Institution: Liverpool John Moores University (LJMU)		
Unit of Assessment: UOA11 – Computer Science and Informatics		
Title of case study: Smart Energy, Smart Care		
Period when the underpinning research was undertaken: 2014-present		
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:**
Carl Chalmers	Lecturer	2017 - Current
Paul Fergus	Professor	2005 - Current
Period when the claimed impact occurred: 2014-present		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

The work presented addressed the need to monitor and support dementia patients at home using smart meters, which resulted in the first technology in the area. We conducted the world's first clinical trial of such technology in partnership with MerseyCare NHS Foundation Trust, which was endorsed by BEIS and SmartEnergyGB. Findings show that the technology was supportive, cost-effective and allowed families and clinicians to assess patient wellbeing in real time. Moreover, the work generated 5 policy documents, supported 4 spin-out companies, and influenced the replacement of SMETS1 with SMET 2 meters to support the delivery of healthcare services.

2. Underpinning research

This approach is a world-first support platform that captures the detailed habits of an individual's interactions with electrical devices and identifies anomalies or changes in routine to facilitate early intervention practice (EIP) by monitoring deviations in behaviour that correlates with disease progression. The system identifies individual appliance usage to model normal and abnormal behaviour. The system can identify kettle, toaster, microwave, cooker, and washing machine usage. Interactions with these devices are used to detect significant variations in activities of daily living (ADL), and safeguard patients. This system provides access to fine-grained information about how and when a person conducts ADL. Practitioners have never had access to this type of real-time information, meaning care packages and interventions are at best retrofitted using patient and carer feedback. This often results in insufficient care packages and delays that don't fully support the unique needs of each patient. Our system provides a clearer assessment of a patient's well-being and their ability to cope using real-time data from the appliances patients use to perform ADL [A]. This means the data is objective, reliable and not dependent on interpretation from patients or carers who have different cognitive viewpoints and biases. The results demonstrate that the system can monitor and support patients in an unobtrusive and personalised manner.

The system was trialled with Mersey NHS Foundation Trust in 2016 - 2017. The trial proved we could:

- Analyse electrical usage and identify appliances through load disaggregation and machine learning to model behavioural routines [1]. To date this is the only algorithm that can successfully identify appliance usage using 10-second smart meter data and the standard government approved hardware installation.
- Achieve encouraging detection accuracy across all appliance classes. In many cases, the algorithm can detect appliances from aggregate load with very high sensitivity and specificity values [1].
- Use collected data to create a personalised behavioural baseline to continually analyse and detect dementia progression or sudden relapses [1]. The results from the clinical trial show that the system can accurately establish patient routines, while detecting anomalies in behaviour [1], [A]. This is an important advancement in dementia care as clinicians only

see patients annually with the result for a 12-month period and thus are unaware of how the patients are coping or the disease is progressing. Our system provides 24/7 assessment and reporting using a traffic light approach to record normal, worrying and abnormal behaviour [A]. This is a world first solution [B].

- Deliver clinical benefits that allow clinicians to:
  - Understand the ADL for specific patients and identify routines of normal and abnormal behaviour using the five devices. Clinicians in old age psychiatry have never before been able to access this level of information about the patients they care for, providing a truly ground-breaking approach to ambient assistive living [2], [3], [4], [A], [B].
  - Provide personalised care packages tailored to the unique needs of each patient [5], [6].

3. References to the research

Peer-reviewed outputs:

[1] Chalmers, C., Fergus, P., Montanez, C., Sikdar, S., Ball, F. and Kendal, B. (2020). Detecting Activities of Daily Living and Routine Behaviours in Dementia Patients Living Alone Using Smart Meter Load Disaggregation. IEEE Transactions on Emerging Topics in Computing. DOI: 10.1109/TETC.2020.2993177.

[2] LJMU has filed patent applications in a multitude of countries after promising search results from a GB priority application. The patent is now in WIPO (PCT) status and has been filed in the UK, EU, Australia, South Africa, Japan and the USA. Patent Ref (WO2018025019A1).

[3] Chalmers, C., Hurst, W., Mackay, M., Fergus, P., Al-Jumeily, D. and Kendall, B. (2018). Intelligent Health Monitoring Using Smart Meters. Intelligent Computing: Proceedings of the 2018 Computing Conference, Volume 1, 1104-1113. DOI: https://doi.org/10.1007/978-3-030-01174-1_84.

[4] Chalmers, C., Hurst, W., Mackay, M. and Fergus, P. (2016). A Smart Health Monitoring Technology. In: Intelligent Computing Theories and Application, 832–842, Springer Nature. DOI: 10.1007/978-3-319-42291-6_82.

[5] Chalmers, C., Hurst, W. Mackay, M. and Fergus, P. (2015). Smart Meter Profiling for Health Applications. In: 2015 International Joint Conference on Neural Networks (IJCNN). Institute of Electrical & Electronics Engineers (IEEE). DOI: 10.1109/ijcnn.2015.7280836.

[6] Chalmers, C., Hurst, W. Mackay, M. and Fergus, P. (2019). Identifying Behavioural Changes for Health Monitoring Applications Using the Advanced Metering Infrastructure. Behaviour & Information Technology, 38(11), 1154-1166. DOI: 10.1080/0144929X.2019.1574900.

Research grants:

[7] Hurst, W., Data Analytics for Health-Care Profiling using Smart Meters, EP/R020922/1, EPSRC, June 2018 – July 2019, £100K.

