Institution: University of Plymouth		
Unit of Assessment(s): UoA11		
Title of case study: Securing UK food production through soft and robust robots		
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:**
Dr Martin Stoelen Dr Ian Howard Dr Alan Millard	Lecturer in Robotics Associate Professor Lecturer in Robotics	22/09/2014 - present 01/11/2012 - present 03/09/2018 – 31/01/2020
Period when the claimed impact occurred: 2014 - present		
Is this case study continued from a case study submitted in 2014? No		

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

Horticulture in the UK is under considerable pressure to help achieve food security and affordable produce, while relying almost entirely on imported labour for the most time-consuming task, harvesting. This case study is centred around the UoP spin-out company Fieldwork Robotics Ltd, which is field-testing the world's first selective harvesting robots for raspberries, while developing an international multi-crop robotic harvesting service. Currently valued at £3.5M, the company pursues commercialization of selective and autonomous picking of crops with advanced variable-stiffness robotic technology developed at UoP. The UoP research behind this technology includes the GummiArm, the world's first open-source and 3D printable robot arm with variable-stiffness, which has been replicated in research groups across the world.

2. Underpinning research (indicative maximum 500 words)

There is extensive international interest in soft robot platforms, but few have made it to practical real-world applications so far. This case study at UoP is helping to change this, by offering low-cost approaches to building robots that can be soft when needed (e.g. to absorb impacts) and stiff when requiring accuracy. The GummiArm [1] was developed as part of the UoP Developmental Context-Driven Robot Learning (DeCoRo) project. This was funded by a Marie Curie IET Post-Doctoral Fellowship. The arm combines structural components that are printable on hobby-grade 3D printers, and rubbery tendons in an agonist-antagonist configuration. This enables easy replication, robustness to unforeseen high-energy impacts, a repair cycle of minutes when something does break, and stiffness and damping when required. The design can be downloaded and assembled from here: https://mstoelen.github.io/GummiArm/

Requirements from three parallel research directions drove the development of the arm: 1) the need for robustness to imperfect world/body models when exploring the world around a robot, and its own sensorimotor capabilities, as investigated in the DeCoRo project; 2) the need for being safe when working around and in close cooperation with humans, especially those with low mobility [3.2]; and 3) the need for robustness to noisy sensory data and hidden obstacles when physically interacting with crops in horticulture [3.3 & 3.4]. The work in [3.2] details a novel approach to achieving mutual adaptation in the shared control of an assistive manipulator, by actively learning from previous collisions with the environment. A robot that is robust to such interactions is required for this to work, and for enabling prolonged and safe usage by a disabled user at home in general. The ability to vary stiffness, and absorb high-energy impacts, distinguishes the technology of the GummiArm from all current assistive manipulators.

For horticulture, the ability to perform explosive movements, by taking advantage of the energy stored in the elastic tendons, was exploited to separate tomatoes from the plant [3.5]. This work was supported with Newton Network+ grants, and in collaboration with partners in Shanghai, China. The ability of the technology to absorb vibration from cutting devices, and robustly interact with cauliflowers during harvesting, was shown in [3.6]. This work has been funded through EU ERDF, and was undertaken with the largest cauliflower producer in Cornwall, Riviera Produce. Finally, the technology is an intimate part of the commercialisation of robotic raspberry picking, where the variable stiffness, and modularity of the robot arms, enable resilience to autonomous operations with full sensorimotor coordination in a complex and organic environment. This work is supported by a £650k total project for Innovate UK, and with the largest raspberry producer in the UK.

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

3.1 2016, Co-exploring actuator antagonism and bio-inspired control in a printable robot arm. A Cangelosi, F Bonsignorio, MF Stoelen, in International Conference on Simulation of Adaptive Behavior (pp. 244-255). Springer, Cham.,
Link: http://hdl.handle.net/10026.1/6711

3.2 2015, Distributed and adaptive shared control systems. MF Stoelen, VF de Tejada, AJ Heute, V Balaguer, FP Bonsignorio, IEEE Robotics & Automation Magazine, 22(4), pp.137-146,
Link: http://hdl.handle.net/10026.1/4550

3.3 2015, Low-cost robotics for horticulture: A case study on automated sugar pea harvesting. M Stoelen, K Krzysztof, VF Tejada, N Heiberg, C Balaguer, A Korsaeth, in 10th European Conference on Precision Agriculture (ECPA),
Link: https://www.wageningenacademic.com/doi/abs/10.3920/978-90-8686-814-8_34

