WirelessFlexSENSE

Flexible Sensor Cooperation for Structural Health Diagnosis/Prognosis

State of the art – Background

The integrity of aerospace structures is affected by their severe use profiles over a wide range of loads and environments. Thus, development of approaches to monitor excessive and unforeseen loads and forecast the 'health' of aerospace structures on a permanent and continuous basis, provide a valuable extension of the structural integrity knowledge gained by regular NDE inspections and enhance the damage tolerance of the structure predicted during the structural design and certification phase.

In addition, rapidly increasing use of advanced composite materials in primary aerospace structures increases the internal structural complexity and their vulnerability to uncertain scenarios which cannot be anticipated during the design of the structure, such as in-service accidental damages, impact events, local buckling, lightning strike, overheating, etc. These uncertain events change the loading history of the aircraft structure and should be tracked and accounted. In addition, most of them cause barely visual damages which change the residual stiffness and strength, therefore, should be detected, monitored and, when exceeding a critical threshold, to be repaired.

Different physical scenarios apply to metallic structures, for instance, local buckling, plastic deformation, fatigue cracks, strike, corrosion etc. While physically different, the need of event detection and damage monitoring remain the same. Therefore, the need to detect of unforeseen events, monitor damage has made the development of new generation of advanced structures with enhanced damage tolerance a major concern for aerospace industry. Considerable research is being directed towards development of structural health monitoring (SHM) approaches and systems. This is fueled by the availability of new transmitters and sensors suitable for attaching or embedding into the composite structure which provide new capabilities and opportunities for in-situ SHM. Implementation of multiple types of sensors for event and damage detection and correlation between the sensors has also become a great scope of research in the current SHM technology.

Objectives

The aim of the present project is to develop a multi sensor network and SHM hardware/software interface to ease the data management during event and damage detection on composite/metallic structures. The software side covers the design and programming of a user friendly graphic interface, development of analytical algorithms for event and damage detection (impact detection and localization, buckling and overload and damage detection) and data management. On the other hand, hardware covers active and passive system for event and damage detection based on multi type sensor data measurements.

The main objectives of the work are defined by the four main work packages proposed:

WP1: *Demonstration of Current SHM and Assessment of Individual Sensing Techniques*. The objective of this work package is to review individual sensing techniques, select sensor candidates based on sensor characteristics, perform structural tests and physical or virtual simulations with different sensors to evidence usage suitability for specific purposes.

WP2: *Definition of Cooperation of Scenarios.* The objective of this WP deals with the design of the network and the rational to select and combine different types of sensors together with the strategy to combine the captured information and processing of raw data to accomplish the final goals of event detection, allocation, identification and damage detection and prescription.

In other words: Rational and theoretical principles and sensors net proposals plus engineering evidence (up on analytical simulation existing or preliminary testing) of conceptual sensors net performance.

WP3: *Verification Testing Scenarios.* This WP accounts for the core testing phase to prove suitability of the net to accomplish goals.

WP4: *Design Enhancement.* In this package the malfunction/failures system risks is identified providing solutions against the foreseen contingencies. In addition enhancements dealing with sensors miniaturization, wireless improvements, incidence of repairs and maintenance of the structure being monitored or regarding to sensors replacement or regarding to net malfunction are addressed

Description of work

WP1:

(1) Assessment of sensory potential for the sensing techniques for Event Detection/Characterization and Damage Detection/Characterization in composite and metallic components. Impact, buckling, overload and lightning, over temperature and fatigue crack and corrosion are identified. Composite coupons and panels are manufactured for future testing.

(2) State of the art of potential sensing methods and techniques for event and damage characterization in metallic and composite structures in order to: **1)** Identify candidate sensors and sensory techniques, **2)** Provide rationale for each sensor type, **3)** Assess the capabilities and limitations of each sensor type and **4)** Suggest candidate sensor for the upcoming deliverables. This work emphasizes in impact event detection and localization as well as overload-buckling detection.

