Recent Advances at KAIST in In-process NDE and Smart Hangar for Aerospace SHM

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ABSTRACT

Recently, we are in transition from metallic to composite in operation and manufacturing of aerospace structures. NDE, SHM, and PHM are all over used, in design, manufacturing, operation and overhaul stages in their life. In this invited talk, opto-electronic systems capable of in-process NDE, in-situ NDE and integrated SHM and their real world applications are introduced. In addition, their field implementation scenario are proposed and advances in Smart Hangar are introduced.

1. INTRODUCTION

Composites have superior specific strength and specific stiffness compared to metal materials, and the transition from metal to composite materials is underway in the operation and manufacturing of aerospace structures. However, current composite materials in aerospace structures also has a disadvantage that it is difficult to visually detect damage caused by external impacts or internal defects (Armstrong, 2005). In order to detect the internal damage of the composite structures, non-destructive evaluation (NDE), structural health monitoring (SHM), and Prognostics and Health Management (PHM) are all over used, in design, manufacturing, operation and overhaul in their life. In this paper, opto-electronic systems capable of in-process NDE, in-situ NDE and integrated SHM and their real world applications are introduced.

2. SMART HANGAR WITH IN-PROCESS NDE, IN-SITU NDE, INTEGRATED SHM AND DIAGNOSTIC ARTIFICIAL INTELLIGENCE

Ultrasonic propagation imaging (UPI) is a NDE & SHM technique based on laser ultrasonic scanning and sensing. The UPI system generates thermal elastic waves through a laser beam which is impinged on a surface to be inspected. Then, ultrasound signals are acquired through contact / non-contact sensors and ultrasonic wave propagation images are generated in real time by an image processing PC (Chia, Lee & Park, 2012). Here, through-transmission (TT) UPI system is introduced as an in-process NDE technique that is able to visualize internal defects. Then, the Smart Hangar system is an integrated in-situ NDE & SHM system for aircraft. It consists of mobile UPI systems, pulse-echo (PE) UPI systems, and built-in UPI systems as shown in Fig. 1. The jet engine is damaged by tiny foreign objects, which is inspected by an inspector with a borescope but we added artificial intelligence (AI) to minimize human error in decision making.

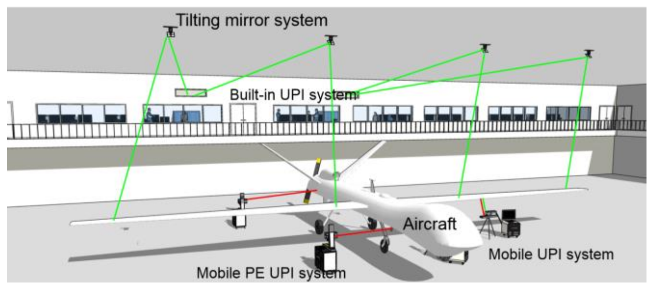

Figure 1. A concept of the Smart Hangar.

3. PROOF-OF-CONCEPTS

3.1 IN-PROCESS & IN-SITU NDE BASED ON BULK WAVE UPIS AND AI

As shown in Fig. 2 (a), TT UPI system was applied for in-process NDE implementation of a carbon composite brake disk of aircraft. Figure 2 (b) and (c) shows ultrasonic wave propagation images where many defects were suspected in the thickness direction inside the brake disk.

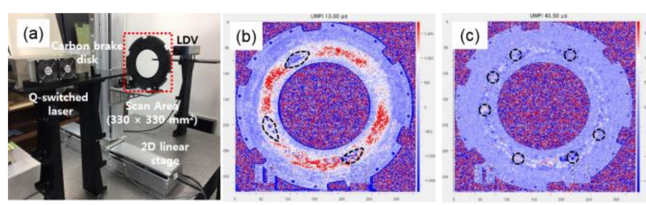

Figure 2. Damage visualization results using TT UPI system, (a) experimental setup, (b) UWPI at 13.60 μs.

For the in-situ NDE of the composite antenna structure of actual aircraft, we performed the damage visualization of aircraft UHF antenna using a mobile PE UPI system as shown in Fig. 3. In Fig. 3(c), the PE UPI system was able to visualize resin-rich region formed between glass/epoxy fabric plies. Curvature compensation algorithms has been developed and the curvature corrected UWPI result clearly visualized manufacturing defects of 40 mm in size by eliminating the curvature-induced global amplitude distribution as shown in Fig. 4(d) (Shin, Park, Hong & Lee, 2017).

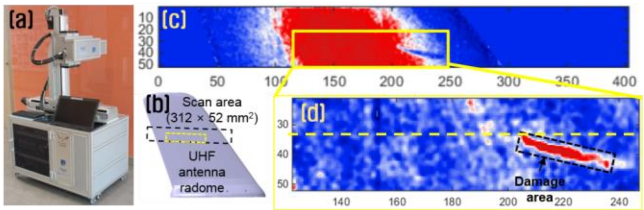

Figure 3. Damage visualization results using PE UPI system, (a) PE UPI system, (b) shape of UHF antenna radome, (c) UWPI at 6.150 µs, (d) curvature corrected UWPI result (Shin, Park, Hong & Lee, 2017).

The jet engine is damaged by tiny foreign objects, which is inspected by an inspector with a borescope. The inspectors easily make mistakes because of long time inspection and many blades to be inspected. Therefore, we implemented convolutional neural network based AI to minimize human error in decision making.

