Institution: Kingston University		
Unit of Assessment: 11 – Computer Science and Informatics		
Title of case study: Intelligent computer vision improving security in crowded public events and agricultural practice on farms		
Period when the underpinning research was undertaken: 2013 – 2018		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Paolo Remagnino	**Role(s):** Professor of Artificial Intelligence and Machine Vision; leader of the Robot Vision Team (ROVIT)	**Period(s) employed by submitting HEI:** Sept 1998 – present
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

Research into computer vision and visual surveillance conducted by Remagnino and ROVIT have improved the welfare and economic prosperity of citizens across Europe by:

- establishing safety and security benefits in large public events through the deployment of the 'MONICA' platform for Internet-of-Things-enabled crowd analysis in 5 European countries, with over 140,000 end-users
- harnessing 5G to provide welfare improvement and cost savings to farmers through improvements to agricultural data analysis using drones, time-saving measures, reducing medical costs, and increasing crop yields
- bringing industrial benefits and strategic redirection to VCA Technology Ltd
- driving forward drone operations with Blue Bear Research Systems

2. Underpinning research

Over the past 10 years, Remagnino and ROVIT have developed machine learning techniques to improve computer vision and video analytics tasks. Computer vision helps computers 'see' and gain high-level understanding of digital images or videos. Much more than image processing, the goal of computer vision is the extraction and analysis of useful information. It can provide automated, real time insights such as object verification, detection or recognition. Improvements to machine learning and deep learning have led to computer vision with higher level applications, such as identifying specific activities, complex counts or object classification.

Visual Surveillance and Deep Learning

Research by ROVIT has focused on tracking pedestrians and detecting potentially dangerous crowd situations in public places. The research has included new methods for extracting useful information on crowd dynamics from images captured by both fixed and mobile cameras, addressing the challenges posed by the visual clutter typical of crowds. For example, ROVIT researchers constructed a model which characterised regular crowd behaviour by learning the spatial and temporal variations of local movements. By learning to recognise regular behaviour, it was then possible for the model to localise regions with abnormal behaviours **[R1]**. Other work proposed a novel learning framework to optimise annotating videos **[R2]** and demonstrated a novel semi-supervised deep learning technique which increased training data volume **[R3]**. In addition, Remagnino has proposed the use of distributed artificial intelligence and machine learning methods to support tracking multiple targets despite complex interactions **[R4]** and abrupt motions **[R5]**. That work was performed with the support of UK funding bodies, NATO, the US department of homeland security and European grants, totalling a sum larger than GDP2 million.

Having demonstrated the feasibility of his methods in real scenarios, Remagnino was awarded a €17.6 million H2020 project MONICA (2017-19), aimed at managing large open-air events in cities, as well as a Knowledge Transfer Partnership project expanding on MONICA's work and two NATO projects. Those projects have led him to start new threads of research, including deep learning methods and the use of drones for video surveillance. He delivered the required technology to take advantage of the camera sensor network that is at the core of the MONICA security solution. This combined research in artificial intelligence and computer vision, including sensor fusion, scene and dynamic modelling, and information retrieval. In addition, that technology also contributed to MONICA's noise reduction applications by providing both better crowd flow control and detection of early disturbances.

Visual Surveillance and Pattern Recognition

In parallel with his visual surveillance work, as visiting researcher with the Royal Botanic Gardens, Kew, Remagnino has developed methods specifically aimed at classifying plants, using advances in pattern recognition algorithms **[R6]**. Due to his expertise in both video surveillance and computational botany, he was awarded the 5G Rural Integrated Testbed project (5GRIT, 2018-19) by the UK Department for Digital, Culture, Media and Sport. Cameras were flown on unmanned aerial vehicles with 5G technology used to stream video data to servers at Kingston University. To address the major machine learning challenges - the lack of available or well-labelled data, the team exploited their latest generative neural networks technology to augment datasets **[R3]**. Using all aspects of the body of research, the drone's video stream was processed in real time for localisation, classification and disambiguation of plants and animals from the aerial imagery.

