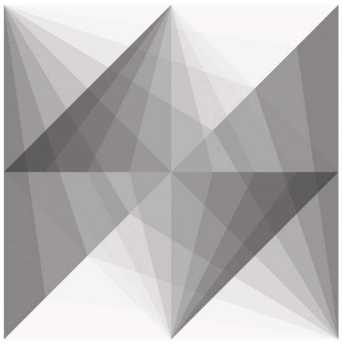

ENHAnCE

Featuring Engineering

END OF YEAR 2 PROGRESS REPORT & PERSPECTIVE

Project Acronym: ENHAnCE	
Project full title: European training Network in intelligent prognostics and Health mAnagement in Composite structurEs	
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1. Introduction

The ENHAnCE project is oriented to train the next generation of scientists targeting a paradigm shift on the health management of composite structures by fusing ad-hoc sensing technologies and prognostics engineering within the structural system leading to a new concept of intelligent structures. Since its beginning on 1st January 2020, 10 Early Stage Researchers (ESRs) are been trained and milestones and deliverables are being accomplished, overcoming the difficulties arising from the pandemic situation suffered all over the world since Mach 2020. As described below, the project has successfully completed its objectives for its second year (M13 to M24), with minor modifications which do not significantly alter the course of the research.

2. General progress of the action

2.1. Deliverables and Milestones

As an efficient way to measure the progress of the action, the deliverables and milestones during the second year of the project are listed below with an indication of verification means (for Milestones) and status, for Deliverables:

Table 1. **Milestones of ENHAnCE achieved during Year 2 (M13 to M24)**

MILESTONE #	SCHEDULED DATE	STATUS	MILESTONE TITLE	MEANS OF VERIFICATION	WORK PACKAGE (WP)
MS5	M15	Accomplished on May 2021, 2 months of delay due to the global pandemic	Mid-Term meeting: Evaluation of Year 2 Summary Report – Beneficiaries plan	On-line meeting successfully held on 11th May 2021 and deliverable D.8.7 ENHAnCE Minutes of Mid Term submitted	WP8 - Management

Table 2 **Deliverables of ENHAnCE submitted during Year 2 (M13 to M24)**

DELIVERABLE #	DELIVERABLE TITLE	DESCRIPTION	SCHEDULED DATE	STATUS	WORK PACKAGE (WP)
D.2.2	Sensor integration and optimal manufacturing	Report on sensor integration on composites and optimal manufacturing strategies	M24	Submitted on time	WP2 - Technology development of intelligent composite components
D3.1	Guided waves models	Report of Guided Waves models developed to simulate damage interaction with ultrasonic waves	M16	Submitted on time	WP3 - Modelling AU-based wave propagation and interaction with damage
D3.2	Manufacturing parameters impact on guided waves	Report on manufacturing parameters impact on guided waves (GW) propagation	M24	Submitted on time	WP3 - Modelling AU-based wave propagation and interaction with damage

DELIVERABLE #	DELIVERABLE TITLE	DESCRIPTION	SCHEDULED DATE	STATUS	WORK PACKAGE (WP)
D4.2	Bayesian damage updating using GW	Development of Bayesian damage updating techniques using guided waves (GW) model interaction	M24	Submitted on time	WP4 - Real-time, self-adaptive prognostics algorithms
D5.2	Integration of communications and SHM data	Hardware system allowing integration of communications and SHM data collected via ultrasonic sensors.	M24	Postponed to M30 in agreement with the project officer	WP5 - Development of a CPS Information System
D7.2	Open Meeting points	Report on Open Meeting points and visits to local schools	M24	Postponed to M30 in agreement with the project officer	WP7 - Dissemination and Outreach
D8.6	Progress Report	Report about the End of Year 1 including the Progress Report and Perspective	M13	Submitted with 2 months of delay, due to delay in celebration of the Mid-term meeting, which was held when all the consortium and the PO agreed on a date.	WP8 - Management
D8.7	Minutes of Mid-term	Minutes of Mid-term Supervisory Board meeting and report about financial, legal and risk management	M15	Submitted with 2 months of delay, for the same reason given above.	WP8 - Management

In total, 1 milestone and 6 deliverables have been produced and submitted to the REA, with 2 deliverables postponed until M30 in accordance with the project officer: the D5.2 and the D 7.2.

