Institution: University of East Anglia		
Unit of Assessment: 11- Computer Science and Informatics		
Title of case study: Spectral Edge Ltd.		
Period when the underpinning research was undertaken: 2006 - 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:**
Graham Finlayson	Professor	2006 to date
David Connah	Postdoctoral Fellow	2006 - 2012
Mark Drew	Honorary Professor	2017 to date
Period when the claimed impact occurred: 2013 to 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

The Colour & Imaging Lab at UEA developed revolutionary algorithms for image fusion with applications in multiple domains including photography, security and accessibility (for colour deficient observers). This research was vested in ***Spectral Edge Ltd.*** which was spun out of UEA in 2011. ***Spectral Edge Ltd.*** attracted a total of GBP6,124,000 investment including, investment from the Iceni and Rainbow Seed corn funds and two rounds of venture capital funding.

In November 2019, ***Spectral Edge Ltd.*** was acquired by Apple Inc. and the Spectral Edge technology is now being incorporated into the Apple product pipeline.

2. Underpinning research

In the EPSRC grant [A] "Colour to Greyscale and Related Transforms" (with Professor Bloj, University of Bradford), **Professor Finlayson's** research group at UEA explored image fusion in humans and, inspired by this work, developed new fusion algorithms for computer vision. At the same moment, the imaging industry started to manufacture devices (e.g. smart phones) equipped with multiple cameras which resulted in a sudden interest in, and need for, effective image fusion algorithms.

For intuitive reasons, most inquiry into image fusion operates in the edge or derivative domain, since edges are proxies for the detail we wish to fuse. In a standard methodology, for image fusion we are given N images from which we then calculate derivatives (or edges). The edges are fused together to create a composite edge-map which is reintegrated to solve for the final output image. Almost all the prior art treats image fusion as a N to 1 problem. Moreover, because the fused gradient field is, necessarily, non-integrable the fused images must both have artifacts and hallucinated detail. Spectral Edge theory teaches how to solve the more general N to M (where M is typically 3 for colour images) gradient fusion problem. In Spectral Edge image fusion [1], the available extra edge information is first be determined and is then used to accentuate the gradient field of a guide image (e.g. the original colour image). As before, the gradient field must then be re-integrated. To avoid the problems of artifacts and hallucinated detail, a new theory of integration was developed [2] which, provably, could not suffer from these problems. Spectral Edge theory was applied directly to many problems including, fusing the Near-Infra Red and visible images and bringing out more detail in diffusion tensor imaging [1].

Subsequently, the researchers at UEA, funded through an EPSRC follow-on award [B], re-imagined the Spectral Edge fusion theory as a tool for general image processing. In a first step a colour image is processed so that a specific property is enhanced. Then this property image is fused – using the spectral edge theory - with the original. As an example, the extra information that is available to observers with normal colour vision (the property image) is fused with the image available to colour deficient observers. The resulting fused image conveys dramatically more detail to colour deficient observers. In other research, a sharpened image was fused with the original to make a new and pleasing output image that had much greater local contrast (but no artefacts). In

[3], colour and thermal images were fused together as part of a solution to pedestrian detection that was both simpler and faster to execute than the prior art.

Research was a key part of Spectral Edge's mission, and UEA researchers continued to collaborate with the spin-out company up to the point of acquisition, at which time the focus was on both developing an extended theory of fusion based on a new definition of edges in images (inspired by operator theory from Physics), and [redacted]. Both of these research areas are part of the current "Future Colour Imaging" project [C], a 5-year EPSRC established career fellowship awarded to Professor Finlayson.

3. References to the research

(UEA authors in bold)

1. Spectral Edge image Fusion: Theory and Applications
   D.R. Connah, **M.S. Drew** and **G.D. Finlayson,**
   (**2014**) *The European Conference on Computer Vision*, 65-80.
   DOI: 10.1007/978-3-319-10602-1_5

2. Look-up Table based gradient field reconstruction
   G.D. Finlayson, **M.S. Drew** and **D. Connah**,
   (**2011**) *IEEE Transactions on Image Processing*, 2827 – 2836.
   DOI: 10.1109/TIP.2011.2134106

3. Multi-spectral Pedestrian Detection via Image Fusion and Deep Neural Network
   G. French, G.D. Finlayson and **M. Mackiewicz**,
   (**2018**) *The Journal of Imaging Science and Technology,* 176-181(6)
   DOI: 10.2352/J.ImagingSci.Technol.2018.62.5.050406

Underpinning Funding

A. C2GART Colour to Grey scale and Related transforms
   PI: G. Finlayson
   Funder: EPSRC
   Value: GBP327,017.00 Dates: Oct 2006 - April 2010

B. Spectral Edge Image Visualisation
   PI: G. Finlayson
   Funder: EPSRC follow-on-fund grant
   Value: GBP63,000.00 Dates: Dec 2010 - Aug 2011

C. Future Colour Imaging
   PI: G. Finlayson
   Funder: EPSRC
   Value: GBP1,046,725.39 Dates: Sep 2019 - August 2024

4. Details of the impact

Company creation and growth

Following the initial research within Finlayson's Colour and Imaging Lab in the School of Computing Sciences at UEA ***Spectral Edge Ltd.*** was incorporated in **2011 [corroborating source A]**. The Intellectual Property which formed the core of the patent portfolio underpinning ***Spectral Edge Ltd.*** included more than 10 patents covering image fusion, the integration of gradient fields, targeting images for different observers (e.g. to help colour deficient observers to see more) and in content-based image processing **[corroborating source B]**.

