Weight Optimization Using Lightweight Data Acquisition Nodes

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Abstract

Instrumenting an aircraft for applications such as Health and Usage Monitoring (HUMS) or Operational Loads Monitoring (OLM) requires the installation of a significant number of sensors to measure vibration and/or strain. The data from these sensors must be gathered to a single point i.e. the line replaceable unit (LRU) that is performing the core function of the HUMS or OLM application. This requires cables, typically shielded twisted pairs that can contribute a significant amount of weight to the aircraft. This weight gain is undesirable, particularly for small vehicles such as UAV's and rotorcraft. In this paper Acra introduces a small, lightweight Remote Data Acquisition Unit (RDAU) that provides interfaces to the common sensor types for HUMS and OLM applications. It performs synchronous sampling, and transports the acquired data over Ethernet to the LRU performing the core function of the application. Example applications and installations will also be comparatively analyzed to highlight the opportunity to achieve weight savings through the use of an RDAU for the remote aggregation and transport of data.

Keywords: Health and Usage Monitoring (HUMS), Operational Loads Monitoring (OLM), Remote Data Acquisition Unit (RDAU)

Introduction

Instrumenting an aircraft for applications such as Health and Usage Monitoring (HUMS) or Operational Loads Monitoring (OLM) requires the installation of a significant number of sensors to measure vibration and/or strain. The data from these sensors must be gathered to a single point i.e. the LRU that is performing the core function of the HUMS or OLM application.

This requires cables, typically shielded twisted pairs that can contribute a significant amount of weight to the aircraft. This weight gain is undesirable [1], particularly for small vehicles such as UAV's and rotorcraft. One solution is a small lightweight Remote Data Acquisition Unit (RDAU) that provides interfaces to the common sensor types for today's HUMS and OLM applications. An RDAU example is shown in Figure 1. It performs synchronous sampling, and transports the acquired data over Ethernet to the line replaceable unit (LRU) performing the core function of the application.

The RDAU supports many different types of sensors. It can have accelerometer, temperature, pressure, differential voltage, quarter bridge and full bridge input channels. Through the use of high speed oversampling Analog/Digital Converters and advanced digital filtering techniques, the user has complete control when defining sample rates. Time correlation of sampled data in the RDAU is straightforward. Parameters sampled at the same rate are sampled at exactly the same point in time – referred to as isochronous sampling. This isochronous sampling holds true for all modules in all chassis for a system, thus it is unnecessary to realign or interpolate samples during analysis. Every analog channel has its own ADC allowing tailored accuracy and bandwidth requirements of a particular sensor or application. Analog circuitry is minimal and incoming signals are digitized early in the signal chain, reducing the noise normally inherent to analog systems. Digital filtering is applied using FIR and IIR techniques for accuracy and repeatability as well as immunity to temperature drifts.

The RDAU gathers the sampled data and sends it to the LRU via Ethernet. Built into the RDAU is an Ethernet network node which is fully IEEE 1588 compliant, meaning all data across all DAUs is synchronized to better than 100ns using the Precision Time Protocol (PTP) [2]. All setup, data acquisition and synchronization is done over a single Ethernet connection.

Figure 1: An example of an RDAU

Weight Reduction

Weight reduction is the primary advantage of the RDAU. *Figure 2* shows a typical system with 9 accelerometers in a remote part of the aircraft connected to a line replaceable unit (LRU). For each sensor a twisted pair is run back to the LRU. With an RDAU the configuration would look more like *Figure 3*. In this case the 9 long twisted pair cables are replaced by 9 short twisted pair cables and a single long Ethernet cable.

