Wireless Sensor Instrumentation for Distributed Sensing in Ground-Test Facilities

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Wireless sensors have a number of advantages over wired sensors for flexible or temporary diagnostic deployment in a field or lab setting. Relative to wireless alternatives, traditional wired systems encounter limitations including spatial and weight constraints, maintenance costs, and signal integrity in high-noise environments. Ground-test facilities often face these challenges and cause increase down-time costs and failure of data integrity. This paper describes the development and implementation of flexible wireless sensor boards for applications within ground-test facilities using different network architectures. These boards implement state-of-the-art STM32 microprocessor chips for high-speed data acquisition and computational power. Additionally, the design integrates long-range radio transceivers with power output of +20dBm, easily reaching 2 km range, while maintaining high interference immunity and minimizing current consumption. The wireless sensor boards were implemented to demonstrate performance through benchmark testing and by taking distributed electrically-isolated measurements on a high-voltage lab apparatus while using different network architectures. Although this test case is in a laboratory setting, this network architecture could be easily repurposed for various other forms of monitoring.

I. Nomenclature

$mARC$ = mini-Arc Research Chamber
WSN = Wireless Sensor Network

II. Introduction

Wireless sensor networks (WSN) have been around since the 1950s but recent advancements have made the hardware inexpensive and the software accessible. This has expnaded the adption of wireless sensors from niche markets from battlefield monitoring to domestic and business applications. One particular area of interest is spacecraft missions and technology, where wired sensors have several drawbacks that wireless alternatives could solve. For example, a study on the Orion Exploration Flight Test (EFT-1) showed that the development flight instrumentation's wiring and wiring connectors contributed 60-percent of the data acquisition system's total mass [1]. WSN technology, in addition, proves efficient distributed sensing for ground-based facilities such as the arc jet complex, high-power facilities simulating extreme aerothermal conditions, at NASA Ames Research Center. Previous work illustrated the performance of wireless sensor networks in the mini-Arc Research Chamber (mARC) II facility for distributed thermal diagnostics and sweep-arm motor automation [2] [3].

Relative to wireless technology, traditional wired systems encounter limitations such as spatial constraints, hindering their application in scenarios where dynamic sensor configurations are imperative. Moreover, wired instrumentation generally include higher costs in installation and maintenance as wires tend to degrade over time. Wireless networks can, additionally, extend coverage more easily than wired networks as methods, such as range extenders and mesh networking, can optimize coverage without the need for installing additional cabling, proving useful for large areas where scalability is a requirement. Furthermore, wireless solutions are particularly advantageous for situations where rapid deployment,

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such as temporary diagnostic applications, is necessary as installation is easier and less time consuming. Lastly, wireless networks illustrate promise for high-voltage environments as wired systems commonly create RF-catchers or ground-loops, producing noise within data signals, and introducing susceptibility to shorts.

Therefore, this project focuses on developing a flexible, easy-to-integrate WSN that offers competitive performances relative to traditional wired instrumentation. Additionally, the project aims to investigate the performance and impact of wireless network architecture within ground-test facilities.

III. Implementation and Design

There are two main types of network topologies, centralized and distributed as illustrated in figure 1, each having its own advantages. Centralized topolgoies have multiple child or outer nodes that measure and acquire data, and then transmit the data to the parent or central node. One caveat to this topology is that the central node acts a single point of failure, meaning if the central node fails the the entire network will collapse. The distributed topology, on the other hand, does not rely on a central node and is useful for sensor nodes that are prone to failure but are significantly more complicated to implement. In this project, a centralized topology is primarily investigated as it is simple for implementation and effective for applications with smaller number of nodes.

