SHM WITH AUGMENTED REALITY FOR AIRCRAFT MAINTENANCE

G.O.C. Prado*, P.A. Silva*, F.M. Simomura*, K.L.O. Pereira*
*Embraer S.A., Brazil

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Abstract

Structural Health Monitoring (SHM) has a great potential to reduce the costs of the current aeronautical maintenance procedures that are done through Non Destructive Test (NDT). These tasks use to be complex, as they are normally done in areas with restrict access that demand the disassembly of several parts of the aircraft.

With the SHM trustworthy systems, it is possible to evaluate the current conditions of the structure without the need of disassembly and thus inform the maintenance company about the presence and location of a structural failure.

Another technology that has shown great potential of use in the aeronautical industry is the Augmented Reality (AR). The integration of the real world with the virtual world allows the time reduction in tasks of manufacturing, maintenance, and training.

This paper shows that, when SHM and AR are combined, the data about the structure - obtained by the SHM technology - can be shown in real time without the need of disassembly, thus reducing the maintenance costs and the "human factors" risks during an inspection.

1 Introduction

This section presents the concept of aeronautical maintenance, followed by details of Non-Destructive Testing and Structural Health Monitoring. The section finishes with a brief introduction on Augmented Reality.

1.1 Maintenance

According to Blanchard [1], "maintenance includes all actions necessary for retaining a system or product in, or restoring it to, a desired operational state". The basic maintenance types are shown below:

- Corrective maintenance - This kind of maintenance is used after the item breaks down or presents malfunction. It includes all unscheduled maintenance actions. The corrective maintenance cycles include failure identification, verification, localization, fault isolation, disassembly to gain access to the faulty item, item removal, item replacement with a spare or repair in place, reassembly, checkout, and condition verification.

- Preventive maintenance - This kind of maintenance is used to prevent failures, safety violations, malfunction, or unnecessary production costs and losses of the item. It includes all scheduled maintenance actions performed to retain a system or product in a specified operational condition. Scheduled maintenance covers periodic inspections, condition monitoring, critical-item replacements (prior to failure), periodic calibration, and the like. In addition, servicing requirements (e.g. fueling & and lubrication) may be included under scheduled maintenance.

- Predictive maintenance - This kind of maintenance constantly monitors the item to determine the exact status of the item, predicting possible degradation. To establish requirements in this area, it is necessary to know how various system components fail (i.e. physics of failure) and to have available the use of such test methods as vibration signature analysis, thermography, and tribology. The objective is to predict when failures will occur and to take preventive measures accordingly.

Maintenance levels pertain to the division of functions and tasks for each area where maintenance is performed. There are 3 maintenance levels, as follows [2]:

- Organizational level maintenance - generally performed by line maintenance personnel and normally used on scheduled inspections/servicing and quick-maintenance actions on the aircraft discrepancies identified during or between aircraft flights (i.e. unscheduled maintenance).

- Intermediate level maintenance - involves more extensive maintenance work such as major inspections and component repair and overhaul (on-wing maintenance).

- Depot or factory level - involves extensive modification or overhaul to major aircraft components. The component is removed from the aircraft and the maintenance is performed in a workshop (off-wing maintenance).

1.1.1 Non-Destructive Testing

The American Society for Nondestructive Testing (ASTM) [3] definition for NDT is “the process of inspecting, testing, or evaluating materials, components, or assemblies for discontinuities, or differences in characteristics, without destroying the serviceability of the part or system. In other words, when the inspection or test is completed, the part can still be used”.

According to ATA MSG-3 [4], inspection is divided in:

- General Visual Inspection (GVI) - “a visual examination of an interior or exterior area, installation, or assembly to detect obvious damage, failure, or irregularity. This level of inspection is made from within touching distance, unless otherwise specified. A mirror may be necessary to enhance visual access to all exposed surfaces in the inspection area. This level of inspection is made under normally available lighting conditions such as daylight, hangar lighting, flashlight, or drop-light, and may require removal or opening of access panels or doors. Stands, ladders, or platforms may be required to gain proximity to the area being checked. Basic cleaning may be required to ensure appropriate visibility”.

- Detailed Visual Inspection (DET) - “an intensive examination of a specific item, installation, or assembly to detect damage, failure, or irregularity. This could include tactile assessment in which a component or assembly can be checked for tightness/security. Available lighting is normally supplemented with a direct source of good lighting at an intensity deemed appropriate. Inspection aids such as mirrors and magnifying lenses may be necessary. Surface cleaning and elaborate access procedures may be required".

