Institution: University of Portsmouth		
Unit of Assessment: UoA 11: Computer Science and Informatics		
Title of case study: Mobility and higher quality of life for children with disabilities		
Period when the underpinning research was undertaken: 2000-2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period employed by HEI:**
David A Sanders MBE TD VR	Professor of Systems Engineering	01/01/1989 - date
Giles E Tewkesbury MBE	Associate Head of School	19/11/1990 - date
Malik J Haddad	Research Fellow	20/10/2017 - date
Martin Langner	Research Fellow	14/05/2019 - date
Alexander Gegov	Reader	01/09/2000 - date
Ilan J Stott TD VR	Lecturer	27/09/2000 - 21/03/2015
Nils Bausch	Senior Lecturer	18/01/2010 - date
Sergey A Khaustov	Senior Lecturer	06/02/2017 - date
Ya Huang	Teaching Fellow	03/07/2009 - date
Rinat Khusainov	Senior Lecturer	01/09/2005 - date
Period when the claimed impact occurred: 2013 to 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Over 2000 children and young people with disabilities in the UK have gained improved mobility and higher quality of life from 2013-2020 through adopting mobility devices underpinned by University of Portsmouth (UoP) research into assistive technology for powered-wheelchairs and disabled users. Other impacts include over GBP250,000 per year savings and professional services identifying powered-wheelchairs as an option more frequently and for children with a wider range of disabilities. These new systems allow some to use wheelchairs for the first time owing to new artificial intelligence (AI) technology developed at UoP, which learns about the user's capabilities and adapts to changing trends and needs.

2. Underpinning research

Research on assistive systems and sensors began after Sanders, Tewkesbury and Stott ran a series of symposia at UoP from 1998 onwards. Langner and others from Chailey Heritage Foundation (CHF) and Sussex Community NHS (NHS) attended the symposia. CHF, NHS and UoP began collaborating and that resulted in networks of tracks in schools, institutions and private homes, and modular systems that could be adapted to fit any wheelchair (S1). This allowed some children to use powered wheelchairs for the first time and provided limited driving opportunities for seriously disabled young people. NHS and CHF supported the research by conducting testing and clinical trials at Chailey Heritage School, a charitable special school for young people with complex physical disabilities (S1, S2). Other industrial partners, including a wheelchair manufacturer, Quest Enabling Designs (QED) and a software company, Key Industrial Software Solutions (KISS), took part in Knowledge Transfer Partnerships (KTPs), secondments and fellowships to support the research (1999-2004). Sensors were created to allow semi-autonomous driving and Langner received an award for the research from WellChild, a UK charity for seriously ill children. Various input devices were created and new object-proximity-sensing systems provided collision avoidance (2004-07). Further research built on that and introduced veer-correction (R1) that reduced tiredness for users and decreased wall and doorway collisions (2008-09). Gegov joined the team and new expert systems were created to interpret hand tremor (R2) (2010-12).

Building on this success, ground-breaking research during this REF period has made the sensors themselves more intelligent and new AI techniques are being used to share control of wheelchairs between humans and intelligent systems (2013-20). This allows enhanced mobility for users, which has improved the lives of children and young people (S1-S6). More recently, Haddad, Bausch, Khaustov and Huang joined the team and new switches were created to improve mobility and manoeuvring, and new input devices were created that were easier for children to use (R6). Further development was made to include intelligent systems to tolerate involuntary movements and provide proportional-response controls.

Work funded by the Academy of Engineering and Leverhulme Trust (2014-16) (G1) concentrated on digitising the sensor systems and then adding AI. CHF then seconded a rehabilitation engineer to UoP and funded prototyping (2016-17) so that new shared control systems were invented (R3). Ongoing research by Sanders, Gegov, Haddad and Langner funded by EPSRC (G3) (2018-2022) and by Sanders, Tewkesbury & Khusainov funded by InnovateUK (G2) (2018-2021) has created non-model-based control methods (R4), and introduced AI decision making, using intelligent sensors and Deep Learning architectures and decision making systems to assist with steering (R5). As part of that research, driver reaction times are being investigated and that work recently won an IEEE Best Conference Paper award (R6). The non-model-based control was applied to a new design of wheeled vehicle pulling two trailers that provided early powered mobility and driving experiences for both disabled and able-bodied children (R4). For the first time all the children could play together on an equal footing. Sanders was awarded an MBE and the Order of Mercy partly because of that work. The Innovate UK work is developing intelligent sensors in collaboration with Gems Controls (G2). Technical and academic research took place at UoP and clinical trials took place at CHF (S1, S2, S6).