The deliverable "D5.2 Integration of communications and SHM data" is a demonstrator that needs the integration of the data acquisition from sensors, the required preprocessing and the following transmission for further analysis, along with its physical realisation within the composite structure. This demonstrator is a tool which allows the ESR to interact physically (in person) to physically build the system. It has research, but overall, training objectives for the ESRs. Due to the pandemic situation, with unforeseen restrictions (overall during the Autumn and Winter 2021), the meetings of the working groups couldn't be celebrated. The submission date has been postponed until June 2022 for allowing sufficient time to ensure that the working groups can meet to obtain enough quality of the results. The following items will be involved in this demonstrator:

- Design of Data Acquisition (DAQ) system and required sensors. (Institutions involved: **DLR/CEA List)**
    - Identify system requirements (maximum number of channels, signal conditioning requirements). **DLR/CEA**
    - Hardware specifications. (Commercial data logger) **DLR/CEA**
    - Sensor specifications (strain gauge or piezoelectric sensor). **DLR/CEA**

- Design of data pre-processing scripts (synchronization, data preparation for transmission). (Institutions involved: **STRATH, UGR)**
- Design and manufacture the composite specimen. (Institution involved: **FIDAMC)**
- Attachment of DAQ system and sensors to the composite specimen. (Institution involved: **FIDAMC)**
- Testing of the system. (Institutions involved: **DLR/CEA/FIDAMC)**
- Writing of the report. (Institutions involved: **DLR/FIDAMC/STRATH/UGR)**

The institutions involved in the project that will develop these actions are:

Table 3. **List of institutions involved in the demonstrator in D5.2.**

INSTITUTION/ COMPANY INVOLVED IN THE DEMONSTRATOR	BENEFICIARY/ PARTNER	REPRESENTATIVE
National center for aerospace, energy and transportation research of Germany (DLR)	Beneficiary	Prof. Peter Wierach
Laboratory for Integration of Systems and Technology (CEA List)	Beneficiary	Prof. Alain Lhemery
Foundation for Research, Development and Application of Composite Materials (FIDAMC)	Beneficiary	Dr. María Rodríguez
University of Strathclyde (STRATH)	Beneficiary	Prof.Athanasios Kolios
Universidad de Granada (UGR)	Beneficiary	Dr. Manuel Chiachío Dr. Juan Chiachío

The deliverable "D 7.2. Open Meeting points" gathers the Communication and Dissemination activities foreseen in the project ENHAnCE to deploy open meeting points and visits to local schools to get public engagement with the project. The intention of this action is to promote the involvement of a large audience and brings knowledge on a particular topic to the general public.

Due to the current pandemic circumstances, there has been no chance to launch any public activity because access to schools is strongly restricted in the majority of the countries of the participants. Also, the open meeting points cannot convoke larger audiences since March 2020. Whenever it is possible, these activities will be launched following these premises:

• A range of face-to-face activities (e.g. school visits, lab "open days", public talks, science festivals) will be planned to target multiple audiences.

• These activities will be performed by the members of the consortium to engage the general public about the ITN operations. Each Beneficiary must promote the project and its results by providing targeted information to multiple audiences in a strategic and effective manner.

• Every member of the consortium will talk to experts at their institution to see what local/national activities they can join in. Activities need to take place across the whole consortium, so it will be necessary to ask the consortium participants for information on what activities they have in their organisation/region/country. Continuously updating each other on activities and results will promote interdisciplinary communication efforts.

• If applicable, there will be explanations on who will help with public engagement activities e.g. Education/Outreach Officer.

The institutions involved in the project that will develop these actions are:

Table 4. **List of Universities involved in the Open Meeting points & visits to schools**

INSTITUTION/ COMPANY	BENEFICIARY/ PARTNER	REPRESENTATIVE
Delft University of Technology (TUDELF)	Beneficiary	Dr. Dimitrios Zarouchas
Politecnico di Milano (POLIMI)	Beneficiary	Dr. Claudio Sbarufatti Dr. Francesco Cadini
University of Strathclyde (STRATH)	Beneficiary	Prof.Athanasios Kolios
University of Nottingham (UNOTT)	Beneficiary	Dr. Rassa Remenyte-Presscot
Universidad de Granada (UGR)	Beneficiary	Dr. Manuel Chiachío Dr. Juan Chaichío
Clausthal University of Technology (TUC)	Partner Organization	Prof. Peter Wierach
KU Leuven University	Partner Organization	Dr. Dimitrios Chronopoulos

2.2.Scientific progress

2.2.1. Work Package 2: Technology development of intelligent composite components

The WP2 seeks a new technology for smart structural components of composites by manufacturing-based integration of an engineered SHM and communications skin. This WP also involves the development of numerical tools for optimisation of the manufacturing process with embedded Acousto-Ultrasonic (AU) sensors, which will be miniaturized and connected to an array of microprocessors providing a first signal analysis and filtering. This work explores a cost-effective production, design and operation of smart composite components by measuring the dielectric properties of the curing process of the structural component.

