EMERGING TECH CONFERENCE – Edge Intelligence

Volume 01, 2022, Page 42 – 47

Proceedings of Emerging Tech Conference: Edge Intelligence 2022

Designing Intelligent Repair of Composite Structures with the Aid of a Laser Equipped Manipulator

Spyridon Psarras*, George Sotiriadis, Theodoros Loutas,Vassilis Kostopoulos

Department of Mechanical Engineering and Aeronautics, University of Patras, GR-26500, Patras, Greece.

spsarras@upatras.gr

Abstract

Low velocity impacts in CFRP's structures cause a variation of size, type and area of damages thus different types of repair methods have to take place. For an ensured and controlled repair selection, numerical models have to be developed and verified against the acquired experimental results. Also, the automation of the repair procedure can increase the repeatability and safety. University of Patras (AML Group) developed an automated repair manipulator for composite structures that reached TRL-4. This manipulator can remove material in various depths and shapes with the aid of a laser module and could behave cognitively for repair aircraft structures. The system will interact with the human users/operators through extended reality modules (augmented reality glasses, haptics interfaces) to increase human situational awareness but also to include human behavior in the design and operation phase. The MRO service providers are expected to use this technology to assist their technicians with real-time support through a virtual immersive world. This will lead to various positive implications such as increased efficiency, cost savings, reduction in human errors, and safety.

1. Introduction

Aircraft are subject to ground and periodic testing to examine their integrity and functionality resorting both to traditional visual inspections and non-destructive testing (NDT) as requested by European Aviation Safety Agency (EASA). Some checks may require up to 40000 man-hours, resulting into high costs for aviation companies. Additionally, human operators can repair internal damages only if localized in the cabin or the proximity of the wingtip or root. For components such as fuselage, horizontal stabilizers and wings, a defect occurrence is often critical because often they are not reachable for inspection and repair operations. The latest pandemic of COVID- 19 has forced aviation organizations and regulators to look at ways to meet social distancing and remote working conditions [1]. On this premise, cognitive robotics can be used for inspection and repair in the aerospace industry across a variety of different functions. For instance, airplane cleaning robots can assist in disinfecting germs and stop the spread of the virus. Several Maintenance, Repair, and Overhaul companies (MROs) are already using robotic systems to assist in checks. Airbus presented the Hangar of the Future, an innovative application of state-of-the- art technologies and methods aimed at increasing operational efficiency for customers' aircraft and rotorcraft worldwide [2]. Testia, which specializes in non-destructive testing,

developed in cooperation with Airbus, a drone- based aircraft inspection system, optimized for inspecting the upper parts of the aircraft fuselage [3]. Rolls-Royce has demonstrated a range of robotic inspection and repair tools able to work, collaboratively, inside aircraft engines that are remotely controlled [4]. Lufthansa Technik's Hamburg base equipped with 5G networks to support the huge demands of information data rates for live data transmission. The technicians on site always can check the current position of all planned components and, additionally, to coordinate any necessary changes with the developers through collaborative video functions.

The complexity of aircraft maintenance activities is based on the use of skilled and specialized workers that operates on aircraft recovered in hangar. To apply maintenance task operators, provide preparatory operations in terms of both set-ups (stands, platforms, stairs), removals and disassembles for access to the work areas to carry out the inspection and repair activities, which also include aspects such as work at height and within confined areas. In heavy maintenance activity the effort related to these preliminary actions is about 50% of personnel costs. Furthermore, the activity related to asset the damage and design the repair also defines a big effort in terms of time (Workflow) and expertise. However, human operators can repair internal damages only if localized in the cabin or the proximity of the wingtip or root. Components such as fuselage, horizontal stabilizers and wings, where a defect occurrence is often critical, are not reachable for inspection and repair operations. During the CompInnova project, University of Patras - AML Group (UPAT/AML) developed an automated repair manipulator for composite structures that reached TRL-

The manipulator could remove material in various depths and shapes with the aid of a laser module. the developed laser module was envisaged to perform stepped lap material removal on composite plates. This manipulator could go a step further and be encased with intelligent features and distinguish. The roadmap of doing this is explained in the following section.

2. Automatic Repairs using Robotic manipulator

Focusing on advanced composite structural components in aeronautics, they are characterized by very high production costs, complex shapes and expensive forming equipment. Composite materials use in aircraft has increased in the last 10 years because of their low weight and fuel consumption reduction. However, there are no fix strategies, or a one size fits all solution currently available to repair them and the components, often very expensive, must be discarded. It is estimated that by 2035, unless maintenance, repair and recycling increases across the aviation industry, an astonishing 23,360 tonnes per year of end-of-life carbon fibre will accumulate. For this reason, aircraft constructors plan huge investments for defects avoidance during the forming processes of CFRP and to develop effective, robust and reliable repair tools and methods. Laser processing can support a precise ply- by-ply removal in composite structures and a complex load path optimized geometry is feasible. This way higher ultimate peel stress and interlaminar tension shear strength of the repaired area are anticipated [5-7]. The interaction of the laser with polymer composites can modify the physical and chemical properties of the material through photo-thermal and photo- chemical processes depending on the laser parameters and material properties [8, 9].