- Special Detailed Inspection (SDI) - "an examination of a specific item, installation, or assembly, making use of specialized inspection techniques such as Non-Destructive Testing and/or equipment (e.g. boroscope, videoscope, tap test) to detect damage, failure, or irregularity. Intricate cleaning and substantial access or disassembly procedure may be required".

GVI and DET are classified as visual inspection. Approximately 80% of all NDT procedures are accomplished by using visual inspection methods [5].

1.1.2 Structural Health Monitoring

For Embraer, the SHM means a monitoring and management technique that uses calculation methods and on-board sensors to assure the aircraft continued airworthiness from the structural viewpoint, aiming at the improvement of design, operation, and maintenance [6].

For years, Embraer has been studying different SHM technologies with possible application scenarios for structural damage detection.

There are some SHM damage monitoring technologies under evaluation by Embraer's R&D department, such as Electro-Mechanical Impedance, Acoustic Emission, Lamb Waves (LW), Fiber Bragg Gratings, Comparative Vacuum Monitoring (CVM), etc.

The SHM application scenarios investigated by Embraer are related to the type of structure monitored.

Metallic structures can be monitored by SHM technologies in order to enable the detection of damage such as cracks (including size and location), crack growth, corrosion (including location and severity), and accidental damage (including location and intensity).

Composite structures can also be monitored by SHM technologies in order to enable detection of delamination (including size and location), debonding (including size and location), and accidental damage (including location and intensity).

The ATA MSG-3 [4] document has already been updated in 2009 to allow initial use of Scheduled SHM (S-SHM). This inclusion demonstrates the maturation of SHM technologies as promising ones to improve aircraft structural maintenance [7].

It was recognized that SHM can be implemented in two operation modes:

- Scheduled SHM (S-SHM): The act to use/run/read out an SHM device at an interval set at a fixed schedule [4].
- Automated SHM (A-SHM): that relies on the SHM system to inform maintenance personnel that action must take place [8].

In terms of airplane design, SHM offers potential benefits such as structural efficiency improvements and weight savings.

In order to incorporate SHM technologies into aeronautical structures, some SHM issues still must be considered for system reliability (for the entire life of the aircraft), durability, and qualification, in accordance with the applicable aviation regulations.

After demonstrating strong results on ground tests and in the flight test aircraft, Embraer decided to develop a project using the S-SHM approach for the qualification of CVM and LW technologies and to validate the performance of such systems in real-life operational environment. This project included laboratory tests for the assessment of detection capabilities and tests with systems installed on a number of operator's aircraft to check operational behavior [9].

1.2 Augmented Reality

AR is the combination of the physical real world and the virtual world in real time with the user interaction. The virtual information is spatially rendered in the physical world, usually using a tablet, smartphone, or augmented-reality glasses.

The AR-process basic flow starts in the video capture by a camera. This video is split in frames in which each frame/image is processed so that a position is identified, normally through a marker. Once this marker is detected, the camera position is calculated considering its inherent parameters. After this position is found, the virtual object is then rendered in the same frame/image by applying perspective angles, translations, and rotations. As shown in the Fig. 1.

The fiducial marker is one of the most-used techniques to position a virtual object in the physical world. It is a bidimensional image that is added to the scene so that it can be captured by the camera and then, when it is processed, it can identify its position.

There are also initiatives for the use of AR without markers. In this case, the application is capable of getting the position of the physical real world. One example of this technique is the recognition of the edges of an object based on its previously-known geometry. The match of these edges makes the object itself be a marker.

Many advances in the technology have made feasible the use of AR in the aeronautical industry. The 3D models created in the aircraft design can be reused in this context, allowing new possibilities of use in aircraft manufacture, training, and maintenance. Combined with the use of mobile devices, it is possible to expand the accessibility and make it easier the presentation of virtual information in the physical world.

