Institution: University of Westminster		
Unit of Assessment: 11 Computer Science and Informatics		
Title of case study: Optimisation of Imaging Quality in the Security and Smart Phone Sectors		
Period when the underpinning research was undertaken: 2009 - 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): 1. Sophie Triantaphillidou 2. Alexandra Psarrou 3. John Jarvis	**Role(s) (e.g. job title):** 1. Professor 2. Reader 3. Senior Researcher; then Visiting Professor	**Period(s) employed by submitting HEI:** (1) 05/1996 ongoing (2) 12/1992 ongoing (3) 11/2011 – 10/2015; then 11/2015+
Period when the claimed impact occurred: Aug 2013 – Dec 2020		
Is this case study continued from a case study submitted in 2014? ~~Y~~/N		

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

The research presented in this case study has impacted the practice of a number of organisations seeking to optimise the quality of image/video capture and processing:

- Transport for London adopted a standardised approach to setting CCTV recording compression levels on the London bus network, resulting in optimised quality recordings for use in police investigations.
- Spectral Edge, a UK start-up company, changed its practice by adapting the methodology and data from the above project, resulting in the enhancement of the quality of their surveillance and security products and its subsequent acquisition by Apple Inc.
- Huawei Ltd, China, streamlined its research and development methods for quantifying phone camera quality, facilitating the development of cost-effective camera systems that retain excellent image quality.

2. Underpinning research (indicative maximum 500 words)

The research of Prof Triantaphillidou, Prof Jarvis and Dr Psarrou focuses on the quantification and optimisation of image and video quality, achieved by investigating the interrelationships between visual perception, camera physics and image signal processing (ISP). The Westminster team's interdisciplinary expertise (combining physics, engineering, computing, visual science and psychometrics) makes their research unique in this field.

Research carried out during a project led by Triantaphillidou and funded by the UK Home Office identified *for the first time* lower end limits of video compression that would allow for successful face identification for policing purposes [1,2]. Rigorous methodologies were pursued for the recording of suitable CCTV footage to bus environments. Large amounts of visual image data were collected from expert and non-expert user groups (CCTV analysts, police officers, public) and subsequently analysed with high accuracy. The research was significant because it accounted for a broad range of image contents that are affected differently by video compression – skin colours, facial proximity, the angle of the face to the camera, and a number of different illumination conditions – and thus resulted in the researchers formulating video compression limits that were adjustable and relevant to the different bus scenarios and conditions.

Another strand of research undertaken by Triantaphillidou's team innovated the measurement of human vision and subsequently developed human vision models that are more suitable than traditional models for use in imaging system design and applications. Aspects of the human visual system, such as visual acuity (concerned with sharpness/blur) and sensitivity to different visual frequency ranges, are traditionally measured from viewing designated test charts (e.g. optometrists' letter charts, Gabor and sinusoidal functions). Although such test charts are well established and are universally employed, they do not provide a full account of the visual ability of humans, which, in ordinary seeing, changes in accordance with different levels of local image contrast and complexity. Over the course of a 4-year project funded by the UK's Ministry of Defence (MoD) that combined human vision modelling, image signal processing and image psychophysics, the research team developed and applied a novel experimental method for measuring human vision in relation to shape, form and detail, by replacing relevant charts with digital images depicting natural scenes. Thousands of hours of observations and rigorous analysis

returned results that allowed the team to successfully modify and subsequently validate prevailing mechanistic visual models [3,4].

The resulting models better reflect the complexity of the human vision workings when viewing images, thus making them more relevant to the design of imaging products and solutions that produce visual outputs (e.g. digital cameras, laptop, tablet screens). This was further demonstrated when the team sought to predict and enable the optimisation of the visual image quality of mobile phone cameras, via a highly productive 6-month research contract with Huawei Ltd., China [5].

