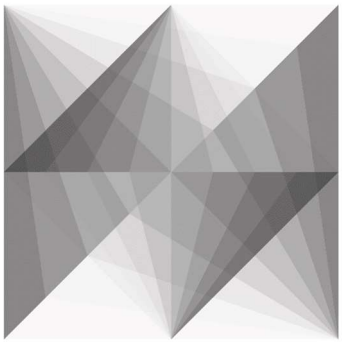

ENHAnCE

Featuring Engineering

END OF YEAR 3 PROGRESS REPORT & PERSPECTIVE

Project Acronym: ENHAnCE	
Project full title: European training Network in intelligent prognostics and Health mAnagement in Composite structurEs	
Call: H2020-MSCA-ITN-2019	
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1. Introduction

The ENHAnCE project has progressed accordingly to expectations during its third year, by training 10 Early Stage Researchers (ESRs) in fusing state of the art sensing technologies with prognostics engineering throughout the structural system. Since its beginning on 1st January 2020, the project has overcome the difficulties arising from the pandemic situation suffered all over the world since Mach 2020, achieving milestones and completing deliverables. The objectives for its third year have suffered some modifications to adapt them to new circunstances that will be explanined next, however they 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 completed are summarized in the table bellow. There are no milestones located during the third year.

Table 1. **Deliverables of ENHAnCE submitted during Year 3 (M25 to M36)**

DELIVERABLE #	DELIVERABLE TITLE	DESCRIPTION	DATE	STATUS	WORK PACKAGE (WP)
D8.8	End of Year 2 Summary Report & Perspective	Report about the achievements during year 2021	31 Jan 2022	Submitted	WP8 - Management
D5.2	Integration of communications and SHM data	Computational platform to integrate prognostics and operational decision making using on-line data from sensors	31 Dec 2021 (Initially Scheduled)	Agreed delay and submitted on 22 May 2022	WP5 -Development of a Cyber-Physical Structural Information System
D7.2	Open Meeting points and visits to local schools	Report on dissemination activities such as visiting local students and performances of live experiments during students science weeks	31 Dec 2021 (Initially Scheduled)	Agreed delay and submitted on 30 June 2022 due to pandemic circumstances	WP7 -Dissemination and Outreach
D4.3	Open Access tool for real-time collecting SHM measurement	Computational platform acting as open access tool for real-time collecting structural health monitoring measurement	30 Jun 2022	Submitted	WP4 - Real-time, self-adaptive prognostics algorithms
D7.3	ENHAnCE Minisimposium, thesis contest and Showcase at JEC Paris	Report on the participation of the ENHAnCE team in symposiums and attendance at international composite showcases	30 Jun 2022	Submitted	WP7 -Dissemination and Outreach

In total, 5 deliverables have been produced and submitted to the REA, presenting the research results and informing about the progress of the project.

The deliverable "D5.2 Integration of communications and SHM data" is a demonstrator that needed 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 has been a tool allowing the ESR to interact physically (in person) in order to 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 was postponed to allocate sufficient time to ensure proper interactions between the ESRs, and was successfully submitted in May 2022.

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 pandemic circumstances, there was no chance to launch any public activity because access to schools was strongly restricted in the majority of the countries of the participants. Also, the open meeting points cannot convoke large audiences since March 2020. Whenever it was possible, these activities were launched, mostly since the beginning of the 2022 year, thus the deliverable was successfully submitted in June 2022.

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) collaborate on this WP and work on the development of the deliverable *D 5.3. Analytics O&M Platform (HAPMS) and results of O&M simulations,* which will be submitted in June 2023. One of the results that can be highlighted in this WP is the development of a computational method to understand the effects of large loads on AU sensors, a successful experimental campaign to test the integration of AU on thermos-plastic composites subject to high loads, and the successful test of a novel integration method of AU sensors within the thermo-plastic composite using ultrasound excitation.

