Institution: Ulster University

Unit of Assessment: Computer Science and Informatics (11)

Title of case study: ICS6 Technologies for Self-Management in Healthcare

Period when the underpinning research was undertaken: 2008 - 2020

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:
Dr. Ian Cleland	Lecturer in Data Analytics	2012 - Present
Prof. Chris Nugent	Prof of Biomedical Engineering	1998 - Present
Dr. Joe Rafferty	Lecturer in Data Analytics	2015 - Present
Mr. Andrew Ennis	Lecturer in Computer Science	2015 - Present
Dr. Federico Cruciani	Research Fellow	2016 - Present
Dr. Mark Donnelly	Senior Lecturer in Computer Science	2009 - Present
Dr. Paul McCullagh	Reader, Computer Science	1993 - Present
Prof. Jane Zheng	Professor of Computer Science	2006 - Present
Mr. Richard Davies	Lecturer in Computer Science	1999 - Present
Prof. Luke Chen	Prof in Data Analytics	2005 - Present

Period when the claimed impact occurred: 2014 - 2020

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

1. Summary of the impact

Ulster's research on digital solutions for self-management of health conditions led to novel software architectures, communications infrastructure, sensing technologies and eHealth apps, resulting in a number of impacts including:

I1 Establishment of a free-to-use, national, IoT communications platform (LPWAN-NI) accessed by >130 companies to develop approximately 19 products/services.

I2 Development of an open software infrastructure to underpin the collection of sensor data for self-management solutions in Northern Ireland and Italy.

I3 Creation of a self-management product, incorporating behaviour change strategies, for an SME in Northern Ireland, currently being sold in 22 countries.

2. Underpinning research

The case study is underpinned by research from the 2008 SMART2 Project (EP/F001916/1) which investigated the potential of technology to support self-management of long-term health conditions. Ulster (Davies, Nugent, Zheng & McCullagh) was the lead technology partner in the project which, for the first time, moved beyond a focus on symptom monitoring to incorporate aspects of rehabilitation, behavioural change and education.

These technologies have been diversified and applied to the management of other long-term conditions including Chronic Obstructive Pulmonary Disorder, Pain, Stroke **[R3]**, Dementia **[R5-R6]**, Sedentarism, Cerebral Palsy **[R4]** and Autism **[R1]**. This research increasingly combined novel approaches for the collection and processing of sensor data with psychological behavioural change models incorporating gamification strategies **[R4]** and goal setting **[R5]**. These technologies support fundamental computer science research and facilitated the development of a suite of comprehensive technological self-management solutions.

Significant research advances that underpin the impacts **[I1-I3]** are clustered in three main topics and mapped to references **[R1-R6]** and supported by corroborating evidence **[C1-C9]**. The links between underpinning research and the impact are illustrated in Fig.1.