The ESRs 1 (Shankar Galiana), 2 (Aravind Balaji), and 4 (Tasdeeq Sofi) are collaborating on this WP and have submitted the deliverable *D 2.2. Sensor integration on composites and optimal manufacturing strategies.* During this year, the involved ESRs along with their supervisors have successfully achieved a laboratory integration of the acoustic-ultrasonic sensors within a thermoplastic composite panel, and have solved the cabling issue. Also, they've provided numerical simulations of the mechanical state of the sensors and their adhesive layers, along with the mechanical behaviour of the ultrasounds signal, for a number of loading scenarios. Moreover, this WP team have

obtained promising results about the simulation of the manufacturing process of the composite panel with the sensors embedded.

2.2.2. Work Package 3: Modelling AU-based wave propagation and interaction with damage

The WP3 focuses on modelling guided waves (GW) propagation and interaction with damage in composite structures. The methodology involves identifying an efficient approach with brittle failure modes at the microscale (fibre fracture, debonding, delamination and brittle cracking), and also dissipation using a phase-field simulation approach. Proper multiscale FE approaches are examined to communicate the microstructural information at a coarser computational scale through benchmark tests of escalating complexity along with the development of surrogate models.

The ESRs 3 (Amond Sarr Allouko) and 8 (Wen Wu) are working on this WP and have submitted the deliverables *D 3.1. Report of Guided Waves models* and *D 3.2. Manufacturing parameters impact on Guided Waves.* This WP team have successfully obtained a smart formulation of wave propagation along with a composite plate, with consideration of damage and the boundary effects. Also, they've provided a Bayesian inference scheme to infer the damage position and severity within the plate.

2.2.3. Work Package 4: Real-time, self-adaptive prognostics algorithms

WP4 investigates fast and efficient filtering-based prognostics algorithms to predict the Remaining Useful Life (RUL) of composite materials under damage conditions using online data from onboard SHM sensors. The surrogate models of SHM-damage interaction developed in WP3 are to be encoded within Bayesian filtering algorithms to provide multistep ahead predictions of failure scenarios with quantified uncertainty.

The ESRs 5 (Morteza Moradi) and 6 (Tianzhi Li) are working on this WP and have submitted the deliverable *D 4.2. Bayesian damage updating using Guided Waves*. Tianzhi Li has also published a scientific paper named *Particle filter-based hybrid damage prognosis considering measurement bias* https://onlinelibrary.wiley.com/doi/10.1002/stc.2914 . This work has provided algorithm description to properly include on line ultrasound data within particle filtering algorithms to make real-time damage predictions, and has allowed a new variant of the work with the consideration of delamination damage, which is undergoing.

2.2.4. Work Package 5: Development of a CPS Information System

In the WP5 the focus is on the development of an integrated expert system to allow adaptive, yet autonomous, decision-making from post-prognostics information. The resulting expert system will shift the burden of managing a composite structure from maintenance engineers to an autonomous system that acts under the guidance of monitoring data and maintenance policies implemented as rules. This WP is firstly facing the integration of the predicted information from component level (from WPs 3 & 4) to a system-level, which encompasses a significant research challenge due to the heterogeneity of operational information when applied to the level of an engineering system. Novel methodological frameworks like Plausible Petri nets (PPNs) are being investigated to efficiently incorporate monitoring data, expert knowledge, and/or data-based and model-based prognostics algorithms within the expert system.

The ESRs 7 (Javier Contreras), 9 (Juan Fernández) and 10 (Ali Saleh) are working on this WP and the deliverable *D 5.2. Integration of communications and SHM data,* which corresponds to a demonstrator, is currently postponed until June 2022 (M30), as mentioned previously. Juan Fernández has published a scientific paper named *Uncertainty quantification in Neural Networks by Approximate Bayesian Computation: Application to fatigue in composite materials* https://www.sciencedirect.com/science/article/pii/S0952197621003596?via%3Dihub and Ali Saleh has also sent a paper for publication, which was just accepted very recently: https://authors.elsevier.com/tracking/article/details.do?aid=108365&jid=RESS&surname=Chiachio, allowing a method to reduce the complexity of the maintenance models within a rational approach.

