Institution: Plymouth University

Unit of Assessment: B11

Title of case study: Robotics Applications in Health, Education and Entertainment

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

The Centre for Robotics and Neural Systems (CRNS) uses its research to address societal challenges, both nationally and internationally. It notably responds to practical problems and evaluates its robotics research in the real world, exposing it to use and users beyond the lab. This has generated both economic and social impact in clinical practice, education, entertainment and outreach: the use of robot companions for patients and disabled users; inspiration of school-children; engagement of thousands with the possibilities of robotics through high-profile robot competitions. Economic impact is reflected by commercial investment, and world-wide sales of robotics technologies by spin-off companies.

2. Underpinning research (indicative maximum 500 words)

Professor Tony Belpaeme and colleagues in the CRNS have undertaken a programme of research into the social role and uses of robotics. Led by Belpaeme, a specialist in human-robot interaction and social robotics, the team included Dr Guido Bugmann (focusing on artificial intelligence), Dr Phil Culverhouse (electronics and computer vision), Dr Paul Robinson (control systems), and other postgraduate and post-doctoral researchers.

Bugmann, Robinson and Culverhouse initially worked on issues of robot movement and physical abilities, looking specifically at the issue of creating robots capable of playing football. The problem was chosen because control of robots within a football competition context poses very specific scientific and technical challenges. Robot players need to move quickly (several metres per second) and time-delays in processing and communication pose significant problems. Given the size of the pitch and the robots, image processing has to identify and detect the orientation of objects of only a few pixels wide. This has to be fast to minimize computational delays, and needs to be robust against variable lighting conditions. In addition, robots need to be mechanically robust to withstand the harsh competition conditions. Between 2004 and 2010 the group designed and constructed table-top mobile robots, devised techniques for robot path planning using a vector field histogram solution, and developed advanced vision research specific to robot control.

It was realised that wider applications of these ideas to areas of human-robot interaction depended on the production of realistic facial images for robots that remained subject to mechanical control. From 2010 the work was broadened into the implementation of innovative robot faces, using retro-projection rather than mechatronics. Cheaper and more robust than previous techniques, retro-projection is also more versatile, and allows rapid, real-time facial animation and social signals (e.g., blushing and crying) that are difficult to implement with mechatronics. This pointed to the production of robots with true social capacities for acceptable human interaction.

The research into physical and social skills of robots was linked to a wider concern for the emotional support offered by human-robot interaction. The success of the early stages of the research led to direct research into this issue as a result of a request by the San Raffaele Hospital in Milan, who were looking for a cheaper and more hygienic alternative to their successful therapy programme using pets. The sponsored part of this research began in March 2010 with the ALIZ-E project coordinated by Belpaeme and involving 8 other European partners, who contribute constituent science and technology. The research aimed to integrate all the previous work on physical and social capacities to create a robot that was more than simply a hygienic pet substitute. The aim was to construct robots that could also act as social companions and educators for those who interacted with them. The research investigated the extent to which, as a companion, a robot can realise the psychosocial objectives of pet therapy and, as an educator, can assist with or take over tasks normally undertaken by medical personnel in educating and

informing young patients. The research established that the learning capacity of robots is crucial for long-term interaction: a robot that adapts to the user is experienced as more positive, is interacted with for longer periods, and has a positive impact on the learning experience. It was discovered that children were especially keen interactants with robots: robots are perceived as social agents by children and when interacting with the robot the children treat it as a peer. It was discovered that this peer acceptance could be built on in the use of robots for both learning and comforting. The possibilities of social interaction on a peer basis means that robots are more persuasive and so more effective in communicating a message than is possible with alternative forms of presence such as computer programs or on-screen avatars.

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

Wolf, J.C., Oliver, J.D., **Robinson, P.** and Diot, C. (2005) Multi-site development of a FIRA large league robot football system. Proceedings of Third International Conference on Computational Intelligence, Robotics and Autonomous Systems, Singapore (CIRAS) 2005, (ISSN: 0219–6131) IEEE Conference. . Peer-reviewed publication, which generated international interest in the Miabot Kit.

