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## Novel Digital Twins for Compliance Debts in Smart Manufacturing

### Project Team:



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### Industry Partner:



*\*Collaborators also include a number of leading scientists from China, USA and Australia.*

### The project

This was a novel investigation into “Compliance Debts” in smart manufacturing - a technical debt phenomenon, characterised by the gap between what levels of compliance can be achieved under uncertainty, with the available resources and information, and the hypothesised “ideal” compliance level. Compliance in smart manufacturing refers to the industry’s responsibility to operate within established laws, regulations, standards, and specifications. Managing compliance is ultimately an investment activity under uncertainty for value creation and debt avoidance. It is a daunting engineering challenge to ensure optimality and assurance for compliance in the presence of uncertainty, and some engineers often take suboptimal and/or “quick and dirty” compliance engineering decisions and choices to meet urgent demands (e.g a deadline; budget), compromising quality and compliance. Such compromises are viewed as “debts”.

### What the project achieved

- Literature review on Digital Twins, Circular Economy, and Compliance management in smart manufacturing and re-manufacturing
- Identifying a scoping case from the EPSRC AutoReman project, held by Prof Pham, Mechanical Engineering, University of Birmingham. We have looked at the Assembly phase of the digital re-manufacturing process using a combination of human and robots, which formed the basis of a case study on human-robot compliance in smart remanufacturing.
- Fundamental research into the area of Digital Twins in the general area of Cyber Physical Systems, with explicit focus on intelligent/cognitive digital twins to benefit the investigation.
- Developed a family of compliance-oriented cognitive digital twins architecture patterns for smart remanufacturing, which can serve as a reference/conceptual architectural patterns/models.
- Identification of technical debt attributes for smart (re)-manufacturing case and developing a conceptual model capturing attributes and dependencies.
- Instantiation/implementation and evaluation of the cognitive digital twins architecture patterns for a smart (re)-manufacturing with the help of one of our PhD students.

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- Mechanism design for compliance technical debt management in smart remanufacturing, leveraging reinforcement learning techniques. The view is to integrate these models into the digital twins' architectures.
- Knowledge equivalence of the physical and digital worlds (with application to the case of human-machine compliance in smart remanufacturing).
- Digital twins for modelling human-machine teaming (technical compliance vs human factors).

## Publications

- Nan Zhang, Rami Bahsoon, Nikos Tziritas, Georgios Theodoropoulos: Knowledge Equivalence in Digital Twins of Intelligent Systems. CoRR abs/2204.07481 (2022), Under review. ACM Transactions on Modelling and Computer Simulation.
- Nan Zhang, Rami Bahsoon, Nikos Tziritas, Georgios Theodoropoulos: Explainable Human-in-the-loop Dynamic Data-Driven Digital Twins. CoRR abs/2207.09106 (2022), In submission. International Conference on Computational Science.
- H. Tri Nugroho I and R. Bahsoon. A Conceptual Reference Model for Human as a Service Provider in Cyber Physical Systems, In the 16th International Symposium on Software Engineering for Adaptive and Self-Managing Systems, SEAMS(2021), in conjunction with the 43rd ACM/IEEE International Conference on Software Engineering (ICSE).
- S. Funprasertkul, R. Bahsoon. Managing Technical Debt Under Uncertainty, IEEE Software, 2021.
- B Ojameruaye, R Bahsoon(2021). ArchDebts: An Economics-Driven Approach for Evaluating Sustainable Requirements (focus on compliance requirements). Book Chapter. Software Sustainability.
- N. Zhang, R. Bahsoon, G. Theodoropoulos(2021). Towards Engineering Cognitive Digital Twins with Self-Awareness, IEEE International Conference on Systems, Man and Cybernetics (SMC), TORONTO, CANADA, OCT 11-14, 2020, IEEE.

## Next Steps

The team hope to submit to EPSRC for a standard mode application to further the research. The team will also continue to develop Digital twins Autonomous Software Architectures theme within the core research group. This is a vibrant small group of international collaborators and UoB researchers working on the theme, and multidisciplinary investigations, including compliance in smart remanufacturing, infrastructure resilience, utilities, and circular economy.

## Contact details

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