3. Career Development plan for each researcher

The Career Development Plan of every Early Stage Researcher (ESR) is part of the action implementation in line with the European Charter for Researchers. These plans aim to achieve a realistic and well-defined set of objectives in terms of career advancement for the ESRs to develop and widen the competencies of the researchers, particularly in terms of multi/interdisciplinary expertise, inter-sectoral experience and transferable skills.

Each ESR has produced a PCDP at the start of their research fellowship, which is composed of an individual training plan and a plan for the research objectives, and is in agreement with their main supervisors.

The ESRs revise their PCDP once a year based on the progress made, the changing needs of the research and the suggestions from their supervisors and mentoring bodies and shared this document with the consortium to ensure coherence within the network and with the training needs of both industry and academia. A pendant task after the start of a new project year is to revise the PCDPs of all ERS.

4. Training

4.1. Monthly meetings

To get closer to the developments of the ESRs and promote their communication skills along with their commitment, monthly meetings were held online during the second year of the project. In these meetings, the ESRs are encouraged to present their work during 10-15 minutes, show their progress and manifest any doubt or problem they might have to find a solution with the cooperation of all participants. Needs and gives are welcome in these sessions, making the most of sharing to get ways of collaborations between researchers. Supervisors, co-supervisors and other members of the project committees are invited to these meetings.

Figure 1. **Online monthly meeting with the ESRs**

4.2. Training weeks

During the second year of the project, the training weeks: "Introduction to Composite Science and Technology (TW3)" and "Latest trends in manufacturing of intelligent composites (TW7)" were combined in one Training Week organised by DLR and FIDAMC and held in person at the facilities of FIDAMC in Madrid (Spain) on 15th to 19th November 2021. This fusion conferred a richer and wider view about composite structures, gathering a first introductory perspective with a more advanced view as a journey across the development of this material.

Table 5. **Training weeks scheduled in Year 2 (M13 to 24) of the project**

MODULE TITLE		SUMMARY OF CONTENT	LEAD INSTITUTION	INITIALLY SCHEDULED PROJECT MONTH	RE-SCHEDULED DATE	STATUS
3	Introduction to Composite Science and Technology (TW3)	An introduction to key composite design technologies including understanding of the principles of mechanical behaviour, testing & characterisation, and manufacturing.	Institute of Composite Structures and Adaptive Systems (DLR)	12M	23M	Held in person in FIDAMC facilities, jointly 2 TWs to avoid further delays in the scheduled
	Latest trends in manufacturing of intelligent composites (TW7)	Manufacturing engineering of composite parts with embedded sensors, monitoring of manufacturing quality.	R&D Department (FIDAMC)	27M		
4	SHM methods using GWs and AE in composites (TW4)	Foundations about simulation and study of GWs interaction with composite damage, as well as mixture monitoring techniques between GWs and AE.	List Institute research on Non Destructive Testing (CEA)	18M	30M	To be hold jointly with the H2020 - MSCA project GW4SHM-ITN

Table 5. **Training weeks scheduled in Year 2 (M13 to 24) of the project**

MODULE TITLE		SUMMARY OF CONTENT	LEAD INSTITUTION	INITIALLY SCHEDULED PROJECT MONTH	RE-SCHEDULED DATE	STATUS
5	Understanding the fatigue damage in engineering materials (TW5)	Fatigue quantification methods, training about laboratory experiments, design and calculation methods, latest trends for fatigue damage mitigation.	Dept. Mechanical and Aeronautical Engineering (TUDelf)	21M	27M	Preparation under progress

Figure 2. **The ENHAnCE team at the 3rd Training Week in FIDAMC facilities (Madrid, Spain)**

5. Dissemination, communication and outreach

A Dissemination and Outreach Plan was launched in the first semester of the project and has been updated during the implementation, with a final version to be handed at the end of the project. This plan comprises the strategy and actions related to the protection, dissemination and exploitation of the project results, which are conceived to be consistent and proportionate to the impact expected from the action. The target group comprises both the researchers and the scientific community, fully in line with the purposes and nature of the Marie Skłodowska-Curie Actions programme.

The Dissemination and Outreach work package aims to transfer the scientific and technological knowledge developed into the project including open data and benchmark studies. The target audience is not only the scientific network and the engineering community (especially institutes, universities and companies interested in PHM) but also the general public, politics and society in general.

