Institution:
University of Plymouth

Unit of Assessment:
UoA11

Title of case study:
Social robotics: from foundational research to commercial solutions

Period when the underpinning research was undertaken:
2014 onwards

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:
Tony Belpaeme	Professor in cognitive systems and robotics	2005 – present
Swen Gaudl	Lecturer in computer science	2018 – present
Angelo Cangelosi	Professor in AI and robotics	1997 – 2017
Serge Thill	Associate Lecturer in computer science	2016 – 2018

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 (indicative maximum 100 words)

Research into human-robot interaction, in which the Centre for Robotics and Neural Systems (CRNS) plays a leading international role, has demonstrated the significant benefit of social robots for technological support in domains where personal interaction is essential. Funded by 11.9 million GBP in large-scale European grants, Plymouth's innovative social robotics research developed and promoted applications of social robots for personalised and long-term interaction. Responding to societal challenges -specifically the need to address population ageing, the need to deliver personalised education, or the need for novel mental health support- the centre collaborates with leading manufacturers, such as Softbank Robotics, and transnational policy makers, to shape societal, governmental and industrial decision-making to invest in social robots, having an impact on the nascent social robotics market valued at over 1B USD.

2. Underpinning research (indicative maximum 500 words)

The research at the Centre for Robotics and Neural Systems (CRNS) hinges on the observation that people, from children to adults, treat robots as social agents. Both the robots' appearance and behaviour promote the attribution of social characteristics, and it is the latter that the CRNS focuses on. Using techniques from artificial intelligence, machine learning, robotics and signal processing, the team builds social robots that can be used to support children, adults and the elderly in a range of settings. While the research often is foundational, the methods and insights gained are applied to force breakthroughs in application domains ranging from therapy for Autism Spectrum Disorders [3.1], to education [3.2], and support for the elderly [3.3].

The CRNS is interdisciplinary and consists of computer scientists, engineers, cognitive scientists, and healthcare workers, which allows a smooth collaboration with medical professionals, pedagogists, linguists, psychologists and service users and providers often across international borders.

The CRNS take a two-pronged approach to Human-Robot Interaction: working on the technical aspects as well as on the cognitive science underlying HRI [3.4]. In the latter, for example, the

CRNS studied trust and social influence between people and robots, looking at which cognitive mechanisms are at play and what elements of the robot lead to changes in trust and social peer pressure [3.5]. This is complemented with technical research, for example the interactive machine learning work for social robots [3.6] or the deep learning for social signal processing [3.7]. Finally, most of the research has had applied impact, with research results forming the foundations for applications in healthcare, elderly care, education and edutainment. As such, the CRNS' research output not only captured the attention of international colleagues in academia, but was also picked up by policymakers, national and international industries working on automation and robotics and has had an impact on public attitudes towards social robots.

The research in social robots at Plymouth attracted 11.9 million GBP in funding since 2014, the majority of which came from large research projects initiated and coordinated by the CRNS. The FP7 ALIZ-E project, the H2020 L2TOR and the EPIC Regional Development Project introduced the use of robots as social support mechanisms in healthcare, education and regional elderly care respectively. Our research was noticed far beyond national borders, with the US Air Force investing in research on trust in social robots through the THRIVE project, or Softbank Robotics Europe headquartered in Paris initiating a doctoral training collaboration with Plymouth through the H2020 APRIL European Industrial Doctorate network.

Next to these initiatives, the University of Plymouth also was a key partner in several other high-profile projects. For example, the FP7 DREAM project studied the use of social robots for Autism Spectrum Disorder therapy, FP7 ROBOT-ERA focused on social human-robot interaction to support independent living for the elderly, and the H2020 SECURE Initial Training Network studied the safe physical interaction with robots.

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

CRNS research is published in top-tier journals, such as Science Robotics (IF 18.7), Neuroscience & Biobehavioral Reviews (IF 8.83) or Philosophical Transactions of the Royal Society B (IF 6.14). CRNS staff contributing to this impact case are frequently asked as keynote speakers at leading conferences (e.g. Nobel Prize Dialogue, International Conference on Auditory-Visual Speech Processing, IEEE/ACM Human-Robot Interaction, ACM Interaction Design for Children) and their publications have attracted over 6.600 citations for the reporting period (source Google Scholar).

3.1 Thill, S**.**, Pop, C.A., **Belpaeme, T.**, Ziemke, T. and Vanderborght, B. (2012) Robot-assisted therapy for autism spectrum disorders with (partially) autonomous control: Challenges and outlook. *Paladyn Journal of Behavioral Robotics.* 10.2478/s13230-013-0107-7.

3.2 **Belpaeme, T.**, Kennedy, J., Ramachandran, A., Scassellati, B., & Tanaka, F. (2018). Social robots for education: A review. *Science Robotics*, 3(21), eaat5954.