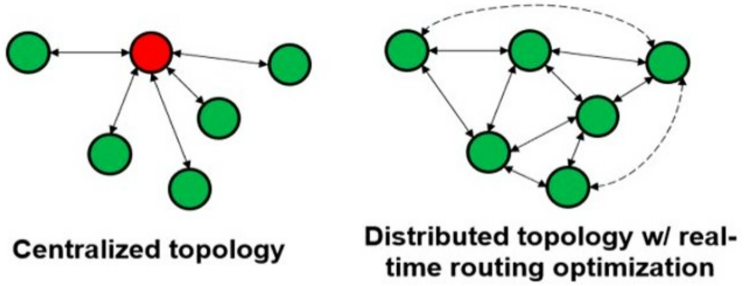


Fig. 1 Diagram illustrating the conceptual difference between centralized and distributed network topology.

The latest design iteration of the wireless sensor board, as shown in figure 2, offers a small footprint of 46mm x 51mm. The design implements the popular RFM95 radio transceiver board for 915MHz communication and has high RF power output of +20dBm, where communication can reach up to 20km with directional antennas and configuration tweaks. This radio transceiver, additionally, provides high interference immunity while maintaining minimal current consumption. The board design, furthermore, implements the microprocessor STM32F446RE, performing at a clock rate of 180 MHz and contains a flash and RAM memory size of 512kB and 128kB, respectively. This microprocessor chip has three 12-bit analog-to-digital converters that reach up to 2.4 MSPS (or 7.2 MSPS in interleaved mode). With the addition of up to 20 communication interfaces and optimized power efficiency, the STM32F446RE was an ideal choice for this project. Furthermore, the design implements electro-static-discharge (ESD) protection such that, unlike most off-the-shelf solutions, are protected from short-circuits that may originate externally when implemented in high-power environments, such as the arc jet facilities. Lastly, the design implements switching voltage regulator for minimal power consumption, LiPo battery connector and charger circuit, and circuitry for easy-programming using open-source Arduino and Python libraries.

Furthermore, this project included developing LabView software for quick and easy implementation while still accessing the powerful features included within these wireless sensor boards without having to manually program them. For example, as shown in figure 3, is an image of the software interface that allows the user to set-up serial communication with the parent node and wireless communication channels with available boards. Additionally, the software allows the user to easily access the high-speed Analog-to-Digital channels and other novel interfaceable sensors such as the LSM6DSOX, STM32 accelerometer and gyroscope with machine-learning coupled core for advanced applications, while being able to write the received data on file in real-time.

IV. Conclusion

All in all, wireless sensor technology offers an innovative solution to wire-based technology and significantly contributes to ground-test facilities such as arc jet modernization and monitorization. The goal of this paper was to