WP2:

(1) Developed algorithms for **1)** Impact Event Detection and Localization, **2)** Overload Event Detection, **3)** Buckling Event Detection and **4)** Damage Detection and Localization are extensively documented and validated using finite element techniques or experimental data when available. Experimental data provided by Topic Manager is used to validate impact event detection and localization and damage detection algorithms. Experimental testing on composite plates is also performed in order to validate the proposed methodology. Sensor location assessment is given for a 3 bay stiffened and a 9-bay stiffened panel to be tested. Cooperation of scenarios (multiple events) is defined and hardware/software implementation for each scenario is introduced.

(2) Network sensor for cooperation of scenarios is defined in order to detect impact, multi-impact and buckling-overload events. Cooperation of sensors is defined for optimization of sensor usage. SHM software and hardware systems implementation and guidelines are defined. Developed hardware is reported.

(3) Frame 4 impact event passive data from 6 different sensors is used to perform a probabilistic study of event detection (POD) and localization upon failure of some of the sensors. Cumulative distribution function (CFD) of response is calculated in order to assess probability of success.

(4) A video demonstration of the developed hardware integrated to software is recorded showing capability of the system for event and damage detection/localization on composite panels.

WP3:

(1) Impact testing is performed on a manufactured 3-bay CFRP Stiffened panel at different energy levels and locations in order to validate impact event detection and localization and damage detection algorithms. The structure is monitored during the physical test. Impact detection and localization algorithm is validated as well as for damage detection. Prognosis assessment is performed as well by using ABAQUS/Explicit coupled with micro-mechanics-based GENOA VUMAT. Impact simulation is performed and damage is predicted. Prognosis simulations are compared with C-Scan from the damaged specimen as well as prediction from Damage Detection algorithm. Wireless passive SHM hardware system is evaluated and validated by performing impact tests on a composite plate.

(2) Prognosis blind simulations on FST structures (Bulkhead, Frame 9 and Frame 4) by TM are performed in order to show capability of FE approach for damage prediction for prognosis assessment.

WP4: Summary of reached goals and lessons learnt.

Results

1. Algorithms and Methods. The following algorithms have been developed during the present project:

-Impact Event Detection using passive PZT sensors.

-Impact Event Localization analyzing de response from passive PZT sensors (time-of-flight is used).

-Buckling Event Detection from the response of aligned strain gauge sensors (rotational acceleration is calculated) .

-Overload Event Detection using bi-axial strain gauge measurements based on bi-axial failure envelope previously predicted using MCQ-Composites.

-Damage Detection using active PZT sensors based on pitch-catch technology and damage index calculation.

-Damage Localization using data from active PZT sensors and Delenay triangulation.

2. Hardware. Hardware for SHM is developed during the present project:

- Wireless Passive SHM Hardware System for Impact Event Detection and Localization using Wi-Fi technology.

- Wireless Passive System for Accelerometer/Vibrometer monitoring using Wi-Fi technology.

- Active system for pitch-catch technology.

3. Software. Algorithms and hardware are brought together in single software oriented to Structural Health Monitoring. This is implemented in GENOA software under SHM Module.

4. Assessment on POD. Probability of detection assessment is performed based on experimental data.

5. Implementation of the Developed Technology. The developed technology is evaluated on a 3-bay stiffened panel that is impacted at different energy levels and locations. Results of predicted damage based on developed algorithm are compared with C-Scan images and prognostic analysis based on finite element analysis.

