The Habitat Demonstration Unit Project: A Modular Instrumentation System for a Deep Space Habitat

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Abstract

NASA is focused on developing human exploration capabilities in low Earth orbit (LEO), expanding to near Earth asteroids (NEA), and finally to Mars. Habitation is a crucial aspect of human exploration, and a current focus of NASA activities. The Habitation Demonstration Unit (HDU) is a project focused on developing an autonomous habitation system that enables human exploration of space by providing engineers and scientists with a test bed to develop, integrate, test, and evaluate habitation systems. A critical feature of the HDU is the instrumentation system, which monitors key subsystems within the habitat. The following paper will discuss the HDU instrumentation system performance and lessons learned during the 2010 Desert Research and Technology Studies (D-RaTS). In addition, this paper will discuss the evolution of the instrumentation system to support the 2011 Deep Space Habitat configuration, the challenges, and the lessons learned of implementing this configuration.

In 2010, the HDU was implemented as a pressurized excursion module (PEM) and was tested at NASA's D-RaTS in Arizona [1]. For this initial configuration, the instrumentation system design used features that were successful in previous habitat instrumentation projects, while also considering challenges, and implementing lessons learned [2]. The main feature of the PEM instrumentation system was the use of a standards-based wireless sensor node (WSN), implementing an IEEE 802.15.4 protocol. Many of the instruments were connected to several WSNs, which wirelessly transmitted data to the command and data handling system via a mesh network. The PEM instrumentation system monitored the HDU during field tests at D-RaTS, and the WSN data was later analyzed to understand the performance of this system. In addition, several lessons learned were gained from the field test experience, which fed into the instrumentation design of the next generation of the HDU.

In 2011, the HDU is being upgraded to a Deep Space Habitat (DSH) configuration, adding a hygiene module and an inflatable second floor for crew living and sleeping areas. The instrumentation design will also expand to accommodate these new modules. In addition, two types of Radio Frequency Identification (RFID) sensing technologies are being added for evaluation and demonstration: passive tags for inventory management, and temperature sensors. The WSNs are being upgraded as a result of lessons learned from 2010 testing,

implementing an ISA100.11a protocol [3, 4] and eventually encompassing a modular design to allow flexibility for data communication, power, and sensor types. Finally, a technology demonstration will be performed, simulating micrometeoroid damage detection on the exterior of the HDU.

Through the upgrades and development of the 2011 DSH instrumentation configuration, a process for HDU instrumentation implementation has been developed. A core set of interfaces exist for instrumentation to connect: WSNs (mesh network), USB, Ethernet, RFID, Bluetooth, and WiFi. While all of these interfaces exist, the focus for the instrumentation system is on WSNs as the primary interface with Ethernet and RFID as secondary interfaces because the software development for the data handling is minimal with these three interfaces. In addition, this process focuses on refining the existing interfaces based on lessons learned from integrated testing each year. An example of this is the upgrades to the WSNs from 2010 to 2011. Furthermore, since the HDU is an analog test bed, new technologies will be demonstrated and evaluated as redundant to the existing core instrumentation. These new technologies must use the existing interfaces and will be evaluated against the core instrumentation (i.e. the current HDU “gold standard”). If they are found to perform well, they will be considered for upgrade into the HDU for the following year. Finally, technology demonstrations will be incorporated as standalone tests because these technologies tend to be beyond the scope of the current HDU configuration.

The instrumentation implementation process will be evaluated throughout the integration of the 2011 DSH configuration. The challenges and lessons learned of implementing this process and the 2011 instrumentation design will be invaluable to future habitation instrumentation systems.

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NASA is focused on developing human exploration capabilities in low Earth orbit (LEO), expanding to near Earth asteroids (NEA), and finally to Mars. Habitation is a crucial aspect of human exploration, and a current focus of NASA activities. The Habitation Demonstration Unit (HDU) is a project focused on developing an autonomous habitation system that enables human exploration of space by providing engineers and scientists with a test bed to develop, integrate, test, and evaluate habitation systems. A critical feature of the HDU is the instrumentation system, which monitors key subsystems within the habitat. The following paper will discuss the HDU instrumentation system performance and lessons learned during the 2010 Desert Research and Technology Studies (D-RaTS). In addition, this paper will discuss the evolution of the instrumentation system to support the 2011 Deep Space Habitat configuration and a process for implementing and upgrading future instrumentation systems for the HDU project.

