Wireless Sensor Units for HUMS Data Acquisition

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Abstract

This paper describes the wireless architecture developed for Honeywell ECA HUMS systems. This wireless architecture provides all the traditional benefits of wireless technology, such as decreased weight, simplified installation, and improved maintainability. In addition to these compelling benefits, wireless connectivity also enables expansion options for current and new HUMS installations beyond what the HUMS box itself provides. This is achieved through a clever architecture consisting of a wireless concentrator unit (WCU) communicating with wireless sensor units (WSU). The WCU communicates to the HUMS box via an Ethernet connection and standard protocols. Each wireless sensor unit consists of multiple analogue-to-digital converters capable of supporting the data acquisition needs of HUMS applications. Adding multiple WSUs to a single HUMS+WCU installation provides significant I/O expansion capabilities for existing HUMS installations. In addition to describing the overall HUMS wireless architecture, this paper discusses some of the aspects of technology development that supported this work. The paper describes work related to power optimization of the WSUs to enable the possibility of self-powered nodes. The paper will also discuss elements of data time stamp synchronization across multiple WSUs as well as sensor inputs directly into the HUMS system.

Keywords: Wireless Sensors, Power Optimization, Measurement Synchronization

Introduction

Health and Usage Monitoring Systems (HUMS) have become invaluable enablers of rotorcraft safety as well as condition-based maintenance [1]. HUMS systems consist of a HUMS processor, which may be permanently installed or portable. In some HUMS systems the processor connects to the various digital buses on-board the platform (e.g. Arinc 429, MIL-STD-1553, etc.). On rotorcraft, HUMS systems generally include a collection of accelerometers, tachometers, and blade tracker(s) to measure the dynamic behaviour of the airframe, rotor(s), bearings, gearboxes, and other components. These sensors are located in many different places around the helo to maximize their sensitivity to the movements of the various components. Data collected from all of these sensors must be relayed back to the HUMS processor for analysis. Communication between the HUMS box and the various sensors is achieved via a wired connection. In a HUMS installation, hundreds of feet of wiring may be required. This wiring constitutes a substantial part of the overall HUMS system weight. Similarly, a substantial part of the HUMS system installation results from running and securing wiring. In addition, the extensibility of a HUMS system may be limited by the number of physical interfaces to connect with new sensors. There are potentially great gains to be had by introducing wireless technology into HUMS. As part of the Efficient Systems and Propulsion for Small Aircraft (ESPOSA) program, Honeywell has been developing the necessary technology to support a wireless-based HUMS system architecture. This paper will describe the architecture as well as some of the drivers behind the decisions. It will also briefly discuss some of the technical background work involved in developing the prototype.

Wireless HUMS Architecture Considerations

There is a fairly extensive list of requirements that must be satisfied if wireless technology is to be incorporated into a HUMS system. These requirements have been considered critical-to-success factors during the wireless HUMS architecture development. One of these factors is referred to simply as – silence. The military constitutes a very large portion of existing HUMS users. Mission security is of paramount importance to this user base. It is crucial that transmissions from wireless HUMS components may be proven to be turned off when they not intended to be active to avoid creating an unwanted signature that may expose the helo and its passengers to unfriendly engagement. Another aspect of security to be considered is that of the wireless connection itself. Military users in particular may be interested in the implications of attackers gaining access to the HUMS wireless network or being able to sniff packets being sent over the wireless connection. These threats may be of different levels of concern. There may or may not be very much concern if an outside party can see the commands to a wireless sensor node and the returned data back to the HUMS processor. However, it might be much more concerning if an attacker can gain control of a HUMS box that has connections to the various digital buses on-board the aircraft, though in many cases HUMS units are low design assurance level systems that do not connect to critical aircraft buses anyhow.

Another crucial requirement unique to HUMS wireless systems relates to the types of advanced algorithms HUMS units are capable of performing. Such algorithms, like synchronous time averaging, for example, rely on being able to align speed and vibration measurements sufficiently accurately so the averaging does not excessively attenuate the signals of interest. A distributed HUMS architecture, such as that provided by a wireless HUMS architecture, enables the possibility that a user may want to collect data with an accelerometer and align that with data from a tachometer that was collected by a different physical system entirely, with its own clocks. These clocks will include an offset and drift from each other. The wireless HUMS architecture must ensure sufficient synchronization capabilities between disparate data collection points to still achieve the performance afforded by the existing HUMS systems.

Some of the other crucial success factors are a bit more generic, but important. There can be no reduction in data quality using the wireless system. Customers expect a level of data quality from existing HUMS installations, and that cannot be compromised just to achieve wireless. Also, data integrity must be maintained. The collection and transmission of data must be guaranteed as though a wired connection were present. In addition, the mechanical design of the wireless system must be commensurate with the benefits it is trying to provide (e.g. it should not add excessive weight, be too difficult to install, etc.). Furthermore, the mechanical and electrical design of any specialized wireless equipment must meet the relevant standards for the intended operational environments.