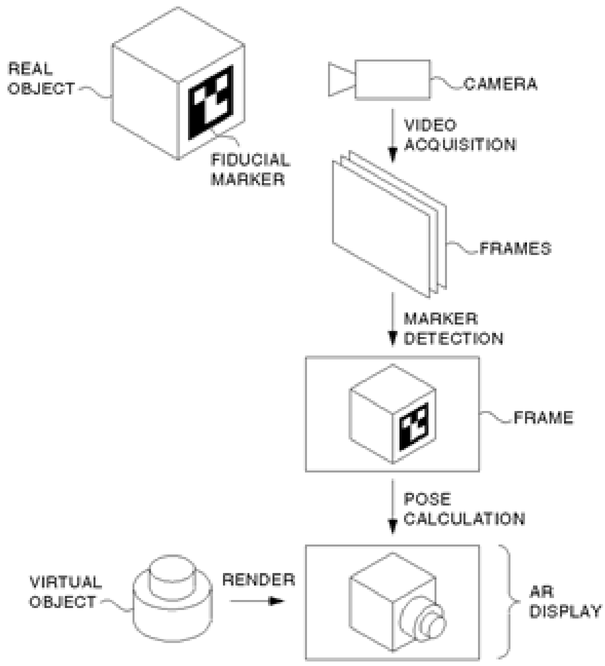

Fig. 1 Augmented-Reality-process basic flow with fiducial marker

2 Structural Health Monitoring With Augmented Reality For Aircraft Maintenance

Scheduled maintenance and inspection activities can take advantage of the SHM technologies by evaluating the structural integrity of an aircraft and performing less time consuming procedures, compared to the current NDT technologies.

The SHM technologies cannot only reduce the amount of time and burden of those activities, but can also early detect, without great effort, the possibility of finding structural damage in restricted access areas, reducing maintenance costs due to less time-consuming and less complex maintenance procedures.

Another important advantage is the possibility of minimizing the effects of "human factors" during an inspection, because it is an automated damage detection application and the automated data analysis has the potential of reducing human errors induced by fatigue and repetitive tasks. [10].

Fig. 2 shows an example of a maintenance inspection task and it is possible to understand the complexity and time required to perform the activity.

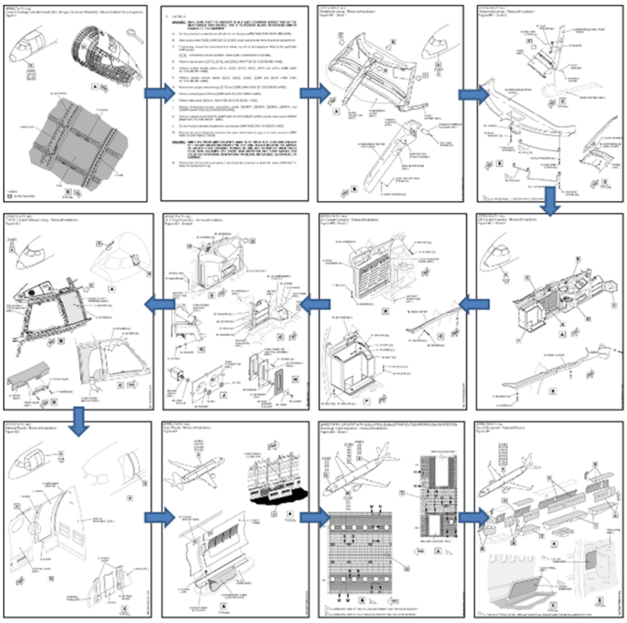

Fig. 2 Example of traditional disassembly to perform a maintenance procedure with NDT

Fig. 3 shows an example of an inspection task with SHM technology. During the installation of the SHM on the aircraft, the data acquisition points are left in an easily-accessible location for the inspector. In this example, it is necessary to remove only a ceiling panel to perform the structural inspection with SHM.

It is important to note that SHM can prevent disassembly processes, which may eventually cause undue damage to the structure.

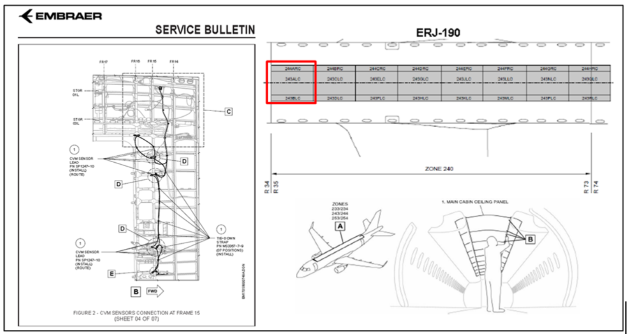

Fig. 3 Example of an easy disassembly to perform a maintenance procedure with SHM

In the future, SHM will be capable of providing means for the replacement of the current time-based maintenance practices by Condition Based Maintenance (CBM) [11].

2.1 Structural Health Monitoring enhanced by Augmented Reality

Embraer is always focused on exploring ways to reduce maintenance costs and increase efficiency of its services. The use of AR technology is directly connected with this Embraer's philosophy.

