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| **Institution: University of the West of England, Bristol** | | |
| **Unit of Assessment: 12** | | |
| **Title of case study: More efficient and sustainable agriculture through advanced techniques in machine vision and machine learning** | | |
| **Period when the underpinning research was undertaken:** 2007 – 2020 | | |
| **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:** |
| Prof Melvyn Smith | Director of the Centre for Machine Vision (CMV) | 1991 – present |
| Prof Lyndon Smith | Professor in Computer Simulation and Machine Vision | 1994 – present |
| Dr Mark Hansen | Associate Professor in Knowledge Exchange and External Engagement | 2008 – present |
| Dr Wenhao Zhang | Senior Lecturer in Machine Vision | 2016 – present |
| **Period when the claimed impact occurred:** 2018 – 2020 | | |
| **Is this case study continued from a case study submitted in 2014?** No | | |

## 1. Summary of the impact

Research into 3D imaging and deep learning by the Centre for Machine Vision (CMV) at the University of the West of England, has led to innovations in the agricultural industry. An automated cattle monitoring system based on CMV research is improving welfare and productivity at dairy farms across the UK and has played an important role in the sustainable farming programme of the UK's largest milk supplier. A system for the real-time monitoring of root crop production information during harvesting informs marketing, planning and agricultural practices, and has been successfully brought to market by a newly formed company. An automated system for weed detection has been used to guide application of herbicides, saving on costs and environmental impacts. The application of research into machine vision and deep learning has made farming more efficient and sustainable, with benefits to business, consumers, animal welfare and the environment.

## 2. Underpinning research

From 2007 to 2019 the CMV team worked on the application of 3D imaging for detecting and describing objects of interest in challenging applications. This included novel methods for characterising the morphology of aggregate particles, facial recognition, and detecting hidden objects for security purposes. The technology was later adapted for animal condition monitoring. CMV pioneered new technologies for animal condition monitoring in dairy farming (**R1**), for in-field crop data capture, and for automated weeding in pasture (**R2**).

### Animal condition monitoring

Using state-of-the-art data capture, analysis, and machine learning techniques, CMV

developed an automated data-driven approach, bettering unreliable, subjective, and labour-intensive methods of manual scoring of animal condition. A novel 'rolling ball algorithm' (RBA), which the CMV team previously developed for characterising complex 3D morphologies (e.g. in petrographic analysis of aggregate particles) (**R3**), was applied for the first time for quantifying animal body condition (essentially how lean/fat the animal is). RBA's significant advantage is global operation; obviating the requirement to detect and track local animal features, such as the 'hook' and 'pin' pelvic bones which are usually considered to be critical features for body condition monitoring. CMV also successfully introduced 3D imaging for tracking and analysing gross body movements, as a proxy for conventional leg gait motion in lameness detection (**R4**). Height movements, readily captured from the animal's back while walking beneath a sensor, form locomotion signals analysed using a Hilbert transform and machine learning, to give better than 96% accuracy in lameness detection. Hence, via a sequence of related projects (**G1**, **G2**, **G3**), CMV pioneered work on improved farm productivity, farm animal husbandry and welfare (**R1**).

**In-field root crop data capture**

Research on isolating 3D structures in plant phenotyping tasks (**R5**), formed the basis for developing technology for live crop metrology data-capture on the harvesters (**G4**). In this case, the size and shape distribution of fast-moving potato tubers is captured using an overhead RGB-D camera mounted within the vehicle, where segmentation, sizing, and shape characterisation are accomplished in real-time. A Yolov3-tiny object detection network identifies individual potatoes that are then converted to real world measurements using 3D camera parameters. Double counting is avoided by triggering this process only when the entire frame changes through use of an optical flow tracker. Combining with real-time GPS (**R2**) enables the generation of timely production statistics, such as crop counting and sizing distributions, together with produce-yield field heat maps, allowing producers to monitor yield, market crops more profitably and, via targeted agronomic performance data, to assess field performance and plan future soil treatments.

**Automated weed detection**

Research on the synergistic use of computer vision and state-of-the-art deep learning techniques, in the form of convolutional neural networks (CNN), allowed pioneering work in the detection, recognition and localisation of plants species in the natural environment, with significantly improved results, setting a new standard in accuracy and applicability (**R6**). Using an SSD-mobilenet-v2 CNN, accuracy is better than 96% for a three-class dataset detecting dock and clover leaves in grass - a task that has proved impossible using conventional computer vision and hand-crafted features. Significantly, the use of transfer learning and COCO (Common Objects in Context) weights, means that fewer than 50 training samples are required per class. This is important for agricultural businesses because, due to the high cost of collecting and processing large amounts of training data, they have not yet been able to employ Neural Network models. The employment of a CNN and transfer learning offers a very powerful method for classification of weeds in grassland, making the practical precision-targeted application of herbicide possible from a moving vehicle, equipped with cameras and a controlled spray boom.