6. Full Scale Testing simulations assessment. Full scale structures are studied using FEA approach.

a) Timeline & main milestones

1. Down Selection of Sensor Systems (4 Months)
2. Down Selection of Cooperation of Scenarios (7 Months)
3. Definition of Sensors to be Build and Tests to be Performed (12 and 24 months)
4. Support for testing and evaluation of CDR on FST (24 Months)
5. Completion of POD, enhancements proposal and other sensitivity analysis regarding structural and system modifications (24 Months)

b) Environmental benefits

The technology developed in this project can be used for real time monitoring of aircraft components that eliminates onsite inspection especially under harsh condition can definitely contribute as an environment benefit.

c) Maturity of works performed

The algorithms and sensor system developed in this project for real time monitoring of aircraft components are validated in the laboratory environment are fairly matured.

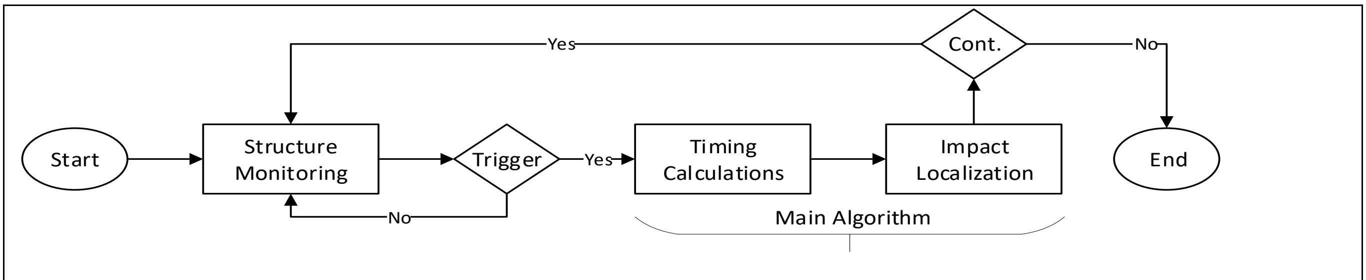


Figure 1. Workflow for Impact Localization

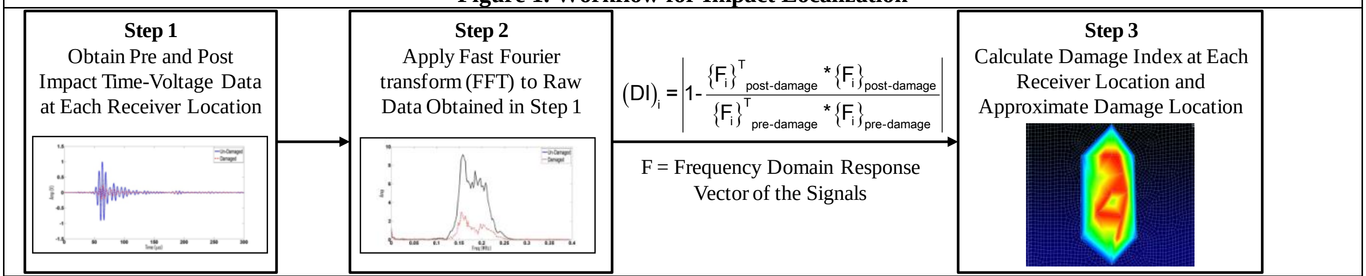


Figure 2. Flowchart for Impact Damage Detection

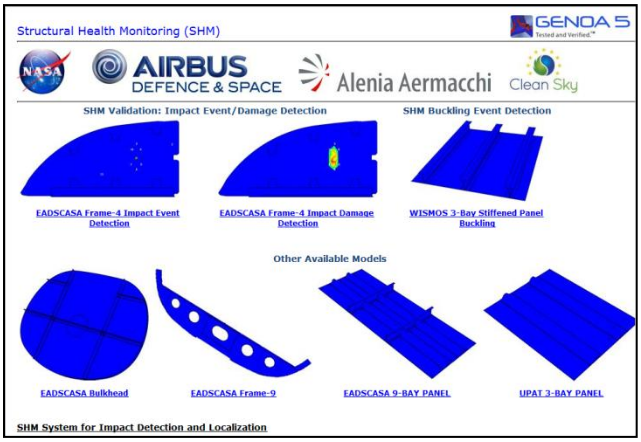


Figure 3. GENOA SHM Module improved with developed technology

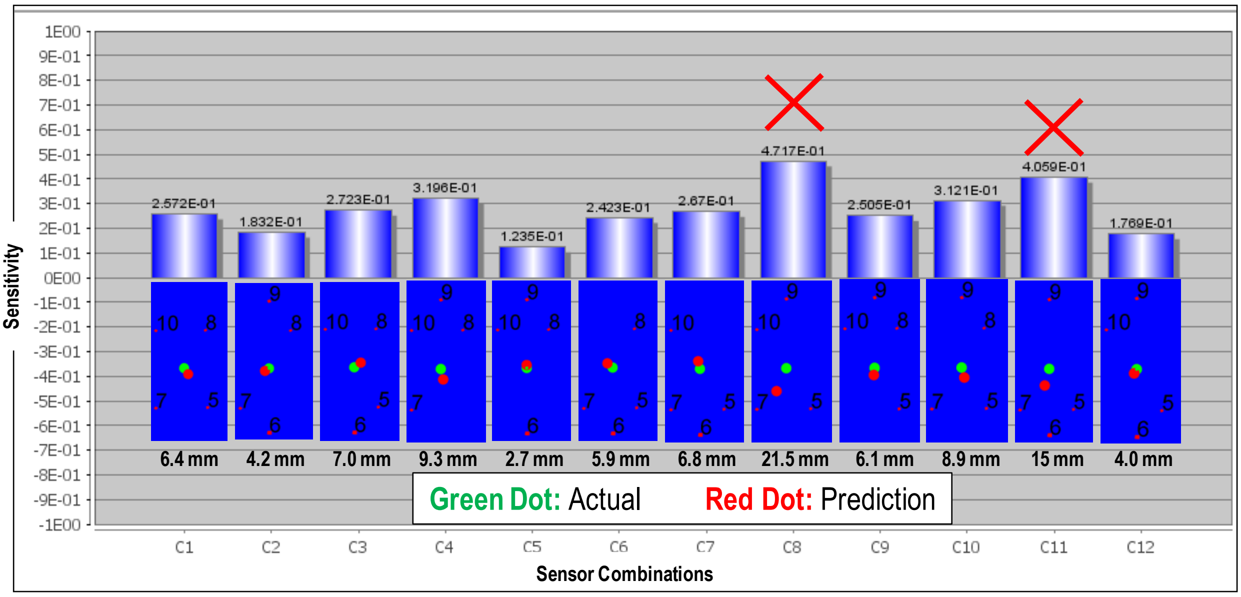
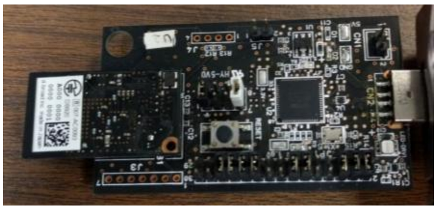
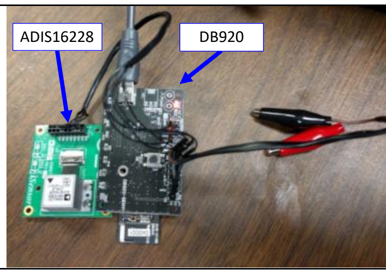


Figure 4. Probabilistic sensitivity of threshold distance for each 4 sensor combination