3.3 Di Nuovo, A., Broz, F., **Belpaeme, T.**, **Cangelosi, A.**, Cavallo, F., Esposito, R., & Dario, P. (2015). Toward usable and acceptable robot interfaces for the elderly: The ROBOT-ERA project experience. *International Psychogeriatrics* (Vol. 27, pp. S179-S179).

3.4 **Gaudl, S. E.**, & Bryson, J.J. (2018) The Extended Ramp Model: A Biomimetic Model of Behaviour Arbitration for Lightweight Cognitive Architectures. *Cognitive Systems Research*, 50, *1-8.*

3.5 Vollmer, A. L., Read, R., Trippas, D., & **Belpaeme, T.** (2018). Children conform, adults resist: A robot group induced peer pressure on normative social conformity. *Science Robotics*, 3(21), eaat7111.

3.6 Senft, E., Lemaignan, S., Baxter, P. E., Bartlett, M., & **Belpaeme, T.** (2019). Teaching robots social autonomy from in situ human guidance. *Science Robotics*, 4(35).

3.7 Patacchiola, M., & **Cangelosi, A.** (2017). Head pose estimation in the wild using convolutional neural networks and adaptive gradient methods. *Pattern Recognition*, 71, 132-143.

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

Commercial robots

The CRNS, under the lead of **Belpaeme** and **Cangelosi**, has thriving knowledge transfer partnerships with key players in the social robotics industry. The recent work for example in the H2020 L2TOR project, which studied the use of social robots to support children in education, has led to considerable commercial interest. Embodied Inc., a start-up in the California, has based its Moxie robot on Plymouth's research [5.1] and Softbank Robotics Europe (SBRE) adopted robot tutors in their strategic vision, showcasing the use of robot tutors in their Paris headquarters as a future market for their social robots [5.2]. Plymouth has a longstanding relation with SBRE, who developed and sell the two most popular social robot platforms, the Nao and the Pepper humanoids. SBRE and Plymouth have collaborated since 2010 through four EU projects (FP7 ALIZ-E, FP7 DREAM, H2020 L2TOR, H2020 APRIL) which SBRE match funded for a total of 522,717 EUR, demonstrating a sustained relationship with the global leader in commercial social robotics.

The centre also has long-standing relationship with Zorabots, a leading social robot solutions provider based in Belgium. The company sells robots which consist of imported hardware with bespoke social robotics software. The collaboration, which originated in 2014 during a joint EU research project, continues with Zorabots relying on research from Plymouth to steer their commercial offer. Zorabots collaborates with Plymouth to scout application areas and to procure or develop technical solutions and AI to support social interaction on robots. In 2019 Zorabots, when employing 15 people FET, attracted a VC injection of 10 million EUR spread over 3 years by Versluys group allowing it to invest in new robots and development of software. Tommy Deblieck, co-CEO, says "*We relied on the expertise of the Plymouth team and Prof Belpaeme specifically to expand into social robotics, a nascent market which was brought to our attention by Plymouth's research.*" [5.3]

Zorabots achieved worldwide attention during the Covid-19 crisis, when they made their social robots available to care homes for free to use as a telepresence robots and to monitor for Covid-19 symptoms and the correct wearing of PPE. In 2020, the United Nations Development Programme (UNDP) purchased Zorabots robots to distribute to understaffed hospitals in Rwanda to support their Covid-19 efforts. Again, these applications are an outcome of the collaboration started with the CRNS, as software and expertise was used in the robot deployed during the pandemic [5.3 & 5.4].

Finally, Gaudl works for borobo Ltd, a UK-based robotics and design start-up founded in 2018 in London with the aim to develop novel interaction and design concepts to enrich user experiences. In 2019, borobo was attracted to the Southwest due to the support and strong connection to the research of the University of Plymouth through the EPIC project. Borobo collaborates with Plymouth and Edinburgh Robotics. Their current robot, Maah, marketed as a "sentient domestic artefact" and part of their Konpanion brand is designed as a low-cost social robot that offers companionship and investigates ways of helping with isolation.

Robots for therapy and care

The work in the ALIZ-E, DREAM, and EPIC projects involved evaluating social robots in medical and healthcare settings. This required a mentality shift in the institutions we worked with (for example, San Rafaelle hospital in Milan, Italy, Kernow Health, UK, The patients association, UK and the Meander Ziekenhuis in Amersfoort, NL), and has resulted in a culture change across

many healthcare and care institutions. Plymouth's work on social robotics in healthcare is showcased in professional periodicals and medical conferences (e.g. in 2019 Belpaeme was keynote speaker at the Innovation in Paediatrics Symposium, Amsterdam, and in 2020 he lectured on the potential of social robots at the ORSI Academy in Melle, Belgium). These efforts have helped move attitudes from cautious scepticism to active participation in social robotics trials and deployments [5.5]. For example, Thill and Belpaeme were involved in the first randomised control trial proving the effectiveness of robot therapy for Autism Spectrum Disorders (ASD), which relied on a collaboration with the Babes-Bolyai clinic in Cluj (Romania) to test 70 children with ASD [5.6]. The focus on healthcare not only has a long-term horizon, but has immediate effects, such as the prompt adoption of robots in healthcare during the Covid-19 crisis [5.4].

