry Conference (ETC 2006) Germany, May 02-05, 2006.
3. Berdugo Albert, and Hildin John "A System Approach to Network Centric Data Acquisition System", Proceedings of the 42nd Annual International Telemetry Conference (ITC 2006), USA, October 23-26, 2006.
4. Portnoy Michael and Pesciotta Eric. "An Implementation of Dynamic Data Acquisition Measurements", Proceedings of the 42nd Annual International Telemetry Conference (ITC 2006), USA, October 23-26, 2006.