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TITLE: **Database structure for storing and processing SHM data for SHM analyses and SHM algorithm research**
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Abstract

Damage identification in aircraft structures is a complex task. Especially in structural components made out of fiber composites and fiber metal laminates the traditional non-destructive methods for the detection of damage are time consuming and expensive. Structural health monitoring (SHM) can potentially reduce maintenance time and cost, but also be an enabler for condition-based maintenance as well as be used as an information source for the digital twin. The guided wave-based SHM System uses a network of transducers spread over the monitored structure. Additional information from other sensing systems may be also recorded. The data is locally acquired on the aircraft and it needs to be pre-processed, stored and accessible for analyzation.

A meaningful implementation of SHM requires the integration of the SHM workflow into the aircraft processes as well as machine learning tools to analyze the acquired data in an adequate time frame.

The current work focuses on a sever based application including a database which is storing the data and collating other sensing systems to it, as well as data preprocessing steps. Via the application programming interface, the results, with neglectable data volume, can be handed over for local processing or other web-based tools. Latter enables easy accessibility to demonstration and analyzation of the examined structure in different conditions.

Furthermore, this infrastructure provides a good base for machine learning algorithm research (supervised classification and neural networks) in order to gain knowledge out of the additional sensing systems data.

This data-management and -processing infrastructure is a necessary step towards the ultimate goal of in-time SHM.

Introduction

The introduction of composite materials in aeronautics has brought many advantages though it requires in-depth inspections in certain circumstances, such as accidental damages. Conventional non-destructive inspections (NDI) are necessary but are expensive. As a result, the so-called Structural Health Monitoring (SHM) has gained interest as a cost and time effective alternative. Due to its in order of magnitudes shorter runtime, SHM has the additional goal of enabling condition-based maintenance as well as providing significant structural information to a digital twin. (Sinapius et al. 2017)

In SHM waves travelling through the structures are used to inspect those. In particular Lamb waves are used. These are a particular kind of waves, traveling in plate-like structures with the property of little damping resulting in a good propagation range. An elemental characteristic of Lamb waves is, them propagating in different wave modes. These different modes are coexistent and differ in their propagation properties thus providing more information than a single wave package. Damage affects the wave propagation in form of wave reflection, attenuation or mode conversion. Therefore, Lamb waves are very suitable as a wave in an SHM system. Described phenomena are shown in Figure 1. (Sinapius et al. 2017)

