NON-TRADITIONAL FLIGHT TEST SENSING SYSTEMS

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ABSTRACT

Traditional flight test sensing applications require installation of not only the sensor but also supporting cabling and interfacing infrastructure. The cost of this supporting infrastructure increases when it must cross pressure vessel boundaries, extend long distances, or interfere with operation of the aircraft. The continuing cost and schedule pressures on flight test programs demand approaches that minimize installation complexity and reduce the need to modify the aircraft under test. Some emerging approaches have leveraged wireless techniques for data transmission but this can only be used in certain circumstances and does not address the problem of power distribution. This paper describes ongoing research into alternative sensing approaches that utilize a mix of video processing, distributed processing, and power harvesting to provide additional solutions.

KEYWORDS

Flight Test Instrumentation, Sensors, Video Processing

INTRODUCTION

Full flight test programs require a significant investment in instrumentation hardware, made up of DAUs, sensors, and infrastructure. Current-generation DAUs are costly, interconnected pieces of hardware specialized for particular tasks, typically built on decades of legacy code. Often, they are unable to adapt to changing flight test needs without extensive rework and possibly the introduction of new, expensive hardware modules.

Smaller flight test programs may not have the benefit of having an aircraft complete with a full data acquisition and telemetry system. Instead, these programs rely on getting the data required for their tests by physically tapping into existing avionics buses on the aircraft. The work required to perform these activities is invasive, time-intensive, and costly.

Both scenarios leave open the opportunity for alternative sensor approaches, using hardware built from commodity parts that can bypass legacy acquisition methods and communication standards in favor of adaptability and agility, while maintaining the sensing accuracy and reliability requirements necessary to supply usable data. This paper explores methods that Southwest Research Institute (SwRI) is actively researching that can exploit the use of these commodity parts to develop a non-traditional DAU.

COMMODITY SENSOR DAU

The commodity parts we are evaluating have been in the hands of hobbyists pushing their boundaries since their initial release, especially the Raspberry Pi, originally released in February 2012. The Raspberry Pi is a low-cost option for managing or performing data acquisition. It is a full computer, the size of a credit card, and comes with both 802.11n capabilities and Bluetooth 4.1, giving multiple options for wireless communications [1]. It can run a standard Linux Operating System, including the ability to run cross-platform languages such as Python, which gives multiplatform options for the software framework.

These boards have been showing up in areas from weather sensors [2] to automobiles [3], which is very promising for our approach. Figure 1 shows a sighting of one board in a Ukrainian missile prototype at the Bezpeka Security Trade Show [4], which shows that even military applications are not out of the realm of possibility for this class of device.

Figure 1 – Raspberry Pi in Ukrainian Missile Prototype

Sensors, DAUs, and associated wiring for carrying power and information are also a source of significant weight during flight test. Worse, when mounted in the wings or other non-easily accessible areas, they either require aircraft disassembly to remove, or are simply left as an expensive ballast when the test article is delivered to the customer. DAUs outside the pressure vessel, whether using legacy PCM or modern network-based data transport, must pierce the pressure vessel to carry data back to the central test infrastructure within the plane, requiring expensive modifications to aircraft structure.

There are several ways to mitigate these problems. First, the sensors can be made wireless, as has been shown in emerging products in the industry previously [5]. Curtiss-Wright has developed a protocol built on the IEEE 802.15.4 standard for Lossless Extended Range Synchronized wireless data [6]. By building on their techniques, we can create a working wireless implementation for the flight test environment. This removes the wiring necessary between the DAU and the sensor for carrying information, but does not alleviate the need for supplying power to the sensor.

To solve the power issue, we plan to explore energy harvesting techniques alongside our wireless solution. Use of a piezoelectric transducer can capture power on the order of 0.5 Watts of practical power per 1.5” x 2.5” by .0075” sheet [7], which is not enough to power a device by itself. However, it can augment power stored in supercapacitors or rechargeable batteries which are hardened for the target conditions. Induction charging can be used before the flight test to charge the devices without the necessity of physical access. The Qi Standard [8] for wireless power transfer provides for inductive charging across distances of up to 7 mm and resonant charging up to 45 mm, significantly more than the airframe skin on a Boeing 737 of .04 in (1.02 mm) [9], which is aluminum and thus not ferromagnetic, and so should not interfere with the charging process. By mounting devices (or only the induction coils) near the edges of the airframe skin, power reservoirs can be charged without any internal cabling needing to be laid.