I. Introduction

NASA'S exploration goals are to expand human presence into deep space and to pursue technology development that will allow humans to travel farther into the solar system. One challenge to reaching these goals is the challenge of long-duration habitation. Through the Habitat Demonstration Unit (HDU) Project NASA is working out these habitation challenges by providing an Earth-based analog for evaluating different mission architectures, mission scenarios, and technology development. Within the HDU there are several subsystems, one of which is the instrumentation system that provides monitoring of the habitat and the surrounding environment. In this paper, the

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D-RaTS testing of the Pressurized Excursion Module (PEM) configuration instrumentation system will be reviewed. In addition, the Deep Space Habitat (DSH) configuration will be briefly outlined and the instrumentation system for the DSH configuration will be discussed in detail.

II. D-RaTS Testing of the Instrumentation for the Pressurized Excursion Module Configuration

In 2010, the HDU was implemented as a pressurized excursion module (PEM) and was tested at NASA's D-RaTS in Arizona (Ref. 1). For this initial configuration, the instrumentation system design used features that were successful in previous habitat instrumentation projects, while also considering challenges, and implementing lessons learned (Ref. 2). The main feature of the PEM instrumentation system was the use of a standards-based wireless sensor node (WSN), implementing an IEEE 802.15.4 protocol. Many of the instruments were connected to several WSNs, which wirelessly transmitted data to the command and data handling system via a mesh network. The PEM instrumentation system monitored the HDU during field tests at D-RaTS, and the data was later analyzed by the various subsystems to understand the performance of the PEM.

During the field tests, there were both organizational challenges and technical challenges. For the HDU team, this was the first time the HDU team had performed field testing as part of a larger team and there were learning curves in all areas. One of the largest organizational challenges during testing was communication. There were not clear timeframes of the schedule and not all of the tests to be performed were detailed in those schedules. Consequently, the instrumentation was affected when power was shut down without warning. As a result, the performance of the WSNs could not be established because it was unknown whether the system became unresponsive as a result of the WSNs malfunctioning or as a result of power being removed from the system.

The technical challenges experienced in the field ranged from integration hindrances to technology drawbacks. As part of field testing, the team wanted to evaluate the mission architecture of a habitat that could traverse to different locations. This required setup and tear down at two different sites. Since the WSNs were critical to the instrumentation infrastructure, it was decided to remove them and reinstall them at each site. Unfortunately, the integration design for the WSNs were more focused on permanence and thus created difficulty when wanting to quickly uninstall and reinstall them. In addition, if a WSN failed, a replacement needed to be installed in the same location. This would have presented an even greater challenge, as the bolt hole patterns for installing the WSNs was not consistent across each of the WSNs. Thus, for future iterations, it is necessary to implement an integration strategy that allows quick disassembly and reassembly of the WSNs, along with a standard implementation method across all WSNs.

The configuration of the WSNs used during this testing had several drawbacks as well. For instance, there was minimal self protection on the WSNs, causing the nodes to fail if there were unexpected power spikes. In addition, the survivability of the nodes during intense vibration had not been evaluated and it was not advised to leave them installed during transportation. If the nodes were more robust mechanically, it might be possible to leave them installed during transportation, eliminating the need for quick disassembly and reassembly of the system. Also, the WSNs did not have a memory buffer on board. Therefore, if a WSN is unable to send data due to a network dropout, the old data is overwritten with new data collected. If a memory buffer were in place, it would be possible to transfer all the data that was collected, given the network dropout is not so great as to overflow the memory capacity.

Another set of challenges with the WSN configuration were a result of the housing design. This housing did not provide accessibility to the electronics of the WSN and whenever a firmware update needed to be implemented, all the electronics needed to be removed. Furthermore, there were no indicators on the exterior of the housing to provide feedback information on whether the WSNs were receiving power or were connected to the mesh network, for example. In addition to having indicators on the WSN, it would be advantageous to have WSN feedback information on the crew display, providing useful information for troubleshooting if needed. If this information was accessible on the crew display, additional alerts could be implemented to notify the flight controller of the concern, as well as send out text messages or emails to the instrumentation and avionics team alerting them to potential problems.

One of the largest technical challenges experienced at D-RaTS was interference from other multiple wireless systems, especially when at the base camp. Unfortunately it was difficult to estimate how many other wireless systems would be in use during D-RaTS and the instrumentation system was not adequately tested for this amount of interference. In addition, the instrumentation team did not get a chance to adequately optimize the locations and types of antenna that would be most beneficial for the WSN system. Performing this testing prior to D-RaTS would have helped to mitigate some of the interference challenges that were experienced.