Wireless HUMS Architecture Technical Challenges

There were a few particular technical challenges that needed to be addressed specific to wireless technology incorporation into HUMS. One of the first questions that arises in design of wireless applications is the reliability of the wireless connection. HUMS systems must get the data they expect to get. It may be possible to retain non-volatile memory at the remote end of the wireless connection to be able to retrieve data in the event of wireless communication failure, but this is a clumsy and frustrating approach. It is much better to ensure that data arrives “over the air”. Generally speaking, it was not seen as crucial to ensuring data delivery on a low latency basis. Rather, it was deemed more crucial to ensure delivery within a reasonable amount of time. Therefore, technologies and protocols that use mechanisms such as packet retransmission were seen as viable means to achieve the required reliability. Another more practical implication of reliability is the performance of the wireless architecture in a real operating environment. Can a wireless node bolted to the outside of the helo skin near the tail rotor reliably communicate with another wireless node centrally located inside the aircraft? Is this communication reliable in all operating conditions (on the ground, in hover, in flight, near metallic and non-metallic structures, etc.)?

Another consideration with use of wireless technology is the sufficiency of the bandwidth of the technology. The wireless architecture must support transmission of the appropriate amount of raw data in a reasonable amount of time to enable algorithms which require raw data comparison between sensors. Furthermore, a centralized wireless receiver communicating with several wireless sensor nodes must be able to receive the data at a sufficient rate such that all wireless sensor nodes may offload their data in a reasonable amount of time and such that the data is available to the HUMS processor in a timely manner. As mentioned previously, immediate reception of collected data by the HUMS processor is not essential, but reception of the data in a reasonable amount of time is. Therefore, the wireless technology should support sufficient bandwidth to ensure the HUMS processor can receive the desired amount of data from wireless sensor nodes in a reasonable amount of time.

As mentioned earlier, synchronization between data collected from different wireless sensor nodes can be important as well. At the outset of the project, the general belief was that existing commercial wireless technology would not be capable of synchronizing the wireless sensor nodes to the microsecond-level synchronization it was anticipated such systems would require. As part of the ESPOSA project, Honeywell is exploring ways to achieve such a level of synchronization using the wireless technologies available to support this architecture. The prototype architecture of the Honeywell wireless HUMS system provides a way to avoid this concern entirely in certain circumstances.

One last technical challenge that will be discussed here relates to powering the wireless sensor nodes. Currently sensors derive their power from the HUMS box. To completely “cut the cord” between the HUMS processor and the sensor nodes, power must be addressed as well. There are a few different scenarios possible to provide power to the wireless sensor nodes. First, long-life batteries may be utilized. This is a relatively simple solution, but adds weight to the wireless sensor nodes, requires periodic replacement, increases the system cost, and is less desirable than a battery-less solution. One other potentially simple solution is to tap into power sources in the immediate vicinity of the wireless sensor node. The general impression is that there is enough power cabling around the aircraft that this approach would still permit the wireless sensor nodes to have minimal wiring compared to the current installations. Finally, it is possible to consider powering the wireless sensor nodes using energy harvesting techniques. This is quite attractive in terms of an “indefinite” lifetime and requiring truly no wiring to be installed when the wireless sensor node is installed. Furthermore, the system remains fully isolated from the aircraft power distribution system. However, energy harvesting is still a relatively young field; a good deal of technology maturation would be required before energy harvesting could support an application such as is intended here. As part of ESPOSA, Honeywell was careful not to preclude any of these methods to power the wireless sensor nodes. This will be described in more detail in the next section.

Honeywell Wireless HUMS Architecture

The architecture designed by Honeywell to satisfy the requirements for the wireless HUMS architecture is shown below in Fig. 1. The design consists of two main architectural elements: the wireless concentrator unit (WCU) and the wireless sensor unit

(WSU). A WCU and a collection of WSU's form a wireless sensor network wherein the WCU acts as a base station providing network coordination, bridging between the HUMS unit and the WSU's, and data aggregation. Each WSU has interfaces for multiple sensors as well as for multiple power source types. The WCU and WSU's communicate over a low-rate wireless personal area network as specified by IEEE 802.15.4, having a maximum data transfer rate of 250 kb/s. A custom network stack has been implemented to strip out unneeded features.