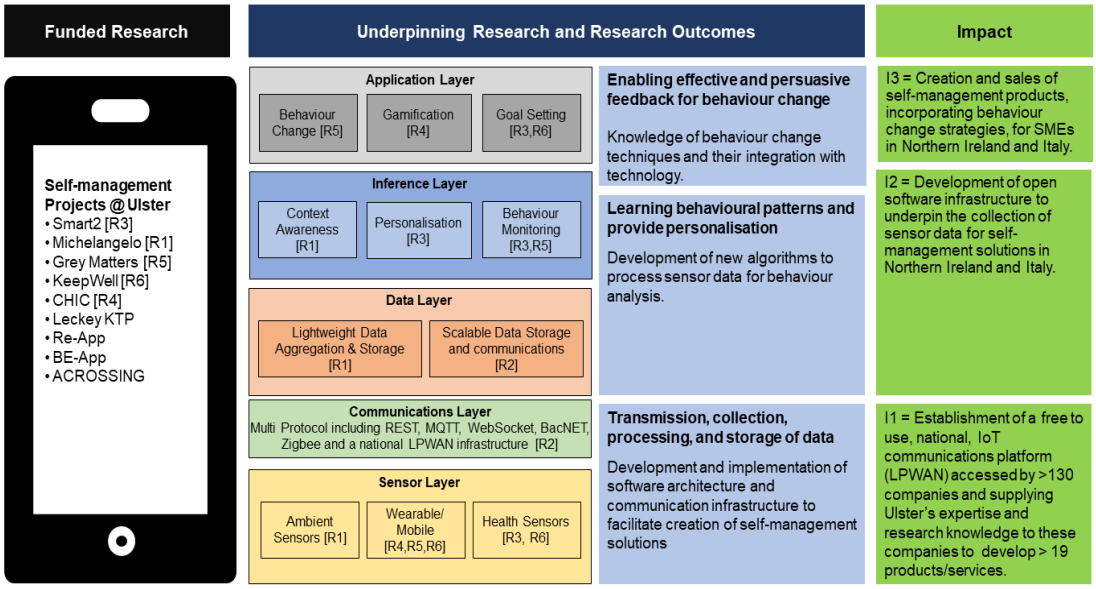

Fig. 1. Illustration of areas where underpinning research has been undertaken to create self-management solutions across R1-R6 and how these are mapped to the identified impact (I1-I3).

Transmission, collection, processing, and storage of data from sensors/self-reported information [R1 & R2].
These solutions rely on the ability to collect and aggregate quantitative and qualitative data from wearable, mobile, ambient and health sensors, in addition to self-reported information. This research developed a family of generic data storage and processing platforms which can scale from small, embedded solutions to server/cloud deployments and hyperscale cloud/edge computing (Rafferty, Cruciani and Paggetti). This research **[R1-R2]** has provided the data aggregation solutions in **[I1]** and **[I2]**. The platform is an open, reusable framework providing core infrastructure to allow authorised clients to share any data, regardless of format. These frameworks include the ability to collect data from low-power, long-range communications solutions such as a Low Power Wide Area Network (LPWAN).

Learning behavioural patterns and providing personalisation and context awareness [R1, R3, R4].
Ulster research (led by Nugent) used emerging sensing solutions for applications such as tracking gait parameters and postural imbalance **[R3]**, measuring physical activity in children using mobility aids **[R4]** and treatment of children with Autism **[R1]**. This research resulted in the design, implementation, and evaluation of techniques to process sensor information and extract accurate measures of behaviour. These insights provided personalised interventions to the user **[R3].**

Enabling effective and persuasive feedback for behaviour change [R3-R6].
These solutions increasingly incorporate behaviour change techniques, including gamification **[R4]**, self-monitoring [R5] and goal setting **[R3, R6]**. The evaluation of these solutions provided insight into how technology can be designed to best engage users. The Gray Matters project demonstrated the effectiveness of technology-based interventions on clinical outcomes for prevention of Alzheimer's. Disease **[R5]**. Through a randomised control trial (n=146) the results demonstrated that consistency of engagement was important, participants who engaged most with the app showing the best improvements in clinical measures. Similarly,

Cleland and Ennis demonstrated the use of technology to increase physical activity through gamification **[R4]**. The project used accelerometers, integrated in a mobility aid, to quantify steps and pedal revolutions. This data was used to drive an avatar towards a personalised goal. The user was rewarded with virtual badges based on their performance.

3. References to the research Outputs can be provided by Ulster University on request.

R1 Lucia Billeci, Alessandro Tonacci, Gennaro Tartarisco, Antonio Narzisi, Simone Di Palma, Daniele Corda, Giovanni Baldus, Federico Cruciani, and Michelangelo Study Group (incl. Mark Donnelly). "An integrated approach for the monitoring of brain and autonomic response of children with autism spectrum disorders during treatment by wearable technologies." Frontiers in Neuroscience 10 (2016): 276.

R2 Joseph Rafferty, Jonathan Synnott, Chris D. Nugent, Andrew Ennis, Phillip A. Catherwood, Ian McChesney, Ian Cleland, Sally McClean. "A scalable, research oriented, generic, sensor data platform.' IEEE Access 6 (2018): 45473-45484.

