Institution: University of Lincoln		
Unit of Assessment: 6 – Agriculture, Food and Veterinary Sciences		
Title of case study: Agricultural Robotics: Data Driven Technologies to Transform Agriculture		
Period when the underpinning research was undertaken: 2010 - 2019		
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:**
PEARSON Simon	Director of LIAT/Professor of Agri-Food Technology	22 Sep 14 to date
GOULD Iain	Senior Lecturer	17 Oct 16 to date
FROM Pal	Professor Agri-Robotics	1 Oct 16 to date
BOCHTIS Dionysis	Professor Agri-Robotics	1 May 16 to date
Period when the claimed impact occurred: 2017 - 2020		
Is this case study continued from a case study submitted in 2014? N		

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

The University of Lincoln has led the adoption and development of robotics and autonomous systems to underpin the sustainable intensification of agriculture. Research has influenced the data driven transformation of farming and food production, with UoL's agricultural robotics underpinning: **(1) changes to policy** (i) within the UK, with changes to investment in farming, (ii) informing EU policy on agricultural workforces, and (iii) informing strategic responses to labour shortfalls arising from COVID and Brexit; and **(2) benefits to agricultural business productivity, sustainability, growth and external investment** (including £9.5M of private sector investment in Saga Robotics, now a world leading agri-robotic company)**.**

2. Underpinning research (indicative maximum 500 words)

The global agri-food sector is under unprecedented pressure to sustainably intensify and increase productivity whilst reducing its impact on the environment. In addition, the sector's reliance on seasonal migrant workers for crop harvesting (69,000 in the UK alone) is challenged by the combined effects of the COVID-19 pandemic, changes to UK immigration policy post Brexit and global demographic trends of age and urbanisation. Whilst there is no single panacea to these issues, agricultural robotics and autonomous systems provide vital and emerging opportunities to drive food system resilience.

Since 2016, Lincoln has led significant agri-robotics research that is highly interdisciplinary and co-created between agriculture and computer science practitioners. Scale of the research is significant, evidenced by UoL winning £18.9M in agri-robotics research funding since 2016, including; £6.9M EPSRC AgriForwards CDT (50 PhD cohort), £6.3M Research England Expanding Excellence Lincoln Agri Robotics centre (30 posts including 7 new ECR Lecturers and capital facilities), 15 IUK collaborative agri-robotics research awards (£2.5M value to UoL, plus £5.5M private match funding), spanning 10 funding calls and working with 29 companies. Research addressed key challenges across a broad body of activity including the integration of robotic technologies into complex agricultural systems, understanding impacts on agricultural workforces, deployment of novel platforms to harvest crops, measure and react to biological diversity. Key research advances to address sector challenges include:

- **Crop harvesting robotics**. The £1.6BN UK fresh produce sector is reliant on 69,000 seasonal migrant workers each year to harvest crops. The businesses engaged, who act as economic anchors across rural UK, employ c.20,000 permanent positions whilst providing highly nutritious, low carbon fruit and vegetables at accessible prices to UK society. However, the combined effects of Brexit and COVID-19 pandemic are jeopardising the future of this sector of the agricultural economy (EFRA Select Committee Report, Dec 2020). Robotic and autonomous systems that selectively harvest labour dependent crops, such as broccoli and strawberries, offer an emerging opportunity to drive labour productivity, but these systems rely on novel technologies that can detect (in 3D), measure and manipulate key crop components within highly diverse biological systems. Research at Lincoln has pioneered the development of such vision systems to underpin robotic harvesting, with foundational research **[3.1]** demonstrating how low-cost 3D cameras can be used for high speed and robust image recognition in commercial crops. Results showed that purely technical/robotic solutions (image recognition for harvesting) are unlikely to be successful without a full appreciation of the biology / variability of a crop and within an agricultural system. This foundational publication led to a larger body of research at Lincoln on crop vision technologies, including the underpinning detection system **[3.2]** subsequently deployed as a prototype robotic strawberry platform and harvester.

- **Environmental monitoring of soils**. Existing agricultural soil management practices are widely accepted as unsustainable, with reliance on high mass agricultural machines compacting soils, energy intensive cultivation leading to unacceptable soil carbon emissions and inefficient use of critical resources such as water. Effective farmer decision support for soil management is only possible through improved soil monitoring, measurement and mapping, yet existing technologies were highly labour dependent, expensive and subject to sampling errors. UoL has led foundational research on the application of robotics for soil mapping, including new algorithms for efficient soil mapping and sensors to detect soil moisture (first agricultural demonstration of a cosmic neutron rover) and compaction **[3.2, 3.3]**

- **Barriers to adoption**. UoL has conducted theoretical assessments of how robotic systems might be scaled across agriculture **[3.4]** and change the nature of work **[3.5, 3.6].** These studies demonstrated socio-economic barriers to the deployment of robotics in agriculture, including impacts on the existing workforce and economic challenges to transition conventional systems, reliant on few high mass machines (diesel powered tractors), towards a new operational paradigm underpinned by fleets of smaller electric robotic platforms.

