Automation of composite repairs

a preliminary design study

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Summary

The present study aims at understanding and addressing certain challenges of automation of composite repairs. This research is part of the SIA-RAAK funded project FIXAR.

The approach consists of two steps. First, identification of the feasibility and most promising procedures for automated composite repair by analysis of common practices. Processes which are tedious or contain health risks qualify for automation. Second, an analysis of human-made composite repair errors is used in order to create a benchmark for automation. This benchmark can be applied to define lower limits and prevent over-optimization. The employed methodology includes data collection, analysis, modelling and experiments.

Introduction

While manufacturing technology has increased the level of automation over the past years, mainly with the objective to reduce costs, lead times and scrap while increasing quality [1], composite repairs are still mostly a matter of hand labour. Several parties are working on solutions for automation of composite repair procedures. Examples can be found at Lufthansa's CAIRE, a mobile device for removing material layers, while hanging onto the structure using suction cups [2], and the Reply5 machine by BAYAB [3] using water jet abrasion for removing layers of fibres. A recent initiative is project FIXAR [4], a Dutch government (SIA-RAAK) funded initiative by 3 universities of applied sciences. The research program is ongoing and will have a project delivery deadline in September 2021.

The objective is to support Small and Medium Enterprises (SMEs) by implementing new technologies and knowledge which in the case of FIXAR focuses on the automation of repair procedures.

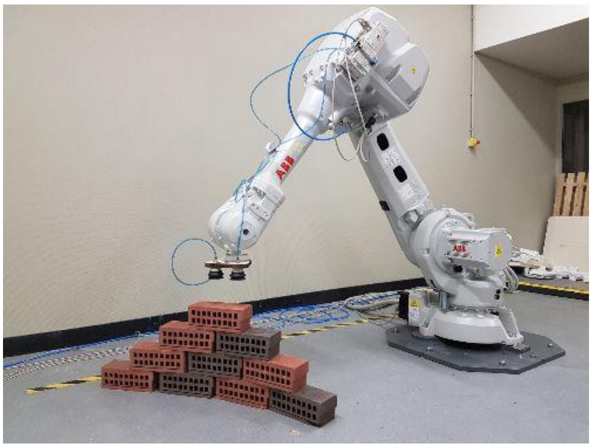

Figure 1: IRB4600 at AUAS faculty of engineering (AUAS)

Main research questions in the present studies are: "What are the requirements for an acceptable composite repair, matching current human made repairs and what features need to be included in the system".

To answer this question, the approach is to first identify the main actions in a composite repair procedure, select appropriate processes that qualify for automation and next identifying the main sources of human error by creating a Failure Mode, Effects and Criticality Analysis (FMECA). Second, a preliminary design is created, featuring the required tools and fixtures for a robotic arm end-effector.

Amsterdam University of Applied Sciences has several robotic systems, including the IRB1200, IRB2600 and IRB4600 (shown in Figure 1) articulated arm robots. The objective of this study is to design an end-effector for one of the available arms, suitable for repair of composites. For the near future a conceptual and final design of the end-effector will be made and an effective program for commissioning of the equipment.

Methodology

In order to set a benchmark for automation it is important to know the current performance of human beings in repair. This will help in preventing an overdesigned automated process and sets the lower boundaries for quality. A typical repair process is analysed in a flow diagram in order to identify the main steps.

The question whether a repair step applies for automation is answered using two approaches. First a very simple approach stating that automation applies most for dull, repetitive tasks, as well as tasks that may impose a serious health danger to the operator (e.g. due to high body loads, or release of harmful particles). The second approach assumes automation is best suited for tasks that are prone to errors. In order to find the sensitivity to errors and to identify the most challenging steps in the process, an FMECA is performed for each of these steps. Apart from the FMECA, the repair process steps are rated for their suitability for automation. Finally, a conceptual design is presented for an automation solution regarding the process step that appears most feasible for our setup.

FMECA

The FMECA is a bottom up approach for identifying and analysis of possible failures and their relative impact on other structures. The criticality component is important since it sets the probability of a failure against the severity of the failure. This tool reveals failures that have a high probability and severity.

Three parameters that are used in the FMECA, are severity, probability and detectability. Each of these parameters is scored using its own weighting factor: Table 2, Table 3 and Table 4, which eventually leads to a criticality number. All steps in the repair procedure are scored, the step (or steps) with the highest criticality number will be used for future analysis.

