Institution: City, University of London

Unit of Assessment: Engineering

Title of case study: Self-sensing railway electrification system for efficient operation and improved maintenance

Period when the underpinning research was undertaken: 2012 - ongoing

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:
Professor Tong Sun OBE FREng	Faiveley Brecknell Willis/Royal Academy of Engineering Research Chair	1st March 2001 - Present
Prof Kenneth Grattan OBE FREng	Royal Academy of Engineering/George Daniels Research Chair in Scientific Instrumentation	1st October 1983 – present
Dr Fei Xiong	Post-doctoral Research Fellow	1st November 2013 – 28 February 2015
Dr Ye Chen	Post-doctoral Research Fellow	1 August 2015 – 31 July 2019
Dr Miodrag Vidakovic	PhD student + Postdoctoral Research Associate	1st October 2015 - Present
Dr Mathias Fabian	Research Fellow	1st July 2011 - present

Period when the claimed impact occurred: 2015 - ongoing.

Is this case study continued from a case study submitted in 2014? N

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

Professors Tong Sun OBE FREng and Kenneth Grattan OBE FREng have developed a self-sensing railway current-collecting pantograph in collaboration with Faiveley Brecknell Willis (FBW), a UK-based world-leader in rail electrification. The 'smart pantograph', mounted on the roof of electric trains, is able to provide remote monitoring of the contact conditions of the pantograph with the overhead wire, reducing delays due to loss of wire contact ('dewirement'), enhancing operational safety and informing timely maintenance. This innovation minimizes failure of the rail electrification system; avoiding costly and time-consuming site access by maintenance staff to repair or replace failed units, powered at 25,000 Volts; significantly reducing maintenance costs, and resulting in more trains being in service, creating a more frequent and punctual service for railway travellers.

2. Underpinning research (indicative maximum 500 words)

The technological breakthrough underpinning the impact was made by City, University of London in collaboration with Faiveley Brecknell Willis (FBW), a UK-based world leader in railway electrification. The project has developed an active railway current-collecting pantograph system, which facilitates remote monitoring of the interaction between the

current-collecting pantograph mounted on the roof of an electric train and the overhead wire, when the train operates at a high speed and operates at 25,000 Volts. The key innovation lies in exploiting the ideal insulator nature of the optical fibre itself which forms the basis of the sensor system as it detects the pantograph condition changes, transmitting operational data using light rather than electrical current: therefore, it is intrinsically safe under such high voltage conditions. In addition, the fibre used is small and lightweight, so its integration into a pantograph to allow sensing causes minimal change in the original mass of the pantograph and facilitates retrofitting. Integral to this is the innovative use of the Fibre Bragg Grating (FBG) sensor technique, which allows a single fibre to be inscribed with the required number of sensors (FBGs), allowing effective sensor multiplexing along the pantograph.

This research comprised a body of work that has developed over a number of years, in 3 major phases: Phase One being a feasibility study; Phase Two full-stage research and development to confirm the findings; and Phase Three a full-scale deployment in the industrial context.

In Phase 1, the key technical challenge identified was measuring accurately the contact force, its signal being 30 times weaker than that of its surrounding thermal noise, caused by the cross-sensitivity of FBGs used. Using a conventional temperature compensation approach, e.g. with a separate temperature sensor for thermal compensation, the measurement error would be too large to be meaningful.

In Phase 2, an innovative approach was explored, aiming to address the challenge identified, by identifying the correlation between neighbouring FBGs integrated into the pantograph, when subjected to various random temperature cycles. An abundance of data collected, which simulated all-weather working environments, have confirmed the existence of such a correlation that the research group has been searching for. These results have paved the way for the success achieved by Dr Ye Chen, Mr Miodrag Vidakovic and Dr Matthias Fabian using a mathematical approach – a key breakthrough of this project. As a result, a UK patent GB1700573.7 was filed in January 2017 and converted to international patent PCT/EP2018/025006 in January 2018. Building upon this breakthrough, the sensors were installed into the pantograph at three different locations, allowing the location of the contact force to be retrieved, in addition to the static/dynamic forces captured.

In Phase 3, the smart pantograph was successfully commissioned at Network Rail on HOPS train in October 2017 and a series of vehicle runs started from March 2018 onwards, continuing until the end of 2020 with speeds and durations of the tests continuing to increase. These activities involving all parties were coordinated by Network Rail, both for inspection of existing overhead lines and for newly installed electrification systems to ensure their reliability and safety. The feedback from Network Rail has been very positive and the data obtained, presented to their clients using a custom-developed user-friendly data presentation, also has been used by Network Rail with the data collected contributing to Network Rail's Condition Based Monitoring of the Great Western Line.