There were also some challenges during troubleshooting due to integration methods that were implemented. Typically when creating wiring harnesses, the wires are tightly bundled together for cleanliness purposes. Unfortunately, troubleshooting of the sensors was hindered because the wires were so tightly bundled that the labels on the wires were difficult to see or handheld meters could not be placed around the wires to ascertain whether the instrumentation was defective.

The challenges during 2010 D-RaTS testing led to many lessons learned that were implemented in the DSH configuration to improve the instrumentation system and D-RaTS testing in 2011.

III. Deep Space Habitat (DSH) Configuration

In 2011, the HDU-PEM will be reconfigured to a Deep Space Habitat (DSH) configuration (Figure 1) to evaluate an architecture for visiting a Near Earth Object (NEO). The DSH will reconfigure the main element as the lab/core and keep the airlock as an airlock/dust mitigation module (A/DMM). The configuration will add an HDU hygiene module (HHM) and an inflatable second story (X-Hab) that was part of an academic competition. The HHM and X-Hab allow the HDU-DSH to be used as a full-scale habitat prototype that crew can live in for 7-10 day missions.

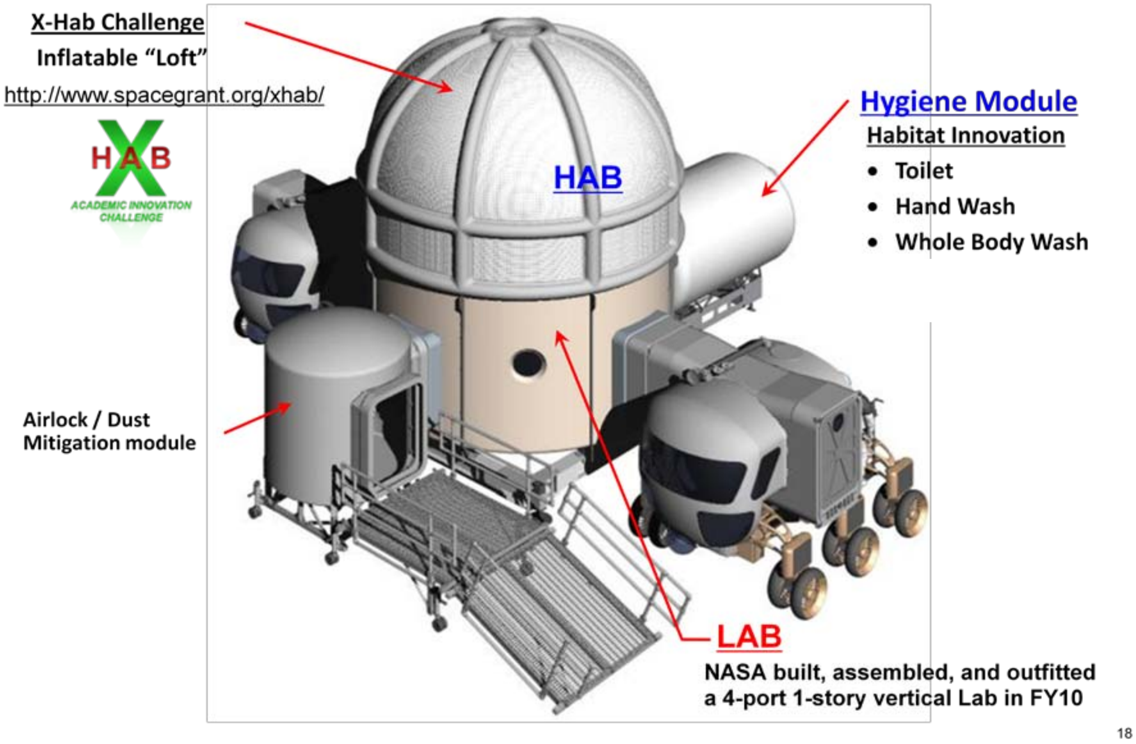

Figure 1: Deep Space Habitat (DSH) configuration.

The Core/Lab space of the HDU-DSH will be broken up into several segments that contain the following subsystems: Life sciences/Medical Operations, Geoscience, Telerobotics, and General Maintenance. These sections are shown in Figure 2.