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

3.1 Kusumam, Keerthy, Krajnik, Tomas, Pearson, Simon, Duckett, Tom and Cielniak, Grzegorz (2017) 3D-vision based detection, localization, and sizing of broccoli heads in the field. Journal of Field Robotics, 34 (8). pp. 1505-1518. ISSN 1556-4959 http://dx.doi.org/10.1002/rob.21726

3.2 From, Pal and Grimstad, Lars and Hanheide, Marc and Pearson, Simon and Cielniak, Grzegorz (2018) RASberry - Robotic and Autonomous Systems for Berry Production. Mechanical Engineering Magazine Select Articles, 140 (6). ISSN 0025-6501 http://dx.doi.org/10.1115/1.2018-JUN-6

3.3 Pulido Fentanes, Jaime and Gould, Iain and Duckett, Tom and Pearson, Simon and Cielniak, Grzegorz (2018) 3D Soil Compaction Mapping through Kriging-based Exploration with a Mobile Robot. IEEE Robotics and Automation Letters. ISSN 2377-3766 http://doi.org/10.1109/LRA.2018.2849567

3.4 Pulido Fentanes, J., Badiee, A., Duckett, T., Evans, J., Pearson, S. and Cielniak, G., 2020. Kriging-based robotic exploration for soil moisture mapping using a cosmic-ray sensor. *Journal of Field Robotics*, *37*(1), pp.122-136. https://doi.org/10.1002/rob.21914

3.5 Lampridi, M.G., Kateris, D., Vasileiadis, G., Marinoudi, V., Pearson, S., Sørensen, C.G., Balafoutis, A. and Bochtis, D., 2019. A case-based economic assessment of robotics employment in precision arable farming. *Agronomy*, *9*(4), p.175. https://doi.org/10.3390/agronomy9040175

3.6 Marinoudi, V., Sørensen, C.G., Pearson, S. and Bochtis, D., 2019. Robotics and labour in agriculture. A context consideration. *Biosystems Engineering*, *184*, pp.111-121. https://doi.org/10.1016/j.biosystemseng.2019.06.013

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

UoL's innovative agri-food research has underpinned a series of impacts for the agricultural sector, with activity including a series of strategic engagements with government, industry and the production of a pivotal white paper **[5.1].** UoL's research materially contributed to the development of a cohesive national strategy for agri-robotics resulting in **(1) changes to policy** (i) within the UK, enhancing investment in farming, (ii) within the EU, informing policy on agricultural workforces, and (iii) informing UK strategic responses to labour shortfalls arising from COVID and Brexit; and *(2)* **benefits to agricultural business** productivity, sustainability, growth and external investment.

1) **Impacts on policy**

i. **Changes to UK Government policy and investment in farming**
As a consequence of the scale and significance of UoL's research, Pearson was invited by Sir Peter Kendal to chair the Robotics and AI Task and Finish Group (TFG) reporting to the Agricultural Productivity Working Group (APWG) of the DEFRA/BEIS Food Sector Council. The TFG report **[5.2]**, which included evidence from the UoL body of research on selective harvesting articulated the challenges, timelines and government support for accelerated adoption of robotics by UK farmers and formed part of the APWG's report to the Sector Council in 2019 **[5.3]** . Recommendations directly reflected critical lessons from UoL research [particularly 3.2] that adoption of agri-robotics technologies requires scaled interdisciplinary research at a full systems level; this included the recommendation that the UK government should invest in infrastructure to support the roll-out of robotics (*Recommendation 5*, focused on 5G and data infrastructure) and that UK research policy should increase focus on collaborative, mission-led approaches (*Recommendation 3,* which includes robotics). This APWG report informed government policy, seen in the DEFRA Future for Framing Report, 2020 **[5.4]**, particularly with the new Farming Transformation Fund **[5.4],** that provides grants to farms for large scale investments in research and infrastructure, specifically allowing payment for "*increasing the use of automation and robotics"*.

ii. **Informed EU policy on the future of agricultural workforces**
UoL research informed EU policy, where a commissioned report for the AGRI committee of the EU Parliament **[5.5]** cited Lampridi *et al* [reference 3.4] and Marinoudi *et al* [3.5] to substantiate hypotheses that robotics will change the nature of work within EU agriculture. Reflecting key learning from UoL research, one of the reports key conclusions was that *"the challenge for farmers to take up such innovation should not be under-estimated, hence the importance of vocational training, advisory services and knowledge exchange within and outside the framework of the CAP"* **[5.5,** page 103]. EU Parliament AGRI committee recommendations are pivotal for strategic reviews of the new Green Deal and CAP transition policy.

iii. **Informing policy responses to the protection of farming businesses incurring staff shortfalls arising from COVID and Brexit.**

In 2020, as part of an urgent COVID-19 response, UoL with the National Farmers Union and the Innovate UK Agri-EPI centre created and led the national “Accelerated Automation” initiative. UoL’s leadership role was a direct consequence of its body of research on agri-robotics and initiated after discussions (minuted with EPSRC) with the industrial steering board of AgriForwards CDT. The objective was to complete and scale emerging robotic technologies to mitigate serious shortfalls in farm labour as an immediate consequence of COVID-19 pandemic, as well as medium term impacts of changes to migration policy post Brexit. This national consultation engaged over 100 different companies and organisations across the fresh produce and robotics sectors. It focussed on establishing whether fast track robotic development and scaling could resolve critical shortfalls in labour supply. Pearson reported this in written evidence to the EFRA Select Committees on “COVID-19 and food supply” and “Labour in the food supply chains” **[5.6].** Throughout the Accelerated Automation process, UoL and Agri-EPI have actively engaged with government (up to Ministerial level). This activity directly led to the allocation of new national open-competition funding for agri-robotics by Innovate UK (agri-robotics became in scope for funding from the ISCF Robotics for a Safer World Challenge). businesses.