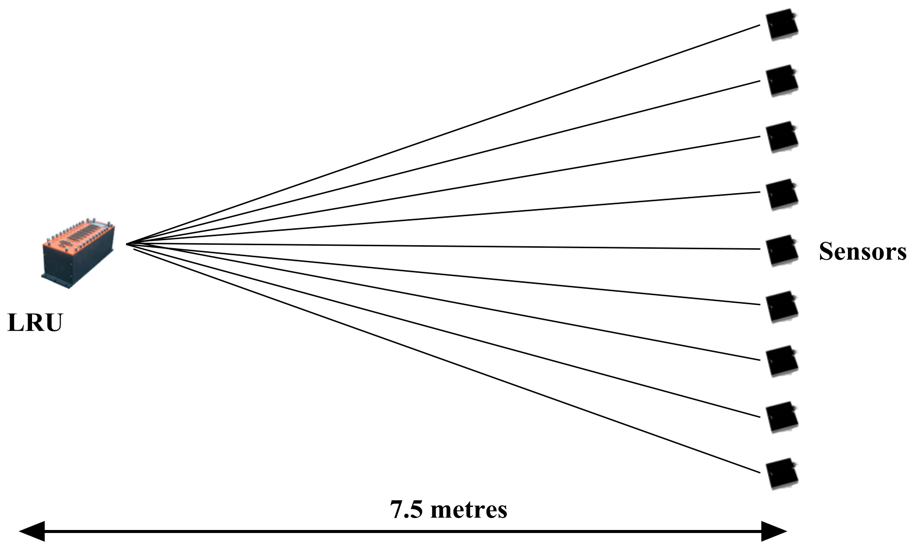

Figure 2: Standard LRU

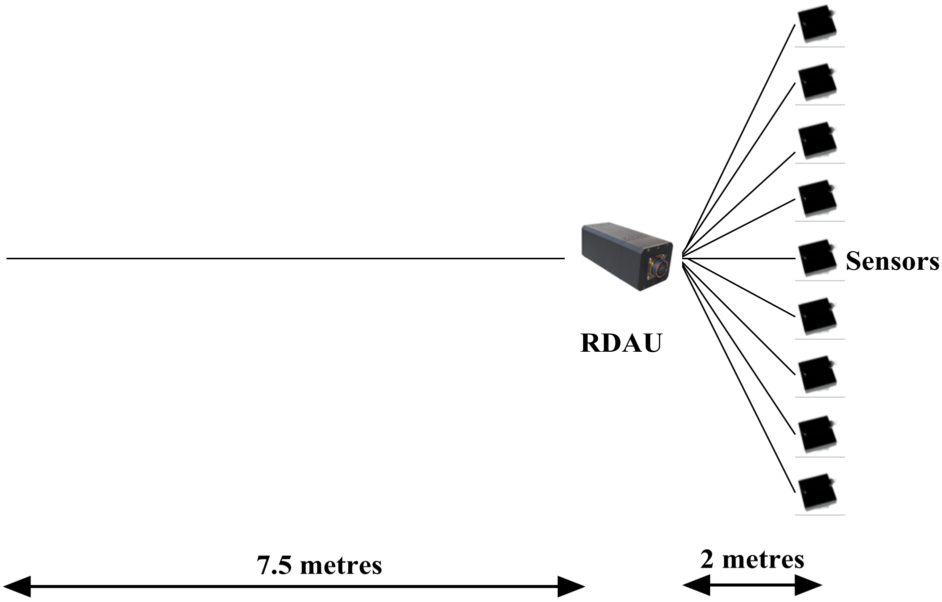

Figure 3: RDAU

The typical weight of a twisted pair would be 19.5 grams per meter whereas Ethernet cable typically weighs 28.5 grams per meter. For example, consider a sample vibration data acquisition system with nine sensors – three rotor accelerometers, gearbox accelerometers and drive-shaft accelerometers. Table 1 shows that the RDAU configuration reduces weight by 30 % (491.5grams).

Table 1: Standard vs. RDAU configuration

Standard Configuration		**RDAU Configuration**	
Wire	Weight (grams)	Wire	Weight (grams)
9x7.5m shielded twisted pair	1,316.25	9x2m twisted pair	351
		RDAU	260
		7.5m CAT5 cable	213.75
Total	1,316.25	Total	824.75

Installation Gains

Apart from reduced weight there are other advantages to a reduction in wiring. Multiple cables will often be bundled together as a loom. Running a long loom across the body of an aircraft can bring challenges.

- They take time to physically route as each cable needs to be pulled through, wrapped and supported. This may need extra design time to determine the cable routes as sometimes it may not be easy due to the circumference of the cable loom.
- They may need to be taken through a bulkhead and if there is not a spare connector, usually for future expansion of systems, then a new hole and connector will need to be made.