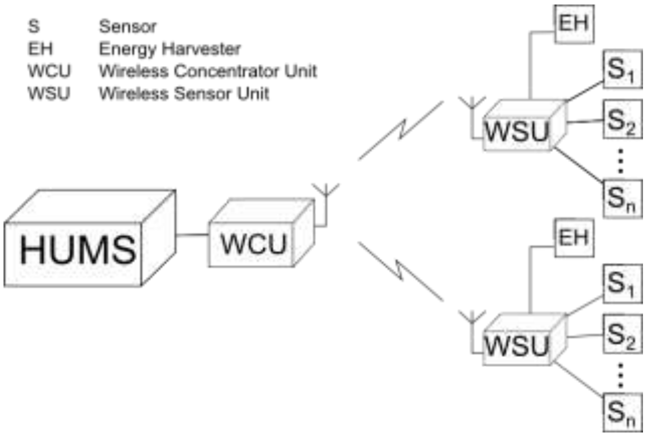

Fig. 1: Honeywell HUMS wireless architecture

The idea behind this architecture is to locate WSU's as close to a collection of HUMS sensors as possible. In this way, while there is some wiring locally between the individual (existing) sensors and the WSU, the total wiring will be much less than running from each sensor back to the HUMS unit. Each WSU is then responsible for sensor data acquisition and for communication with the WCU. Specific to HUMS applications, the prototype WSU's are designed to accept input from multiple accelerometers as well as a tachometer. The design of the prototype WSU's is flexible in such a way that extension to sensing other quantities (temperature, pressure, flow, etc.) will not require a significant amount of redesign. Power use minimization techniques (ultra low power components, etc.) were employed during the design to minimize the load on a battery or energy harvesting system. The WSU software is also written to accommodate software controlled power management schemes. The WSU's are very compact in size and small in weight, with the prototypes weighing just over 100 g. This allows a great deal of flexibility to strategically place the WSU's near a collection of sensors (at the tail rotor, for example).

The WCU has greater responsibility than do the WSU's. The WCU needs to communicate with the outside world, which typically means a HUMS processor (such as the Honeywell Zing 1134) but conceivably could be any outside system if the WCU/WSU's worked in more of a standalone configuration. Communication with the outside world is generally achieved via an Ethernet connection, though provisions have been included in the prototype design to support serial or Arinc 429 communication. In the prototypes that have been built and tested as part of this project, Ethernet connections have been used to communicate between the HUMS unit and the WCU, using standard protocols to facilitate communication.

From a software standpoint, the WCU includes some relevant software constructs found in the HUMS processor. Specifically, the WCU borrowed elements from the HUMS On-Board System (OBS) for measurement control and data management as it relates to governing the behaviour of the various WSU's that may comprise an installation. The prototype WCU has also been programmed with some of the signal processing capabilities of the HUMS processor. This supports the extension of the HUMS system to include additional data sources while providing supplemental processing power to help with the new data processing load introduced by the additional sensors. Furthermore, this allows the possibility that a network consisting of a WCU and multiple WSU's could be used in a standalone fashion and could provide a limited HUMS capability.

As mentioned earlier, in a distributed HUMS architecture, synchronization between measurements taken at different nodes (in this case, with different WSU's) becomes important. With the WSU prototype design, multiple accelerometers may be sampled along with a tachometer, all by the same WSU. If the system installation allows for all vibration measurements and corresponding tachometer measurements to be collected by the same physical unit, then synchronization is not a problem. However, if multiple WSU's are involved, the situation becomes more complicated. Synchronization is difficult to achieve due to clock offset errors (zero order effects), clock frequency disparities (first order effects), variations due to temperature, aging, etc., (higher order effects) and noise.

As part of this project, Honeywell is exploring the conditions necessary to achieve the level of synchronization required by HUMS applications. The HUMS wireless architecture provides many advantages to support the ability to achieve a high level of synchronization, such as commonality in design and performance between different WSU's as well as low variance in signal paths between the various wireless components. Using a combination of clever hardware design and suitable communications protocols, the goal is to allow HUMS systems to use their advanced algorithms on all data, regardless of which hardware collected it.

To date lab testing has been done to evaluate the performance of some of the technical design details of the Honeywell Wireless HUMS system. Lab results have indicated the data acquisition capabilities of the WSU are sufficient to achieve the expected HUMS data analysis goals. Furthermore, in the idealized lab environment, the wireless communication system performed flawlessly (no retransmissions, packet drops, corruptions, etc.), which is expected for a system that needs to perform well in a rather harsh environment. The results from lab testing were acceptable, and the team has conducted a limited set of ground tests on-board a helicopter with the rotor turning. Initial results from these tests have been promising as well, showing a high level of communication integrity as well as good data collection integrity.

Conclusion

There are potentially many benefits to realize by introducing wireless technology into HUMS systems both for retrofit and forward fit applications. Retrofit application benefit from ready expansion of the number of sensors a HUMS system can monitor. Forward fit applications may benefit from the ease of installation and weight savings afforded by wireless solutions. Honeywell has designed and built a prototype of a HUMS wireless system to achieve all such benefits, tackling technical issues such as power management, synchronization, and data integrity that arise in wireless system design. Testing to date has been promising and has shown no technical roadblocks to achieving success.

Acknowledgements

The research leading to these results has received funding from the European Union Seventh Framework Programme (4th call FP7 EU - ACTIVITY 7.1.4. IMPROVING COST EFFICIENCY) under grant agreement n° 284859.

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