In repair technology for composites, bonded composite scarf repairs are widely used, because they ensure high efficiency of joints, adequate reliability and high finishing of sculptured surfaces. This latter aspect is very important for the repair of external aerodynamic surfaces (external skin

panels) but it is also appreciated in interior repairs. Furthermore, several research studies proved that this repair technology ensure higher performance and reliability than other repair techniques (resin injection and doubler-based techniques, mechanically fastened patches, etc.). For these reasons, bonded composite scarf repairs are increasingly applied in aeronautics manufacturing with successful results, and a relevant research effort is currently focused on this technology in order to improve its efficiency and solve the open issues. Scarfing repair process consists in replacing, by bonding, the damaged parent material (original component) with new and mechanically functional material (patch), as in Fig.1.

The main issues of bonded scarf repairs are mainly related to the scarfing geometry, precision and bonding technological parameters. Regarding the scarfing geometry, an adequate scarf angle implies the removal of a large quantity of undamaged material, aiming to avoid delamination damages in parent material. Important bonding parameters are mostly related to the surface curing (treatment pressure and temperature). These issues are still challenging for repair techniques of CFRP. UPAT's methods deliver results were in average 67% of the ultimate tensile strength was recovered as well as over 95% of the stiffness. More specifically the highest recovered strength was at 69%, obtained from the laser treated repairs with dry patch, while the milled repair with wet patch followed with 68%. Finally, the laser treated repairs with wet patch had a recovered strength of 65%. Concerning the stiffness, the results were outstanding and when comparing with similar research it can be said that UPAT's method is a step ahead. Definitely the standardization of the method and its implementation for industrial use definitely will be a great asset.

The degree of novelty can be explained by three dimensions:

1 enhancing composite repair (performance opportunity),
2 automating composite repair (cost reduction and error reduction opportunity), and
3 digitising composite repair (augmented human opportunity).

Figure 1: Stepped scarf repair.

2.1 Enhancing Composite Repair

The quality of the bonded repair depends by several factors: parent and repair materials, surface treatments, adhesive type, curing conditions, joint design. These factors are accurately evaluated and designed, in order to guarantee an adequate stress distribution in the repaired region. The entire process consists of six steps: a) damage assessment; b) material removal; c) surface preparation; d) patch fabrication; e) design; f) monitoring and automation. FE models have already been validated previously and revealed the influence the scarf ratio played to the performance of the repaired composite parts. The next step that will be investigated is the importance of scarf

shapes. The outcome will be that the optimized stepped scarf repair increases the strength of the damaged panel with the main advantage the decreased material removal during the repair process, which relates to saving time, material and cost in comparison with the conventional repair shapes. Care should be taken to the necessity of parametric analysis before carrying out the repair for the optimal geometry, combining the recovered strength with a small volume of removable material Until now, the machining is performed manually by a skilled operator (scarfing) or through more accurate Unmachined tools and robots (scarfing or milling); here the automation of the scarfing process will be evolved. Since the amount of material to be removed from the original component depends not only on the damage features but also on the geometrical parameters of the designed patch, in the repair design an important step is the optimization. The shape and the scarf angle of the patch should be optimized in order to minimize the undamaged material to be removed which also results in a reduction of machining and repairing time. The choice of the repair surface shape should also take into account other aspects such as curvature of the component and other structural constraints such as presence of local reinforcements, edges, thickness changes, bolted joints, etc. In some cases the repair surface belongs to a local planar region without constraints, the scarf angle can be constant, and the scarfing surface can be flat and simple such as circular or elliptical for low and high damage aspect ratio respectively. These latter shapes are considered “standard” and effective geometries for simple repairs and do not require complex tools to generate the toolpaths. More often, the repair surface must assume curved and irregular shapes due to the component geometry and structural constraints and these circumstances significantly increase the complexity of toolpath generation and machining process. Therefore, the toolpath generation can be a complicated task which requires specific numerical tools (i.e. CAD/FE software) in order to create a Digital Twin (DT). DT is an important driving technology that is leveraged in this objective in providing interoperability between all development platforms and creates a potential bridge for the success of Holistic modelling, Simulation and AI training. The simulated activities of the single robot will be connected to DT to produce DT simulation models. DT will be supported by 5G network to improve real time accuracy in order to gather real-time data from the field and communicate commands from DT and XR user interface devices for better visual presentation of the model.

Leveraging a Digital Twin (DT) technology in model-based design for inspection and repair of aircraft structures aiming at creating a new model-based design paradigm via: Holistic modeling, simulation and AI training: we structure a modeling orchestration mechanism that under the same framework will capture the system level functionalities using a Model of Models approach and that can include specialized components to handle cognitive and secure behavior at robot level and the system level (e.g., SPL/ML algorithms and safety and security by design features). UPAT/AML aims to create a simulation orchestrator that can bridge various simulation engines like Intra and intercommunication simulators, hardware simulators, software computation simulators as well as use case-specific simulators. Using the models of the robot and system as well as models of user behavior and physical environment, specific scenarios emulating abnormal conditions will be fed to the simulators in tolerating appropriate data sets for providing training to the cognitive artificial intelligence entity.