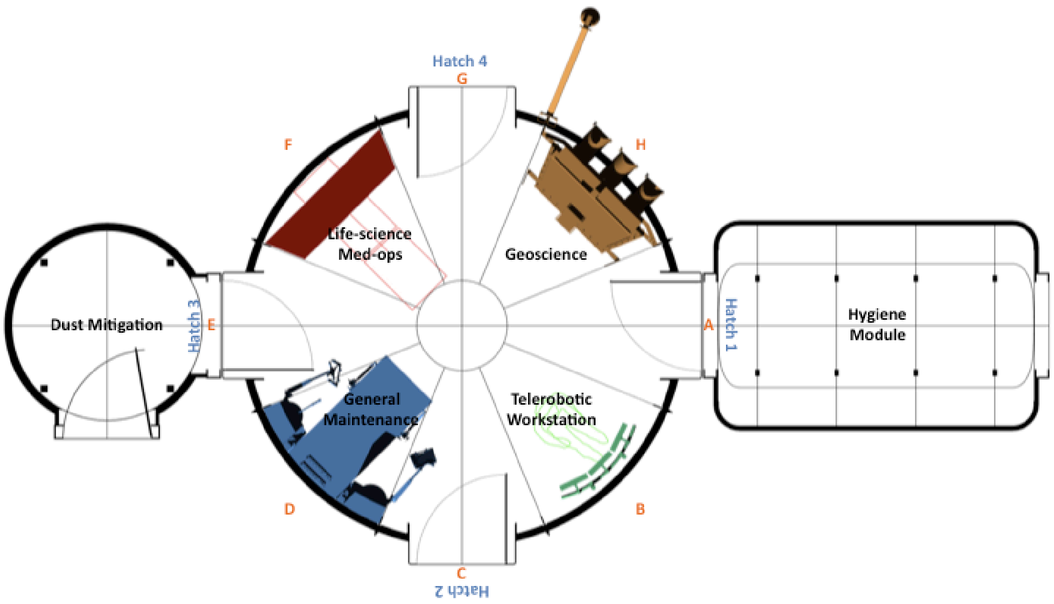

Figure 2: Overhead view of the HDU-DSH (excluding the X-Hab).

The HDU Project is designed as an analog test bed, and in addition to evaluating mission architectures/operations scenarios, the HDU is focused on testing several new technologies and innovations. In the DSH configuration, the technologies and innovations being implemented are the following:

- Inflatable Loft (X-Hab Competition)
- Logistics-to-Living: recycling and repurposing the logistics systems into useable components and elements throughout a habitat or laboratory; examples include furniture, outfitting, and partitions, to mention a few.
- Autonomous Ops (“Intelligent” Habitat System Management Software): providing the capability to effectively and efficiently “manage” the Habitat/Laboratory resources (i.e. electricity, lighting, air, HVAC, communications, water, waste, etc.)
- iHab Digital Double (D^2)
- Power management systems: monitoring of major energy using devices and controlling the peak electrical energy demand
- Environmental Protection Technologies
    - Dust Mitigation Technologies
        - Electrodynamic Dust Screen to repel dust from surfaces
        - Lotus Coating
        - Vent Hood at the General Maintenance Workstation
        - Operational Concept for End-to-End Dust Contamination Management
        - Vacuum Cleaner
    - Micrometeoroid Mitigation Technologies
        - Micrometeoroid Detection
    - Radiation
        - Operational Demonstration of Cargo Transfer Bags to deployable blankets for Radiation Protection
- HDU Core Computing, Wireless Communication and RFID
- Standards-based Modular Instrumentation System: Wireless Sensor Nodes
- Flat Surface Damage Detection system: monitoring of the integrity of a habitat shell during in situ system health monitoring
- MMOD Hab impact monitoring system: monitoring of potentially damaging impacts on a space structure from micrometeoroids and orbital debris (MMOD) in the near-Earth environment, from micrometeoroids and lunar

secondary ejecta (MMSE) on the lunar surface, and from micrometeoroids in interplanetary space (including surfaces of asteroids
- Telerobotic Workstation
- General Maintenance/EVA Workstation
- Medical Ops/Life Science Workstation: evaluating medical procedures and kits
- Geo-Science Lab Glovebox/Workstation: testing of hardware and operations related to preliminary examination of astromaterials for sample return and early curation decisions.
- Material Handling
- Food Production (Atrium concept): supplementing the crew's diet with fresh, perishable foods and herbs while on missions
- LED Lighting
- 3-D Layered Damage Detection System for Surfaces
- Habitability / Habitation: evaluating volume needs, human/computer interactions, physical interferences, cleanliness, and logistics needs
- Hygiene Module: evaluating hygiene related activities

The technologies related to the instrumentation system are the following: RFID, Standards-based Modular Instrumentation System: Wireless Sensor Nodes, and the Flat Surface Damage Detection system. The following section will outline the HDU-DSH instrumentation system in more detail.

