Damage Detection Sensor System for Aerospace and Multiple Applications

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ABSTRACT

The damage detection sensory system is an intelligent damage detection 'skin' that can be embedded into rigid or flexible structures, providing a lightweight capability for in-situ health monitoring for applications such as spacecraft, expandable or inflatable structures, extravehicular activities (EVA) suits, smart wearables, and other applications where diagnostic impact damage monitoring might be critical. The sensor systems can be customized for detecting location, damage size, and depth, with velocity options and can be designed for particular environments for monitoring of impact or physical damage to a structure. The operation of the sensor detection system is currently based on the use of parallel conductive traces placed on a firm or flexible surface. Several detection layers can be implemented, where alternate layers are arranged in orthogonal direction with respect to the adjacent layers allowing for location and depth calculations. Increased flexibility of the damage detection sensor system designs will also be introduced.

Keywords: damage detection, sensor, flexible, expandable, inflatable, aerospace

1 INTRODUCTION

The NASA Kennedy Space Center (KSC) has been working on technologies whereby damage to materials, components and structures can be detected. A need for damage detection and verification, and its importance in meeting NASA mission needs in many applications is undeniable and has been identified in multiple NASA technology roadmaps. Technology gaps or needs for Space exploration include such areas as integrated health monitoring for space debris impacts [1], on government or commercial crew space vehicles [2], smart habitats and materials systems applications and lightweight flexible materials for expandable, inflatable or deployable structures.

The multi-layered orthogonal arrangement of damage detection system or sensory panel allows for pinpointing the exact location and depth of the damage or space debris impact if implemented in a space environment. Design options also include spacing options of the detection layers, graphical user interfaces (GUIs), and wireless communication for in-situ monitoring of the sensor system. The technology has been successfully demonstrated in the NASA Habitat Demonstration Unit (HDU) Deep Space Analog platforms [3] and via a secure network for remote sensing using single and multi-panel approaches.

2 SENSOR SYSTEM DESIGN

The multi-layered or flat surface damage detection sensory system was designed to demonstrate and evaluate the following capabilities: 1) the efficiency and accuracy of patterned conductive traces for damage detection on multi-layered materials systems or flat architectures and 2) the feasibility of detecting damage three-dimensionally in conjunction with intelligent software algorithms to identify the location, depth, and extent of damage. The prototype system consists of three main custom designed subsystems: the four-layer sensing panel with mounting frame, the embedded monitoring system, and the graphical user interface (GUI). One design option of the sensing panel consists of four monitoring layers with conductive traces oriented perpendicular to each other, thereby creating a three-dimensional grid pattern. Additionally, this design option includes each layer consisting of a printed flexible circuit sheet with 168 parallel traces 0.020 inches wide with a trace-to-trace spacing of 0.020 inches. To simulate a layered structure, Kevlar™ or Buna-N rubber are some of the materials options (Figure 1) that were sandwiched between each circuit sheet and glued together with a specialized contact adhesive to form the sensing panel. For demonstration, the mounting frame aligns and mounts the sensing panel to the embedded monitoring system. The embedded monitoring system consists of a rigid printed circuit board (PCB) that interfaces with the sensing panel. A microcontroller actively monitors the health of all traces and reports status to the GUI software. Flash memory is used to store the damage ID and the broken line numbers associated with each ID number. The on-board memory is required to log historical data. Knowing the sequence of damage events and which sensing lines were broken for each event allows the GUI software to sort and accurately assign the damage location. The microcontroller status is wirelessly reported to a laptop running the GUI. The GUI software prototype is currently written in LabVIEW and uses a custom developed damage detection algorithm to determine the damage location based on the sequence of broken sensing lines. It estimates the damage size, the maximum depth, and plots the damage location on a graph (colored coded for user friendly displays) and can include simultaneous and remote capability for multiple-panels (Figure 2).