The project investigated the relationship between camera sensor resolution (pixel numbers) and visual image quality, as displayed in high quality desktops and in handheld displays and perceived by the observers at relevant viewing distances. Large amounts of visual data were again collected, under strictly calibrated viewing conditions, and analysed using a variety of psychometric methods (image paired comparisons, star rating test, and acceptable/unacceptable quality tests) and relevant analysis techniques, which allowed results from different experiments to be mapped in a novel manner [6]. The research was significant because it demonstrated the extent to which higher camera sensor resolutions benefit image quality, and how optimum camera resolution is intrinsically related to the resolution characteristics of the display devices used for image viewing. The novel analysis of the research results was subsequently adopted by Huawei's camera evaluation R&D team, as described below.

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

1. A. Tsifouti, **S. Triantaphillidou**, E. Bilissi, M.C. Larabi, Acceptable bit-rates for human face identification from CCTV imagery, *Proc. SPIE*. 8653 (2013)
2. A. Tsifouti, **S. Triantaphillidou**, M.C. Larabi, E. Bilissi, and **A. Psarrou**, A case study in identifying acceptable bitrates for human face recognition tasks, *Signal Processing: Image Communication*, 36,14–28 (2015).
3. **S. Triantaphillidou**, **J. Jarvis**, G. Gupta, Spatial contrast sensitivity and discrimination in pictorial images, *Proc. SPIE*. 9016 (2014).
4. **S. Triantaphillidou**, J. Jarvis, **A. Psarrou**, G. Gupta, Contrast sensitivity in images of natural scenes, *Signal Processing: Image Communication*, (2019).
5. E. Fry, **S. Triantaphillidou,** R. Jenkin, R.E. Jacobson, J. Jarvis, Scene-and-Process-Dependent Spatial Image Quality Metrics. *Journal of Imaging Science and Technology*. 63 (6), pp. 060407-1–060407-13 (2019).
6. **S. Triantaphillidou**, J. Smejkal, E. Fry, H. H. Chuang. Studies on the effect of MegaPixel sensor resolution on displayed image quality and relevant metrics, *IS&T Electronic Imaging: Image Quality and System Performance XVII* (2020).

Funding details

- **2018/2019:** PI: Triantaphillidou, project *"Mobile phone camera image quality – Phase 1"*, 6-month commercial research contract, funded by Huawei, China, grant value £136,000.
- **2009/2017:** Director of Study, project *"Image usefulness in security recording systems"*, p/t PhD grant, funded by the UK Home Office's HOSDB (CAST, post-2011), grant value £16,000.
- **2014/2015**: PI: Triantaphillidou, project *"Understanding human spatiotemporal visual sensitivity to real scenes in the presence of noise – Phase 2",* 1-year government research contract, funded by MoD's Defence Science and Technology Laboratory (DSTL), grant value £120,000.
- **2011/2014**: PI: Triantaphillidou, project *"Understanding human spatiotemporal visual sensitivity to real scenes in the presence of noise",* 3-year government research contract, funded by MoD's DSTL, grant value £310,000.

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

Changing practice at Transport for London (TfL)

By 2009 it had become apparent that CCTV recordings in London were too often of limited usefulness in the investigation of crime. A key reason for this lack of usefulness was that CCTV system providers to TfL set their cameras in a non-standardised manner, resulting in the CCTV cameras on board its London buses producing visual imagery of varying quality. It was revealed

by the Metropolitan Police Service (MPS) that, despite the high expenditure on CCTV in London (£200m across 10 years), "for every 1,000 cameras in London, less than one crime is solved per year" [a-i].

Thus, with the participation of the TfL and the funding of a PhD studentship by the Home Office's Scientific Development Branch (HOSDB), Triantaphillidou and her colleagues undertook an applied research project aimed at addressing CCTV quality in this context, **for the first time, resulting in the standardisation of CCTV recording on London buses**.

On the basis of their investigation, the team produced a set of standards that would ensure facial recognition from CCTV recordings of bus passengers within the variety of sitting/standing scenarios and lighting conditions relevant to London Buses. It also established a methodology to derive such standards, as described in output [1]. TfL implemented the Westminster's team recommendations for CCTV recorded video in all London buses in 2014. Andrew Hyman, the Analytics Research and Data Outreach Manager at TfL, confirms that the research team's "**findings were used to set minimum CCTV quality levels for the CCTV fitted to all new buses**. This was implemented through the ITT Bus Build Specification, which sets out the bus build standards for all new buses as part of the requirements for all bus route tenders. This is mandatory" [a-ii]. This change in practice is such that, as of April 2020, the TfL have approximately 9,000 buses in the fleet that have been fitted with CCTV cameras on the basis of these specifications [a-iii].