3. References to the research

R1 – Thida, M., Eng, H.L., **Remagnino, P**, 'Laplacian Eigenmap with Temporal Constraints for Local Abnormality detection in crowded scenes', IEEE Trans. Cyber, 43, 6, (2013), pp 2147-2156. DOI: 10.1109/TCYB.2013.2242059

R2 – Gu, F., Sridhar, M., Cohn, A., Hogg, D., Monekosso, D.N., **Remagnino, P.**, 'Weakly supervised activity analysis with spatio-temporal localisation', Neurocomputing, 216, (2016), pp 778-789. DOI: 10.1016/j.neucom.2016.08.032 REF2ID: 11-55-1384

R3 – Dupre, R., Fajtl, J., Argyriou, V**.**, **Remagnino, P.**, 'Improving dataset volumes and model accuracy with semi-supervised iterative self-learning', IEEE Transactions on Image Processing, (2019). DOI: 10.1109/TIP.2019.2913986

R4 – Thida, M., Eng H.L., Monekosso D.N., **Remagnino, P.**, 'A particle swarm optimisation algorithm with interactive swarms for tracking multiple targets', Applied Soft Computing 13, 6, (2013), pp 3106-3117. DOI: 10.1016/j.asoc.2012.05.019

R5 – Lim, M.K., Chan, C.S., Monekosso, D., **Remagnino, P.**, 'Refined particle swarm intelligence method for abrupt motion tracking', Information Sciences 283, (2014) pp 267-287. DOI: 10.1016/j.ins.2014.01.003 REF2ID: 11-52-1381

R6 – Lee, S.H., Chan, C.S., **Remagnino, P.**, 'Multi-organ plant classification based on convolution and recurrent neural networks', iIEEE Transactions on Image Processing, 27, 9, (2018), pp 4287-4301. DOI: 10.1109/TIP.2018.2836321

4. Details of the impact

KU's research in the areas of computer vision and deep learning, as a result of the MONICA and 5GRIT projects, has impacted security, ecology, and the economy. These projects pioneered a variety of applications of computer vision, improving crowd safety, environmental stewardship, and benefitting commercial interests.

MONICA, 2017-19

The H2020 Project MONICA (2017-2019) provided a very large-scale demonstration of multiple existing and new Internet of Things (IoT) technologies for Smarter Living **[S1]**. Involving 143,000 end-users, MONICA offered applications addressing issues related to noise, acoustics and security. By collecting large scale data from a variety of devices, the project was able to track noise and anti-social behaviour. This required building on Remagnino's research in artificial intelligence and computer vision, including sensor fusion, scene and dynamic modelling, and information retrieval. MONICA was deployed in European cities (Hamburg, Lyon, and those below) across 41 events **[S2]**.

Impact on Security and Safety

- Tivoli Gardens, Copenhagen.
  "Friday Rock" concerts take place in a crowded and cluttered amusement park. Up to 500,000 guests visit the park during the concert season meaning public flow control requires many safety personnel. MONICA's ability to track individuals enabled security staff to be routed towards areas where they were needed. As a result, response time to detected incidents was significantly improved **[S2]**.

- San Salvario, Turin/Torino.
  The increase of popularity in this night life district and the outdoor socialising known as 'The Movida' phenomenon has caused great disturbance to residents, attracting a growing number of drug dealers and generating security issues **[S3]**. The Torino 2019 Renovation Plan related to Movida **[S4]** raises specific solution to the acoustic pollution caused by crowds in San Salvario. Enrico Gallo, Torino's Environmental Engineer, said that MONICA helped combat these problems, by allowing them to identify crowd activity: '*by clustering the sound with crowd data, we have* identified patterns on which to act upon and build new strategies of crowd *awareness*' **[S2]**. In addition, community support and engagement has been invoked through Urban Spaces Hackathons, relying on MONICA data as the basis for solutions **[S2]**.

- Headingley Stadium, Leeds.
  Crowd analysis data during two Leeds Varsity rugby matches supported an app to provide an interactive map detailing crowded areas. 90% of survey respondents said the app improved their Varsity experience. The Project Coordinator wrote that '*the information contained in the app may have contributed to*' the '*positive outcome*' of fewer incidents and sanctions and of reduced queuing time. MONICA solutions were also deployed at T20 cricket matches, addressing sound and crowd control of 150,000 visitors **[S2]**.