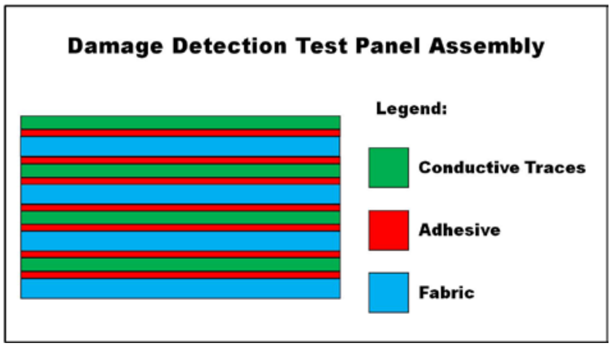

Figure 1: Example of Damage Detection Sensory Panel Assembly Drawing

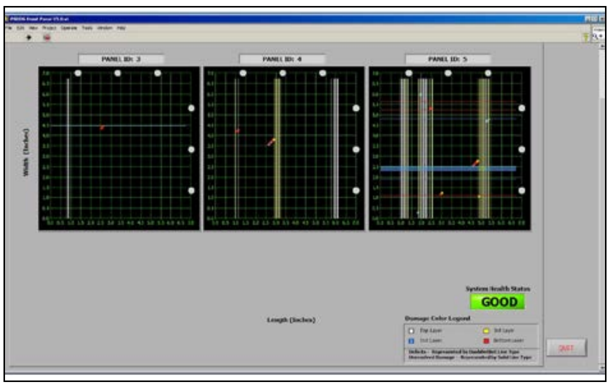

Figure 2: Screen capture of LabVIEW display of integrated testing of 3-panel damaged system

3 TESTING AND DEMONSTRATION

The ultimate goal of the in-situ damage detection system is to be fully integrated into a structure for real-time system health monitoring. However, for testing and demonstration of the technology, simulation and prototypes were designed and fabricated and protocols were carried out to validate system designs.

Enclosures for the sensory panel systems were Pro-E designed and fabricated or 3-D printed to serve as protective housing for the sensing panels, circuit boards, power supplies, and Bluetooth™ transmitters. It was expected that these enclosures would be durable and be able to survive harsh environments such as the HDU analog field demonstrations; a window was added over the opening above each sensing panel and gaskets were added. As additional protection against potential liquid exposure, 90-degree cable grips were added at the point where the power cables passed through the enclosures lids (Figure 3) in this demonstration model. The power supply for both the circuit board and the Bluetooth™ transmitter is included the enclosure and in addition, a serial connector was added to the lid of each enclosure that allows hard-wired data transmission in the event of a Bluetooth™ failure.

For testing the system, the labview GUI interface includes a configuration tab (Figure 4) that allows the operator to view the system's configuration and status. Only during manual mode operation is the operator permitted to initiate commands, edit parameters, and reconfigure the system.

In one testing configuration with software modifications, the sensor panel system was integrated into a simulated Avionics crew display during a HDU Mission Operation Test (MOT) demonstration allowing for identification of damaged lines in simulating the monitoring of a damage impact event (Figure 5). In another configuration demonstration, multiple panels were included for integrated and remote testing using a secure network where one sensory panel system was separated by over 1,000 miles. The remote testing provided successful real-time monitoring of all three damage sensor systems at two different locations as already shown in Figure 2, demonstrating monitoring capability at more than one location. This capability is very important to the application of integrating sensor systems from multiple locations and the potential of monitoring systems in remote environments like expected in long duration exploration and habitation. Also applicable to real-time damage impact monitoring in aircraft which might be located in a different location than the monitoring operator or station.

