1.0 Institution Details

1.1 University / PhD Awarding Body:

University of Strathclyde

1.2 Department:

Mechanical and Aerospace Engineering

1.3 University Address

75 Montrose street, Glasgow G1 1XJ

Country: Lanarkshire

2.0 Lead Academic Contact

2.1 Title (Example Prof, Dr):	Dr
2.2 Surname / Family Name:	Trendafilova
2.3 Middle Name:	Nikolova
2.4 First / Given Name:	Irina

2.5 Correspondence Address

Department of Mechanical and Aerospace Engineering, University of Strathclyde, 75 Montrose street Glasgow G1 1XJ

Country: Scotland, UK

2.6 Landline: (0) 141 5482322 Mobile:

2.7 E-mail Address: Irina.Trendafilova@strath.ac.uk

2.8 CV of lead academic contact attached: ☑ Yes ☐ No
(Submit as attachment Appendix A, max 4 pages)

3.0 Proposal

Please check the application form before submission to ensure all information is complete and correct.

Please ensure all text is contained within the boundaries of these areas. (Tip: Print Preview functionality will show you the entire document). Any content which is not visible on the form will not be passed to the peer review panel. The typeface, font size and colour for the text boxes are predetermined and cannot be changed. This document must be saved and submitted as pdf.

Additional information, such as images, graphs etc. can be submitted as an Attachment, Appendix B. Clearly label and cite for crossreferencing purposes.

Before completing this section, refer to Lloyd's Register Foundation's "Foresight Review of Structural Integrity and Systems Performance" as the proposal should be related to at least one of the research themes.

3.1 Theme:

(Please select the appropriate theme of the proposal)

- [ ] Safety of additive manufactured parts
- [x] Advancing the state of the art to maximise safety
- [ ] Whole-system approaches to demonstrate safety and integrity
- [ ] Data-centric engineering
- [x] Minimising the risks associated with maintenance and inspection

3.2 Project Title (Max 50 words)

Vibration-based structural health monitoring through self-diagnosing structural components made of nano enriched composites

3.3 Provide a summary of the research (Max 500 words)

The main goal of this proposal is to develop the foundations of dynamically self-sensing and self-diagnosing structures capable of measuring their vibrations and using them to diagnose their structural integrity . This will be achieved by using conductive or piezo-electric nano-inclusions and applying vibration-based monitoring and health assessment methods.

The idea of self-diagnosing structures opens the road towards autonomous structures, capable to not only self- diagnose their condition but eventually even take some repair steps. This is applicable for a wide variety of structures including aerospace, mechanical and civil engineering ones like e.g. aircrafts, turbine blades, buildings and bridges.

The idea of using nano-inclusions as sensors is based on the piezo-resistive and piezo-electric properties of some materials. The first relate the conductivity and the strain of the structure and hence its vibrations, while the latter convert the strain into voltage and vice versa and they are used for dynamic/vibration transducers. This proposal suggests to employ piezoresistive and/or piezo-electric nano-inclusions for measuring and assessment of the structural vibrations and use them to estimate the structural health. The rationale for using vibration-based structural health monitoring (VSHM) is two-fold: 1) there is a vast amount of research and more than 30 years experience in VSHM and 2) most structures are naturally subjected to some kind of vibrations which can come e.g. from the work of an engine or a motor, or from traffic and wind.

The suggested approach is based on a no-intervention principle, coupled with new integrated within the structure sensing technology. It proposes a unified approach comprising 1) a new self-sensing theory, coupled with 2) a vibration-based monitoring and diagnostic methodology for detecting anomalies in both short term (damage) and long term (fatigue or wear) scale. A data-centred VSHM approach is suggested which deals with the extraction and handling of appropriate information obtained from the self-measured signals and with the derivation of data-driven models and damage detection and assessment methods.