IV. HDU-DSH Instrumentation Design

The DSH instrumentation design follows from the PEM instrumentation design (Ref. 2) in that much of the instrumentation remained the same. This decision resulted from the budgetary and schedule challenges encountered, and resulted in greatly reducing the workload for both the software and integration teams. Therefore, the core instrumentation remained in the Lab/Core space of the HDU with additional instrumentation to accommodate the growing Vegetable atrium and the new X-Hab element. New instrumentation was also added for evaluation in the Lab/Core space. This instrumentation was an RFID system that will be used by the Geolab to track inventory and data of samples being examined. A block diagram of all the instrumentation in the lab/core space is shown below in Figure 4. An additional technology demonstration (not shown in the block diagram) is placed on the exterior of the DSH and is called the Flat Surface Damage Detection System (see Figure 3). This technology can detect where damage is located on the exterior shell and can determine the severity of the damage. It is primarily developed for monitoring of micrometeoroid damage to the structure, but can also be used for monitoring other types of structural damage as well.

Figure 3: Flat Surface Damage Detection System - shown damaged.

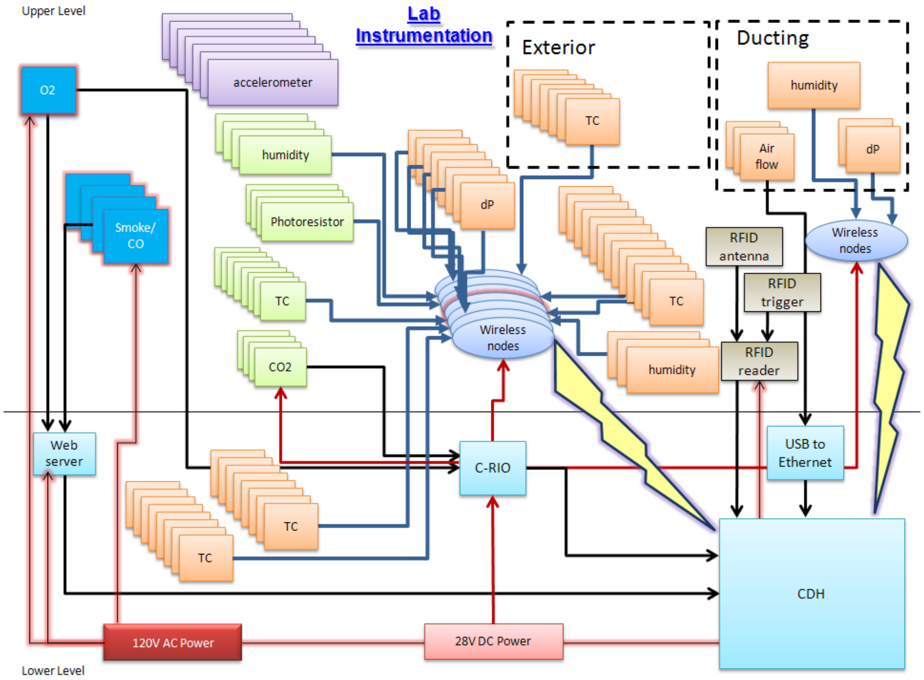

Figure 4: Block diagram of core/lab space in HDU-DSH. Instrumentation in purple is for the structures subsystem, in orange is for the thermal control subsystem, in bright blue is for the environmental control subsystem, in green is for the Vegetable growth subsystem, and in brown is the for the Geolab. Instrumentation containing a red haze around it signifies battery power. Lightning bolts signify wireless communication.

The airlock/dust mitigation module (A/DMM) remained mostly the same as the PEM configuration, with the addition of an airflow sensor and carbon dioxide sensor. The block diagram for the A/DMM is shown below in Figure 5.