Previously, powered-wheelchairs were mainly provided to people with sufficient dexterity to control a joystick. The research at UoP has resulted in more and more children being able to use some form of powered mobility (S6). Features have included obstacle avoidance and effort-reduction systems with sensor fusion (S5) and new predictive and interactive AI. All that has meant children can drive for longer and in some cases for the first time (S1, S2). The most recent AI innovations include new software to help drive but that also learns about a user's capabilities and adapts to their changing trends and needs. Systems assign different levels of responsibility to automatic systems based on users' skill and development (R3, R5).

Work on digitization received two Institute of Engineering Technology (IET) Innovation Awards in 2016 and the most recent AI work was awarded two IET Engineering & Technology International Innovation awards in 2020: "*Outstanding Innovation in Digital Health and Social Care*" and "*Excellence in a Smarter World*" (https://eandtinnovationawards.theiet.org/winners-and-finalists).

Several hundred people including clinicians and potential beneficiaries have been directly engaged during the REF period through presentations, demonstrations, academic seminars, symposia and international workshops run by the UoP team every year (workshop proceedings published by IEEE and Springer). Work presented recently included the analysis of reaction times and time-delays, intelligent HMI, and control for steering, use of Microcomputers for Expert Systems, sensing, steering, and analysis of user data (R6).

3. References to the research

R1	**Sanders, D**., **Langner, M**., & **Tewkesbury, G.E**. (2010). Improving wheelchair-driving using a sensor system to control wheelchair-veer and variable-switches as an alternative to digital-switches or joysticks. *Industrial Robot: An International Journal 37*(2), 151-167. https://doi.org/10.1108/01439911011018939
R2	**Sanders, D**.,**Stott, I**., Graham-Jones, J., **Gegov, A**., & **Tewkesbury, G**. (2011). Expert system to interpret hand tremor and provide joystick position signals for powered wheelchairs with ultrasonic sensor systems. *Industrial Robot: An International Journal 38*(6), 585-598. https://doi.org/10.1108/01439911111179101
R3	**Sanders, D. A**. (2017). Using self-reliance factors to decide how to share control between human powered wheelchair drivers and ultrasonic sensors. *IEEE Transactions on Neural Systems and Rehabilitation Engineering 25*(8), 1221-1229. https://doi.org/10.1109/TNSRE.2016.2620988
R4	**Sanders, D.A** (2018). Non-model-based control of a wheeled vehicle pulling two trailers to provide early powered mobility and driving experiences. *IEEE Transactions on Neural Systems and Rehabilitation Engineering 26*(1), 96-104. https://doi.org/10.1109/TNSRE.2017.2726443

R5	**Haddad, M.J**. & **Sanders, D.A.** (2019). Selecting a Best Compromise Direction for a Powered Wheelchair Using PROMETHEE. *IEEE Transactions on Neural Systems and Rehabilitation Engineering 27*(2), 228-235. https://doi.org/10.1109/TNSRE.2019.2892587
R6	**Sanders, D**., **Haddad, M**., **Tewkesbury, G.**, **Bausch, N**., Rogers, I. & **Huang, Y.** (2020). Analysis of reaction times and time-delays introduced into an intelligent HCI for a smart wheelchair. *Proceedings of 2020 10th International Conference on Intelligent Systems*, 217-222. Winner of IEEE Best Conference Paper. Extended paper selected for publication in Advances in Intelligent Systems. https://doi.org/10.1109/IS48319.2020.9199945