3.2 LAMB WAVE UPIS FOR SHM

A demonstrator based on a built-in UPI system consists of a multi-area scanning UPI system and a tilting mirror system was performed with a real aircraft (CESSNA C-150) to verify the applicability in a Smart Hangar as shown in Fig. 4(a). Multi-area scanning UPI system was designed to scan two areas at the same time with one system, and combines with a tilting mirror system that can change the laser scanning area to inspect a specific upper surface area of the aircraft. As shown in Fig. 4(b) and (c), the damage visualization results clearly show the back surface cracks with a size of 10 mm in each scan area of both wings using ultrasonic energy mapping (UEM) method (Shin & Lee, 2017). Meanwhile, the mobile UPI system has been demonstrated to cover a large scan area with multiple PZTs serial-connected with a conductive fabric tape as shown in Fig. 5 (a). The damage visualization result clearly shows all of cracks in a real aircraft fuselage, which were located at A-E points by the multi-time-frame UEM method as shown in Fig. 6(b) (Bae & Lee, 2016).

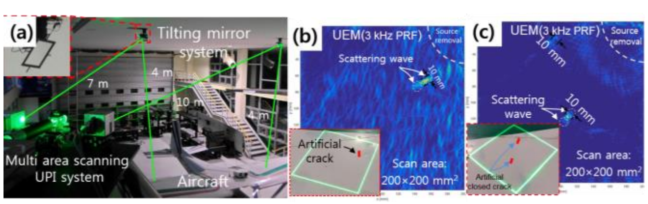

Figure 4. Damage visualization results (a) implementation of built-in UPI system in Smart hangar, (b) UEM result of right wing, (c) UEM result of left wing (Shin & Lee, 2017).

The damage visualization result clearly shows all of cracks in a real aircraft fuselage, which were located at A-E points by the multi-time-frame UEM method as shown in Fig. 6(b) (Bae & Lee, 2016).

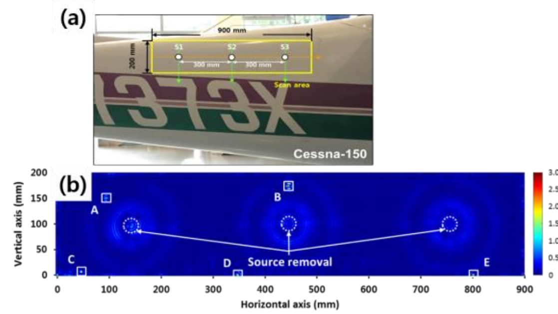

Figure 5. Damage visualization results of fuselage (a) Inspection setup, (b) multi-time frame UEM result (Bae & Lee, 2016).

4. CONCLUSION

In this invited paper, we introduced opto-electronic systems capable of in-process NDE, in-situ NDE, integrated SHM and diagnostic AI and their real world applications. The TT UPI system visualized internal defects of carbon brake disk and The mobile PE UPI system showed internal a resin-rich region of an aircraft antenna radome clearly. The damage visualization results in the main wings and fuselage by the mobile and built-in UPI systems with PZT sensor arrays showed excellent damage visualization results for the real aircraft. Also, a jet engine VT was demonstrated by an AI. Consequently, this work demonstrates the possibility of the proposed opto-electronic systems and AI as in-process NDE, in-situ NDE and integrated SHM technology.

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BIOGRAPHIES

JR Lee is (Full name in Korean: Jung-Ryul Lee) is associate professor of the Department of Aerospace Engineering in Korea Advanced Institute of Science and Technology, South Korea. He served as a co-director of the Engineering Institute-Korea between Los Alamos National Lab and Chonbuk National University from July 2011 to Dec 2014. He was a visiting scholar of Los Alamos National Laboratory in US from Aug 2013 to July 2014.

He received his MS from KAIST in Korea, and Ph.D from Ecole Nationale Superieure Des Mines de Saint-Etienne in France with the 1st class honor in 2004. Before joining the university, he has been a scientific staff member at the National Institute of Advanced Industrial Science and Technology in Japan and a research associate at Ecole Nationale Superieure Des Mines De Saint-Etienne. His research interest includes Smart Hangar (Inventor), integrated systems health monitoring, fiber optic, remote and wireless sensing, advanced nondestructive evaluation and measurement, pyroshock, laser ultrasonics, optics in engineering, microwave imaging, and diagnostic artificial intelligence. His application field encompasses space launchers, unmanned air vehicles, engines, wind turbines, power plants, railway structures, automobiles, public safety and radome/stealth structures. He has published over 300 articles and patents in this area, and received several awards, including Emerging Researcher Award in 2007 by the Japanese Society for Nondestructive Inspection, one of 16 Excellent Emerging Researchers Award in 2011 by Ministry of Education, Science & Technology in Korea, Excellent R&D Achievement Award in 2013 by Jeonbuk Province, and Young Scientist Awards in 2015 and 2016 by Korean Composite Material Society and International Sustainable Aviation Research Society (SARES), 2016 KAIST R&D 10, respectively. His research team was appointed as Global Research & Development Center in 2011 and Boeing-KAIST Technical Contact Lab. A proof-of-concept paper of Smart Hangar authored by him and his student won the grand prize of the best papers in 2013 from Ministry of Land, Infrastructure and Transport in Korea.

He serves a co-chair of International Conference on ASHMCS2012 and 2014, and an editorial board member of SHM-IJ, ACM, MST. He produced 2 professors in India and Malaysia and 6 Ph.Ds by Feb 2016. Contact: leejrr@kaist.ac.kr.