This research will advance the concept of vibration-based structural health monitoring expanding it to self-health monitoring by applying piezo-resistive and piezo-electric nano inclusions. It will also promote our understanding for the dynamic properties and behaviour of piezo-resistive and piezo-electric materials and their influence on the global dynamic properties of the structure in which they are included. The suggested research will further the knowledge about the sensing properties and capabilities of the conductive and piezo-electric nano-inclusions in terms of sensitivity to different damage types and precision. This will be done employing a joint approach combining an experimental track coupled with modelling approach to achieve the envisaged knowledge and results. The proposed self-diagnosis methodology will bring the paradigm of monitoring and prognosis on a new level eliminating the need of external sensors and thus removing the error due to contact and improving the precision of the measurements. It will introduce the viability of in operation continuous monitoring through self-measurement thus reducing the need for additional maintenance and intervention and hence minimizing the risk of introducing faults associated with maintenance and inspection.

3.4 How will the proposed research make a novel contribution to structural integrity and systems performance? Please use Lloyd's Register Foundation's "Foresight Review of Structural Integrity and Systems Performance" as guidance. (Max 500 words)

This project will contribute to the understanding and the ability to predict the dynamic performance of materials enriched with nano -inclusions, which is one of the gaps in our knowledge. This is a crucial issue regarding the safety and the reliability of structures since most structures are subjected to vibrations during their operations and life time. We need to be able to predict this behaviour in order to properly design the structures so that are capable to perform their operations without posing threat to the people and the environment.

This proposal suggests the development of self-sensing and self –diagnosing structures which will advance the understanding and the applications in the area of measurement and sensing. The challenge in this research involves the inclusion of the sensing material within the structure so that it is able to assess its vibrations and from it make conclusions about its integrity and condition. This will improve the precision of the dynamic sensors eliminating issues related to their mass and contact with the structure, which otherwise affect the precision of such instruments significantly.

The simulation and the modelling of the behaviour of the structures enriched with nano-materials is one of the key aspects of this proposal. These are novel structural elements and materials and we need to be able to model and simulate their behaviour for the purposes of their proper design and exploitation. There are no current standards that can be used for the design of such structures so the development of some standards will follow from the development of models and modelling strategies to simulate their behaviour.

This proposal addresses the reliability of nano-enriched structures to ensure that they are able to maintain their operations safely and perform their functions without presenting any risk or danger to the people and the environment. This includes the estimation and the prognosis of possible damage and delamination or other failure modes in such structures so that when designing them one is able to guarantee that they will not fail and that their performance will not pose a threat to the people and the environment.

An important aspect of this proposal is that it will address one of the key gaps in our knowledge and understanding, the measurement of the state of a material during its operation. This is one of the main objectives of the current proposal. The inclusion of the sensor within the material and within the structure as a whole will provide the availability of monitoring around the clock while the structure is in operation.

The in service monitoring will provide crucial information about the state of the material and the structure, but in the same time it will provide important data regarding the material and the structural behaviour during the operation.

3.5 State how this research will contribute to safety of life and property and what the likely impacts will be once the research is completed. (Max 500 words)

The main idea of this research is to develop a new and improved sensing and diagnosing procedures for a number of critical structures thus bringing down the probability for undetected faults and catastrophic failures. The idea of using nano-inclusions for self-diagnosis purposes is applicable and will be beneficial for a wide range of structures including mechanical, civil , aerospace and space ones thus increasing their life-span their reliability and safety while in the same time bringing down the maintenance costs.

Composite materials and in particular nano inclusions are known to have a lot of advantages including the increased structural stiffness which will increase its resistance under certain loadings. On the other hand delamination is one of the main failure modes for most composites and it can lead to failure if undetected while it is very difficult to detect as most composites remain visually unchanged while they may lose up to 60% of their stiffness. The use of nano-inclusions will bring down the probability for delamination between the layers where it is included while the self-diagnosis will diminish the risk of undetected delamination between the non-enriched layers. These effects will contribute to the increased safety of the structure.

An important aspect of including the sensor within the structure is that this practically brings the error from contact and the one due to the mass of the instrument of the instrument to zero. Thus the included within the structure nano sensors will guarantee an increased measurement precision which in turn will enhance the precision of the structural integrity assessment thus reducing the missed faults and the false alarms.

Including the sensor within the structure will also ensure continuous measurement and assessment of the structural health and integrity which will bring down or nearly eliminate the need for additional monitoring and inspection. This will reduce the probability for introducing faults through the inspection/maintenance process.