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

3.1 Chen, Y., Vidakovic, M., Fabian, M., Swift, M., Brun, L, **Sun, T.** and **Grattan, K. T. V**. (2017). A temperature compensated fibre Bragg grating (FBG)-based sensor system for condition monitoring of electrified railway pantograph. *Proceedings of SPIE - The International Society for Optical Engineering*, 10323, UNSP 103236T

3.2 **Sun, T.**, Fabian, M., Chen, Y., Vidakovic, M., Javdani, S., **Grattan, K. T. V.**, Carlton, J., Gerada, C. and Brun, L. (2017). Optical fibre sensing: a solution for industry. *Proceedings of SPIE - The International Society for Optical Engineering*, 10323, UNSP 103231H

3.3 **Sun, T.**, Fabian, M., Chen, Y., Vidakovic, M., Javdani, S., **Grattan, K.T.V.**, Carlton, J., Gerada, C. and Brun, L. (2018) Optical Fibre Sensors for Remote Condition Monitoring of Industrial Structures. In: Peng GD. (eds) *Handbook of Optical Fibres*. Springer, Singapore

Indicators of quality for underpinning research:

Patents:

Optical Monitoring System United States Patent US 9,587,995 B2 Mar. 7, 2017

Optical Monitoring System International Patent WO 2018/130427 A3 12.01.2018

Grants awarded:

1. £94,628 from EPSRC (EP/J500781/1); Title: Instrumented Railway Current-Collecting Pantograph; 2012-2013
2. £499,828 from Innovate UK (99030-571163) (TS/R009074/1: £149,500 to City); Title: Smart railway/metro transportation using optical fibre sensing and Internet of Things (IoTs); 2018-2020
3. £999,416 from Innovate UK (88387-550271) (TS/R002150/1: £270,994 to City); Title: Self-sensing railway electrification system for efficient operation and improved maintenance; 2017-2020
4. £543,700 from the Royal Academy of Engineering to Professor Tong Sun for her Faiveley Brecknell Willis/RAEng Research Chair; Title: Smart railway electrification: evolvable from contact to contactless; 2018-2023
5. £60,000 from the Royal Academy of Engineering to Dr Miodrag Vidakovic for an Enterprise Fellowship to support the commercialization of the activity
6. £43,429 from Brecknell Willis, UK; Title: Brecknell Willis Pan Head Sensor Integration for Electrical Trains; 2014-2018
7. £88,654 from Brecknell Willis, UK; Title: Brecknell Willis Pan Head Monitoring and Control for Electrical Trains; 2015-2018
8. £50,000 from Brecknell Willis, UK and Network Rail; Title: Electrical train current collecting pantograph vertical displacement measurement; 2016-2018
9. £7,400 from Brecknell Willis, UK; Title: Software design for an automatic rail position gauge; 2017

4. Details of the impact (indicative maximum 750 words)

Industry engagement: Industry giant Faiveley Brecknell Willis (FBW), which specializes in the field of electrification/traction for all types of transportation systems, has been a key partner to and supporter of the project from the outset. The company's capability covers design, manufacture, supply, testing, installation and maintenance. FBW has collaborated successfully over the past 8 years with the City, University of London research team in order to develop the capability of the ‘smart pantograph’ [5.4]. Thanks to this collaboration the company has experienced several successes including the Best Innovation Award which was accompanied by a £300k monetary award [5.1], the development and presentation of the prototype to industry [5.2][5.3] and participation in two Innovate UK projects which have garnered substantial funding, designed to improve efficiency and reliability as well as the

development of advanced asset and fleet management tools, including remote diagnostics [5.5a] [5.5b]. More importantly, building on the longstanding history of mutual support, FBW is now making detailed plans for the route to market, including the necessary product development of the sensor packages and software, plus a robust spares supply chain, so that customers can maintain this new product in service [5.4].

Technological Success: The 'smart pantograph' developed was installed on a Class 90 Loco from July 2019 onwards, this replacing the IEP (Intercity Express Programme) test vehicle currently in use, aiming to provide a more affordable service by August 2019 (ready to validate the welsh portion of the Great Western Electrification). Network Rail expressed their strong support following the successful performance of the 'smart pantograph' and associated instrumentation as it allowed the company to complete testing of three route sections (7c, 8, 9) and use the data to satisfy the conditions of the Notified Body and Office of Rail and Road to both prove system safety and to allow trains to be in contact with the overhead line within 5 days [5.6]. Following a recent exhibition of the smart pantograph from 14 to 16 May 2019 at the NEC in Birmingham, discussions with both Angel Trains Ltd and Eversholt Rail Ltd have been made for subsequent installation of 'smart pantographs' on their assets, for remote condition monitoring of their vehicles [5.7].