3.4 2017, Proof-of-concept robot platform for exploring automated harvesting of sugar snap peas. VF Tejada, MF Stoelen, K Kusnierek, N Heiberg, A Korsaeth, Precision Agriculture, 18(6), pp.952-972,
Link: http://hdl.handle.net/10026.1/10183

3.5 2019, Soft manipulator robot for selective tomato harvesting. A Mohamed, J Shaw-Sutton, BM Green, W Andrews, EJ Rolley-Parnell, Y Zhou, P Zhou, X Mao, MP Fuller, MF Stoelen, in 12th European Conference on Precision Agriculture (ECPA),
Link: http://hdl.handle.net/10026.1/14873

3.6 2019, Proof-of-concept modular robot platform for cauliflower harvesting. FB Klein, A Wilmot, VF de Tejada, BL Rodriguez, I Requena, S Busch, A Rondepierre, T Auzeeri, T Sauerwald, WFP Andrews, H Rihan, MP Fuller, MF Stoelen, in 12th European Conference on Precision Agriculture (ECPA),
Link: http://hdl.handle.net/10026.1/14874

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

Creating a spin-out company, Fieldworks Robotics Ltd

The research has led to the creation of the spin-out company Fieldwork Robotics Ltd of Plymouth, UK. Founded by Dr Stoelen, the primary aim is to develop robotics technologies for agriculture, in particular the use of soft robot arms developed by Dr Stoelen and collaborators to pick crop for fresh consumption (8 patents submitted, see [5.1]). The company has been supported by over £650k in investments from Innovate UK, enabling industry partners to adopt the technology into their working practice. Andrew McLay from Innovate UK reported [5.3]:

"*Fieldwork Robotics' close engagement with industry partners has helped change attitudes towards, and generate support for, robots in agriculture within and outside Innovate UK."*

The company has had two successful funding rounds so far, the latest in December 2020, with over £700k invested in total. The company also set up a branch dedicated to RD&I in Norway in February 2020. This branch is working with leading fruit and berry experts in Norway. Statement from Stein-Harald Hjeltnes, Director of Njøs Frukt og Bærsenter, a leading fruit and berry R&D organisation in Norway [5.9]:

"The ongoing collaboration we have with Dr. Stoelen and Fieldwork Robotics Norway has positively impacted the way we see the future of fruit and berry growing in our region. From an industry heavily dependent on imported labour, and struggling with high costs and very thin margins, to one where robotics and advanced information technology adapted to our local needs can help make these traditional activities sustainable for the foreseeable future."

The company has also attracted the attention of Bosch UK (part of Robert Bosch GmbH), and in summer 2020 the companies signed a collaboration agreement to accelerate development of Fieldwork Robotics' robot technology for fruit and vegetable harvesting.

Securing future of UK food production through increased automation
UK food production relies on >90% imported labour for harvesting fruits and vegetables; therefore, both food security and the competitiveness of UK producers depend on the continuing availability of seasonal workers at the right price. A successful service offering robotic harvesting across a range of crops in the UK, but also EU and the US, would have a very large potential for impact both economically and socially. The spin-out company Fieldwork Robotics Ltd is expanding rapidly to bring robotic systems for picking soft fruit and vegetables into production.

Fieldwork Robotics Ltd has collaboration agreements with two of the UK's largest raspberry producers, Hall Hunter Partnership and The Summer Berry Company. These growers support development and testing, and work to adjust the robots to the needs of the national supermarket chains. The growers get first refusal of the first 100 robot platforms, with field-testing underway at their facilities in Chichester. The growers are also working with the company to understand how the platforms can also be used for more accurate yield prediction, which could dramatically improve planning, and help reduce waste and costs.

David Green, Chief Operating Officer at Hall Hunter Partnership, which produces 14,000 tonnes of soft fruit for Waitrose, Marks & Spencer and Tesco, among others, says [5.4]:

"The state of berry occlusion in a raspberry crop and the sensitivity of the berry are all much more challenging than in a table-top strawberry environment. If they can crack raspberries, I think strawberries will become a lower technical challenge."