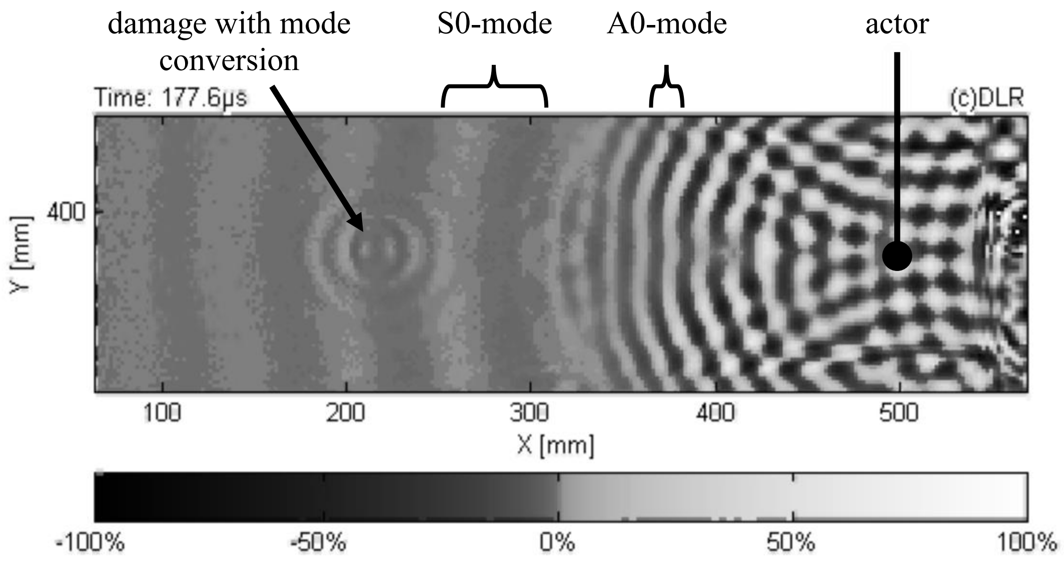

Figure 1 C-Scan of Lamb waves in a composite plate interacting with a damage

To detect and locate a damage in the structure a network of piezoceramics are used. Piezoceramics are transducer that can be used as an actor as well as a sensor, therefore enabling to measure many signal-actor paths with minimal hardware. Figure 2 illustrates the SHM data acquisition process, in which step by step every transducer is used as an actor while the remaining transducers are used as sensors.

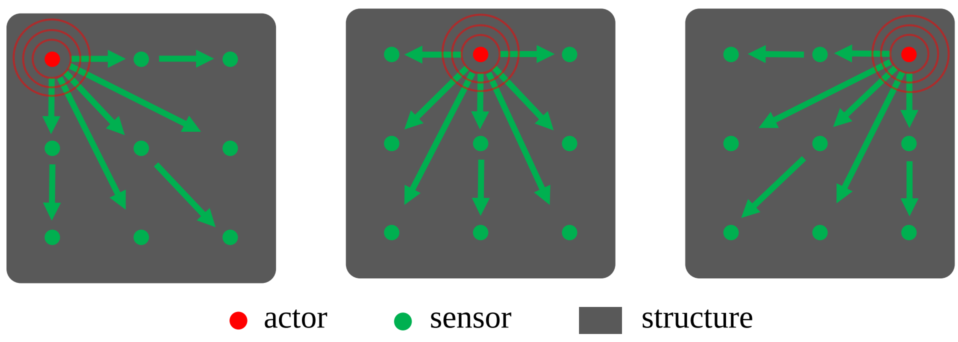

Figure 2 SHM data acquisition process

The data acquired this way is called the SHM-Data and is the basis for damage detection in the structure. As the propagation of lamb waves is influenced by various environmental and operational conditions, depending on the project, these data are logged as well (Salamone et al. 2009). To get an understanding on the projects in which SHM is used and at the same point are used to improve the damage detection the Projects will give a brief overview of the projects that have been worked on in the past. This will also highlight the environmental and operational data which is available.

Up to now each project was analyzed on its own and analyzation algorithms needed manual adaptation to work on multiple projects. To standardize and generate more benefits form all the available project data there is a new structure concept in form of a sever based database. In this the all environmental and operational data will be structured according to the SHM data structure. Preprocessing and feature extraction will run hand in hand with the database thus creating an infrastructure to support machine learning based research for new and more robust damage identification algorithms. Moreover, it is an interface for web-based analyzations of SHM structures. The concept of this database is presented in the chapter

SHM-Database-Concept.

Projects

This chapter gives an overview of projects carried out by the SHM team in of the *Institute of Composite Structures and Adaptive Systems* of the *German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, DLR)*. The focus in the projects lay on different structural complexity and/ or the environmental and operational influences.

In the EU-Project SARISTU a realistic and complex fiber composite fuselage with an integrated SHM system was built. With the SHM network consisting of 584 piezoceramic transducers, it was possible to detect and locate damages in such a large, complex and realistic structure. Figure 3 displays the structure with the integrated SHM network. (Moix-Bonet et al. 2017)