This proposal intends to enhance our knowledge about the dynamics of nano-enriched structures. This will help to better understand their failure mechanisms and eventually improve their design and maintenance bringing up their safety, reliability and life span.

Having said the above the inclusion of nano-sensor(s) within the structure will eventually make such structures much safer and more reliable, bringing down the risk of collapses and catastrophes. This in turn will make our environment safer by diminishing the risk and the damage for the people using and operating such structures and for the environment.

3.6 Provide details of outline project plan (Max 200 words)

The objectives of this research will be achieved through the following main tasks
1. Establishment of an optimum configuration for the conductive and the piezo-electric nano-inclusions
2. Research on the dynamic and vibratory behaviour of the materials for the nano –enrichment. This task seeks to study the dynamic behaviour of the material used as sensor in order to determine its sensor capabilities. This will be achieved through modelling and experimentation.
3. Research on the influence of the nano-enrichment on the macro-properties of the structure and especially its dynamic properties. This will be established through a coupled modelling and testing procedure.
4. Assessing the sensing capabilities of the nano-enriched structure. This will be done on the basis of comparison with a conventional sensor.
5. Damage sensitivity analysis and assessment of the nano-enriched structural element. This will assess the sensitivity of the nano-sensor to different damage types .
6. Development and assessment of a vibration-based diagnosis procedure based on the self-measured signals
7. Building a prototype of a self-diagnosing structure
8. Testing and validation/verification of prototype self-diagnosing structure

3.7 Provide a list of equipment required for conducting the research and identify any equipment that will be provided by the university (Max 200 words)

The equipment required for this proposal is related 1) to the production and the embedding of nano-inclusions within the structure and 2) the dynamic and vibratory testing of the specimens. 1) Currently our specimens are produced by our collaborator - the DIN at the University of Bologna and by CAT Proggetti. But in order to perform the envisaged research in this direction we shall need our own equipment. This includes an electrospinning machine to produce the nano-inclusions. The cost of such a machine with basic accessories is around £10,000.

2) Regarding the Dynamic equipment we currently have some basic equipment. We will need a more advanced shaker in order to simulate realistic loading conditions and vibration meter the total price being~£9,500.

It is expected that ~ 50% of the price of this equipment will be covered by the University.

3.8 What is the length of PhD programme in your University? Does your university PhD programme require the student to take any compulsory modules, trainings etc., if so, provide detail. How much time is the student expected to spend at the university? (Max 200 words)

The typical length of the PhD programme is 3 years for research and 6 months for writing, when no fees are paid. The student is expected to get a certain number of credits through completing a number of specially designed courses which will help him/her to build essential skills like writing research papers, developing presentations, presenting his/her research. This courses usually take a couple of days up to one week. The time that the student spends in the University is not regulated by the University. We will provide the student with appropriate space for work but he is not required to spend a certain time in the University. The time that the student spends in University largely depends on the program of his research like e.g time he needs to spend for experiments and time he needs to spend with the supervisor and other colleagues to aid his work.

3.9 One of the criteria for selection will be the fiscal contribution provided towards funding the PhD research. What are the typical costs associated with running the PhD programme in your institution(such as tuition fee, stipend etc)? (Max 200 words)

The typical costs for running a PhD program at Strathclyde include the fees , the stipend and some funding for travel and conferences. The fees and the stipend for a home/EU studentship for the three years are £55,400, £12,400 in fees the rest is the stipend. The University provides up to £400 for the three years for each student for travel and conference participation. The costs for running and international studentship are around £96,300 - £52,100 of which are fees. The faculty and the University will typically cover the costs for a home/EU student.