CMV research has demonstrated:

- The benefits of rich 3D data for revealing, and helping to better describe and characterize, attributes of interest to farmers, such as body condition, lameness and weight in animals (**R1**, **R4**).

- The benefits of richer 3D data for isolating and tracking features of interest in plants and crops (**R2, R5**).
- The power of deep learning in complex and challenging detection and recognition tasks, within highly unstructured agricultural applications (**R6**).

## 3. References to the research

**R1** Hansen, M., Smith, M., Smith, L. (2018) Automated monitoring of dairy cow body condition, mobility and weight using a single 3D video capture device. *Computers in Industry*. Vol.98 pp. 14-22 https://doi.org/10.1016/j.compind.2018.02.011

**R2** Smith, L., Zhang, W., Hansen, M., Smith, M. (2018) Innovative 3D and 2D machine vision methods for analysis of plants and crops in the field. *Computers in Industry*. Vol 97 pp. 122-131 https://doi.org/10.1016/j.compind.2018.02.002

**R3** Lee, J., Smith, M., Smith, L. (2007) A new approach to the three-dimensional quantification of angularity using image analysis of the size and form of coarse aggregates. *Engineering Geology*, 91, pp. 254-264. https://doi.org/10.1016/j.enggeo.2007.02.003

**R4** Abdul Jabbar, K., Hansen, M., Smith, M., Smith, L. (2017) Early and non-intrusive lameness detection in dairy cows using 3-dimensional video. *Biosystems Engineering*. Vol 153 pp. 63-69 https://doi.org/10.1016/j.biosystemseng.2016.09.017

**R5** Bernotas, G., Scorza, L., Hansen, M., Hales, I., Halliday, K., Smith, L., Smith, M., McCormick, A. (2019) A photometric stereo-based 3D imaging system using computer vision and deep learning for tracking plant growth. *GigaScience*, 8/5. pp.1-15 https://doi.org/10.1093/gigascience/giz056

**R6** Smith, L., Byrne, A., Hansen, M., Zhang, W., Smith, M. (2019) Weed classification in grasslands using convolutional neural networks. *Applications of Machine Learning, SPIE Optics Photonics*. Vol.11139. https://doi.org/10.1117/12.2530092

### Evidence of the quality of the underpinning research

**G1** Smith, L. *Precision cow health management*, Technology Strategy Board, 2013 – 2016, £210,046.
**G2** Smith, M. *Automated welfare monitoring of dairy cows using 3-dimensional imaging and deep learning*, BBSRC, 2019 – 2020, £35,192.
**G3** Smith, M. *Agsenze KTP*, Technology Strategy Board, 2019 – 2021, £182,834.
**G4** Smith, M. *Smart Storage' solution for the potato sector to reduce waste by 110kt and improve packer profitability by £108 million per annum*, Innovate UK, 2018 – 2019, £99,966.
**G5** Smith, M. *GrassVision: Automated application of herbicides to broad-leaf weeds in grass crops*, Innovate UK, 2016-2018, £107,053.
**G6**, Smith, M. *GrassVision 2 - A retainable, smart-camera, vision system for agriculture - SKAi, the Soil Essentials KORE Artificial Intelligence platform*, UKRI, 2019 – 2022, £137,961.

## 4. Details of the impact

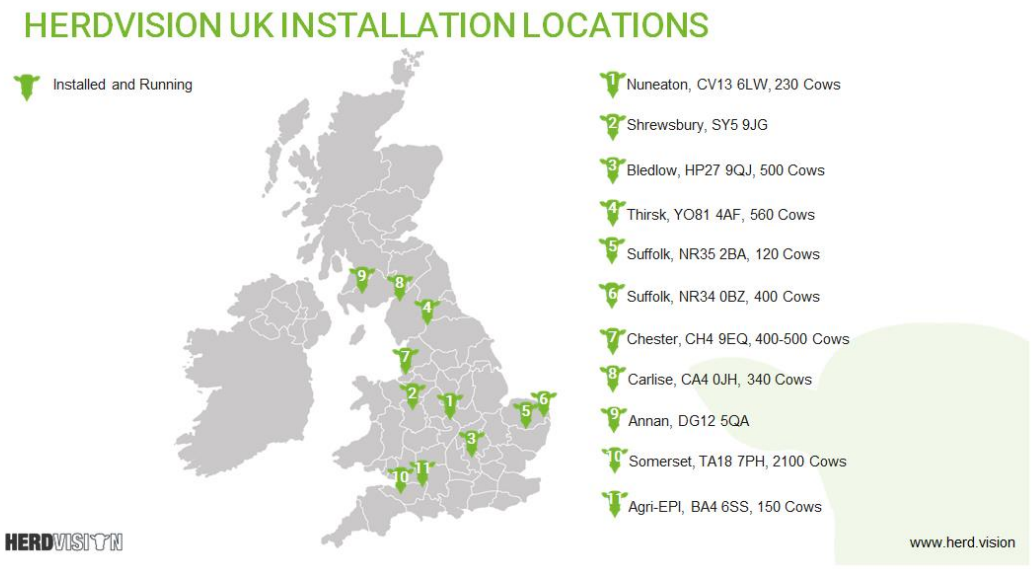
### 'HerdVision' animal condition monitoring system: increasing productivity and animal welfare