Belpaeme, T., Baxter, P., Read, R., Wood, R., Cuayáhuitl, H., Kiefer, B., Racioppa, S., Kruijff-Korbayová, I., Athanasopoulos, G., Enescu, V., Looije, R., Neerincx, M., Demiris, Y., Ros-Espinoza, R., Beck, A., Canamero, L., Hiolle, A., Lewis, M., Baroni, I., Nalin, M., Cosi, P., Paci, G., Tesser, F., Sommavilla, G. and Humbert, R. (2013) Multimodal Child-Robot Interaction: Building Social Bonds. *Journal of Human-Robot Interaction*, 2013, 1(2), 33-53. Journal paper providing an overview of the technology used and the insights gained from the hospital-based evaluations. Non-Plymouth authors are all ALIZ-E project partners.

Wood, R., Baxter, P. and **Belpaeme, T.** (2011). A Review of long-term memory in natural and synthetic systems. *Adaptive Behavior.* DOI: 10.1177/1059712311421219. First publication on the novel memory architecture used in the social robots.

Delaunay, F., De Greeff, J. and **Belpaeme, T.** (2010) A Study of a Retro-Projected Robotic Face and its Effectiveness for Gaze Reading by Humans. In Proceedings of the 5th ACM/IEEE International Conference on Human-Robot Interaction, March 2-5 2010, Osaka, Japan, pp. 39-44, IEEE Press. The first publication describing retro-projected face technology, led to reimplementation at KTH Stockholm and TU Munich, and commercialisation by Syntheligence (Paris, France) and EngineeredArts (Penryn, UK).

ALIZ-E (Adaptive Strategies for Sustainable Long-Term Social Interaction). Integrated Project funded by the European Commission under the 7th Framework Programme (grant agreement number 248116). (2010-2014). 8.25 MEUR funding, 1.4MEUR to Plymouth University. The project is coordinated by Prof **Tony Belpaeme** at Plymouth University.

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

The research has had impact in three areas: (1) on social and clinical care, (2) on public awareness, government and policy makers, and (3) in commercial applications for education and entertainment,

(1) Social and clinical care impact

CRNS has been running the ALIZ-E project as directly applicable research since 2010 and this has resulted in impacts upon the clinical care practices for chronically ill children. Between 2011 and 2013 a robot has been used in sessions with outpatients (diabetic children) to educate and comfort at the San Raffaele Hospital, where consultants have been appointed to support the CRNS experiments, define research priorities, and lead the adoption of robots in the paediatric ward. Similar work has begun in the Netherlands at Zuid Nederlands Ziekenhuis and Gelderse Vallei and

Rivierenland Ziekenhuis. Work has begun on the use and acceptability of robot companions in schools, with demonstrations in UK primary schools between 2011 and 2013 to show the robots use as an educational platform.

Use of the robots has also begun among practitioners and professional services. For example, the robots have been adopted as educational aids by the Italian diabetes society (SOStegno70 association) at their diabetes summer camps in 2012 and 2013 and as tools for diabetes diary management by the Dutch diabetes society (Diabetesvereniging Nederland).

(2) Impact on public awareness, government and policy makers

The robots used in the ALIZ-E project, and the robot footballers have played an important role in the University's outreach and widening participation programmes aimed at enhancing public awareness of the potential impact and benefit of research. They reach hundreds of school children each year through regular appearances at the annual Science and Technology Showcase, where they are among the most popular features. The robots have also made wider public appearances, from Plymouth Argyle Football Club to science festivals and international television programmes. The appearance of the football robots in Plymouth attracted an estimated audience of 15,000.

This public awareness has been crucial in generating further impact at policy level. In 2011, Belpaeme was invited to take part in the UK-Japan mission of the BIS Technology Strategy Board. The team of five academics and industrialists visited Japanese universities and companies to promote UK robotics and scout Japan for collaboration opportunities. The visit resulted in an advisory document for the TSB in November 2011. These recommendations were included in a key speech by the Chancellor of the Exchequer to the Royal Society on "eight great technologies", remarking how the UK needs to catch up with Japan as "the UK has 25 robots per 10,000 employees in non-automotive sectors; whilst Japan leads the world with 235 robots per 10,000 employees". This led to a £35 million investment in robotics in 2013 by the Minister for Universities and Science.