The DAU must also be able to survive in harsh environmental conditions and temperatures. We plan to use a similar approach used in a previous research project titled “Next Generation Neutrally Buoyant Sensors” that developed prototype low-cost neutrally buoyant sensors [18]. Though the water sensor faced different challenges, specifically high pressure and water exposure, where the flight test environment presents an environment of high vibration, low pressure, and low temperature, the techniques used for hardening a commodity board will be similar. Commodity approaches to hardening these types of devices already exist (an example of which is shown in Figure 2). Also, with the advent of the availability of 3D printing to hobbyists, the community has been exploring commodity methods of hardening for environmental conditions, and we can leverage this previous work in the development of our approach.

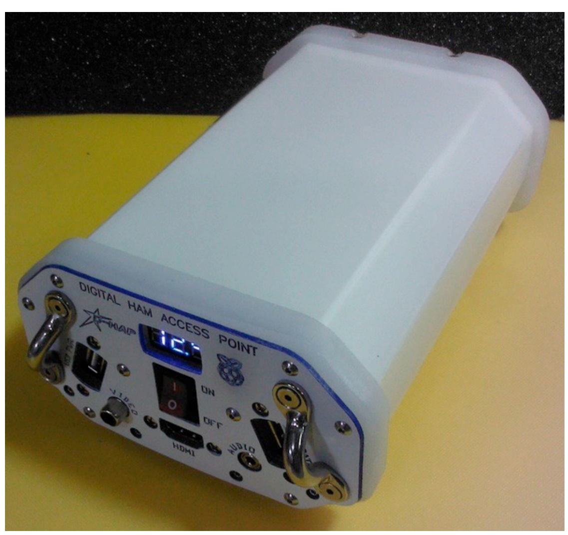

Figure 2 – D□HAP (D□Star Ham Access Point) enclosure/power supply for a Raspberry Pi

VIDEO PROCESSOR DAU

Some of the measurement data in which the test analysts are interested is available, but only to pilots on the cockpit displays. There is a wealth of information present on these displays in a wide variety of gauge shapes and formats, but extracting accurate measurement information from these displays using cameras is not a trivial task. A few existing patents describe methods of reading analog dial gauges in industrial plants [10] or cockpit displays [11, 12], but these approaches only address mechanical gauges and not the virtual displays of modern "glass" cockpits. None of these implementations use the data as input into a flight test DAU.

By using commodity cameras and processors (e.g. CPUs and GPUs), a flight test DAU that outputs cockpit display information can be created that exists alongside traditional DAUs. This method would provide a drop-in solution for companies with existing flight test data acquisition systems, where they could leverage all of their existing tools and processing systems without needing third-party software to interpret the cockpit display information.

While our end goal is to use cameras and computer vision techniques to create a "cockpit display" data acquisition unit, there are a number of technical challenges in proving the feasibility of this approach. The objective of our research is to prove that we can deal with the lighting, vibration, and image distortion problems that present challenges to any computer vision application. There is already some existing research in video processing for cockpit displays [13, 14, 15] that attempts to solve these problems, but each has its shortcomings.

For example, one solution [15] did not deal with the image distortion (skew) that occurs with cameras placed at angles relative to the gauge and required a gauge to be centered directly on the camera. In order to remove this gauge centering requirement, we plan to apply known geometric correction techniques [16] to the gauge images acquired at an angle to restore the view perspective as if it was observed with the camera centered and perpendicular to the imaged plane (see Figure 3 for an example of distorted and corrected images).