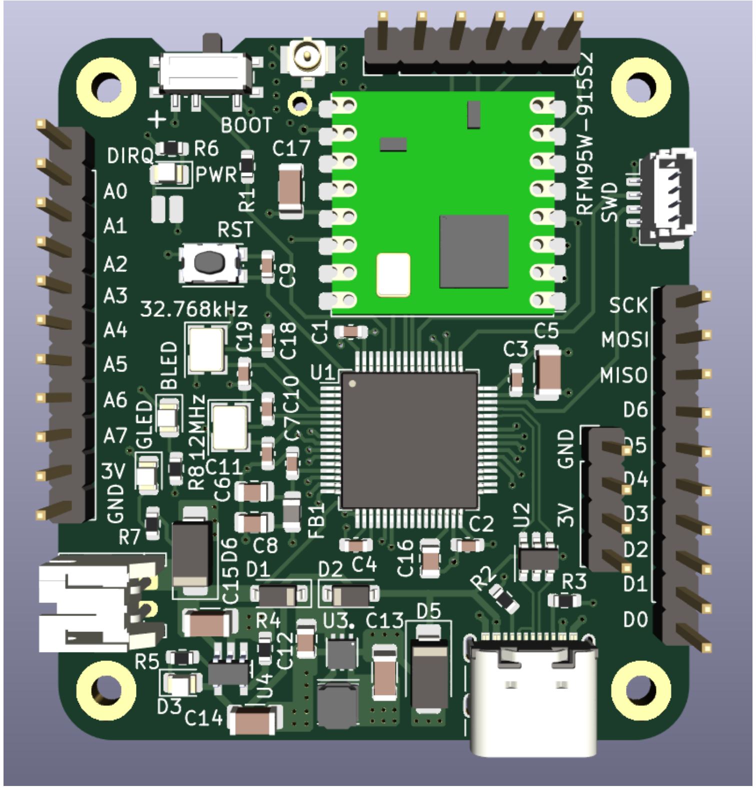
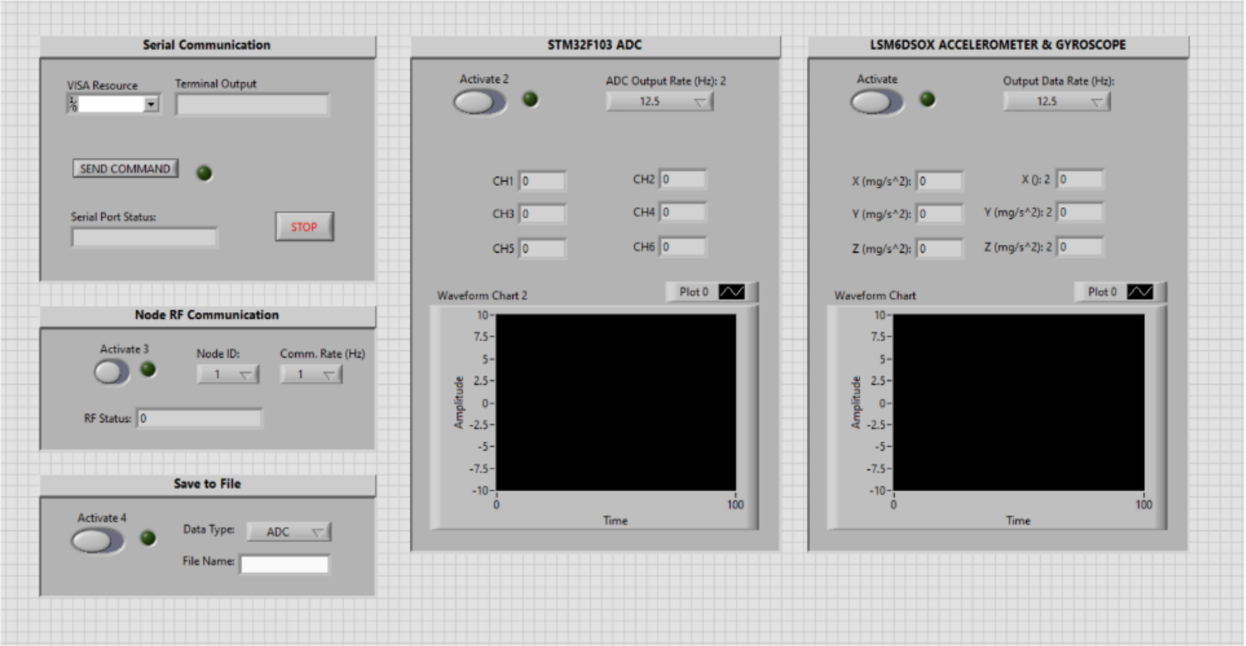


Fig. 2 Top-view image wireless sensor board design iteration (46mm x 51mm) that implements STM32F446RE microprocessor chip with RFM95 radio transceiver designed using KiCAD software.



Node ID: 1
Comm. Rate (Hz): 1
RF Status: 0
Data Type: ADC
File Name:
ADC Output Rate (Hz): 2: 12.5
CH1 0
CH2 0
CH3 0
CH4 0
CH5 0
CH6 0
Output Data Rate (Hz): 12.5
X (mg/s^2): 0
X (): 2 0
Y (mg/s^2): 0
Y (mg/s^2): 2 0
Z (mg/s^2): 0
Z (mg/s^2): 2 0

Fig. 3 LabView interface to serially communicate with parent node and command child-nodes via a set of commands, such starting, displaying, and storing data acquisition in real-time.

investigate in-house developed WSN technology as a novel diagnostic capability for distributed sensing. Results are to published in final paper and presented at the technical presentation.

V. Acknowledgements

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