The significance of this impact on the relevant TfL London bus practices is that human faces can now be consistently, successfully, identified from CCTV footage across all of the TfL buses, allowing it to function as **a vital tool in the investigation of crime**. Writing in 2018, Hyman notes that "[g]ood CCTV significantly increases the chances of detection" and that the TfL's "Bus CCTV is currently recognized as some of the best quality CCTV covering the public domain, which is one reason why the request for it continues to rise annually" [a-ii]. This increase in demand is confirmed by the MPS who provided the following information [a-iv], which encompasses all bus operators that must use the TfL specifications:

Financial Year	2016	2017	2018	2019
Total CCTV Requests (BUS)	10494	10985	10815	11852
Total CCTV requests provided to MPS (BUS)	8408	9268	9558	10723
Retrieval Rate	80%	84%	88%	90%

The increase in MPS demand for access to TfL bus CCTV footage demonstrates the increasing usefulness of this high-quality imagery in police investigations. While neither the MPS nor the Crown Prosecution Service record data on the number of successful prosecutions that use CCTV within its evidence [a-iv, a-v], several high-profile cases demonstrate **the usefulness of Triantaphillidou's optimised recording standards for obtaining convictions**.

Example 1: Demonstrating the effectiveness of the CCTV specifications at night time, a video recording played a vital role in the conviction of four teenagers for their homophobic attack on a lesbian couple in July 2019, which made global headlines following the release of the image of the bloodied women. The judge referred to the CCTV video several times in her judgement, stating that it proved that the suspects "quite clearly targeted this couple" [a-vi].

Example 2: The quality of the CCTV imagery, as tested under wide-ranging conditions, was such that the police were able to trace a suspect who stamped a person to death on a bus in March 2018. The camera that was positioned to film the exit door of the bus caught the suspect pressing his hand against the glass (see image on the right [a-vi]), allowing the police to lift finger prints from it, leading to his identification, arrest, and eventual conviction [a-vi].

As such, the impact on TfL practice regarding their CCTV recording has also had a positive impact on the organisations seeking to solve crime and prosecute criminals by enabling them to pursue these aims in an effective manner.

Changing practice at an imaging start-up

A secondary impact of the above engagement relates to the upskilling of a researcher who would contribute methodologies and material from the TfL project to the development a UK SME (small or medium-sized enterprise), which in turn led to its purchase by Apple Inc.

Dr Anastasia Tsifouti, a then BSc graduate of Westminster and HOSDB employee**,** undertook the aforementioned HOSBD-sponsored PhD studentship at Westminster under the supervision of Dr Triantaphillidou and aided in the successful enhancement of TfL CCTV, as described above. In Spring 2018 Dr Tsifouti joined Spectral Edge, a SME that focusses on improving pictures and videos on mass market devices on a pixel-level, via embeddable technology that can be implemented purely in software or in silicon and through techniques incorporating machine learning in real time [b-i].

Spectral Edge benefited from the methodologies and data obtained from the TfL project, **which were used to enhance the company's approach to computational photography.** This occurred both through the skills and knowledge Tsifouti brought to the company from the Westminster project, and Triantaphillidou's three-day consultancy on the image quality framework of Spectral Edge's SE Fusion technology in January 2019 [b-ii]. Subsequently, the TfL work featured in Spectral Edge's 2019 white paper: *RGB+IR Real Time Fusion for the Security and Surveillance Industry* [b-iii]. The pre-2014 bus CCTV images analysed by the Westminster team feature on page 12 of the white paper, which also communicates how Tsifouti's skills in optimising underexposed, overexposed, and mixed illumination image rendering were used in the development of their flagship SE Fusion technology, which "ensures minimal loss of resolution, while delivering improved contrast, dynamic range and signal-to-noise ratio" within its image capture process [b-iii, p.12].