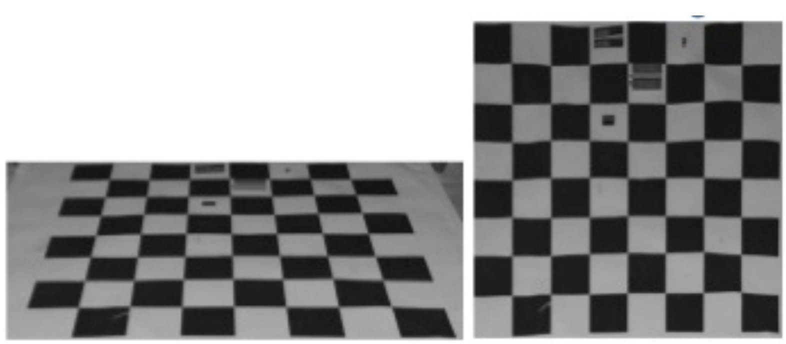

Figure 3 – Geometric Correction Techniques

Upon successful correction, the image can be assumed to be acquired with a perfectly centered camera and the proposed approach for angle detection of the needle can be performed. Other issues of vibration and minimal displacements can be targeted by applying image processing techniques that involve image stabilization [17]. Due to the nature of the problem, the rigid image registration should be sufficient to correct for the small displacements, which requires less computational power than the non-rigid one, thus, promising to be implementable for real-time image processing.

Although the experiments described in [15] include specular reflection effects, the claimed immunity to light reflection is questionable. None of the reported images show the specular reflections in the region of interest, which in this case, is the pivoting center of the needle. Therefore, the approach is expected to fail if the specular reflection happens to be within the region of interest.

EXPECTED RESULTS

The achievable capabilities of these non-traditional DAUs are described in Table 1. From our initial testing, these values are what we think is possible for these types of non-traditional DAUs.

Table 1 – Capabilities

Latency through data acquisition pipeline	50 ms
Time stamping accuracy	100 ns
Wireless fidelity	100% successfully delivered
Power Consumption	1 W
Operational temperature	-55 to +85 °C
Operational vibration	5g RMS
Installation time	75% of conventional DAU

The first capability is concerned with the amount of time a given sample needs, be that bus message or binary discrete value, until it is available for display to a user. This is not simply the processing time, as a 50 ms delay in processing a single bus message would mean that the device would be unable to keep up with the stream of data, but rather that a particular sample would enter the acquisition pipeline and be communicated out of the device and through the other FTI elements within the latency requirement.

The second capability covers the time stamping accuracy of the device, recording the exact time the signal was received. The third capability addresses the reliability of the wireless transmissions, versus those of a wired setup. This capability can be tested by storing the captured data on the device, and comparing the stored data to the data received over the wireless connection. The fourth capability involves using supercapacitors and induction charging to provide sufficient power to the small processor boards and sensors.

The fifth and sixth capabilities address the survivability of these types of DAUs. Environmental requirements for airborne electronics are controlled by the RTCA DO-160 specification. While this specification is targeted for production avionics that are intended to perform over the life of the airframe, some flight test organizations have adopted portions of this specification for requirements on their FTI. However, this has driven the cost and inflexibility of the current FTI offerings. We have set our capability below that required by DO-160, but high enough that we expect will be seen sufficient by flight test organizations.

The last capability looks at the usability of the device by measuring the installation time. There are many factors that determine the usability of a device, but installation time and cost are always issues in FTI scenarios. We expect that a measure of it is important to customer acceptance and a major factor driving the community's interest in wireless technologies.

CONCLUSIONS

This paper described ongoing SwRI research into alternative sensing approaches that utilize a mix of video processing, distributed processing, and power harvesting to provide additional solutions. The basic techniques behind this approach have been explored in previous SwRI projects, including the Remote Neutrally Buoyant Sensors effort which was the recipient of an R&D 100 Award [18], but have not yet been applied to the flight test instrumentation field. We believe that a commodity-based approach to flight test is not only feasible, but necessary as the continuing cost and schedule pressures on flight test programs demand approaches that minimize installation complexity and reduce the need to modify the aircraft under test.

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