Using COTS technology for Structural Health Monitoring in airframes during large-scale testing

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Abstract: COTS sensors and components have been combined into small, robust sensor modules, which can be attached to an aircraft structure. Data is collected and processed onboard the module, then transferred to an external server; the user can display the data and interact with the modules using a bespoke Graphical User Interface (GUI). The Structural Health Monitoring methods include point source techniques: Resistance Strain Gauges (RSGs) and Fibre Bragg Gratings (FBGs); and full-field techniques: Digital Image Correlation (DIC) and Thermoelastic Stress Analysis (TSA). Data is processed in near real-time, and indications of damage initiation and growth are shown as strain and stress field changes during loading.

Keywords: damage detection, optical measurement, data acquisition, real-time analysis, SHM

1. Introduction

Damage location and tracking is an important area of research in the aerospace industry, both during testing of components and structures, and for implementation on in-service aircraft. Current methods of locating and tracking damage through Structural Health Monitoring (SHM) are economically expensive and time and labour intensive; requiring aircraft to be grounded so that skilled personnel can carry out inspections. Therefore, developments in technology that make the SHM process more efficient are of great interest.

A wide range of SHM techniques exist, but not all are appropriate or available for application in industrial contexts. For example, the technology required may be prohibitively expensive, or require controlled conditions which are not feasible outside of a laboratory environment. In other techniques a complicated surface preparation is necessary, which is not possible for larger components or objects.

Recently, developments in full-field sensor technology have resulted in decreases in size and cost of sensors [1,2]. Image processing techniques have also been developed which allow the lower resolution data from these sensors to be used to determine the location and extent of damage present [3]. These developments allow some techniques to be revisited for application in industrial environments, with the possibility of embedding an array of sensors on a test object, to provide real or near real-time data.

The Clean Sky 2 DIMES project (Development of Integrated MEasurement Systems) aims to build on these technological advancements, to develop advanced integrated testing methods to detect damage in metallic or composite structures, with the potential to be deployed as part of an on-board structural health monitoring system for passenger aircraft.

2. System requirements

It was first necessary to define the requirements for the system.

The main requirement for the SHM system is that damage can be detected, which was further sub-divided to answer the first four questions described by Farrar and Worden [4], and collecting data to answer the fifth:

(1) Is there damage?
(2) Where is the damage?
(3) What kind of damage is present?
(4) How severe is the damage?
(5) How much useful life remains?

Using this problem definition, necessary and desired attributes for the integrated system were identified to determine which SHM techniques to implement, including:

(1) The ability to detect damage in aerospace materials.
(2) Real/near real-time data processing.
(3) Low mass and volume of the system.
(4) Low-cost.
(5) Safe operation.

A range of available SHM methods was then scored against these attributes to determine which were suitable. The four highest rated techniques were then chosen to be included in the integrated system: Resistance Strain Gauges (RSGs) and Fibre Bragg Gratings (FBGs) (point source techniques), and Digital Image Correlation (DIC) and Thermoelastic Stress Analysis (TSA) (full-field techniques).

3. Integrated system

The integrated system consists of three components:

(1) Sensor modules attached to the test object.

(2) Network Attached Storage (NAS) where all data is stored.

(3) Control computer with a bespoke Graphical User Interface (GUI) for data collection, access and visualisation.

3.1 Sensor modules

There was a strong emphasis on the use of COTS (Components Off The Shelf) technology when designing the sensor modules, to allow reproducibility, with no customised components. Small infrared sensors combined with a Raspberry Pi board computer have been trialled previously to monitor damage development in the form of crack growth using TSA [2,3]. Here, an updated version of this infrared sensor (FLIR Lepton 3.5 microbolometer, Figure 1, left) is combined with a small visible camera (Sony IMX219, 8MPx, Figure 1, right) which also allows visible images of the region of interest to be collected for processing to generate DIC maps.

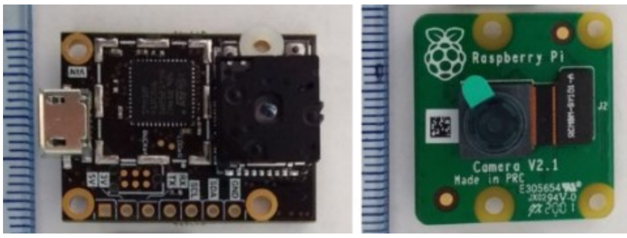

Figure 1. Small low-cost full-field sensors used in the integrated system. Infrared sensor: FLIR Lepton 3.5 microbolometer (left) and visible light sensor: Sony IMX219, 8MPx (right). Scale in mm.

A sensor module combines these full-field sensors with a Raspberry Pi 4B into a robust, self-contained unit with a footprint on the order of 70 cm^2 (Figure 2). The Raspberry Pi also accepts input from an RSG channel. These units can be attached to a test object, such as an airframe.