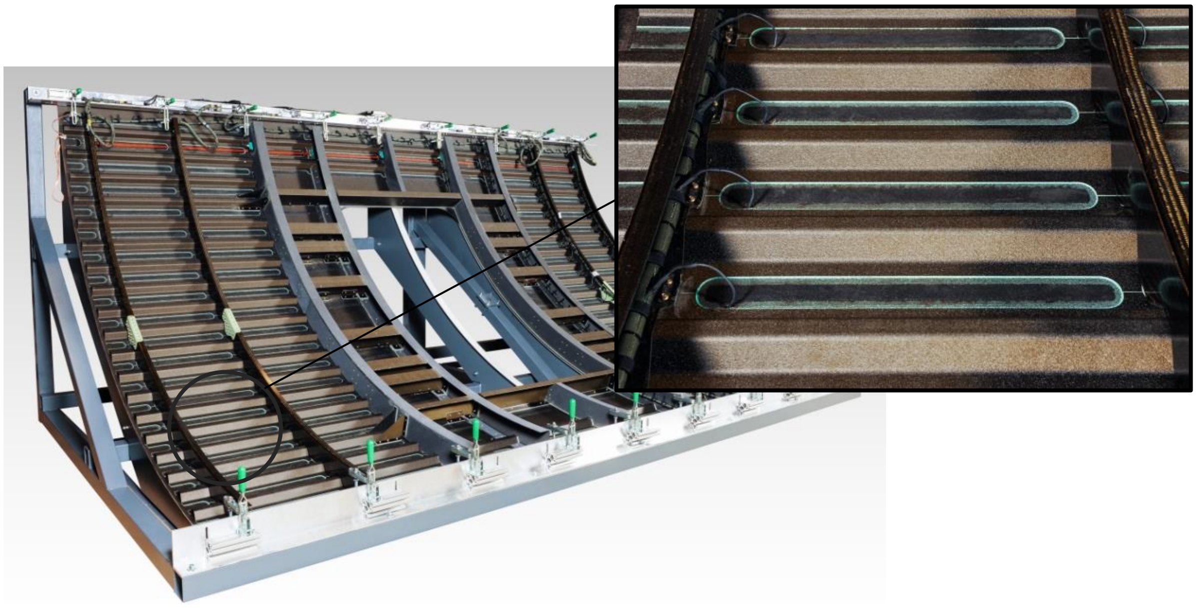

Figure 3 Fiber composite fuselage with integrated SHM network, project SARISTU

KamoS is the follow up project from the SARISTU project as it as well based on a realistic fuselage structure with an integrated SHM network. This time the goal is to perform damage detection and localization while the structure is loaded with mechanical loads. The loads are induced with a servo-hydraulic test rig and therefore can be monitored. Moreover, there are strain gauges applied to the structure to monitor the real time deformation. Figure 4 shows a model of the fuselage structure inside the servo-hydraulic test rig.

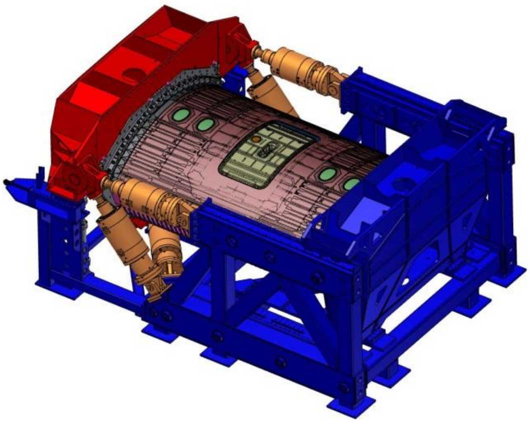

Figure 4 Model of the fuselage structure inside the servo-hydraulic test rig, project KamoS

In the Project DEMETER the environmental influences of humidity and temperature were observed. Four specimen plates – two with stringers – were equipped with an SHM network to detect artificial removable damage and real delamination in various conditions. The two environmental parameter-ranges were defined according to the conditions undergone by an aircraft: a temperature varying between -40°C and 85°C and a relative humidity up to 85% at 70°C. The influence of the environmental parameters on extracted features could be identified. One of specimen plate with stringer and sensors is shown in Figure 5. (Moix Bonet et al. 2018)

Figure 5 Specimen plate with omega stringer and SHM sensors, project DEMETER (Moix Bonet et al. 2018)