In November 2019, Apple Inc. acquired the SME, with *Bloomberg* suggesting that "Spectral Edge's technology could contribute to the AI [Artificial Intelligence] Apple already uses in its Camera app by continuing to improve the quality of photos in low-light environments" [b-iv]. The specific ways in which the SpectralEdge innovations have been incorporated into Apple devices cannot be confirmed due to issues of high confidentiality. Nonetheless, following this acquisition the skills base of SpectralEdge staff, which has been positively impacted by Westminster researchers, has **fed into their role within Apple's Cambridge-based Camera and Photos Team**, which "provides innovative algorithms and image processing solutions for all of Apples world-class devices which include the most successful imaging product, iPhone as well as other camera related systems" [b-v]. Dr Tsifouti, now an Apple Inc. employee, attests to the importance of Dr Triantaphillidou to her development within this unique field: "Image quality is an important field in the development of any technology or investigation that relates to imaging. It is an interdisciplinary field, not very well understood by non image quality scientists. In addition, there are not many image quality scientists in the UK. Dr Triantaphillidou has been a great help to my development, throughout my career, as an image quality scientist. Even very recently, in 2019, I requested her consultation on image quality metrics, when I was working for a startup (SpectralEdge) that was sold to Apple" [b-vi].

Changing practice at Huawei

In their collaboration with Huawei Technologies Co Ltd, China, the Westminster researchers proposed and implemented a successful verification methodology that connected image quality prediction models with customer experience rating methods. Success in this area is confirmed by output [6] and testimony which specifies two specific changes of practice that have resulted in the impact of **creating efficiency and cost-savings within the R&D process of Huawei's Camera Testing Team**: [Text removed for publication] [c-i] [c-ii].

The optimisation of camera image quality on the basis of robust predictions of customer preference, as achieved via the intervention of Triantaphillidou and her team, is **of key significance for Huawei's commercial strategy in this area.** This is because their ever-increasing market share in the smartphone sector is driven by their constant technological improvements to their phone cameras. Huawei is second to Samsung in regard to global market share and is the leader of the China market at 42% / 97.8 million shipments in 2019, a 66% increase on the previous year [c-iii]. As *The Verge* explains, this growth is in spite of the smartphone market "experiencing its own form of recession" in recent years, with Huawei being an "exception" because they have "consistently made huge strides between every device release.

The company has invested heavily in its camera hardware, which has paid off with terrific performance (currently unmatched in low light) and has stirred smartphone owners to hit the 'upgrade' button" [c-iv]. As such, Prof Triantaphillidou and her fellow University of Westminster researchers are impacting upon Huawei's continued commercial expansion in the smartphone market by ensuring they remain the key innovators in the area of camera phone hardware.

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

[a] (i) *The Telegraph* "1,000 CCTV cameras to solve just one crime, Met Police admits" 25/8/09 [link] (ii) Email communication from Andrew Hyman, Analytics Research and Data Outreach Manager, Technology and Data, TfL. 7 August 2018. (iii) TfL FOI Ref: 0052-2021 (iv) MPS FOI Ref: 01/FOI/20/014238 (v) CPS FOI response (vi) PDF portfolio of media reports [1] [2]

[b] (i) Report on Tsifouti hiring [link] (ii) UoW/SE consultancy contract (iii) Spectral Edge White Paper. *RGB+IR Real Time Fusion for the Security and Surveillance Industry* 2019 [link] (iv) *Bloomberg* "Apple Buys U.K. Startup to Improve iPhone Picture Taking" 12/12/19 [link] and media reports on SE Fusion and iPhone [1] [2] [3] (v) *AI Jobs DB*, Camera Software - Image Processing Research Engineer at Apple (Cambridge, UK) (vi) Testimony from Dr Anastasia Tsifouti, previously of HOSBD, now Apple

[c] (i) Testimony from Huawei's Camera Testing team (ii) Approved project agreements with Huawei (iii) PDF portfolio of market share analysis from Statista, IDC, Canalys (iv) *The Verge* "Huawei's phone sales are ballooning while Apple and Samsung's slump" 01/05/19 [link]