Commercial Success: Given the success with the on-going test programme with Network Rail and further developments of the 'packaging' of the sensor system to allow for ready installation when new pantographs are being built by partner FBW, a company, Sentech Analytics, has been successful 'spun off' from City to market the systems developed. This is led by Dr Miodrag Vidakovic, the CEO of the new company, who has been awarded a Royal Academy of Engineering Enterprise Fellowship to take forward this exploitation, working in collaboration with industry partners and commercial mentoring support from the Academy[5.8]. Building on the quality of the technology and the interest that it has attracted from industry, the 'spin out' has already secured a first commercial contract of a value of £50k (March 2020) along with commitments for participating in contracts of approximately £250k and shareholder investment of £300k [5.9].

Reputational Success: In addition to Dr Vidakovic's RAEng Fellowship, Professor Tong Sun received the Royal Academy of Engineering Silver medal recognizing this work, and that led to FBW and Morganite beginning to build new instrumented 'smart pantograph' systems [5.10]. She subsequently was awarded the Faiveley Brecknell Willis/ Royal Academy of Engineering Research Chair in Smart Railway Electrification, with the goal of developing new contact, hybrid and contactless electrification systems, based on her and the team's research [5.11]. She was elected (2020) to the Fellowship of the Royal Academy of Engineering, recognising the work done and impact made in this project [5.11]. Such recognition has also included more than £600k of funding from the Academy (£543,700 Prof Sun, £60,000 Dr Vidakovic) with the intended purpose of enhancing links between academia and businesses through addressing some of these biggest challenges faced by this industry. Professor Kenneth Grattan, himself a RAEng Fellow since 2008, was a Finalist in the 2020 IET Achievement Awards in recognition of his contribution, through making a positive impact from creating novel optical fibre-based solutions for many challenging and hazardous situations for industrial applications, worldwide [5.12].

International Success: The project is on target to achieve significant international impact. The senior management team from Zhuzhou CRRC in China visited FBW and City, University of London on 15 and 18 July 2019 to discuss an agreement on the installation of smart pantographs on their vehicles for Chinese high-speed rail network.

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

5.1 "Something to BRAGG about", Rail Engineer, Issue 128, June 2015, pp. 34-38

5.2 Hewitt, Adam (2015) "An active Pantograph in action", Rail Technology Magazine, RTM June/July 2015

5.3 "Smarter pantograph developed", Railway Gazette International, 20 September 2016

5.4 Letter of Support from Engineering Manager, Faiveley Brecknell Willis UK [Received 7 May 2020]

5.5a Innovate UK Grant 'Self-sensing railway electrification system for efficient operation and improved maintenance', 1 January 2018 – 31 March 2021, Lead Participant: Brecknell Willis UK, Participant: City, University of London. Funding value: £3,252,977. Project reference number: 103839

5.5b Innovate UK Grant 'Smart railway/metro transportation using optical fibre sensing and Internet of Things (IoTs)', 1 June 2018 – 31 August 2021, Lead Participant: Brecknell Willis UK, Participant: City, University of London. Funding value: £333,408. Project reference number: 104027

5.6 Letter of Support from the Head of Engineering, Western and Wales, Network Rail [Received 11 May 2020]

5.7 Letter of Support from the Head of Fleet, Eversholt Rail Limited [Received 6 May 2020]

5.8 Royal Academy of Engineering: Enterprise Fellowships – 2020 Awards

- Dr Miodrag Vidakovic, City, University of London for the project 'smart railway pantograph for predictive condition monitoring of railway assets'

5.9 Letter of Support from the Managing Director of D.A.T.S Limited. [Received 4 May 2020]

5.10 Royal Academy of Engineering: Silver Medals 2016 Award 'to recognise an outstanding and demonstrated personal contribution to British engineering, which is resulting in successful market exploitation' [6 June 2016]

- Professor Tong Sun OBE FREng, Professor of Sensor Engineering, City, University of London

5.11 News Release - Royal Academy of Engineering funds 7 Research Chairs to leading engineers to tackle industry challenges. [17 October 2018]

5.12 The Institution of Engineering and Technology: IET 2020 Achievement Awards winners and finalists

- Prof Kenneth Grattan OBE FREng, George Daniels Professor of Scientific Instrumentation, City, University of London