ALIZ-E research and its outcomes also featured in the 'Big ideas for the future' report of Research Councils UK. ALIZ-E was included as an example of "excellent research taking place in UK higher education [which] demonstrates the value of public investment in higher education and research and the positive impact this has on economic growth and the social wellbeing of the UK".

(3) Commercialisation of robot technology for education and entertainment

In collaboration with Merlin Robotics Ltd, robot football kits have been produced as an affordable entry into an historically expensive niche market. The Miabot Kit has received international acclaim for making football robotics accessible. Between 2008 and 2012, Merlin sold football systems, education kits and training based on CRNS knowledge transfer, to the value of £250k. The kit has also been adopted by universities in the UK (e.g., Reading and Warwick) and beyond, who compete in international robot football competitions that serve as a competitive test environments for advanced research. Merlin and CRNS also developed training packages to meet demand following the sale of ca. 100 robot kits to the Ministry of Education in Malaysia. Additional sales have followed – including to Jordan. The Miabot kit was also sold with a suite of accessories as a mobile robotic platform for education and research. In this form, it was used by Reading University in research on the control of robots by cultures of neurons.

The work on social robotics led to the commercialisation of SociBot by EngineeredArts (Penryn, UK) and the business start-up Syntheligence (Paris, France) to commercialize the retro-projected face technology that provides an economical and robust way of implementing expressive and responsive faces on social robots. Syntheligence received initial investment from French incubators Creative Valley and Agoranov. Prototypes have been sold to the University of Sheffield, the Dutch Centre for Technological Research (TNO), and the Université Pierre et Marie Curie (France).

The collaboration with French SME Gostai led to the development of middleware for robotics that was used in the ALIZ-E project to enable robots to use cloud computing. Gostai invested €192,800 in the ALIZ-E project to enable the company to develop the Urbi system architecture, which is critical in maintaining the company's competitiveness in the robot Operating System market. Collaboration with CRNS also led to the integration of the Urbi architecture with another robot – Nao – from Aldebaran Robotics. In in August 2012 Gostai was acquired by Aldebaran Robotics to power Aldebaran's global growth.

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

Statement from Head of e-Services for Life department, Hospital San Raffaele. Contact Alberto Sanna, (sanna.alberto@hsr.it) for confirmation of uses at San Raffaele. Also reported in Nalin, M., Bergamini, L., Giusti, A., Baroni, I. & Sanna, A (2011) 'Children's perception of a Robotic Companion in a mildly constrained setting', In IEEE/ACM Human-Robot Interaction 2011 Conference (Robots with Children Workshop).

van der Drift, E.J.G., Blanson Henkemans, O., Looije, R., Mol, R., and Nederend, E. (2013) 'Kinderen positief over invullen van dagboek met persoonlijke robot', EADV Magazine: vakblad voor diabeteszorgverleners, 28(2):42-45. Publication in magazine for diabetic care professionals showing that children are positive about completing diary with a personal robot. .

Cohen, I., Looije, R. & Neerincx, M 'Child's recognition of emotions in robots' face and body'. (2011). HRI '11 Proceedings of the 6th international conference on Human-robot interaction Shows use of social robots in primary schools in the UK and Italy.

Statement from Chief Scientific Officer of Aldebaran (http://www.aldebaran-robotics.com/en/), the French SME developing the Urbi middleware and the Nao robot.

Statement from Founder/CEO of Merlin Systems Ltd, Beacon Road, Ivybridge PL21 0AQ.

Statement from Director General and President of Syntheligence, 11 rue Carnot, 4270 Le Kremlin Bicetre, Paris, France.

Speech by the Chancellor of the Exchequer, Rt Hon. George Osborne MP, to the Royal Society (available online at https://www.gov.uk/government/speeches/speech-by-the-chancellor-of-the-exchequer-rt-hon-george-osborne-mp-to-the-royal-society).