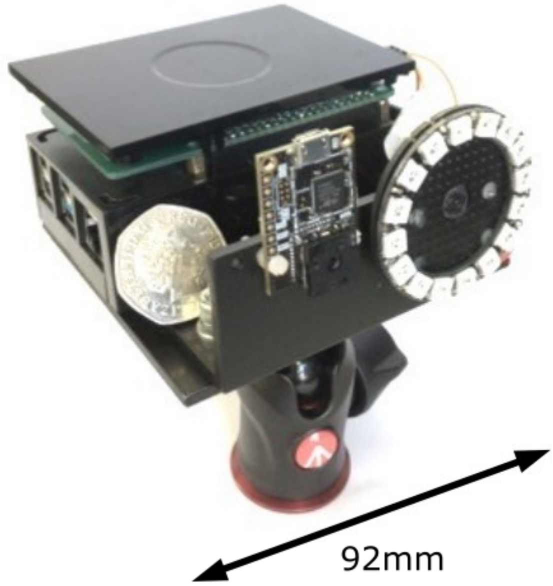

Figure 2. Prototype sensor unit combining sensors and a Raspberry Pi mounted on a tripod head.

3.2 Data collection and processing

The data collection and processing method is shown in Figure 3. Raw visible and infrared images and RSG point data are collected on the Raspberry Pi, then processed to generate DIC and uncalibrated TSA maps in near real-time.

These maps are monitored over time and quantified using feature vectors. Changes of the feature vectors compared to the reference state represent changes in the strain or stress field as damage develops and grows [4]. The maps, feature vectors and a quantitative measure of the changes due to increased damage are then transferred to the NAS from which they can then be displayed in the bespoke GUI (Figure 4).

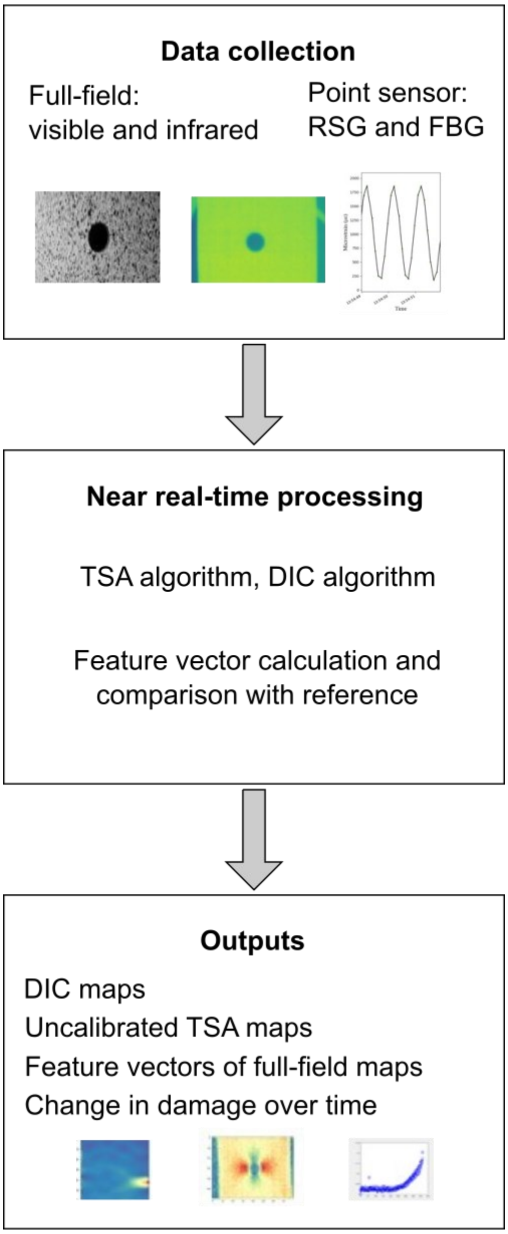

Figure 3. System data flow on the Raspberry Pi.

4. Deployment on a test object

The integrated system has been deployed in a ground test on the outer part of an Airbus A320 wing at the Empa facility (Figure 5). Once modules were installed, the wing was subject to a test regime of quasi-static and cyclic load conditions to grow cracks.

Modules were installed inside the wing bays with sensors positioned to monitor pre-existing cracks. Some surface preparation was required at the regions of interest: for DIC, a speckle pattern was applied (Figure 6). To allow TSA to be carried out on the same area, this pattern had a uniform emissivity and low reflectivity. The point sensors (RSGs and FBGs) were attached to the test object, outside the field of view of the imaging sensors.

The applied loading caused cracks in the structure to propagate from the pre-existing damage in the wing. Initial tests showed that the combined sensor system was able to identify this damage, as indicators associated with cracks were visible in the processed full-field maps. Data from one of these tests can be seen in Figure 6, where a crack-tip observed in visible light imaging (Fig 6, top) was also indicated by a "hot-spot" in the TSA data in the lower image.