R3 Richard John Davies, Jack Parker, Paul McCullagh, Huiru Zheng, Chris Nugent, Norman David Black, and Susan Mawson. "A personalized self-management rehabilitation system for stroke survivors: a quantitative gait analysis using a smart insole." JMIR rehabilitation and assistive technologies 3, no. 2 (2016): e11.

R4 Andrew Ennis, Ian Cleland, Chris Nugent, Laura Finney, David Trainor & Aidan Bennett (2016, November). The Use of Gamification Techniques in a Clinical Setting for the Collection of Longitudinal Kinematic Data. In International Conference on Ubiquitous Computing and Ambient Intelligence (pp. 267- 273). Springer, Cham.

R5 Phillip J. Hartin, Chris D. Nugent, Sally I. McClean, Ian Cleland, JoAnn T. Tschanz, Christine J. Clark, and Maria C. Norton. "The empowering role of mobile apps in behavior change interventions: The Gray Matters randomized controlled trial." JMIR mHealth and uHealth 4, no. 3 (2016): e93.

R6 Timothy Patterson, Federico Cruciani, Ian Cleland, Chris D. Nugent, Norman D. Black, Paul J. McCullagh, Huiru Zheng, Mark P. Donnelly, Suzanne McDonough, and Adele Boyd. "KeepWell: a generic platform for the self-management of chronic conditions." In XIV Mediterranean Conference on Medical and Biological Engineering and Computing 2016, pp. 897-902. Springer, Cham, 2016.

Indicators of research quality
[R1- R6] have been peer reviewed by internationally-based editorial boards of the relevant journals.

Key funding
Grants which have supported or followed the research in **[R1-R6]** include:-

- Black ND, McCullagh PJ, Nugent CD, Zheng H, SMART 2: Self-Management supported by Assistive, Rehabilitation and Telecare Technologies, EPSRC, EP/F001916, 01/2008-06/2012, GBP566,653.
- Galway, L., Nugent, C., Donnelly, M., McCullagh, P., Lightbody, G. & Chen, L. MICHELANGELO: Patient-centric Model for Remote Management, Treatment and Rehabilitation of Autistic Children. CEC - Framework 7. 01/10/2011-31/03/15. GBP202,058.
- Mc Donough, S., Black, N., McCullagh, P., Zheng, H., Nugent, C., Finlay, D. & Donnelly, M. Self-Management Platform for Connected Health, Invest NI. 01/04/13-31/07/18. GBP482,584.
- Nugent C. & McLaughlin J., Connected Health Innovation Centre, InvestNI. 01/06/13 29/02/20. GBP4,531,383.

- Nugent C, McCullagh P, Breslin G and Cleland I. ACROSSING - Advanced Technologies and Platform for Smarter Assistive Living, CEC-H2020-MSCA-ITN, 01/01/16 – 31/12/19. GBP203,014.
- Cleland I., Nugent C., University of Ulster, James Leckey Design Limited Ref: KTP010295, Innovate UK Knowledge Transfer Partnerships, Innovate UK. 29/02/16-31/05/19. GBP134,000.

4. Details of the impact

I1 Establishment of a free to use, national, IoT communications platform (LPWAN) accessed by >130 companies.

In 2018 Ulster established a free-to-use, national, IoT communications platform (LPWAN-NI). LPWAN-NI offers a low-power, wireless, wide-area, network for development of IoT solutions **[R2]**.

LPWAN-NI consists of over 60 gateways covering the geography of Northern Ireland including hard to reach border regions. LPWAN-NI has been accessed by over 130 companies and approximately 17M messages have been sent via the network since its establishment in 2018 **[C1]**. This has been independently verified by Digital Catapult **[C1]**. Ulster was awarded GBP185,000 in funding to support local start-ups with the aim of producing new products leveraging the network **[C1]**. 19 new business ventures have been created, and large public service providers. such as [redacted] are using the network to monitor essential equipment **[C2]**. One exemplar of companies benefiting from the network is [redacted] **[C2]**. [redacted] now employs 3 members of staff (headcount 3, 2.5 FTE) and has been established to drive novel solutions to market based on LPWAN technology and University expertise **[C2]**.