Evidence for the quality of research

Underpinning research was published in high quality, peer-reviewed, international journals and funded by competitive, peer-reviewed awards from the EPSRC, Innovate UK and Royal Academy of Engineering. In 2018 Prof Sanders was awarded the MBE for services to the community as a result of his research in powered wheelchair technology and awarded the Order of Mercy for the impact of the powered wheelchair research. The most recent AI work received two IET Engineering & Technology International Innovation awards in 2020: "*Outstanding Innovation in Digital Health and Social Care*" and "*Excellence in a Smarter World*". Work featured on Solent TV in 2017 (https://www.youtube.com/watch?v=GPTYrclWIgE) with Sanders and on the BBC in 2020 with Langner (https://sites.google.com/port.ac.uk/bbcwheelchair/home), which encouraged adoption of more systems.

Relevant research grant funding during the REF period:

G1	Sanders, D. *Improving mobility and quality of life for children with disabilities*. Funded by the Royal Academy of Engineering, September 2014-August 2015 (GBP42,984)
G2	Sanders, D., & Tewkesbury, G. *KTP with Gem Sensors and Controls*. Funded by Innovate UK, March 2019-May 2021 (GBP189,968)
G3	Sanders, D & Gegov, A. *Using artificial intelligence to share control of a powered-wheelchair between a wheelchair user and an intelligent sensor system*. Funded by the Engineering and Physical Sciences Research Council, November 2018-October 2021 (GBP465,562).

4. Details of the impact

New intelligent and user-friendly navigation, communication and control systems for powered-wheelchairs developed through University of Portsmouth research have together made a significant and positive impact on the lives of users. These have given more than 2000 disabled people an opportunity for independent mobility, some for the first time. Systems have been installed and are in use in special schools, institutions and private homes that support users nationally, including Chailey Heritage Foundation, the Royal National Institute for the Blind (RNIB) and the NHS. The latest systems can be seen at https://www.facebook.com/PortsmouthUniversityMobility.

Health Impact: Transforming lives and delivering independence for users

This technology supports users with the most complex physical disabilities and health needs. In many cases these are children and young people with conditions such as Multiple Sclerosis, Arthritis, Stroke, Paraplegia, Orthopaedic Impairment, Cerebral Palsy and Diabetes, especially if blind or with missing or damaged-limb(s). Users' quality of life has been transformed by the new user-friendly systems, including those who were previously considered to be too disabled to use a hand controlled device. The parent of one 12 year old user who has 'extreme disability' and 'limited quality of everyday life' states: *'[He] expresses great pleasure when performing simple tasks on his own, he must have a feeling of huge self esteem at being able to move unaided, making his own choice of left, right and forwards, we take these decisions for granted, [he] would not have this opportunity without this assistive technology'* (S4).

The obstacle detection and veer-correction systems developed as a result of the research have allowed children with limited dexterity to use powered-wheelchairs for the first time (S2) and the latest research has enabled users to drive for longer and with greater protection so that they can incorporate more activities into their lives. It has made a significant positive difference, giving disabled individuals more motivation, confidence, independence, productivity, and freedom [S6]. New technologies and processes have been adopted and more than 2000 children and young people benefited from the new systems between 2013 and 2020 (S2, S5, S6). Many now have access to independent mobility for the first time.

The systems have proved to be especially useful for disabled individuals with visual impairment, in particular, severely disabled blind children with little cognitive ability (S5, S6). The technology has been taken up by the Royal National Institute for the Blind (RNIB) Sunshine House Schools (and Children's Homes). With about 40,000 people aged 25 or younger being blind or partially sighted in the UK, and more than one in ten blind people using a wheelchair, this provides access to the life-changing technology for up to 4,000 young people in the UK, just for this disability alone (S2, S5, S6).