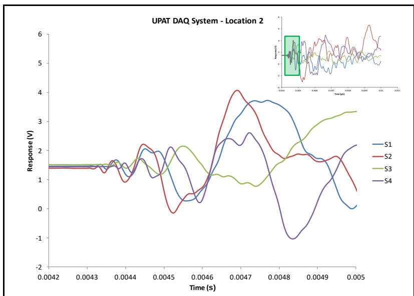


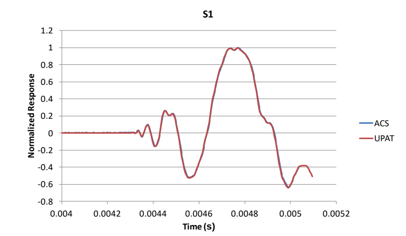
DB920-WCR USB Dongle



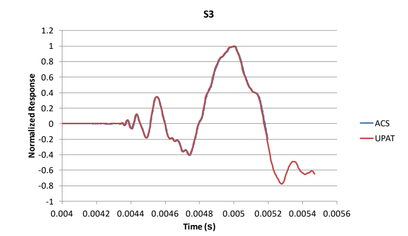
ADS16228+DB920 Board

Figure 5. Developed wireless passive SHM hardware system





Sensor 1



Sensor 3

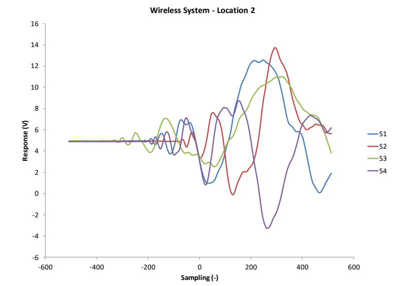
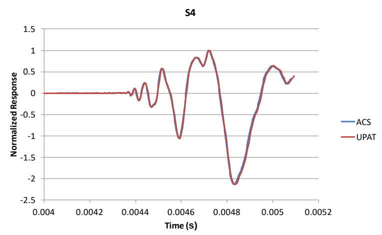
Raw measurement for wired system		
		
Raw measurement for wirless system	Sensor 2	Sensor 4

Figure 6. Sensor measurement comparison for impact event detection: wired system (UPAT) and wireless system (ACS)

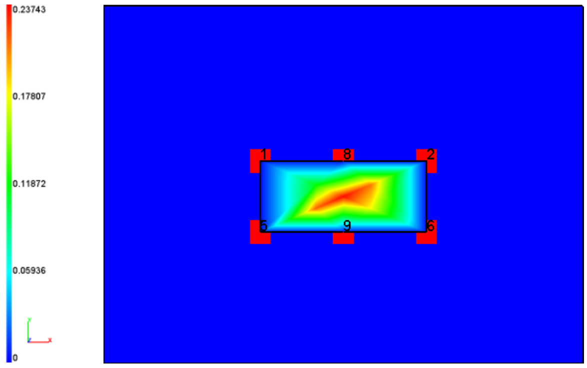
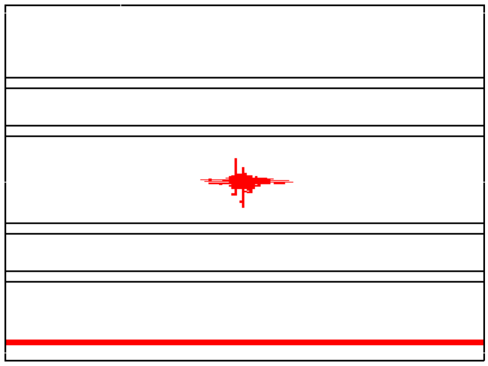
Impact Location D3 – Central Bay		
Energy	Damage Index Algorithm Prediction	All Damages GENOA ABAQUS VUMAT
10J		

Figure 7. Damage predictions based on Damage Index algorithm compared with damages predicted from finite element simulation

Project Summary

Acronym: WirelessFlexSense

Name of proposal: Flexible Sensor Cooperation for Structural Health Diagnosis/Prognosis

Technical domain:	Engineering
Involved ITD:	GRA
Grant Agreement:	JTI-CS-2013-2-GRA-01-054
Instrument:	Clean Sky JU
Total Cost:	350000€
Clean Sky contribution:	262500€
Call:	SP1-JTI-CS-2013-02
Starting date:	April 1st, 2014
Ending date:	March 31st, 2016
Duration:	24 months
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