The 'HerdVision' system, initially developed under a 3-year BBSRC feasibility study grant (**G1**) for which underlying techniques were reported in (**R1**), was developed into a commercial product via follow-on BBSRC (**G2**) and KTP (**G3**) funding. The research has had a significant impact on agri-tech company, Agenze, which has been applying the research to challenges in dairy farming. Since 2014, Agsenze has secured GBP700,000 of investment to

develop the technology based on UWE research, and has created eight new jobs to work on this project (6.5FTE) (**S1**). The Managing Director at Agsenze commented that:

> '*the scoring is produced at least two times a day as opposed to the… [previous] manual system of once every two months – leading to better welfare of the livestock and better productivity for the farmer*' (**S1**).

As of 2020, the HerdVision system is being used to monitor 3,300 cows on 11 farms throughout the UK (**S1**, **S2**), 10 of them owned by Arla, a farmer-owned dairy cooperative. The farmers and cows at these farms benefit from automated body scoring and lameness detection. Arla, the largest producer of milk in the UK, supplies major supermarkets such as Morrisons and Aldi. The Arla farms using HerdVision are part of the 'Arla 360' programme, which uses innovative technology to make dairy farming more sustainable and to improve animal welfare. HerdVision has been used as part of the Arla 360 promotional campaign, in which Arla UK positions itself as a sustainable and ethical brand (**S3**). This has increased the confidence of retailers stocking Arla products and their customers. The Senior Agricultural Manager at Morrisons UK commented '*our customers care about animal welfare, so to know that these trials can improve the well-being of the animals supplying their milk is reassuring*' (**S3**).




'**HarvestEye' in-field crop data capture: providing real-time insight and improving profitability**

'HarvestEye' is a unique system that provides valuable insights on root crop performance during harvest across a whole field, rather than conventional, limited, sample data. The system is based on advanced vision techniques for surface analysis developed by CMV and reported in **R2** (**S4**). The Director of B-Hive Innovations, the company developing HarvestEye, noted '*UWE research contributed materially to the decision to set up B-Hive*' and that '*the Harvesteye system, based on UWE research, is an important part of our portfolio*' (**S5**). In November 2019, B-hive Innovations launched HarvestEye Ltd and announced a partnership with GRIMME UK, to market the system in the UK (**S6**). The successful development of this system has meant that Harvest Eye Ltd now has three new employees (3FTE), has sold 42 units to date, and had plans to employ another three employees in 2020/2021 to cater for further growth in sales (**S4**).

**'GrassVision': upskilling precision farming specialists to reduce environmental damage through targeted herbicide delivery**

Since 2016, CMV has worked in partnership with SoilEssentials Ltd to develop a system for detecting and spraying weeds in pasture. The system is based on findings from an InnovateUK feasibility project (**G5**, **R6)**. A follow-on 3-year InnovateUK project, 'GrassVision2' (**G6**), supported the development of a marketable device, to allow herbicide to be precisely targeted only where needed, increasing productivity, reducing costs and reducing the environmental impact of over-application of herbicides. The resulting Soil Essentials *KORE Artificial intelligence platform* uses 'SKAi', a re-trainable smart camera vision system developed at UWE for agricultural applications. The system is able to reduce the total amount of crop protection products required by 90%, by identifying weeds and delivering herbicide in a targeted way. SoilEssentials is an established provider of precision farming products and services, approaching its 20th anniversary (**S7**). The expertise of the SoilEssentials team has been in database applications, data modelling and agricultural hardware integration. UWE research enabled the SoilEssentials team to develop a high level of expertise in two new areas; machine vision and deep learning. The Managing Director of Soil Essentials commented:

> '*Engagement with UWE research, as reflected in publications such as the 2019 paper on Weed classification in grasslands using convolutional neural networks* [**R6**], *has been invaluable in upskilling our team and creating the potential for new commercial opportunities*. *The team at SoilEssentials have now successfully trialled the weed detection and spraying technology… and have developed many of the skills required to be at the forefront of this pioneering technology. This would not have been possible without our engagement with UWE research*' (**S8**).

**5. Sources to corroborate the impact**

**S1** Testimonial from the Managing Director of Agsenze

**S2** Agsenze slide showing UK farms using Herdvision as of September 2020

**S3** Arla UK press release July 2019

**S4** Testimonial from the Director of B-Hive Innovations Ltd August 2020

**S5** Testimonial from the Director of B-Hive Innovations Ltd March 2019

**S6** HarvestEye press release 21.11.2020

**S7** SoilEssentials Ltd website

**S8** Testimonial from the Managing Director of SoilEssentials Ltd