Chailey Heritage School is a special school for children and young adults with a national reputation for excellence, also providing residential housing for young people from 12 different local authorities. Working in close partnership with the National Health Service, they integrate education with residential care and NHS therapy/health services. Children at the school are using and benefitting from the systems, including some using wheelchairs for the first time. The pioneering technology has made a real difference to the lives of users. Approximately 1,500 children and young people there have had access to the systems, and the technology has been supplied to other specialist schools, including those run by the Royal National Institute for the Blind (RNIB), and in students' family homes. The Headteacher of the school confirms that the research has *'provided [users] with new realistic chances to use powered wheelchairs'* which *'allowed many children to control wheelchairs who would not otherwise have been able to use them'* (S2). A member of staff also concluded that the research *'can offer independence and the degree of independence can depend on the ability of the child … the benefits are that they can go where they want to and choose where they want to go. It is especially beneficial to a child who has no verbal communication as they are at the mercy of whoever is pushing them in their wheelchair'* (S2). New systems have also been installed at Grove Park School, East Sussex; Victoria School and Specialist Arts College, Birmingham (S5).

Economic impact: Significantly reducing healthcare costs

The new devices provide critical assistance, providing individuals with a level of independence that has resulted in significant treatment and healthcare cost savings. Reducing the need for carers has been estimated at more than GBP250,000 per year for existing users (S5, S6). Further, costs of systems have reduced due to new designs and use of cheaper alternatives. For example, scanning collision avoidance costs have been reduced from more than GBP2,000 per wheelchair in 2008 to about GBP1,000 in 2012 and GBP750 in 2018 (S5, S6). The Deputy Director, Institute of Orthopaedics at Royal National Orthopaedic Hospital and Professor of Rehab at Surrey University assessed the collaborative work between the University of Portsmouth and Chailey Heritage in 2016 and confirms that, *'Decisions by health services and regulatory authorities have been informed by research and the lower cost systems mean that the costs of treatment and healthcare have reduced'* (S3).

Changing professional standards, guidelines, practices and training.

'*The quality and efficiency of professional services for children using powered wheelchairs has improved and professional bodies and learned societies have used this research to define best practice … new policy has been implemented and the delivery of services has changed*' (S3).

Recent changes have been made in professional service practices in response to the health impacts, in that powered-wheelchairs are now always considered as an option because children with more severe disabilities can drive with the new systems, increasing the adoption rate (S3).

Chailey Heritage Foundation and Chailey Clinical Services are part of the NHS's Sussex Community Foundation Trust, closely working with doctors, nurses and therapists that make up the Trust's 6,000 members of staff. With their NHS partners, the charity has been at the leading edge of implementing the research developments as a result of the research collaboration with the University of Portsmouth (S1). Since the new technologies and processes have been adopted, changes in practice have been introduced to improve care in that powered wheelchairs are now always considered as an option. New, updated and enhanced technical standards and clinical protocols have been introduced, new policy has been implemented, and professional standards, guidelines, practices and training have been influenced (S3, S5).

Professional guidelines and training have been revised in the light of improved health outcomes because of the availability of the new systems and the new ways that people are trained on them (S1, S3). Methodologies are used by NHS therapists who teach users how to use their new wheelchairs, improving driver competency and increasing the likelihood of further independence (S5).

UoP has identified ways of measuring and improving user competence, leading to new methodologies currently being used by NHS therapists to teach users how to drive (S3). The analysis of driver behaviour and assisted steering led to algorithms that allowed users to crash safely on occasion so that they could learn corrective behaviours (S3, S4, R1-R6). The annual workshops have led to other universities taking up some of the research and institutions using the systems (S3).

5. Sources to corroborate the impact

S1	Statement by Chief Executive Officer at the Chailey Heritage Foundation, responsible for transition provision for young adults with profound disabilities and high healthcare needs (28/10/2020).
S2	Letter from the Headteacher of Chailey Heritage School, a charitable special school for young people with complex physical disabilities that are using the new systems (2020)
S3	Statement - Professor of Rehab at Surrey University / Deputy Director, Institute of Orthopaedics at Royal National Orthopaedic Hospital (29/07/2016).
S4	Letter from parent (20/10/2018)
S5	Independent evaluation of technology: Fox NJ (2016). Getting around using tracks and intelligent wheelchairs. *Journal of Intelligent Mobility,18*(3), 345-351. ISSN 1472-9083.
S6	Independent review paper: Rogers IA (2016). A review of powered assistive mobility systems. *Journal of Computing in Systems & Engineering, 17*(2), 349-379. ISSN 1472-9083.