- They are also heavy and they need extra support and possibly extra holes drilled in the structure to attach support brackets.
- They are more prone to damage as there is more chance that they are chaffed as they go through lightening holes.
- For thermocouples if the cable back to the LRU needs to go through a bulkhead then a special connector will be required with the pins being the same material as the thermocouple metals.
- They are difficult to rework as a lot of access panels will need to be removed to get access to the cable. Often some extra cables are routed so that they can be used if one of the other cables is damaged. This adds more weight. For a short cable run it is easier to replace a cable and so it is less likely that spare cables are needed.

Replacing a long loom with one Ethernet cable solves many of these problems. Any bore holes required will have a much smaller cross section for an Ethernet cable than for a loom containing multiple cables. Ethernet cables are also very flexible – they have a bend radius of typically 4 times their diameter which allows you to route the cable in such a way as to avoid obstacles or potential noise sources. Using transformer coupling and transient voltage suppressors it is also possible to protect components connected to Ethernet cables from power surges due to lightning. Reduced cable length can also have an effect on accuracy. The RDAU captures and digitizes the analog data much closer to sensors. Running the analog signals over longer cables makes the signal more susceptible to noise and the larger resistance of the longer wires will vary more with temperature and this can degrade accuracy. For a long loom it may not be easy to segregate the loom from a strong noise source – e.g. motors, actuators or antenna. Sometimes there is no option but to route the cable past a transmitter cable. Hence cable segregation is harder to achieve.

Reduced cable length often removes the requirement to use cables with extra cores and therefore extra weight. When measuring temperature using resistive temperature sensors, the effect of the cable resistance needs to be taken into account. If the cable is short then it may be possible to use a two core cable whereas for a long cable then a 3 or 4 core will probably be needed. With full bridges for long cable runs, sense wires might be necessary to keep the bridge voltage at the bridge correct. For a short cable sense wires can be omitted, saving cabling weight.

Adding a new sensor is made easier when using an RDAU. The new cable just needs to run from the sensor to the RDAU rather than the length of the aircraft. Even in the event where the max IO of an RDAU is exhausted, the RDAU need only be replaced with a slightly larger version with more IO or 2 RDAUs can be aggregated using a small rugged switch. In both cases the wiring across the vehicle is not affected.

Ethernet

Transporting the data from the RDAU using Ethernet offers many advantages. Ethernet is an open standard which is widely adopted. This means the output of the RDAU can be passed directly and without the need for further processing to any COTS Ethernet equipment for monitoring, recording, switching or aggregation. The output of the RDAU can be added to other streams from other DAUs or RDAUs on the aircraft using a network switch. It can also be recorded in PCAP format using an IP recorder or simply viewed on any typical laptop.

Ethernet also offers high bandwidth – in this case the RDAU uses 100 Megabits per second Ethernet (upgradable to 1 Gigabit speeds). Ethernet also offer the possibility of Power over Ethernet removing the need for a separate power cable to power the RDAU.

Ethernet also offers precision synchronization of data using [2] IEEE 1588. This is a high level protocol (also referred to as Precision Time Protocol or PTP) that permits one node on a network to become a time master (called a Grand master clock), and describes how that node can then distribute time accurately to all other nodes. The protocol addresses transmission delay issues and transmission of time through network switches. Using IEEE 1588 all data across all DAUs is synchronized to better than 30ns.

Conclusion

The use of a RDAU which is a common configurable COTS hardware which is available today can reduce the cost of purchase, cost of ownership, support, reliability and maintainability of a program's requirements. Furthermore, it also offers the possibility to upgrade to new technologies and alter the systems application by virtue of their modular nature and the commonality of hardware. The examples highlight how an RDAU can not only meet the requirements of a DAU program but provide significant weight reduction and installation benefits. Future applications, such as usage monitoring or testing aircraft modifications, could easily be facilitated by simply altering the RDAUs interfaces – if so required. The cost saving from hardware, training, qualification, testing etc. are significant compared to bespoke systems.

The future prospects of fully integrated, smart systems are exciting with the potential for more detailed data with positive implications for flight safety and maintenance programs. Such rapid developments can be exploited by DAUs that are designed to facilitate a future upgrade path via modular replacements. However, these may be some time off and are likely only in new airframes. Many aircraft operators, military and civilian, are keen to collect data with the least number of wires and lowest weight. COTS solutions offer both current affordable ways to do this and the ability to be upgraded or integrated with next generation systems as they are adopted. Integrated systems will likely still use line replaceable units (LRUs) over an Ethernet bus as these are already being introduced on next generation airliners like the Boeing 787.

References

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