According to this view, Embraer has a granted patent on the use of Structural Health Monitoring system with the identification of the damage through a device based on Augmented Reality technology (US20170322119 A1)[12].

The augmented reality combined with Structural Health Monitoring sensors allows the maintenance technician to perform maintenance tasks much quicker and in a more reliable way.

This technology enables the inspector to know your position in relation to the structure that needs to be checked and, with this reference, the SHM data is shared with the AR device. Then, the technician has the real-time information about the structure without any necessary components disassembly, allowing more maintenance tasks to be performed in that time period.

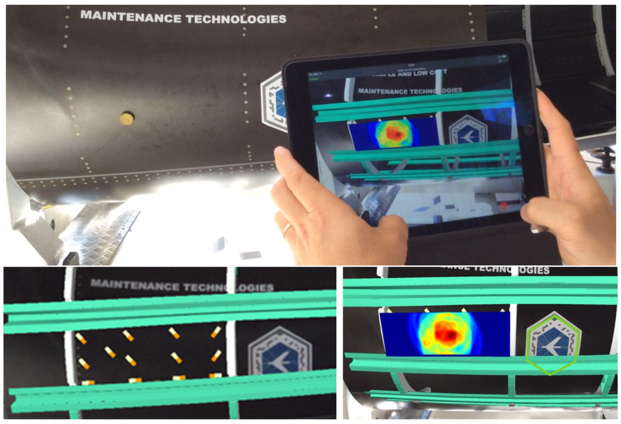

Fig. 4 Example of a non-need disassembly to perform a maintenance procedure with SHM with AR

Fig. 4 shows an example of how the information can be quickly reached through a real-time connection between the data acquired by SHM technology installed in the aircraft and the augmented reality device, without the need of disassembling the aircraft.

Fig. 5 shows a simplified proposal of a system using SHM enhanced by AR that can also generate a maintenance report with the aircraft structural condition, to facilitate the maintenance technician work in registering the inspection data after the end of the inspection activity. This report can also support the engineering group to give a fast resolution of the detected damage and return the aircraft to an airworthiness condition.

3 Conclusion

The combination of the Structural Health Monitoring with Augmented Reality technologies gives the opportunity to decrease the maintenance-activities time in opening and closure of accesses, disassembly and assembly of components, inspection activities, elaboration of reports, register of maintenance activities, etc., and the possibility to decrease the introduction of the damage or wear in the components, due to these activities.

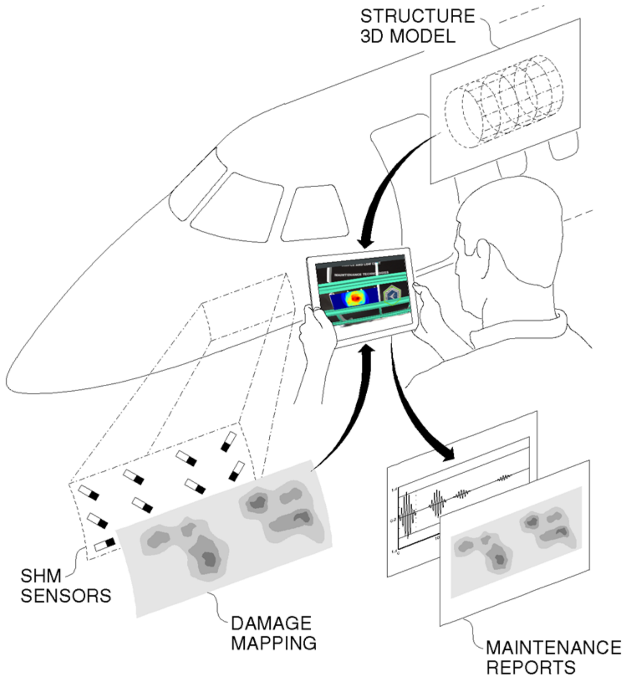

Fig. 5 Simplified proposal of a system using SHM enhanced by AR

Therefore, the combination of these technologies can increase the aircraft availability to Embraer's Customers in the future.

Embraer's team has developed initial studies to present SHM data results with an AR device to the maintenance technicians. In addition to assisting in the accomplishment of maintenance activities at a reduced cost, the main idea of these studies is to share the knowledge of the technology for use in several areas of the company.

4 Contact Author

For further information please contact gabriel.cruz@embraer.com.br.

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