[8] Hurst, W., Mackay, M. and Al-Jumeily, D., Personalised Healthcare Monitoring using Smart Meter Energy Readings, Innovate UK, SetSquared, HEFCE, November 2016 – April 2017, £35K.

4. Details of the impact

We conducted the world's first clinical trial of the technology outlined in Section 2 in partnership with Mersey Care NHS Foundation Trust [A], [G]. Following the trial, the Trust recognised the

value and impact of this technology and its ability to provide a supportive and cost-effective solution to assist people living with dementia to remain independent and at home [A]. More importantly, the Trust confirmed that this technology allows families and clinicians to build an accurate picture of how a patient is living alone in their own home [A]. Independently, the work was endorsed in the SmartEnergyGB commissioned 2020 health report [F]. The report states that reliable recognition of electrical devices and appliances in the home remains an active area of research. They confirmed that the work conducted by LJMU is at the forefront of Non-Intrusive Load Monitoring (NILM) and that we have overcome many of the challenges faced by researchers worldwide by focusing on high energy appliances that give indications of ADL and important behavioural routines. The work on the clinical use of smart meters in healthcare is supported by the government as evidenced in [J.1], [D], [E], [F].

As a result of SmargEnergyGB and National Health Executive (NHE) coverage [G], [J.3], the research generated 5 individual policy documents [D]-[H]. Each of these policy documents utilised our work to lobby the stakeholders of the UK smart metering infrastructure and the healthcare services it can provide [C]. In conclusion [E] is formally a commitment to fund further innovation in this area based on the findings in our work. More specifically, the Department for Business, Energy & Industrial Strategy (BEIS) states “Government is committed to financing further innovation in this area to incentivise and enable continuing progress for the benefit of consumers. BEIS will continue to monitor and where appropriate, support these developments through ongoing research and innovation-friendly policies to ensure that smart meters continue to deliver their intended benefits for consumers” [E]. The document concludes that based on our work, smart meters also have the potential to support the development of new products and services outside of the energy sector such as digital healthcare products that enable those with long term conditions to stay at home longer [E], [D], [H]. [F] formally endorsed the importance of our work and directly informed the ongoing SmartEngeryGB strategy for smart meter services. These policies also identified many other areas whereby services could be developed to support healthcare provision as evidenced in [F].

The work supported four spinout companies [I 1- 4] that benefited from both the research and collaboration between LJMU and Mersey Care NHS Foundation Trust. In [I.1] the research was used to help develop Chameleon’s I•VIE platform which models behavioural routines using our approach. The I•VIE service is used nationally within the UK. We had numerous consultations sessions with [I.2] which led to the development and use of new products in Japan. We also informed [I.3] and [I.4] of the technology through several consultations, which is used in the UK and Germany.

The results of our work influenced the replacement of SMETS1 with SMET 2 meters along with changes to the Smart Data Communications Company (DCC) protocols to support the delivery of health care services [F]. There was a strategic change within SmartEnergyGB that are now developing post infrastructure strategies to support smart meter services. Our 6-year working relationship with SmartEnergyGB influenced the requirement for healthcare services which led to the subsequent policy change as evidenced in this section and widespread media interest in the national press [J.2].

We have an ongoing relationship with national government policy makers [J.3] and as evidenced in this section we have a pivotal role in the smart meter infrastructure and the future services it will provide. As stated from the head of policy from SmartEnergyGB “Over the years Paul and

Carl have kindly presented their work at various events and workshops we have run. By sharing their research, opinions and insights with our stakeholders they have helped our campaign to reach new audiences and have made an important contribution to our work promoting the technology" [C].

5. Sources to corroborate the impact

[A] Mersey Care Testimony
[B] 2020 Health Testimony
[C] SmartEnergyGB Testimony
[D] Policy paper, Smart meters: unlocking the future. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770575/Smart_meters_Unlocking_the_future.pdf
[E] BEIS SMART METERING IMPLEMENTATION PROGRAMME, A report on progress of the realisation of smart meter consumer benefits. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/830668/smart-meters-benefits-realisation.pdf
[F] 2020 Health/Smart Energy GB policy document. https://www.smartenergygb.org/en/smart-living/how-smart-meters-could-transform-health-and-social-care
[G] Sustainability First Policy Document: https://www.sustainabilityfirst.org.uk/images/publications/inspire/Energy%20for%20All-%20Innovate%20for%20All%20(full).pdf
[H] UCL and Smart Energy GB Report. https://www.smartenergygb.org/en/resources/press-centre/press-releases-folder/energising-healthcare?tab=1&docspage=1
[I] Spinouts and company support: 1) Chameleon: https://chameleontechnology.co.uk/2018/07/09/5-ways-energy-data-can-help-your-business/ 2 Informatics: https://www.informetis.com/en/technology/energy-disaggregation/ 3) Solgenium: http://www.solgenium.com/en/ 4) EDF/Howz: https://howz.com/
[J] Dissemination and outreach: 1) Publication in the National Health Executive. http://www.nationalhealthexecutive.com/Comment/utilising-smart-meters-in-assisted-living- 2) The Express. https://www.express.co.uk/featured/life-style/life/1061800/5-experts-reveal-why-this-one-piece-of-new-technology-is-the-key-to-our-future-energy-grid 3) Westminster sustainable business forum. https://www.policyconnect.org.uk/wsbf/blog/smart-meters-%E2%80%93-unlocking-their-social-benefits-uses-assistive-living-and-healthcare