The weight factors are determined as follows: Severity in this study is determined according to MIL-STD-882E. This is a standard practise from the DoD (United States Department of Defence) about system safety. Four different categories are distinguished, each with its own criteria. This makes the method suitable for process analysis. The severity categories that are used are shown in Table 1.

Table 1 Severity categories, MIL-STD-882E

Severity categories		
Description	**Severity/Category**	**Mishap Result Criteria**
Catastrophic	1	Could result in one or more of the following: death, permanent total disability, irreversible significant environmental impact, or monetary loss equal to exceeding $10M.
Critical	2	Could result in one or more of the following: permanent partial disability, injuries or occupational illness that may result in hospitalization of at least three personnel, reversible significant environmental impact, or monetary loss equal to or exceeding $1M but less than $10M.
Marginal	3	Could result in one or more of the following: injury or occupational illness resulting in one or more lost workday(s), reversible moderate environmental impact, or monetary loss equal to ot exceeding $100k but less than $1M.
Negligible	4	Could result in one or more of the following: injury or occupational illness not resulting in a lost workday, minimal environmental impact, or monetary loss less than $100k.

EASA ranks probability on an exponential scale in [5]. Since MIL-STD-882E does not give a severity ranking, the EASA scale is adopted, see Table 2

Table 2 Severity weight factors

Severity		
Description	Category	Factor
Catastrophic	1	1000
Critical	2	100
Marginal	3	10
Negligible	4	1

Probability is described in MIL-STD-882E, with associated weight factors.

Table 3 Probability weight factors

Probability		
Description	**Category**	**Factor**
Probable	1	1000
Occasional	2	100
Remote	3	10
Improbable	4	1

Finally, detectability of a process error is weighted in a straightforward manner. Small errors may go undetected, and the additional set of tools makes detectability better. Simple tools such as tap hammering allow for detection while the method is not very accurate, more sophisticated manners such as the use of ultrasound increase the possibility for detection and therefore rank higher.

Table 4 Detectability weight factors

Detectability		
Description	**Category**	**Factor**
Undetectable	1	10
Hard to detect (Tap test)	2	5
Detectable	3	1

Automation

Numerous components pass through a composites MRO repair shop on annual basis. Filler and potting repairs were not considered since these are significantly less time-consuming and generally used for smaller repairs. The entire process from an unserviceable to serviceable component can be divided into six phases. Figure 2 shows the phases of a repair process in chronological order as observed in practice and supported by literature [6].

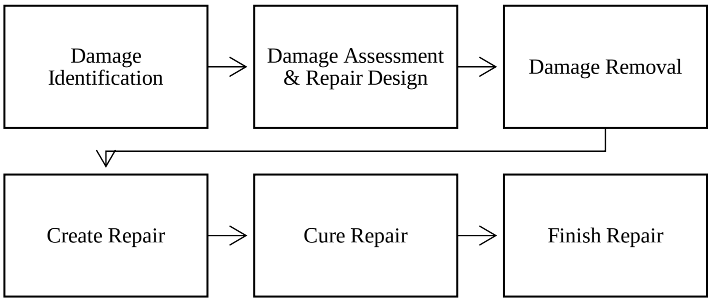

Figure 2 Typical MRO repair process

The automation of a task is also subject to certification. The applicable guidelines that are found in this study are show in Table 5.

Table 5 Referred Articles, AMC & GM

Subject	Article / AMC / GM number
Requirements for approval of repair design	21.A.433 (a)(b) & AMC 21.A.433 (b)
Classification and approval of repair designs	21.A.435 (a)(b) & GM 21.A.435 (a)(b)
Repair embodiment	21.A.441

The regulations regarding use of alternative repair methods require the organisation to prove that the outcome of the new procedure is at least as good as the original procedure. This can also be shown using a capable automated system. A certification programme shall be established to show compliance to airworthiness regulations. Moreover, each different repair needs a different repair approval. Therefore, it is important for the automated solution to be very accurate and have a high precision of repeatability to ensure the same result on each repair.

