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| **Institution:**<br>University of Lincoln | | |
| **Unit of Assessment:**<br>12 - Engineering | | |
| **Title of case study:**<br>STARMS: Online Diagnostics for Improved Operational Behaviour of Industrial Gas Turbines | | |
| **Period when the underpinning research was undertaken:**<br>2010 - 2018 | | |
| **Details of staff conducting the underpinning research from the submitting unit:** | | |
| **Name(s):** | **Role(s) (e.g. job title):** | **Period(s) employed by submitting HEI:** |
| BINGHAM Chris | Professor of Energy Conversion | 8 May 10 to date |
| MALEKI Sepehr | Senior Lecturer | 3 Nov 14 to date |
| **Period when the claimed impact occurred:**<br>2017 to date | | |
| **Is this case study continued from a case study submitted in 2014?**<br>N | | |

**1. Summary of the impact** (indicative maximum 100 words)

Siemens Industrial Turbomachinery Ltd had identified that they were losing substantial operational availability of their Industrial Gas Turbines due to a lack of monitoring fidelity and intelligent diagnostics to detect and repair emerging faults. Researchers at the University of Lincoln's School of Engineering worked with partners at Siemens to create a diagnostic tool, known as the Changepoint Detection Tool, based on algorithms that would enable earlier and more accurate detection of actual and impending faults. This tool was deployed into operations by Siemens in 2017 and, since then, has increased on-site operational availability and reduced customer productivity losses [text removed for publication].

**2. Underpinning research** (indicative maximum 500 words)

Industrial Gas Turbines (IGT) are crucial for high scale manufacturing but require frequent monitoring to gauge whether they are operating normally. Monitoring is often a manual task, incurring staff cost implications, providing incomplete data and delaying responses to anomalous unit behaviour until problems are manually observed.

As one of the leading producers of IGTs, Siemens Industrial Turbomachinery Ltd (SITL) recognised that whilst their IGT units across the globe were extensively monitored, this was primarily reliant on daily manual observations of a small number of selected sensor measurements (vibration, pressure and temperature measurements) as part of the STARMS (Siemens Turbomachinery Applications Remote Monitoring System). A lack of advanced algorithmic agents to monitor units led Siemens to commission UoL to undertake investigative research into the development of intelligent agents to monitor industrial gas turbines and early identification of emerging faults. Beginning in 2010 (two research programmes, **[Grant A and Grant B]** early findings were reported in **[3.1]**, newly demonstrating that real-time detection of sensor faults and the number of sensors that are at fault in a multi-sensor can be identified. Moreover, the reconstruction of measurements that would normally be expected from the sensor at fault was reported that could facilitate improved unit operational availability by allowing continued operation after the faulty sensor had been identified (until maintenance could be carried out), whilst also determining the minimum number of non-faulty sensors that are required to continue unit operation without unduly compromising performance.

Early findings also indicated that the efficacy of burner ignition and control could have a substantial influence on the reliability and maintenance requirements for the IGTs. To verify this, the UoL team developed a number of new statistical/correlation and AI-based techniques for the advanced monitoring of IGTs **[Grant C]**. Experimental results **[3.2, 3.3]** showed that significant reduction in time for identifying developing faults could be made by employing these new agents.

These insights led UoL to develop the Changepoint Detection Tool. This tool enabled the real-time diagnostic and prognostic monitoring of gas path/combustion dynamics and provide early warnings of anomalous behaviour. Initial independent trials were undertaken by Siemens (Germany) on 8 IGTs with a-priori known anomalous dynamic behaviour, with the Changepoint Detection Tool identifying problems on all 8 of them. As a result of the demonstrable benefits of using daily sensor information for monitoring the operation of IGTs, Siemens then further expanded its adoption of the Changepoint Detection Tool to include the active monitoring of IGTs across the globe.

**3. References to the research** (indicative maximum of six references)

3.1 Yang, Zhijing and Ling, B.W.-K and Bingham, Chris (2013) Fault detection and signal reconstruction for increasing operational availability of industrial gas turbines. Measurement: Journal of the International Measurement Confederation, 46 (6). pp. 1938-1946. ISSN 0263-2241
https://doi.org/10.1016/j.measurement.2013.02.016

3.2 Zhang, Yu and Bingham, Chris and Garlick, Mike and Gallimore, Michael (2017) Applied fault detection and diagnosis for industrial gas turbine systems. International Journal of Automation and Computing. ISSN: 1476-8186
https://doi.org/10.1007/s11633-016-0967-5

3.3 Maleki, Sepehr and Bingham, Chris and Zhang, Yu (2016) Development and realisation of changepoint analysis for the detection of emerging faults on industrial systems. IEEE Transactions on Industrial Informatics, 12 (3). pp. 1180-1187. ISSN: 1551-3203
https://doi.org/10.1109/TII.2016.2558181
http://eprints.lincoln.ac.uk/22991/1/Development%20and%20Realisation%20of%20Changepoint%20Analysis%20for%20the%20Detection%20of%20Emerging%20Faults%20on%20Industrial%20Systems.pdf

Grant A Funder: Siemens Industrial Turbomachinery Ltd/Sensor Validation Project[text removed for publication]

Grant B Funder: Siemens Industrial Turbomachinery Ltd/Data Validation Project[text removed for publication]

Grant C Funder: Siemens Industrial Turbomachinery Ltd/STARMS[text removed for publication]
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**4. Details of the impact** (indicative maximum 750 words)

Our ongoing commissioned research programme with Siemens Industrial Turbomachinery Ltd (SITL) has provided not only a range of scientific advancements (communicated via academic papers), but also a range of benefits for Siemens directly **[5.1]**. By adopting the findings of our research into business operations, impact has been generated for Siemens in three primary ways: improving operational activity of the gas turbines, financial saving associated with IGT maintenance and improved effectiveness and productivity of engineering staff.

**Improved Operational Activity of Siemens Industrial Gas Turbines [5.2]**
The development and application of the Changepoint Detection Tool has improved the operational activity of Siemens Industrial Gas Turbines through earlier detection of actual and emerging faults. Algorithms developed at Lincoln were first tested by Siemens on 8 gas turbine units in operation in Germany and are now integrated as agents into the SITLs corporate Prognostic and Diagnostic software suite. Building on the Lincoln research, 4 different configurations of the agents have been developed to suit different types of IGT engines.

The Changepoint Detection Tool focuses on identifying deviations from normal operation, with its success measured by the number of detected anomalies compared to previous methods. Since 2017, the Changepoint Tool has identified 895 deviations from normal operation, classified as events, on 45 IGT engines in the UK and 3,900 events on a further 148 globally distributed IGT engines, including in India, China, Japan, and Azerbaijan.

**Financial Savings Associated with IGT Maintenance [5.2]**
For Siemens, the operational improvements have enabled significant cumulative financial savings in the annual cost of maintaining the gas turbines, calculated from the amount of time it takes to diagnose faults and return a unit to full service. Without the Changepoint Detection Tool, average times from diagnosis to full service is 30 days. With the Changepoint Detection Tool, average time is reduced to 10 days. [text removed for publication]

**5. Sources to corroborate the impact** (indicative maximum of 10 references)

5.1 Testimonial letter from Chief Executive, Siemens PLC.

5.2 Testimonial letter from VP Siemens Industrial Turbomachinery.