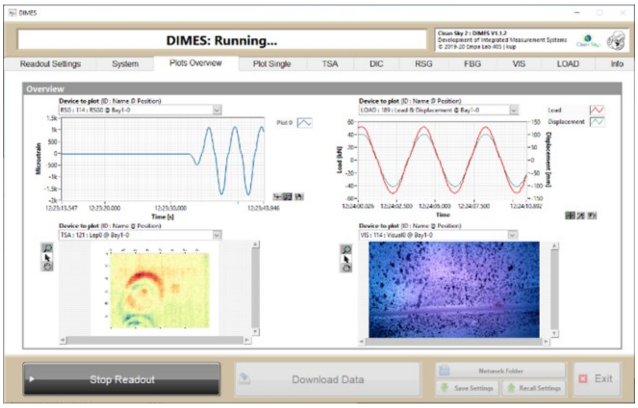

Figure 4. Integrated system GUI view during data collection, showing (clockwise from top left): RSG trace, applied load, visible camera image and uncalibrated TSA map.

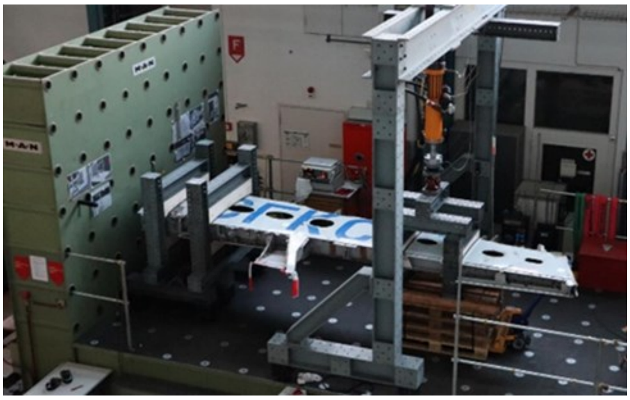

Figure 5. Airbus A320 wing installed on a loading floor at Empa, Switzerland.

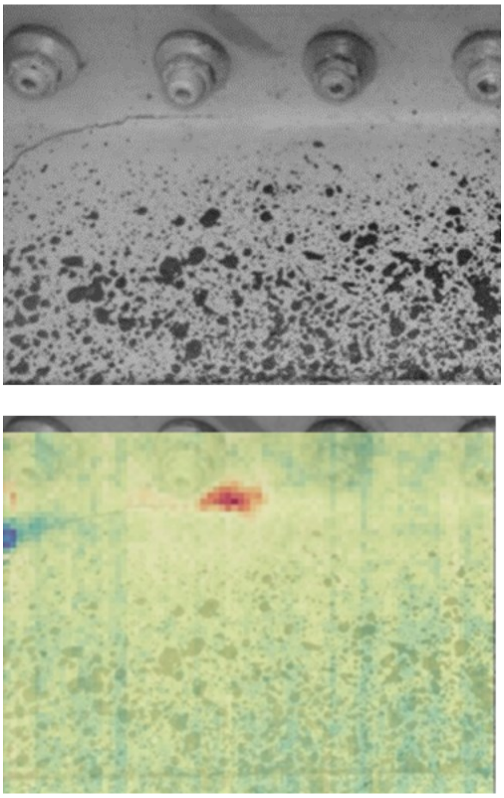

Figure 6. Visible light image of a crack in the wing (top); TSA map overlain on the same area (bottom), showing red "hot-spot" – a stress concentration associated with the crack-tip.

5. Remote installation

Implementation and testing of the sensor modules are ongoing on full-scale aircraft tests at Airbus sites in the UK and in France. Due to travel restrictions related to the Covid-19 pandemic, a remote installation procedure has been developed. A remote installation kit, combining wearable cameras with communication equipment, has allowed the Airbus Topic Manager to install a system on a large-scale aircraft test in Toulouse, with remote support from DIMES personnel (Figure 7).

Figure 7. Installation of DIMES sensors by the Topic Manager on an aircraft fuselage at Airbus, Toulouse, with remote support from the DIMES partners.

6. Conclusion

An integrated system has been developed to carry out Structural Health Monitoring on large-scale aircraft tests. Self-contained sensor modules, constructed using COTS technology, allow data to be collected with two full-field techniques (TSA, DIC) and two point-sensor techniques (RSG, FBG). Data is collected and processed in near real-time, and indicators of damage initiation and growth are visualised using a bespoke GUI.

This system represents an important step towards cost-effective, real-time Structural Health Monitoring, including damage location and growth information, which can be implemented on large-scale tests.

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The opinions expressed in this abstract reflect only the authors' view and the Clean Sky 2 Joint Undertaking is not responsible for any use that may be made of the information it contains.

8. References

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9. Glossary

COTS: Components off the Shelf

DIC: Digital Image Correlation

DIMES: Development of Integrated MEasurement Systems

FBG: Fibre Bragg Grating

GUI: Graphical User Interface

NAS: Network Attached Storage

RSG: Resistance Strain Gauge

SHM: Structural Health Monitoring

TSA: Thermoelastic Stress Analysis