When process steps are ranked based on time consumption, the effect on end quality and the repetitiveness of a task this leads to the following result (Table 6):

Table 6 Process automation selection

Procedure	Time consumption [hrs]	Effect on product [ranked]	Repeating / dull tasks [ranked]	Total [*]
Sanding before inspection	1	1	3	3
(NDT) Inspection	0.75	2	2	3
Damage Removal & Scarfing	1	2	2	4
Create Repair	0.5	3	1	1.5
Cure Repair	0.1	2	1	0.2
Finish repair	0.5	2	1	1

Results

The FMECA yields the following result: The most critical points in the process are almost all related to improper cleaning and thus human influences. It can be concluded that contamination is the biggest hazard in the procedure and therefore will be tested. As a consequence, processes involving human involvement in cleaning apply in this case for automation.

The second study confirms that automation of the damage repair itself is the most promising, although it must be noted that the weighting factors in Table 6 allow for some bias. Sanding and NDT inspection rank quite close to the highest scoring “Damage Removal & Scarfing”.

From the scarfing perspective, the following qualities are to be incorporated in the end effector:

- A rotating sanding disk, in order to remove material
- Proximity measurement, in order to measure distance to the object (described a.o. in [7])
- Contour measurement, in order to visually measure the contours of the sanded area. Sufficient contrast and brightness are required. This subject is further studied by Hogeschool INHolland in [8].
- A sufficiently stiff and strong frame to support the tools and not deform under operation.

This leads to the following preliminary design configuration:

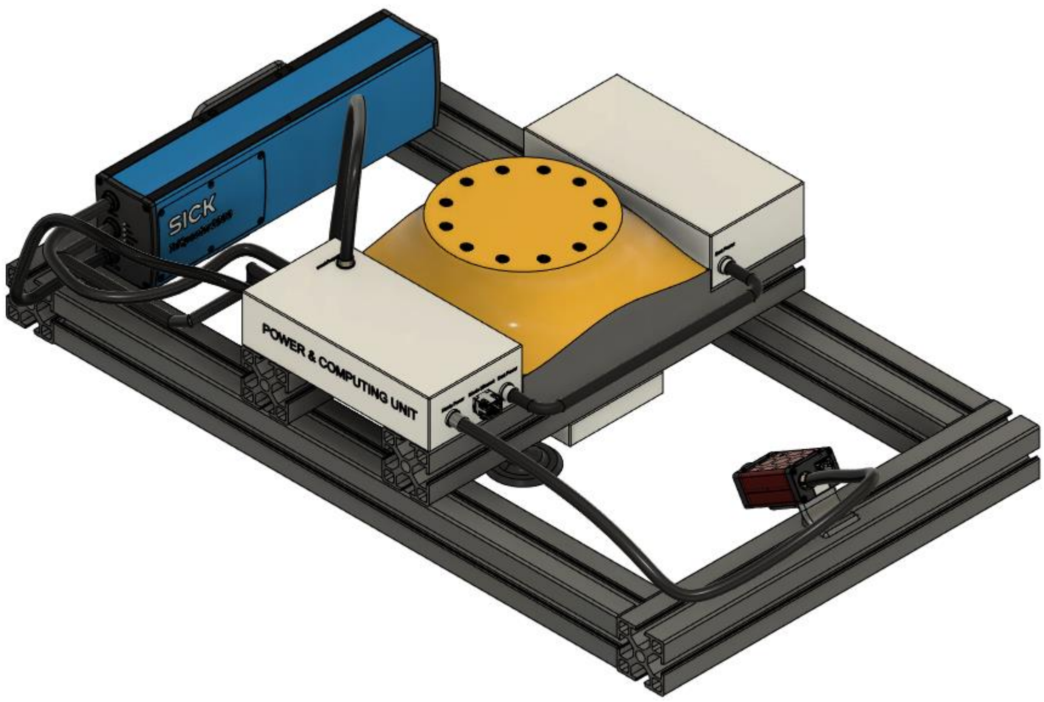

Figure 3 Preliminary design sketch of the end effector for automated scarfing (drawing by Pieter Lugtenburg)

Conclusion

The most promising tasks for automation are tasks that show a high level of human error, are repetitive or dull and tasks that may be harmful to the operator.

Tasks identified as prone to error are mostly involving cleaning tasks. As such, part of the repair process where cleaning and removal of material is involved are selected. For the present study this means that the end effector should be capable of scarfing.

Future work will be on the conceptual and final design of the end effector, as well as a commissioning program for parts and process validation.

Acknowledgements

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