- Pützchens Markt and "Rhine in Flames" (a public fireworks event), Bonn.
  Crowd monitoring provided up-to-date information about the people on the city streets. The City Director of Bonn, with other officials including the Bonn Police Chief, presented the 2018 results, involving 1 million visitors, to the North Rhine-Westphalia Interior Minister, commenting '*I would be happy if this project would find many imitators in the Republic and beyond*' **[S5]**.

Economic Impact on VCA Technology

The project manager with MONICA, now Product Manager at VCA Technology – a British company who shared a two year KTP with Remagnino, described MONICA's '*success with reliable heat maps to support crowd counting, where 86% accuracy was achieved*' **[S6].** He states that MONICA '*has changed and will change industrial attitude to this technology*'. He also explained how the KTP, '*set our course of understanding that deep learning was the future*' and '*to the hiring of a deep learning engineer*' **[S6]**.

5GRIT, 2018-2019

The GDP2.1m government-funded project, 5G Rural Integrated Testbed (5GRIT, 2018-19), was a partnership of SMEs and universities, developing and testing innovative wireless solutions for rural areas. The ROVIT team employed a computer vision system that used 5G enabled technology to provide a real time assessment of visual drone data.

Economic Impact on Blue Bear Systems Research

Blue Bear Systems Research (BBSR), provided the drone innovations for 5GRIT. An Analytics Scientist at BBSR, describes how they and Kingston '*worked together and developed a weed detection model using advanced image processing and AI techniques*', that '*Kingston was particularly involved in design and build of a custom architecture deep neural network*', concluding that Kingston's model was '*crucial for driving the work package forward*'. He believes the monitoring system will have time-saving and safety implications for farmers. It also increased the visibility of BBRS - founding '*a good understanding on exploiting potential Unmanned systems, AI and 5G*' for future projects and drone operations **[S7]**.

Economic, welfare and ecological impacts for farmers and farms

The agritech applications of 5GRIT have led to farmers being able to count animals and monitor arable crop health and weed growth. The Kingston AI network increased the accuracy of real-time image analysis by 1.5 times, paving the way to safely covering 600 hectares of pastureland in 1 hour with the unmanned drone, rather than 3-4 hours on a quad-bike in dangerous conditions. Equally, agronomic data could be gathered and analysed in less than half a day rather than a week **[S7, S8]**.

As well as protecting physical health, the increased efficiency has had an impact on the mental health and wellbeing of agricultural workers. Stephen Leese of Precision Decisions Ltd. noted the above-average suicide risk in the agriculture profession and its connection to current difficulties in communication. Farmer Adam Watson explained that the hours saved through the drone means he '*could spend more time with [his] family or even go away for the day*' **[S9]**.

The economic impacts are broad. Two sheep farms in the North Pennines were studied to monitor sheep in extensive fell-lands. Farmers can save time each day knowing where sheep are, observe remotely any animal in distress and identify individual animals requiring medical intervention. Overall, medical savings could amount to GDP350-390 per year for the average sheep farm, whilst over GDP7,000 could be saved through the time saving measures. Increased real-time monitoring of arable crop health, guiding fertiliser application, increased the average yield of a North Yorkshire Farm from 10.4 to 11.7 tons per hectare. Across the farm, this resulted in an increased income of GDP2,395. In addition, such precision agricultural techniques lead to a more targeted usage of fertilizer and agrochemicals **[S8]**.

5GRIT was granted a 6-month extension by DCMS, with then Digital Minister Margot James saying 'I'm pleased 5GRIT will continue its important work to ensure our rural communities can harness the power of 5G, bringing benefits across agriculture, tourism and wider society' **[S10]**.

5. Sources to corroborate the impact

S1 – MONICA Deliverable 8.3 - Consolidated Demonstration Platform Pilot Progress Report 2

S2 – Collection of Reports on Monica Events.

S3 – Turin Council Webpage Summary of MONICA

S4 – Piano Di Risanamento Acustico Comunale 2019 (in Italian)

S5 – City of Bonn Press Release, 2019

S6 – Testimonial by the Product Manager at VCA Technology

S7 – Testimonial by an Analytics Scientist at Blue Bear Systems Research

S8 – 5GRIT Project Reports: D3.3 & D4.3

S9 – NS Business Hub' News Report on 5GRIT, 2019

S10 – 5GRIT Newsletter, Issue 3, April 2019