Standards-Based Wireless Sensor Networks and Modular Instrumentation for Space Flight Applications

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Wireless instrumentation provides a powerful new data-gathering paradigm for space flight applications. Outfitting sensors with radios to form nodes in a wireless sensor network (WSN) opens a new range of possibilities in measurement and monitoring. Eliminating wire runs and their associated harnesses and connectors can substantially reduce vehicle launch weight—a principle advantage of WSNs. Freeing sensors from wires also allows sensors to be added to a vehicle or relocated during a vehicle's operational phase, well after its initial design and construction period. This allows unprecedented flexibility in increasing situational awareness as lessons are learned and sensing needs that were initially unanticipated become apparent. Wireless sensors can also be used to augment a vehicle's permanent sensing suite during its initial checkout, only to be easily removed once the vehicle becomes operational. Finally, WSN nodes can be reused between vehicles on orbit. For example, a node can be relocated from a spent vehicle, such as a supply vehicle, to one currently in service, such as an International Space Station module or cislunar/near-Earth-object cycler. This transfer of hardware augments the operational capabilities of the in-service vehicle using equipment that would otherwise be a loss once the spent vehicle is discarded.

Cutting a sensor's wires—for both communication and power—is not without its perils. To conserve onboard power resources (e.g., battery power), a wireless sensor node must sparingly communicate using a low-power radio. This requirement renders WSNs especially prone to interference from a variety of sources. Time-varying multipath interference can induce local signal fades, which are difficult to overcome. Other, more powerful wireless systems operating in the same frequency band (e.g., Wi-Fi) can monopolize access to the wireless channel. Crew members and equipment moving in microgravity can create unpredictable physical barriers to radio frequency (RF) communication, and wideband noise from equipment such as pumps and fans can also generate RF interference.

Fortunately, a number of wireless communication standards aimed at mission-critical monitoring and control applications in the terrestrial world have arisen in the last decade. These technologies, such as Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 and its derivatives—International Society of Automation (ISA) 100.11a and ZigBee standard—show great promise in being applicable to the unique needs of both space flight applications and ground-based spacecraft testing and launch processing. The Johnson Space Center (JSC) team created a program to study these and similar technologies in the laboratory and field environments in pursuit of standardized NASA approaches to wireless instrumentation. The team employs the Consultative Committee for Space Data Systems approach: adopt existing technologies when possible, adapt them as needed, and develop new technologies from scratch only if necessary. The key to this effort is evaluation of all candidate technologies in controlled laboratory environments as well as real-world field environments. This allows the team to determine its strengths and shortcomings in relevant aerospace applications and propose, implement, and evaluate modifications as necessary.

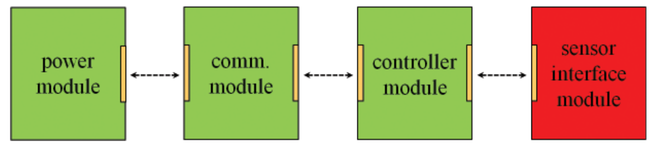

Fig. 1. *Modular Instrumentation composed of stock (green) and mission-specific (red) components.*

To enable this approach, the team developed a suite of modular instrumentation components that allow it to mix and match stock modules with custom sensor interfaces to form integrated, wireless sensor nodes (figure 1). Development of modular instrumentation begins with the definition of generic classes of modular components and the interfaces between them. A processor (e.g., a microcontroller or single-board computer) anchors the design and manages the data acquisition, processing, and transport. Depending on the processor's native capabilities and the application requirements, it may interface with an analog-to-digital conversion module, a memory module, a data-processing module (such as a digital signal processing chip), etc. A communication module (IEEE 802.15.4, ISA 100.11a, ZigBee, etc.) provides a path for data out of the network, and a power module sized appropriately to the application requirements and resources (e.g., mains, battery, or power-harvesting) rounds out the set of stock components. Only the sensor interface specific to a particular application needs to be designed from scratch.

The benefits of this approach are twofold. First, laboratory studies can be accomplished merely using the control, radio, and power modules. The team generated synthetic data in software on the controller module, allowing it to characterize the performance of each radio in representative environments (figure 2) while carefully regulating the type and level of interference (e.g., competing 802.11 Wi-Fi traffic). Guided by these laboratory studies, the team can then quickly infuse the new radio modules (and their interface software) into the field for real-world trials by incorporating them into the modular instrumentation suite.

Fig. 2. *Johnson Space Center wireless habitat test bed.*

Second, this approach allows the JSC team maximum reusability across applications. The team developed a communication infrastructure, identifying a set of well-understood, open standards suited to a particular set of requirements (power consumption, reliability, cost, etc.), which can apply across multiple distributed sensing applications. Pairing the stock control, radio, and power modules with an application-specific sensor interface allows for quick assembly of modular, add-on instrumentation units capable of addressing a wide variety of sensing applications as they arise. Importantly, it reduces the frequency of "square peg, round hole" difficulties encountered when applying monolithic add-on instrumentation systems to measurement tasks for which they were not specifically designed.

In combination, these activities are allowing the JSC team to study and apply commercial WSN standards to real NASA operational requirements, with a quick and cost-efficient path from the lab to the field and beyond.