Figure 3: 3-panels with enclosures at HDU and MOT analog testing

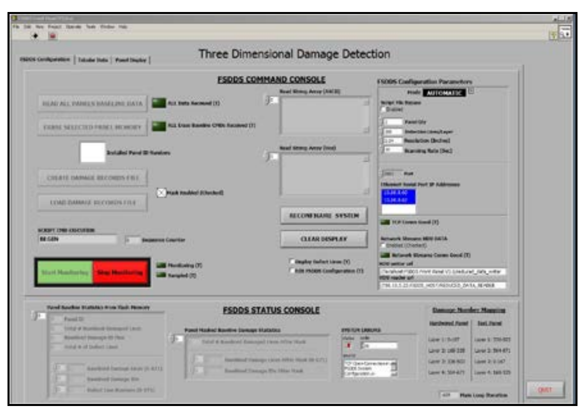

Figure 4: Screen capture of Configuration Tab feature for viewing system configuration and status

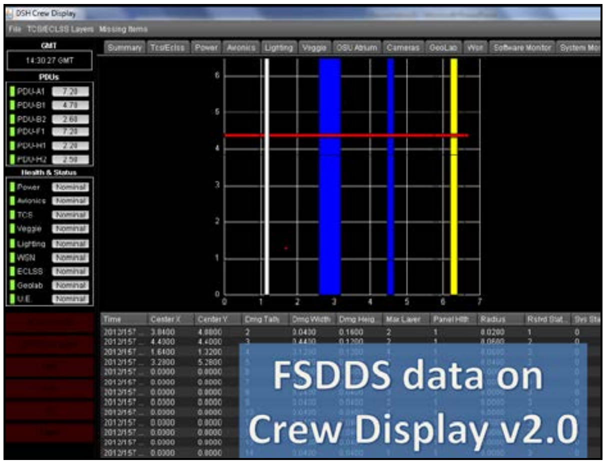

Figure 5: Screen capture of integrated sensory system in HDU Avionic crew display. FSDDS references Flat Surface Damage Detection System.

4 IMPLEMENTATION APPROACHES

Designs and approaches for implementation of some applications presented include flight experiment designs for the International Space Station (ISS) environment where the real-time monitoring of damage impacts due to space debris [4] continue to be a challenge. Consideration for design for flight experiments would include multiple sensor panels with single board controllers and data BUS interfaces for maximum area coverage and monitoring impact damage providing some differentiation between orbital debris (OD) and micrometeoroid (MM) impact. Optional system designs can also include capability for calculating velocity and independent camera inspection and verification. In designing the sensory panels architecture for flight experiment, multiple parameters must be considered for maximum sensing area and detection resolution. Using a mathematical simulator and predictive modeling tools like NASA Johnson Space Center (JSC) Orbital Debris Engineering Model (ORDEM 3.0) and Marshall Space Flight Center (MSFC) Meteoroid Engineering Model (MEM), a three-sided architectural layout of the flight experiment would be proposed. For implementation and infusion into more flexible architectures, improved designs in advancing embedded software and GUI interface, and increasing flexibility, modularity, and configurable capabilities of the system are currently being addressed. Advancing enabling capabilities are expected to be very valuable to NASA's future exploration, military applications and other industry users of in-situ system health monitoring.

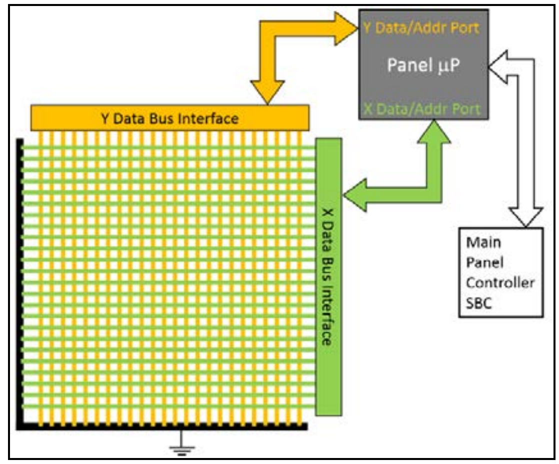

Figure 6: Sensory panel control schematic for flight experiment approach [5]

5 ACKNOWLEDGEMENT

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