Engineering and Innovation Research Studentship October 2021

Project title:	Data-driven Residual Stress Mapping Tool using Artificial Intelligence
Discipline	Engineering
Key words:	Residual stress, Contour Method, Artificial intelligence
Supervisory team:	Foroogh Hosseinzadeh, Richard Moat, John Bouchard (Technical Advisor)
URL for lead supervisor's OU profile	http://stem.open.ac.uk/people/fht7

Project Highlights:

- Developing an an accessible and user friendly tool for residual stress mapping that will be widely used by the user community, research academics and industry nationally and around the world.
- Fitting closely with the planned research agenda for the proposed National Stress Engineering Centre (N-SEC) to be built at the ISIS Facility.
- Complementing the existing experimental measurement capability at ISIS and N-SEC by integrating the developed tool into SScanSS software.

Overview:

Manufacturing processes often introduce locked-in stresses, namely residual stresses, in the fabricated parts. These stresses can cause distortion and cracking, influence function, and potentially reduce a product's lifetime through premature failure; all of which will result in lower productivity. Management of residual stress has been identified as a focal challenge by experts working in the development and industrialisation of manufacturing processes and design of components for high demand applications. It is of paramount importance to characterise the state of residual stress in manufactured parts. Prediction of residual stresses requires sophisticated and time consuming computer modelling. But the reliability of such predictions depends on the expertise of the modeller and quality of the input data.

Experimental characterisation of residual stresses requires access to specialist measurement facilities and expertise. Often multiple residual stress measurement techniques have to be applied to unlock useful information. This approach can be costly, time consuming, difficult to implement and often results in destructive sectioning. Neutron diffraction is a commonly used technique for characterisation of residual stresses. However, obtaining detailed cross-sectional maps of residual stresses requires a significant amount of beam time. In most cases prior knowledge of the distribution of residual stresses is required in order to plan a neutron diffraction experiment in the most efficient way. Industry is increasingly aware of the need to integrate control of residual stress within decision processes for design and manufacture. Ideally, engineers need a simple tool that can predict fabrication residual stresses at the early stages of component design. The tool would allow users to "tune" some of the governing variables in order to introduce controlled levels of residual stress or to mitigate unwanted distortion. The emerging field of data science offers an excellent opportunity to exploit advances in cloud computing and artificial intelligence to learn from large datasets obtained from measurements. The proposed PhD project will use data analytics and intelligent algorithms to predict cross-sectional maps of residual stress in components of interest based on historical measurement data.

The new residual stress mapping software will be integrated with current SScanSS software and thereby provide strain scanning neutron users with a complementary tool for experiment planning and optimisation. This will reduce the beam-time required or at least make best use of allocated time. This research project also fits closely with the planned research agenda for the proposed National Stress Engineering Centre (N-SEC) to be built at the ISIS Facility, and will support future experimental work on the Engin-X, IMAT and (future) ε-MAP instruments. More widely the proposed predictive platform will contribute to the Industrial Digitalisation Technologies (IDTs) that will underpin the UK's future manufacturing industry. It will provide a vital resource for industry in developing new products and optimising manufacturing techniques.

Aim and Objectives:

The aim of the proposed project is to create a data-driven predictive tool for 2D mapping of residual stresses in welded structures.

An Artificial Neural Network (ANN) model has been developed at the Open University and applied to predict through-wall line profiles of residual stress in austenitic stainless steel pipe girth welds [1,2]. The ANN model is currently being updated. Specifically, a user-friendly tool is being developed to extend application of the ANN to Rotary Friction Welds (RFW). A further powerful feature of the ANN type of approach is that it lends itself to image recognition. The innovation and challenge of the proposed PhD project is to exploit this innate capability of ANNs by using "contour method" and "neutron diffraction" training data in order to predict/estimate cross-sectional maps of residual stress in families of structures (that lie within the training data parameter envelope). The specific PhD research objectives include:

- To develop and train an ANN tool that can predict cross-sectional maps of residual stresses in stainless steel welds based on data driven intelligent algorithms.
- To validate the trained ANN tool using neutron diffraction and the contour method measurements on newly manufactured mock-ups.
- To create a user friendly interface for the ANN predictive residual stress tool that is accessible to ISIS neutron users, academic researchers and industry, through embedding it within SScanSS, the software that is widely used to assist in the design of neutron diffraction measurements.

Methodology:

The proposed project will be conducted in 4 phases:

Phase 1: Foundation tasks include: (a) conducting a thorough literature review to identify different data analytics, intelligent algorithms and features of ANNs that could be used for image recognition; (b) identifying the most suitable software for developing the platform (including open source codes like Python); (c) sourcing the training data required from published work, data mining relevant neutron diffraction measurements made at ENGIN-X and collating contour method measurements made at the Open University (OU). By the end of this phase the student will have written a probation report (month 9) and defended it via a mini viva (part of the OU's PhD programme). The probation report typically includes a literature review, a concise definition of the research aim and objectives, the proposed methodology, a future work plan, and a review of results obtained to date.

Phase 2: The student will develop a new ANN platform for recognising and learning from cross-section maps of residual stresses in welded components. The type of weld geometry adopted for this study will be chosen based on the amount of high quality data available, noting that AI algorithms need large datasets for effective training. Requirements for measurements from new weldments to validate the ANN will be defined at an early point in this phase so that mock-ups can be designed, manufactured and measured by neutron diffraction and the contour method in Phase 3.

Phase 3: The new mock-ups required for measurements to validate the ANN will be made. Manufacturing parameters for these mock-ups must lie within the envelope of those for the training weldments. But consideration will also be given to making additional mock-ups to extend the range of the training database. Residual stresses in all of the new mock-ups will be measured using neutron diffraction and the contour method. The performance of the ANN stress mapping predictor will then be assessed against the new validation measurements and the algorithms refined where appropriate .

Phase 4: In the final phase, the validated predictive tool will be integrated into the existing Strain Scanning Simulation Software (SScanSS) initially developed by the Open University in collaboration with the ISIS Facility, and an exemplar case study for neutron users prepared. This project impact pathway will benefit future ISIS neutron users of the ENGIN-X, IMAT and (future) ε-MAP instruments.

Further reading:

[1] Mathew, J.et. al. (2017), International Journal of Pressure Vessels and Piping, 150 pp. 89–95.

[2] Mathew, J., et. Al. (2017), Metallurgical and Materials Transactions A, 48(12) pp. 6178–6191.

Further details:

Students should have a strong background in Solid Mechanics, Materials Engineeeing or Mechanical Engineering and enthusiasm for laboratory experimental work and competent programming skills. Please contact Dr Forooh Hosseinzadeh (foroogh.hosseinzadeh@open.ac.uk) for further information.

Applications should include:

- A 1000 word cover letter outlining why the project is of interest to you and how your skills match those required
- an academic CV containing contact details of three academic references
- an Open University application form, downloadable from: http://www.open.ac.uk/postgraduate/research-degrees/how-to-apply/mphil-and-phd-application-process
- IELTS test scores where English is an additional language

Applications should be sent to **STEM-EI-PhD@open.ac.uk by 05.03.2021.**