Communication is also a key activity of the project as a means to give visibility, inform and reach out to the general audience to show the benefits of the research. In this regard, the website of the project ENHAnCE https://h2020-enhanceitn.eu/ offers all the information about the project with the latest news and publications, being continuously updated to serve as a vehicle to spread the upcoming

events and results obtained (scientific publications, open databases, etc.). Besides, to be connected to the general public and the scientific community, the project is linked to the main social media channels to which profiles in LinkedIn (@ENHAnCE ITN - MSCA), Twiter (@ENHANCEITN1) and Facebook (@ENHANCEITN1) have been conveniently updated during the second year of the project.

In addition to this, two press releases[1,2] have been launched in Spanish newspapers (M16), and a TV broadcast is planned for a TV documentary to be cast in at least one regional Spanish TV with whom agreements are already established.

Promotional short videos of every ESR have been recorded (M23) and will be broadcasted as promotional pills into their own space on the ENHAnCE website https://h2020-enhanceitn.eu/esrs/. Supervisors have also been interviewed and a general video of the project will be published for an overview of the ENHAnCE team and facilities.

Brochures, leaflets, flyers and banners have also been ordered (M23) as a graphic means to display in a clear and attractive way what is the project about and the people working on it, trying to excite the curiosity to catch the QR code to go straight to the webpage where they can go deeper inside. All the dissemination & communication means exhibit the EU acknowledge, echoing the role of the EU in promoting research at the top level and the funding impact on society, economy, environment and policymaking.

Nevertheless, due to the situation of the COVID-19 pandemic which is affecting worldwide since the M3 of the project, attendance at congresses and showcases has been suspended as these events were cancelled or postponed. Furthermore, school visits, open meeting points and presentations in schools and universities have not been possible up to date as gatherings of any size are not allowed. It is expected that the situation improves and these events can be recovered during the progress of the project.

6. Data management

ENHAnCE will investigate and contribute to the prognostics and health management of composite structures, hence health/damage data about composite testing, manufacturing data, SHM sensor, numerical simulations, and software codes are expected outputs during the lifetime of the project. This information will become available as datasets to support the project results dissemination through the scientific community, including not only raw data but also pictures, computer simulations, videos, software codes, and technical reports. These sets of data will be discoverable, accessible, intelligible, assessable and reusable, and will constitute a useful source of information for PHM researchers, practitioners, data-science researchers and the entire composite industry (manufacturing and engineering).

The Data Management Plan was delivered at the beginning of the project and covers accessibility, interoperability, licensing, allocation of resources, data security and ethical aspects.

The ENHAnCE project respects the spirit of publicly funded research and endorses the Open Science movement by openly publishing non-confidential data that can be valuable to future researchers.

[1] https://canal.ugr.es/noticia/los-mayores-expertos-del-mundo-en-el-campo-de-la-denominada-tecnologia-de-pronostico-participaran-en-un-congreso-virtual-en-la-ugr/
[2] https://www.ideal.es/miugr/mayores-expertos-mundo-20210415185232-nt.html

Because of this, subject-specific descriptive metadata will be used to help researchers. To ensure data visibility, the metadata system used for the description of the materials hosted in the University of Granada (UGR) repository DIGIBUG, which is Dublin Core Qualified. This is a metadata initiative adopted by the European repository OpenAIRE. DIGIBUG assigns a unique identifier (handle) to each document and/or dataset, which allows the identification and citation of electronic documents.

ENHAnCE data will be shared through the DIGIBUG repository under Creative Commons license which will help to promote our data to be freely available and downloadable from the internet. The data produced during the project lifetime will be updated as soon as available except when an embargo period is requested by any consortium member and agreed upon at the Supervisory Board level.

At this standpoint, it is important to remark that since the last couple of months, coinciding with the previous Supervisory Meeting, Nov. 2021, Getafe (Madrid), the consortium is planning and preparing a consortium level experiment which will feed with data to all ESRs and also to the scientific community, after an embargo period. These data will consist of a repeated sequence of fatigue data in composite panels made of thermoplastic composites with the embedded sensors being developed in this project. These data will be very valuable for the project and for the scientific community since it will be the first time that an experimental test is focused on thermoplastic coupons including the effects of the sensors on the fatigue behaviour and vice-versa.

7. Ethics

The Ethics clearance for demonstrating that the investigated technologies are not going to be used in the military and defence sector, neither in the UE nor outside the EU (as the University of Basilea is a Partner Organization from a Non-EU Member country) has been fully respected during the second year of the project. Also, it is worth mentioning that the University of Basilea is no longer collaborating with the consortium hence the ethics issues with this respect are solved very naturally.

Moreover, the experimental tests to be done with the thermoplastic coupons won't be focused on any military standards or configuration, hence there is no risk of any ethical issue with them.