The technology developed is inherently modular, and by targeting the more difficult raspberries first, the platform can more easily be adapted to for example strawberries, than vice versa. The business model is aimed at an international multi-crop service, which can help maximise utilisation throughout the year. This will also include selective harvesting of cauliflower and other field crops, where the company is working with Riviera Produce, one of the biggest cauliflower producers in Cornwall, and Bonduelle S.A. (Villeneuve d'Ascq, France), one of the world's leading vegetable producers. Claudine Lambert, Group Agronomy Director, Bonduelle Prospective & Development, says [5.5]:

"Bonduelle has a strong commitment to sustainable and diversified agriculture in all of the territories where we operate globally. New technologies can play an important part in meeting that commitment, so we are delighted to be collaborating with Fieldwork Robotics and excited by the potential of its agricultural robots."

Influencing public and industry understanding of the use of automation and robotics in food production within the UK

Fieldwork Robotics has generated significant media interest, with more than 100 news articles in national and international media, in particular around how the robust but precise robotic technology developed at UoP can in the future help solve manual labour shortage in agriculture. The interest was often in light of Brexit and other uncertainties in the sector, where the researchers have tried to help the public and industry understand the likely timelines for agricultural robots to reach market. Specifically, widespread industry roll-out is unlikely in the next 10 years, but specific applications and crops can be targeted in 5 or less. This contrasted the common belief of immediate applicability of this type of robotic technology that existed in much of public discourse on the subject. The researchers have also participated in documenting the current state of the art in agricultural robots [5.2].

As an invited member of the Task and Finish Group on Agricultural Productivity in Food and Farming, Dr Stoelen advised the UK Food and Drink Sector Council on the state of agricultural robots. As part of the group, Dr. Stoelen co-authored a letter to Sir Peter Kendall, the Chair of the UK Agriculture and Horticulture Development Board (AHDB), advising on the current state-of-the-art on agricultural robotics, and on the urgent need for funding long-term and workers visas short-term. Testimony from Prof. Simon Pearson, the Head of the Task and Finish Group on Agricultural Productivity in Food and Farming [5.6]:

"I believe the work in the Task and Finish Group on Agricultural Productivity in Food and Farming helped influence UK policy towards supporting and funding UK agritech, while highlighting the urgent need for labour visas for seasonal workers until these technologies achieve industry-wide adoption. The work on selective harvesting coming out of the University of Plymouth has been an important part of this, both in the Task and Finish Group and outside it."

In December 2020 the UK government announced a significant expansion of the Seasonal Workers Pilot, making 30,000 visas available for seasonal workers to pick and pack fruit and vegetables for the 2021 harvest. At the same time the researchers are working closely with industrial partners to understand the challenges they are facing, and to help them prepare their operations for a future where robots will play a key part in the food supply chain. In addition to the above companies, this includes Teagle Machinery Ltd (Truro, UK), Robotriks (Par, UK), CNC Design Ltd (St Columb Major, UK), and HM Clause (part of Groupe Limagrain, France).

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

5.1 Patents directly related to this impact case:

a. FRUIT PICKING ROBOT BI-DIRECTIONAL: GB20170015007
b. FRUIT PICKING ROBOT - TWO PHASE SENSOR CONTROLLED MOVEMENT: GB20170015005
c. FRUIT PICKING ROBOT - VARIABLE STIFFNESS CONTROLLED MOVEMENT: GB2017001006
d. ROBOTIC ARM PCT: WO2018GB52654
e. CLAIMS TO THE MODULAR ARM CONCEPT: GB201819824
f. CLAIMS TO THE TORQUE VS. SPEED TUNING CONCEPT: GB201819825
g. CLAIMS TO THE VARIOUS NEW END EFFECTOR CONCEPTS: GB20181819824
h. FRUIT HANDLING: GB2019004774

5.2 Author on White Paper: Agricultural Robotics: The Future of Robotic Agriculture

http://eprints.uwe.ac.uk/36839/ Source: eprints.uwe.ac.uk

5.3 Testimonial from Andrew McLay, Innovation Lead – Agriculture & Food, Innovate UK
5.4 Testimonial from Hall Hunter Partnership/The Summer Berry Company
5.5 Testimonial from Bonduelle S.A.
5.6 Testimonial from Prof. Simon Pearson, Head of Task and Finish Group on Agricultural Productivity in Food and Farming, advising the UK Food and Drink Sector Council.
5.7 Fieldwork Robotics Ltd Statement of Capital after investments in December 2019
5.8 Statement from Stein-Harald Hjeltnes, Director of Njøs Frukt og Bærsenter, a leading fruit and berry R&D centre in Norway