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) work on this WP and will submit the deliverable *D 3.3. Computing GW simulation tool and calibration to WP2* in September 2023. The ESR 8 Wen Wu has recently published a paper titled "Guided waves-based damage identification in plates through an inverse Bayesian process" (https://doi.org/10.1016/j.ultras.2022.106773) and a conference proceeding paper titled "*Asset management modelling approach integrating structural health monitoring data for composite components of wind turbine blades*" in collaboration with the ESR 10 Ali Saleh (10.3850/978-981-18-5183-4_R22-24-242-cd) during 2022. The ESRs 3 Amond Sarr Allouko attended the conference "Waves 2022" the 15th international conference on mathematical and numerical aspects of wave propagation, held in France.

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 on-board SHM sensors. The surrogate models of SHM-damage interaction developed in WP3 are 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) were working on this WP and have submitted the deliverable *D 4.3. Open Access tool for real-time collecting SHM measurement*. The ESR 6 Tianzhi Li has also published several scientific papers such as "*Numerical simulation-aided particle filter-based damage prognosis using Lamb waves"* (https://doi.org/10.1016/j.ymssp.2022.109326) and "*Particle filter-based delamination shape prediction in composites subjected to fatigue loading*" (https://journals.sagepub.com/doi/10.1177/14759217221116041). The ESR 5 Morteza Moradi has published a paper titled "*Intelligent health indicator construction for prognostics of composite structures utilizing a semi-supervised deep neural network and SHM data*" (https://doi.org/10.1016/j.engappai.2022.105502) and a conference paper "*Intelligent Health Indicators Based on Semi-supervised Learning Utilizing Acoustic Emission Data"* (https://doi.org/10.1007/978-3-031-07322-9_43).

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 firstly faces 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) work on this WP and the deliverable *D 5.3. Analytics O&M Platform (HAPMS) and results of O&M simulations,* which corresponds to a demonstrator that will be submitted in September 2023. The ESR 7 Javier Contreras

has recently published a paper named "A wind turbine blade leading edge rain erosion computational framework" (https://doi.org/10.1016/j.renene.2022.12.050). Juan Fernández (ESR 9) has published two scientific papers named "Uncertainty quantification in Neural Networks by Approximate Bayesian Computation: Application to fatigue in composite materials" (https://doi.org/10.1016/j.engappai.2021.104511), and "Physics-guided Bayesian neural networks by ABC-SS: Application to reinforced concrete columns" (https://doi.org/10.1016/j.engappai.2022.105790). Also, he produced "Probabilistic Safety Assessment in Composite Materials using BNN by ABC-SS" (https://doi.org/10.36001/phmconf.2022.v14i1.3275) presented in the Annual Conference of the PHM Society 2022 held in Nashville, USA. Ali Saleh has also published the papers "Reduction of Petri net maintenance modeling complexity via Approximate Bayesian Computation." and "An assessment of different reinforcement learning methods for creating a decision support system based on the Petri net model" at the PHM Society 2022 conference. Additionally, Ali Saleh recently published "Self-adaptive optimized maintenance of offshore wind turbines by intelligent Petri nets", published in the Reliability Engineering and Systems Safety journal (https://doi.org/10.1016/j.ress.2022.109013).

All of these publications mentioned above, along with others published in the previous years of the project, are openly available from the website of the project: https://h2020-enhanceitn.eu/publications/articles/.

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 produced a PCDP at the start of their research fellowship, 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 with their supervisors based on the progress made, the changing needs of the research and the suggestions from their supervisors and mentoring bodies and shared this document (when insightful modifications are done) with the consortium to ensure coherence within the network and with the training needs of both industry and academia.

Additionally, the ESRs count with the help and support of the Tutor Mentor, Dr. Rafael Muñoz from the University of Granada. Dr. Muñoz attend all the Training Weeks in person and interact with the ESRs during tutoring sessions for boosting their soft skills (like the session recently celebrated in the CENAERO's Training Week, Belgium, during November 2022). Also, the ESRs can have informal and formal face-to-face meetings with Dr. Muñoz to individually talk about their careers and other aspects of their development in the project.