2.2 Automating Composite Repair

The use of automation and robotic technology can certainly define new practices and alternative procedures that ensure significant reductions in time and cost while also reducing personnel

exposure to risks. The collaboration is intended also in the Robot/Human Interface: foreseeing the possibility of work synergy between the robotic units and the operators, based also on workspace sharing, the robotic units comply with the specifications of the ISO/TS15066:2016.

Several Maintenance, Repair, and Overhaul companies (MROs) are already using robotic systems to assist in checks. Airbus presented the Hangar of the Future, an innovative application of state-of-the-art technologies and methods aimed at increasing operational efficiency for customers' aircraft and rotorcraft worldwide. Testia, which specializes in non- destructive testing, developed in cooperation with Airbus, a drone-based aircraft inspection system, optimized for inspecting the upper parts of the aircraft fuselage. Rolls-Royce has demonstrated a range of robotic inspection and repair tools able to work, collaboratively, inside aircraft engines that are remotely controlled.

Currently, robotic repair is comprised of various, autonomous, robots, each one of them having unique performance capabilities, criticality level, priorities, and pursued goals. Finding the methodology to harmonically pursue system-based achievements and collaborate to make system-of-system based decisions is not an easy task. Decentralized cognition becomes more complex when we also consider the amount of data to be exchanged between robots and the processing of that data.

2.3 Digitising composite repair

MRO service providers are expected to use XR technology to assist their technicians with real-time support through a virtual immersive world. This will lead to various positive implications such as increased efficiency, cost savings, reduction in human errors, and safety.

Augmented Reality Rendering and interaction experience is transforming the way inspection and maintenance processes are performed in the aviation industry. Over the years, research on head-worn augmented reality has been complemented by work on new platforms such as handheld AR systems, while hands- free, voice-driven, holographically immersive platforms provide the means to dramatically facilitate the training of human workers. It has been shown that gains of labor qualification, training costs reduction, inspection system and productivity of the business can be provided in aerospace manufacturing using AR. The possible application of different MR technologies as cognitive support systems especially for maintenance has been thoroughly investigated.

Remote operators play a key role in the operation of robots and take many important decisions. Thus, the need to structure a close symbiosis between computer-based systems and human operators/users and constantly enhance human situational awareness. Novel approaches on Human Machine Interfaces that employ XR principles need to be devised in order to help humans gain fast and easy to grasp insight of the robot processes but also to enroll them seamlessly to the overall operation of the robots. These tools for remote MRO collaboration could help adapt workflows to compensate remote working and pave the way for the aircraft maintenance of the future.

3. Conclusions

Currently, robotic repair is comprised of various, autonomous, robots, each one of them having unique performance capabilities, criticality level, priorities, and pursued goals. Finding the methodology to harmonically pursue system-based achievements and collaborate to make system-of-system based decisions is not an easy task. Decentralized cognition becomes more

complex when we also consider the amount of data to be exchanged between robots and the processing of that data.

While UPAT/AML also proposes a robotic system, this will be now integrating multiple repair functions, in a customized- to-the-actual-needs system, at low cost /limited weight / optimized dimensions, employing simple usage and enhanced functions thanks to cognitive technology.

References

[1]https://rgl.faa.gov/Regulatory_and_Guidance_Library/rgPolicy.nsf/0/48740e29f79f0e7e8625853c005bbbce/$FILE/PS-AIR-21- 1901.pdf.
[2] https://www.airbus.com/newsroom/news/en/2016/12/Hangar-of- the-future.html
[3] https://www.aerospacetestinginternational.com/news/ndt/testia-launches-updated-ndt-inspection-device.html
[4] https://www.rolls-royce.com/media/press-releases/2018/17-07- 2018-rr-demonstrates-the-future-of-engine-maintenance-with- robots.aspx ".
[5] F. Fischer, S. Kreling, P. Jaschke, M. Frauenhofer, M. Kracht, and K. Dilger, "Laser Surface Pre-Treatment of CFRP for Adhesive Bonding in Consideration of the Absorption Behaviour," The Journal of Adhesion, vol. 88:350–363, 2012.
[6] K. Y. Blohowiak, M. N. Watson, Belcher, M. A. E. Castro, J. Baldwin, and S. Koch, "Laser Scarfing For Adhesive Bonded Composite Repairs. Used by the Society of the Advancement of Material and Process Engineering with permission," Boeing. Education & Green Sky – Materials Technology for a Better World. Proceedings 2013.
[7] C. Leone, I. Papa, F. Tagliaferri, and V. Lopresto, "Investigation of CFRP laser milling using a 30W Q-switched Yb:YAG fiber laser: Effect of process parameters on removal mechanismsand HAZ formation," Composites: Part A vol. 55 129–142 2013.
[8] C. Chan, T. Ko, and H. Hiraoka, "Polymer surface modification by plasmas and photons," Surface Science Reports, vol. 24:1–54, 1996.
[9] T. Lippert, "Interaction of photons with polymers: from surface modification to ablation," Plasma Processes and Polymers vol. 525–546, 2005.