I2 Development of open software infrastructure to underpin the collection of sensor data for self-management solutions in Northern Ireland and Italy.

Collection of qualitative and quantitative healthcare data lends itself to a wide range of applications including psychology, sports, health and wellbeing. Researchers at Ulster have produced an open, scalable, and flexible software architecture for the collection and sharing of such data **[R1-R2]**. Variations of this architecture have been adopted by the SMEs [redacted] and [redacted]. Since 2016, [redacted] has been using the data aggregator, which collects data from health devices, mobile apps and self-reporting, as a self-management platform for various Chronic conditions ([redacted]). It has confirmed that the integration of Ulster research into its product portfolio has led to the following impact **[C3]**:

- Development of a new self-management app for long term chronic conditions.
- Used the aggregator to secure contracts of over EUR130,000 (10-2020).
- Established collaborations with more than 15 international partners.

The software architecture has additionally been utilised by [redacted], to collect data from sensor technology in a care home and prison environment. The solution was the subject of two Invention disclosures within Ulster **[C4]**. The solution was subsequently licensed for evaluation by [redacted] on 23/08/2017 **[C5]**. Since licensing this technology, [redacted] has diversified its company from security, establishing a health division ([redacted]).

I3 Creation of a self-management product, incorporating behaviour change strategies, for an SME in Northern Ireland, currently being sold in 22 countries.

Ulster's research into the design, development and evaluation of self-management technologies, specifically processing for sensor data for behavioural insights **[R3-R4]** and the development of health apps **[R5-R6],** has directly led to the creation of new products for SME [redacted]

Following the underpinning research **[R3-R6],** knowledge was transferred to the company through a KTP project. The impact of this research partnership has been acknowledged by the Senior Knowledge Transfer Adviser from KTN **[C8]**. The partnership was also rated as "Outstanding" by a panel of independent reviewers as part of the KTN assessment **[C9]:** *"This project has embedded a very significant new capability into the business, which has allowed the company to capture clinically important data (KTN, Knowledge partnership adviser)"* **[C8]**.

[redacted] consists of a connected sensor that quantifies movement and a mobile app that contains elements of goal setting and gamification to encourage participation in physical activity. Both measurement and gamification were investigated within the fundamental research **[R4]** and taken forward through the KTP. This is the first software enhanced product to be offered by [redacted] **[C6]**. The first product in this range, [redacted], was launched in December 2019 and is currently being marketed in 22 countries, including the UK, Europe, Middle East, and new markets in Australia. [redacted] have been delivered with 25 demo units produced and sales of approximately [redacted]. In [redacted] 2020 [redacted] was acquired by [redacted]. The innovation, as demonstrated by product lines such as the [redacted], has been critical in attracting such an acquisition. *'[redacted] have been impressed by the innovative approach to research and development at [redacted] and are keen to grow the [redacted] of their business with [redacted] in Northern Ireland"* **[C6]**.

It is estimated that over 100 children have already positively benefited from using the product. A case study with a child using the device, his parents and care team has highlighted the impact this technology has on children's quality of life. Physios have reported improvements in standing time from 20 to 48 seconds in 8 weeks. Classroom assistants have reported that '[redacted] *is now able to stand up much straighter and needs less help in and out of his wheelchair than before"* **[C7]**.

5. Sources to corroborate the impact

C1: Letter from Digital [redacted] confirming the reach and significance for LPWAN.
C2: Testimonial letter from [redacted] corroborating the impact of LPWAN on their business.
C3: Testimonial from [redacted] corroborating the integration of Ulster research within the company and summarising the related impact of this.
C4: Invention Disclosure forms for the Behaviour Monitoring solution.
C5: Licensing Agreement with [redacted] demonstrating the technologies which have been licensed from Ulster.
C6: Testimonial from [redacted] demonstrating the integration of Ulster research into their [redacted] product.
C7: Marketing Material from [redacted], including case study with child who has used the device over an 8-week period.
C8: Letter from Knowledge Transfer Network highlighting the impact of the partnership with [redacted].
C9: Assessment of Knowledge Transfer partnership letter from Innovate UK showing the project as being rated "Outstanding".