4. Training

4.1. Coordination, supervision and ESRs meetings

To get closer to the developments of the ESRs and promote their communication skills along with their commitment, meetings were held online during the third year of the project. In these meetings, the ESRs are encouraged to present their work, 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. These meetings, which were celebrated on-line and in a montly basis during 2021, have been scheduled mostly in person, during the Training Weeks, and some times are devoted to a thematic aspect, with a group of ESRs working on a specific development.

4.2. Training weeks

During the third year of the project, three training weeks have been held in person, from which the researchers have taken good advantage of learning and interacting among them and with the institutions visited. In the table bellow (*Table 2*) there is a summary of the trainings celebrated this year (M25 to 36):

Table 2. **Training weeks scheduled in Year 3 (M25 to 36) of the project**

MODULE # / TITLE		SUMMARY OF CONTENT	LEAD INSTITUTION	INITIALLY SCHEDULED DATE	RE-SCHEDULED DATE	STATUS
5	Understanding the fatigue damage in engineering materials	Fatigue quantification methods, training about laboratory experiments, design and calculation methods, latest trends for fatigue damage mitigation.	TU Delft	December 2021	28th February to 4th of March 2022	Held in person in Delft, Netherlands
6	SHM methods using GWs and AE in composites	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-List)	June 2021	20th June to 24th June 2022	Celebrated jointly with the H2020 - MSCA project GW4SHM-ITN in Paris, france
7	Numerical methods for virtual laboratory engineering	Virtual laboratory simulation and cyber-physical systems for optimisation of manufacturing processes	CENAERO - Centre de Recherche en Aéronautique	December 2021	10th October to 14th of October 2022	Held in person in Charleroi, Belgium

Figure 1. **The ENHAnCE team at the Training Week in TU Delft (Netherlands)**

Figure 2. **The ENHAnCE team at the Training Week in CEA-List (France)**

Figure 3. **The ENHAnCE team at the Training Week in CENAERO (Belgium)**

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.

The dissemination through the articles published in journals and congresses has been very fruitful during this year, as it is showed in the table bellow (*Table 3*):

Table 3. **Publications during Year 3 (M25 to 36) of the project**

TITLE	ENHAnCE members colaborating	LINK	JOURNAL/ CONGRESS
Uncertainty quantification in Neural Networks by Approximate Bayesian Computation: Application to fatigue in composite materials.	Juan Fernández, Manuel Chiachío, Juan Chiachío, Rafael Muñoz, Francisco Herrera	https://www.sciencedirect.com/science/article/pii/S0952197621003596?via%3Dihub	Engineering Applications of Artificial Intelligence
Particle filter-based hybrid damage prognosis considering measurement bias.	Tianzhi Li, Francesco Cadini, Claudio Sbarufatti	https://onlinelibrary.wiley.com/doi/10.1002/stc.2914	Structural Control and Health Monitoring
Reduction of Petri net maintenance modeling complexity via Approximate Bayesian Computation.	Ali Saleh, Manuel Chiachío, Juan Chiachío	https://www.sciencedirect.com/science/article/pii/S0951832022000436	Reliability Engineering & System Safety
Risk-based maintenance strategy selection for wind turbine composite blades.	Javier Contreras, Athanasios Kolios	https://www.sciencedirect.com/science/article/pii/S2352484722007922	Energy Reports
Numerical simulation-aided particle filter-based damage prognosis using Lamb waves	Tianzhi Li, Francesco Cadini, Claudio Sbarufatti	https://www.sciencedirect.com/science/article/pii/S0888327022004630	Mechanical Systems and Signal Processing
Structural digital twin framework: Formulation and technology integration	Manuel Chiachío, María Megía, Juan Chiachío, Juan Fernandez	https://www.sciencedirect.com/science/article/pii/S0926580522002060?via%3Dihub	Automation in Construction
Guided waves-based damage identification in plates through an inverse Bayesian process	Wen Wu, Rasa Remenyte-Prescott	https://www.sciencedirect.com/science/article/pii/S0041624X22000816?via%3Dihub	Ultrasonics