2) **Benefits to agricultural business productivity, sustainability, growth and external investment.**

Saga Robotics Ltd (https://sagarobotics.com/) is a world leading agri-robotic start-up manufacturing agricultural robots and providing roboticised services to the farming industry to address key challenges including labour shortages and the sustainability of food production. Their flagship product is Thorvald, a universal, modular mobile platform which can be deployed in many different agricultural scenarios such as crop care, selective harvesting or in-field transportation. In addition to direct sales, the company operates a Farming-as-a-Service (FaaS) business model, offering prototype robotic fruit picking (using UoL’s image analysis system) and commercial autonomous UVC light treatments to reduce powdery mildew on fruit crops in the UK, USA and Norway. Since developing their first robotic system hardware in 2016 in Norway, Saga have actively collaborated with UoL on research-led developments for their software systems and agricultural domain applications for fruit picking, pest control, logistics support, robotic weeding, crop forecasting [reference 3.2]. The enhanced software system directly includes critical applications developed with Lincoln, including 3D image recognition systems for fruit picking [reference 3.1] and robotic mapping technologies [references 3.3. and 3.4, stored in extensive shared GiThuB libraries hosted on UoL servers]. Collaboration with SAGA was directly facilitated by Professor Pal From (Saga CEO) who was an embedded and 25% FTE Chair of Agri-Robotics at UoL from 2017 to 2021.

The collaboration with UoL has resulted in changes to Saga’s business model, leading to growth in both capacity and external investment. Saga made a strategic decision to open its UK office on the University Campus in 2016, where the company currently now employs 21 full-time highly skilled staff, with 3 senior software engineers originating from the UoL team. Saga cite UoL’s research as a key contributing factor to securing £9.5M of Series A venture capital funding to accelerate and scale up the company **[5.7]**.

Beyond Saga, UoL’s agri-robotics research has enabled a range of novel and step-changing solutions for major food producers. Berry Garden Growers, the UK’s leading berry and stone fruit production with a market share over 30% and annual sales of over £300 million, report that using the UoL-enhanced Thorvald system has yielded both economic and environmental benefits:

> *“The deployment of this robotic fleet at Clockhouse Farm in 2020 successfully demonstrated full robotic autonomy, 7km per robot per night deployed, for UVC robots over a whole season. This is a global first, robotic technologies from UoL have transformed our research investment, estimated at £1.2M, over the last 3 years”.* **[5.8].**

Similar findings are reported by one of the largest farms in Norway, Myhrene AS, who in 2020 switched completely to spraying-free production on strawberries across their 5ha polytunnel production, using the UoL-enhanced Thorvald system. Simen A. Myhrene, Chairman of Myhrene states that *"With the robot we get less energy consumption, a better overview over the production, we can use less pesticides, we can save more labour, we take better care of the soil which again give bigger crops. There are so many effects we can gain when we learn how to use this - it's here to stay!"* [5.7].

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

5.1 UoL led white paper on the future of agri-robotics: Duckett, T., Pearson, S., Blackmore, S., Grieve, B. and Smith, M., 2018. White paper-Agricultural Robotics: The Future of Robotic Agriculture. *EPSRC RAS.* https://arxiv.org/abs/1806.06762

5.2. The Potential of Robotics and Artificial Intelligence in Agriculture and Horticulture. Pearson, S., Blackmore, S, Brown, J., Capper, A., Collison, I., Collison, M., Duckett, T., Green, R., Grieve, B., Kirwan, J., Scurlock, J., Stoelen, M. Report Commissioned by the DEFRA FSC APWG (2019).

5.3 APWG report to Sector Council, drawing on TFG chaired by Pearson

5.4 DEFRA Future for Farming Report, 2020 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/868041/future-farming-policy-update1.pdf

5.5 UoL citations in commissioned report for the AGRI committee of the EU Parliament: https://www.europarl.europa.eu/RegData/etudes/STUD/2019/629209/IPOL_STU(2019)629209_EN.pdf

5.6 Written evidence to EFRA Select Committee on (1) COVID-19 and food supply: https://committees.parliament.uk/writtenevidence/5439/html/ and (2) Labour in the food supply chains: https://committees.parliament.uk/writtenevidence/8386/html/

5.7 Testimonial from Saga Robotics Ltd. with company growth, robot sales and software use

5.8 Testimonial from Berry Garden Growers