FaWaSis is a project which meant to point out the potential of lightweight structural components in railway applications. A conventional metal wagon structure was substituted with a lightweight fiber composite structure and monitored with a SHM system. The structure and the network implementation are shown in Figure 6. (Trampe et al. 2021)

Figure 6 Lightweight structural component with integrated SHM system in a railway field trail, project faWaSiS (Trampe et al. 2021)

This project was a field trail going on for seven months, starting in November and ending in early summer, facing all the environmental fluctuation including temperatures form -8°C to 39°C. During the train operations a SHM measuring was taken every 30 minutes. (Trampe et al. 2021)

SHM-Database-Concept

The SHM infrastructure focuses on three main subjects. Firstly, the database infrastructure concept is the place for saving and collating of the SHM as well as the environmental and operational data. Secondly the database infrastructure is the groundline of a combined and generalized SHM analyzation and visualization tool for a quicker process to extract results out of the experiments. And thirdly, it is a platform for algorithm research to improve the accuracy and robustness of damage detection. The concept is depicted in Figure 7.

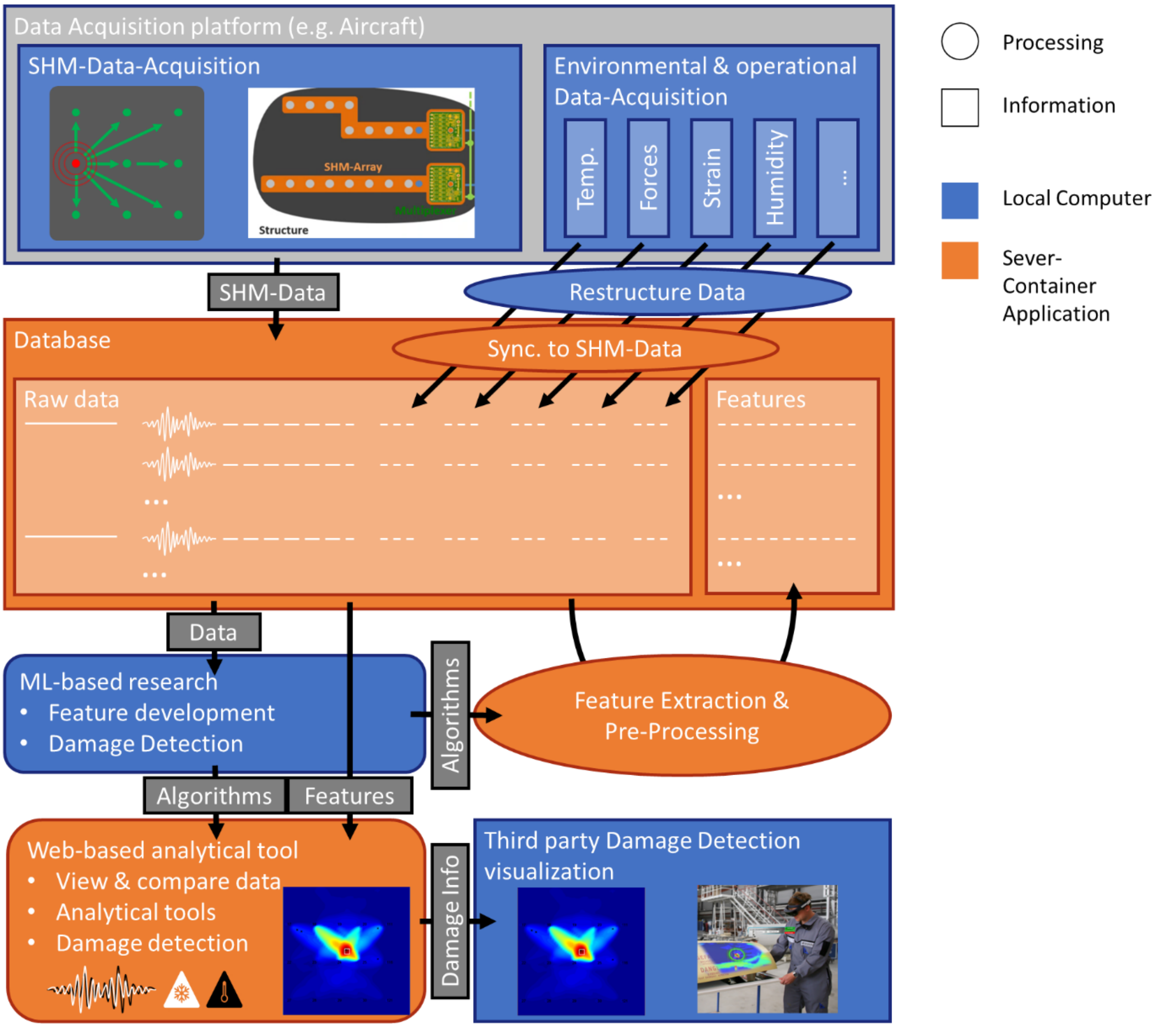

Figure 7 SHM-Database-Concept

Saving and collating the different data

The SHM data lay down the basic structure of the database. The smallest unit of one SHM measurement is the measurement of one path. Meaning the time signal recorded as the waves travels from an actuator transducer through the structure to a sensor transducer. As this wave information is the core of the damage information all the other data will be referenced to each path measurement. The SHM data is always acquired in the same way and match this goal of collating. Though environmental and operational data are recorded in other systems. To match these data to the SHM data they need to be converted in the SHM database structure and synchronized (by time) with the SHM measurements. Given that the environmental and operational measuring systems have different data structures this process has to be adapted for each new system. After synchronizing all data by time, the first part of the SHM-database-concept is fulfilled: all data, from various projects, are in one place and in a uniform structure, ready to be worked with.

SHM analyzation and visualization tool

For the damage detection algorithms, the raw data has to be preprocessed to generate damage-sensitive features. By this the size of the data is drastically reduced and the relevant information is carved out. This way a request to perform a damage detection only requires the transfer of a small amount of feature data. Therefore, occupying only a small bandwidth of the network and enabling fast analyzation as a web-based application.