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Particle filter-based delamination shape prediction in composites subjected to fatigue loading	Tianzhi Li, Francesco Cadini, Claudio Sbarufatti	https://journals.sagepub.com/doi/10.1177/14759217221116041	Structural Health Monitoring Journal
A cross-sectoral review of the current and potential maintenance strategies for composite structures	Javier Contreras, Juan Chiachío, Ali Saleh, Manuel Chiachío, Athanasios Kolios	https://doi.org/10.1007/s42452-022-05063-3	SN Applied Sciences
Asset management modelling approach integrating structural health monitoring data for composite components of wind turbine blades	Wen Wu, Ali Saleh, Rasa Remenyte-Prescott	https://www.researchgate.net/publication/363267167_Asset_management_modelling_approach_integrating_structural_health_monitoring_data_for_composite_components_of_wind_turbine_blades	32nd European Safety and Reliability Conference
An assessment of different reinforcement learning methods for creating a decision support system based on the Petri net model	Ali Saleh, Manuel Chiachío	https://papers.phmsociety.org/index.php/phmconf/article/view/3240	Annual Conference of the PHM Society, 2002
Interpretable Neural Network with Limited Weights for Constructing Simple and Explainable HI using SHM Data	Morteza Moradi, Rinze Benedictus, Dimitrios Zarouchas	https://papers.phmsociety.org/index.php/phmconf/article/view/3185	Annual Conference of the PHM Society, 2002
Probabilistic safety assessment in composite materials using bnn by ABC-SS	Juan Fernández, Juan Chiachío, Manuel Chiachío, Ali Saleh	https://papers.phmsociety.org/index.php/phmconf/article/view/3275	Annual Conference of the PHM Society, 2002
Intelligent Health Indicators Based on Semi-supervised Learning Utilizing Acoustic Emission Data	Morteza Moradi, Juan Chiachío, Rinze Benedictus, Dimitrios Zarouchas	https://link.springer.com/chapter/10.1007/978-3-031-07322-9_43	European Workshop on Structural Health Monitoring

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/ is continuously updated and offers all the information about the project with the latest news and publications 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), Twitter (@ENHANCEITN1) and Facebook (@ENHANCEITN1) have been conveniently updated during the third year of the project.

The ESR8 Wen Wu presented his work within the project to the general public during the British Science Week in Nottingham, with great affluence and general excitement about the work exhibited. His work is related to model risk of failure using guided wave propagation as a warning to avoid accidents. The ESR3 Amond allouko was in charge of visiting local schools, meeting up to 75 alumni in Paris and showing that the use of mathematics in engineering helps to solve real-life problems such as modelling damage aided by acoustic waves.

Figure 4. **The ESR 8 Wen Wu during the British Science Week in Nottingham (March 2022)**

Figure 5. **The ESR 3 Amond Allouko during his presentation at schools in Paris, June 2022**

In Granada, the supervisors Dr. Manuel Chiachío and Dr. Juan Chiachío participated in the Café-con-Ciencia initiative ("coffee with science") with a session about Digital Twin for secondary school students and celebrated in the School of Engineering, University of Granada. Also, the Granada's team participated in the European Researchers Night, with the attendance of the ESR10 Ali Saleh, along with the coordinator of the project Manuel Chaichío and the project manager María Megía, showing to the general public the achievements of the project ENHAnCE so far.

Figure 6. **The ESR 10 Ali Saleh with the coordinator Manuel Chiachío explaining the project to the general public**

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 policy making.

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. 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.

No modifications have been envisaged for the Data Management Plan during this third year.

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 has been fully respected during the third year of the project.

Moreover, the experimental tests done with the thermoplastic coupons have not focused on any military standards or configuration, hence there is no risk of any ethical issues with them.