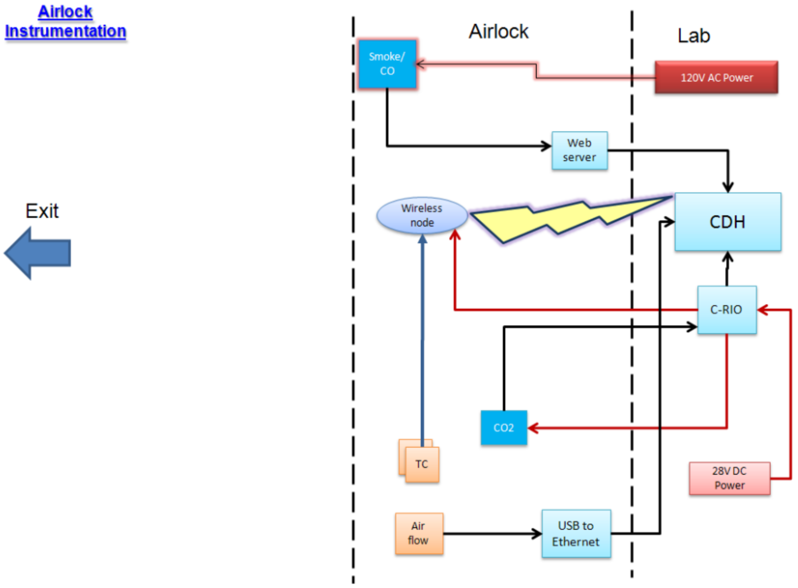

Figure 5: A/DMM block diagram. Orange instrumentation is for the thermal control system and bright blue instrumentation is for the environmental control subsystem.

For the DSH configuration two new modules have been added. The first module is the hygiene module (HHM), which provides the crew with hygiene functionality, such as a toilet and shower. All new instrumentation has been added to this module to monitor the conditions of the HHM. In addition, a new RFID technology has been integrated to evaluate the technology's effectiveness, to provide inventory information on consumables, and to provide engineering data on crew usage of those consumables. The block diagram for the HHM is shown below (Figure 6).

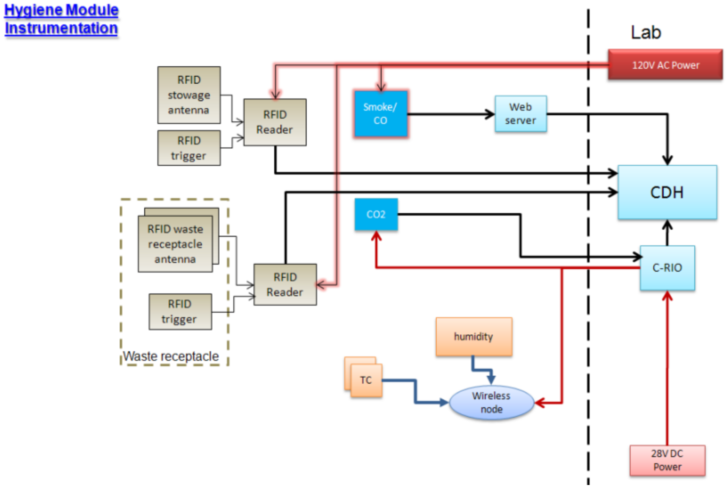

Figure 6: HHM block diagram. Orange instrumentation is for the thermal control subsystem, bright blue instrumentation is for the environmental control subsystem, and brown instrumentation is the RFID technology demonstration for the crew accommodations subsystem.

The second module is the X-Hab, which is the second story loft providing sleep quarters, living/working space, and a galley for the crew. Again, since this was a new module, all new instrumentation was integrated into this element to monitor the environment and the structure. In addition, another RFID technology demonstration is being implemented in the X-Hab. This RFID technology is a wireless temperature sensor that will monitor the temperature in various locations around the X-Hab. A block diagram of the X-Hab element is shown below (Figure 7).

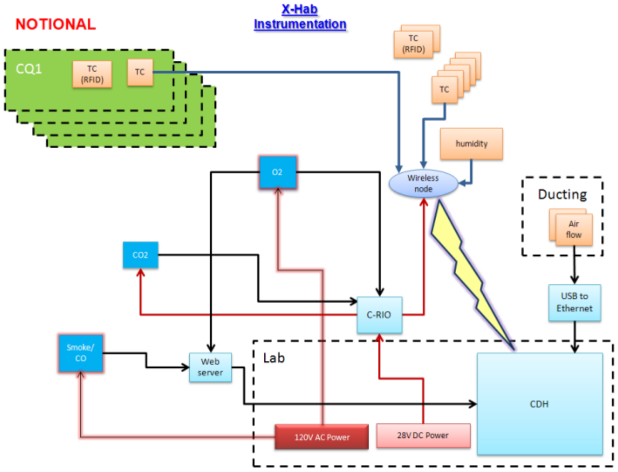

Figure 7: X-Hab block diagram. Orange instrumentation is for the thermal control subsystem, bright blue instrumentation is for the environmental control subsystem, and the spaces in green are the individual crew quarter areas.