The analyzation application is meant to be used by members of the SHM team. It shall enable an in-depth view on the experiments and offer adjustable parameters of understood functions and selectable features for the damage identification. Also, there shall be a benefit in the possibility to easily compare current projects with recent ones hence understanding the data better. The actual damage classification will be performed in this web-based application.

Furthermore, there shall be a visualization so that third party members can access the damage information and get a health status of their structure. The damage identification is autonomously calculated in a closed environment and the damage status is forwarded to third party members. Figure 8 shows a demonstration of a *Typhoon Eurofighter Airbrake* where such damage information is combined with an adaptable structural model and displayed with augmented reality glasses (Kaps et al. 10/1/2019).

Figure 8 Demonstration of a *SHM system combined with structural analyses displayed in augmented reality glasses on the structure of a Typhoon Eurofighter Airbrake (Kaps et al. 10/1/2019)*

Algorithm research and feature extraction

Lastly, the SHM-Data-platform shall be the source for algorithm research. The wave propagation of Lamb waves is influenced by various parameters. To obtain a robust and accurate damage classification these environmental and operational changes need to be taken into consideration. In this context, a ML-based damage detection system will be developed taking into account the environmental and operational data.

Also, as the actual damage detection system only works with features, there needs to be preprocessing to extract qualitative features. This research goes hand in hand with the damage classification.

Approved preprocessing steps, feature extraction and damage detection algorithms will be implemented into the database so that there is a continuous improvement in the damage identification.

Conclusion

In the damage identification process, SHM sensor data as well as environmental and operational data need to be collated, stored and processed. The concept of the SHM-Database handles these requirements by organizing all measurements and processed features to the SHM data structure, creating an infrastructure for algorithm research and online damage identification applications.

Following the database, this infrastructure will be used to build named online damage identification applications and to develop machine learning based algorithms to improve the robustness and accuracy of the damage classification even in near realistic and realistic environmental and operational circumstances.

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