Early funding for ***Spectral Edge Ltd.*** came from a Technology Strategy Board Proof of Concept grant (2012-2013 GBP35,798) and an Innovate UK grant (2014-2015, GBP110,000), for developing and validating using image fusion to help colour deficient observers see more **[corroborating source C]**, together with Seedcorn funding from the ICENI and Rainbow funds

(GBP538,000) **[corroborating source D]**. In 2016 and 2018 respectively, Spectral Edge attracted venture capital investment of GBP1,500,000 and GBP4,000,000 where IQ capital and Parkwalk were the lead investors **[corroborating source E]**.

The company was initially based in Norwich before moving to Cambridge in 2014. Starting in the IdeaSpace (an incubation hub for early stage innovation), the company soon grew to a scale (6+ employees) where commercial offices were required. On acquisition at the end of 2019, ***Spectral Edge Ltd.*** was based in the Bradfield Centre on the Cambridge Science Park and employed 15 staff (headcount = 15; FTE = 15) of which 12 were software and hardware engineers.

Spectral Edge technology

Spectral Edge is a platform technology in the area of image fusion. In contradistinction to the prior art which focussed on fusing N images to 1, in the Spectral Edge approach all the detail is made available in a fused colour image (N to 3). Moreover, uniquely, the Spectral Edge algorithms produce images without artifacts or hallucinated detail, a major step forward.

Spectral Edge Ltd. first developed an algorithm called **Eyeteq** where the detail that a colour-blind observer can see is fused with the extra detail available to observers with normal colour vision. An empirical evaluation of Eyeteq processed TV and video content by the independent company *i2 media research* in 2015 showed that the resulting fused colour images convey much more information to colour deficient observers whilst simultaneously preserving colour fidelity for everyone else **[corroborating source F]**.

Nighteq followed in 2016, providing blue light reduction technology for night-time viewing and in 2017 **Vividteq** was launched, in which contrast enhanced images are fused with a colour original to deliver a pleasing more detailed and artefact free image. Vividteq was licenced to NTT Data Italia in 2018 for inclusion in their broadcast infrastructure, which allowed their broadcast customers (including Sky Italia) to deliver high-dynamic range (HDR) like images irrespective of the limitations of the end-user hardware **[corroborating source G]**. A major focus of the company was the fusion of IR and visible images, which resulted in the Spectral Edge Fusion technology being launched in 2019. ***Spectral Edge Ltd.*** built its own cameras and processing pipeline which could fuse video streams in real time. This technology was being deployed commercially shortly before acquisition **[corroborating source H]**.

Throughout development the Spectral Edge Technology proceeded with help and advice from industry experts, including the CEO of Agile Analog:

> "I was very impressed with the core technology, and leapt at the chance to join the Spectral Edge Advisory Board, to enhance and assist in the future technology direction.
>
> Given the quality of the underlying technology it is no surprise that Spectral Edge was acquired by such a global technology leader."
>
> **[corroborating source I]**

Acquisition of Spectral Edge Ltd. by Apple Inc.

In November 2019 ***Spectral Edge Ltd.*** was acquired by Apple Inc. with the Spectral Edge technology now being incorporated into Apple's product pipeline. The Director, Cameras and Photos Software Engineering at Apple has confirmed that:

> "Through Apple's relationship with Professor Finlayson and University of East Anglia we were able to monitor the steady progress of Spectral Edge as they built their core technologies and talented team of engineers - several of which were a product of UEA's Colour & Imaging Lab. The development of fundamental Spectral Edge algorithms into practical engineering deliverables gave us the confidence that these could quickly make an impact on Apple products and improve experiences for our customers. This team has also helped us attract new talent to grow our expertise at a new Apple facility in Cambridge."
>
> **[corroborating source J]**

An additional benefit of the acquisition is that the initial investments made in ***Spectral Edge Ltd.*** returned a significant profit to the investors, including the University of East Anglia, with the investment returns to both the ICENI Seedcorn Fund and IQ Capital now being invested in new ventures **[corroborating sources D and E]**. The acquisition was also significant for a number of ***Spectral Edge Ltd.*** employees, with 10 of the engineers being hired by Apple Inc. and the core Spectral Edge team being at the heart of Apple's major expansion of its business in Cambridge.

5. Sources to corroborate the impact

[A] Companies House certificate showing formation of Spectral Edge Ltd. in 2011

[B] Underpinning IPR portfolio details

[C] Technology Strategy Board (TSB) Grant 2012-2013 and from page 7, Innovate UK Grant 2014-2015 details

[D] Letters from the Investment Director of the UK Innovation & Science Seed Fund and from the Fund Advisor for the Iceni Seedcorn Fund confirming funding amount, both November 2020.

[E] Confirmation of venture capital investment from the Managing Partner at IQ Capital (Dec 2020) and the CEO of Parkwalk (Nov 2020)

[F] i2 media research report (Oct 2015) on the evaluation of Eyeteq processed TV and video content

[G] NTT Data and Spectral Edge bring HDR-like experience to any TV – article from advanced-television.com 05.04.2018 (Downloaded September 2020)

[H] Spectral Edge Launches RGB and NIR Spectral Edge Solution for Surveillance Market - article from risk-uk.com, 29.03.2019 (Downloaded September 2020)

[I] Testimonial from CEO, Agile Analog (March 2021)

[J] Supporting statement from the Director, Cameras and Photos Software Engineering at Apple Inc. (Jan 2021)