In addition to the instrumentation added to the new elements and the incorporation of technology demonstrators, there was a complete redesign of the WSNs that are used as the main method of data collection and communication to the command and data handling system. The redesign was a result of the challenges faced during D-RaTS testing in 2010 and the lessons learned that came out of that experience. The basic functionality of the WSNs remained: 10 sensors could be connected to one node, all 10 channels could collect data at a low data rate of once per minute and 2 of those channels could also be used for high data rate collection of once per second, and the data is sent in packets of 20 seconds to the command and data handling system. However, the internal components of the WSN were redesigned to be more robust and to protect the hardware from environmental anomalies, such as power spikes. The radio component was also changed out to an ISA100.11a protocol (Ref. 3, 4) and a patch antenna was placed on the top of the WSN to provide more robust communication. In addition, there were features added to provide performance data that could be analyzed at a later date to evaluate how well the WSNs functioned in the D-RaTS environment. Furthermore, the housing was completely redesigned to provide feedback information, such as LEDs to signify there is power to the WSN, and to provide capability to reprogram and update the firmware without having to disassemble the units. An example WSN is shown below in Figure 8.

Figure 8: Example of an upgraded WSN.

V. Instrumentation Implementation Process

Through the upgrades and development of the 2011 DSH instrumentation configuration, a process for HDU instrumentation implementation has been developed. A core set of interfaces exist for instrumentation to connect: WSNs (mesh network), USB, Ethernet, RFID, Bluetooth, and WiFi. While all of these interfaces exist, the focus for the instrumentation system is on WSNs as the primary interface with Ethernet and possibly RFID as secondary interfaces because the software development for the data handling is minimal with these three interfaces. In the DSH configuration, this is the first time RFID has been implemented as an interface, and it will be evaluated for use in future HDU project. Additionally, in future iterations of the HDU, it would be advantageous from a software development standpoint to minimize USB interfaces.

The process also focuses on refining the existing interfaces based on lessons learned from integrated testing each year. An example of this is the upgrades to the WSNs from 2010 to 2011. The WSNs and other interfaces will continue to be refined as additional lessons learned are gathered.

Since the HDU is an analog test bed, new technologies will be demonstrated and evaluated as redundant to the existing core instrumentation. These new technologies must use the existing interfaces and will be evaluated against the core instrumentation (i.e. the current HDU "gold standard"). If they are found to perform well, they will be considered for upgrade into the HDU for the following year. An example of this process in the DSH configuration is the RFID temperature sensors implemented in the X-Hab loft.

Finally, technology demonstrations will be incorporated as standalone tests because these technologies tend to be beyond the scope of the current HDU configuration. In the DSH configuration, the main instrumentation technology demonstration is the Flat Surface Damage Detection System. It is a standalone system in the DSH configuration and is being tested out. If it performs well this year, then in the following years, additional integration efforts will continue to incorporate the technology into the core HDU instrumentation infrastructure.

This instrumentation implementation process will be evaluated throughout the integration and testing of the 2011 DSH configuration. The challenges and lessons learned of implementing this process and the 2011 instrumentation design will be used to further refine how the instrumentation system of the HDU is upgraded and expanded with each iteration.

VI. Summary

The HDU-DSH instrumentation system is a follow-on from the HDU-PEM instrumentation system, reconfigured to meet the mission goals for a deep space habitat traveling to near Earth objects. As a result of lessons learned during D-RaTS testing in 2010, the DSH instrumentation system has been upgraded to improve upon its previous design. In addition, the instrumentation has increased as a result of additional modules being added to the HDU. Finally, a process of implementing new instrumentation and upgrading core instrumentation has been detailed. Evaluation of this implementation process will occur throughout the integration and testing phases of the project. The lessons learned during this experience will prove invaluable for future HDU upgrades and for the development of instrumentation systems for deep space habitats.

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