3.10 Do you have a suitable candidate for this application? ☐ Yes ☑ No

If yes, please attach their CV with the application as Appendix C, max 2 pages (The purpose of requesting this information is to proactively engage with the university, if the application is shortlisted. There will be no impact to the selection of proposal, if you do not have a suitable candidate)

Does the candidate require a visa? ☐ Yes ☐ No

3.11 Provide a list of references related to the proposal. Please use this section to support your proposal. (Max 500 words)

References on nano-inclusions and their use for measuring and diagnosis

1. A.Oskouyi et al., Tunneling Conductivity and Piezoresistivity of Composites Containing Randomly Dispersed Conductive Nano-Platelets, Materials 2014, 7, 2501-2521

2. J. Dosch et al, A Self-Sensing Piezoelectric Actuator for Collocated Control, J. of Intell. Mater. Syst. and Struct., Vol. 3 -January 1992

3. D. Fritsch, et al, Nanocomposite based structural health monitoring approaches for fibre reinforced polymers, 7th European Workshop on Structural Health Monitoring July 8-11, 2014. La Cité, Nantes, France

4. G Yin et al, A carbon nanotube/polymer strain sensor with linear and anti-symmetric piezoresistivity, Journal of Composite Materials, 0(0) 1–8

5. N Hu et al. , Investigation on sensitivity of polymer/carbon nanotube composite strain sensor, Carbon 48 (2010),680-687

6. J.L. Abot et al. Delamination detection with carbon nanotube thread in self-sensing composite materials Composites Science and Technology 70 (2010) 1113–1119

7. I Kang et al, A carbon nanotube strain sensor for structural health monitoring, Smart Mater. Struct. 15 (2006) 737–748

8. D Garcia and I Trendafilova, A study on the vibration-based self-monitoring capabilities of nano-enriched composite laminated beam, IoP Smart Materials and Struct.(2016) SMS-102890

9. Pandey et al, Electric Time Domain Reflectometry Sensors For Non-Invasive Structural Health Monitoring Of Glass Fiber Composites, Progress In Electromagnetics Research, Vol. 137, 551- 564, (2013)

10. F Pinto et al, Multifunctional SMArt composite material for in situ NDT/SHM and de-icing, Smart Mater. Struct. 21 (2012) 105010

11. Sodano et al., The Use Of Macro-Fiber Composites In Structural Vibration Applications, http://www.researchgate.net/publication/253489528

12. T N Tallman et al, Damage detection and conductivity evolution in carbon nanofiber epoxy via electrical impedance tomography, Smart Mater. Struct. 23 (2014) 045034

13. T N Tallman et al., Damage Detection Via Electrical Impedance Tomography In Glass Fiber/Epoxy Laminates With Carbon Black Filler, Structural Health Monitoring 14(1), 100-109

14. T. Thostenson et al.,Carbon Nanotube Networks: Sensing of Distributed Strain and Damage for Life Prediction and Self Healing, Adv. Mater. 2006, 18, 2837–2841

15. F Ubertini et al, Novel nanocomposite technologies for dynamic monitoring of structures: a comparison between cement-based embeddable and soft elastomeric surface sensors, Smart Mater. Struct. 23 (2014) 045023

References on Vibration-based methods for structural health monitoring

S1. C-P Fritzen, Vibration-based Structural Health Monitoring – Concepts and Applications, Key Engineering Materials Vols. 293-294 (2005) pp 3-20

S2. New Trends in Vibration Based Structural Health Monitoring, Editors A. ,Deraemaker and Worden K., Springer Verl. 2010

S3. C R. Farrar, Doebling S., Nix D., Vibration–based structural damage identification, In Experimental Modal Analysis, Eds.N. Lieven and D.J. Ewins, Philosophical transactions of the Royal Society (2010)

S4. D. Montalvão, N.M.M. Maia and A.M.R. Ribeiro, A Review of Vibration-based Structural Health Monitoring with Special Emphasis on Composite Materials, The Shock and Vibration Digest, Vol. 38, No. 4, July 2006 295–324

3.12 Provide any additional information supporting the proposal. (eg. awards, recognition for the research group, proposal follow on from previous research, etc.)

This is a new direction in my research. I currently have 1 PhD student supported by the Faculty of Engineering and the University of Strathclyde, working in this direction. I have collaboration with the University of Bologna in this direction which is suppoted by an RS international grant and by the Italian research Council (CNR). I am currently applying for support from the Levrhulme trust and the European Research Council. I recently won an RSE-Scottish Government Research fellowship for the investagation of the dynamic and vibratory behaviour of composite structures.