The EPIC projects (E-health Productivity and Innovation in Cornwall and the Isles of Scilly), funded by the European Regional Development Fund project and involving Belpaeme, Cangelosi and Gaudl, looked at how social robotics and eHealth can serve to meet the needs of fragmented care, as for example found in Cornwall and the Isles of Scilly. Due to its expected positive impact on healthcare, the project received a new round of funding running until 2023 of £4.15M, including investment of £255,000 from local SMEs. As part of EPIC, two robotics companies were founded and 97 additional SMEs were closely engaged and supported, based on the environment created through the University of Plymouth. One of the new companies is Robotriks Ltd., founded in 2018 by Plymouth graduate Jake Shaw-Sutton Gibson and employing 2 staff, which designed and built the social robot ComPet in collaboration with the CRNS.

Public awareness and policy

The Organisation on Economic Cooperation and Development recruited Belpaeme and other thought leaders in smart education to author a policy document for their OECD Centre for Educational Research and Innovation. The document is used to support OECD member governments in future proofing education [8]. The joint work between Plymouth and Zorabots resulted in an invitation to shape the EU's Civil Law Rules on Robotics initiative chaired by Mrs. Maddy Delvaux (MEP), for which both parties were regularly consulted and invited to the European Parliament [5.9].

Foundational insights and research have had considerable impact beyond academia. The work on social peer pressure by robots attracted widespread media attention in 2018 following the publication of the research results in Science Robotics. The news was picked up by over 150 global news outlets, including Science, BBC, and New Scientist. The topic was debated during a Facebook Live event of Science magazine which was viewed by 6.3K viewers and led to invitations for keynotes to Belpaeme at public events. Based on the work with start-up borobo, Gaudl was invited to present the 2019 IET Christmas lecture on the future of robotics. Since 2014 the work on social robotics has featured in dozens of international media outlets, including printed press (New Scientist, Le Monde, the Guardian, Scientific American, …) and television (BBC, NBC, CNN, National Geographic, …) and was part of a 4D video installation at the London Science Museum's blockbuster exhibition on robots in 2017.

Belpaeme and his team contributed to several TV-programmes for UK television, including Channel 4's "The robot will see you now", in which Belpaeme presented the science of social robots and their use in therapy, and BBC2's "Six robots and us", which aired in two parts during the primetime evening slot over Christmas 2017. The programmes showed how robots will integrate in our lives in a not too distant future and what the potential applications of robots are in care and retail.

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

5.1 The value of social and entertainment robot market worldwide:
https://www.statista.com/statistics/755684/social-and-entertainment-robot-market-value-worldwide/

5.2 Embodied Inc., The science behind Moxie, referring to research by **Belpaeme** et al.: https://embodied.com/blogs/news/science-behind-moxie.

5.3 Mr Alexandre Mazel, Software Innovation Director, Softbank Robotics Europe. https://www.softbankrobotics.com/emea/en/index.

5.4 Letter of support from Mr Tommy Deblieck, co-CEO, of Zorabots. https://www.zorarobotics.be/.

5.5 Examples of press reports on the use of social robots during the Covid-19 crisis. The Guardian: https://www.theguardian.com/technology/2020/may/31/the-five-robots-helping-to-tackle-coronavirus, the New York Times: https://www.nytimes.com/reuters/2020/05/29/technology/29reuters-health-coronavirus-belgium-robots.html, or IET Engineering & Technology: https://eandt.theiet.org/content/articles/2020/03/robots-keep-elderly-connected-with-loved-ones-during-coronavirus/

5.6 Letter of support from Dr Rosemarijn Looije (Business Intelligence Consultant and project manager, Universitair Medisch Centrum Utrecht) and Dr Alberto Sanna (Research Director, San Raffaele Hospital, Milan, Italy).

5.7 AAAS Science Facebook live event on robots for mental healthcare, elder care and other applications, that could be critical for dealing with pandemics (receiving 8.5K views): https://www.facebook.com/ScienceRobotics/videos/723562598183476/

5.8 Billing, E., **Belpaeme, T.**, Cai, H., Cao, H. L., Ciocan, A., Costescu, C., **Thill, S.** & Ziemke, T. (2020). The DREAM Dataset: Supporting a data-driven study of autism spectrum disorder and robot enhanced therapy. *PloS one*, *15*(8), e0236939.

5.9 Letter of support from Mr Stéphan Vicent-Lancrin, OECD Deputy Head of Division.

5.10 Mrs Maddy Delvaux, MEP, retired. Summary report by European Parliament: https://www.europarl.europa.eu/RegData/etudes/ATAG/2017/599250/EPRS_ATA(2017)599250_EN.pdf. Agenda of European Parliament media event on robotics law initiative with keynote by **Belpaeme**: https://www.europarl.europa.eu/resources/library/media/20170201RES60617/20170201RES60617.pdf.