

Institution: The University of Manchester		
Unit of Assessment: 11 (Computer Science and Informatics)		
Title of case study: Ground breaking computer vision research revolutionises digital entertainment		
Period when the underpinning research was undertaken: 2000 – 2010		
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:
Professor Chris Taylor	Professor	1970 – present
Professor Tim Cootes	Professor (2005 – present) Senior Lecturer (2002 – 2005) Lecturer (2001 – 2002) Research Fellow (pre 2001)	1991 – present
Dr Carole Twining	Lecturer (2010 – 2020), RCUK Fellow (2005-2010), PDRA (1999-2005)	1999 – 2020
Dr David Christinacce	PDRA (2004 – 2009) PhD Student (2000 – 2004)	2000 – 2009
Dr Kola Babalola	PDRA	2003 – 2011
Dr Vlad Petrovic	PDRA	2002 – 2016
Period when the claimed impact occurred: 1 August 2013 – 31 December 2020		
Is this case study continued from a case study submitted in 2014? Y		
1. Summary of the impact		
<p>Computer vision research developed ground-breaking methods for model-based image interpretation that can be used for accurate facial motion capture. The research underpinned the commercial success of two companies founded by members of the University of Manchester research team: Image Metrics and Cubic Motion. Their technology, which allows super-realistic performance capture, has been used extensively in prize-winning films, computer games and mobile apps, resulting in significant cultural impact, over [text removed for publication] jobs, and turnover in the assessment period of over [text removed for publication]. Cubic Motion was acquired in 2020 by leading game developer Epic Games.</p>		
2. Underpinning research		
<p>The research was undertaken by a University of Manchester team led by Taylor and Cootes, including external collaborators Gareth Edwards and Kevin Walker (previously Taylor and Cootes' PhD Students). The aim was to build on previous work, to develop robust methods of automated image interpretation, with applications in face image interpretation. The team had previously introduced the idea that interpretation of a particular class of images could be based on generative models of shape and appearance, learnt from a training set of similar images. In this period they extended the approach, writing the definitive paper on the topic [1], and developing extensions that improved its applicability and performance significantly. The key findings were:</p>		
<ol style="list-style-type: none"> 1. Active Appearance Models (AAMs), joint statistical models of shape and photo-realistic appearance, could be 'learnt' from a training set of images and fitted automatically to unseen images of the same class, using a new iterative algorithm. Face images were used as a practical example. This provided a basis for tracking faces in videos, locating individual facial features, and recognition (identity, expression, gender, age) [1]. 2. The approach in [1], which could only deal with face images that were $\pm 10^\circ$ of full frontal, could be extended to deal with face images of arbitrary pose, by building, and selecting automatically from a small library of AAMs, generated from images obtained in different poses [2]. 		

3. The method in [1] for building an AAM, which involved manual mark-up of corresponding points in the training images, could be automated, and improved, by identifying statistically distinctive points in a set of images of a given individual, and finding a maximally consistent set of matches across the set [3].
4. The accuracy and reliability of fitting an AAM to medical and face images could be improved significantly by including non-linear representations of local image structure in the appearance part of the model [4].
5. The method of representing joint variation in shape and appearance in [1] could be improved by decomposing the appearance into a set of local 'patch' models. This allowed fitting of the joint model to unseen images to be driven directly, by finding, at each iteration, positions of best match for each of the patches, resulting in more accurate tracking in face videos [5].
6. High quality joint shape and appearance models of faces could be generated automatically, generalising, and improving significantly, on the method in [3], by using a group-wise registration method. The approach was based on varying, simultaneously, a deformation field for each image in the training set, so as to optimise an objective function that favoured well-matched normalised intensities and low deformation gradients [6].

3. References to the research

The research was published in leading journals, including one of the top journals in the field (IEEE Transactions on Pattern Analysis and Machine Intelligence), and leading conferences. Output [1] is in the top 0.38% of papers (26/6721) by citations*, in the leading journal in which it was published, with 2972 citations (still averaging 200 citations *p.a.* over the past 5 years).

* All citations Web of Science (WoS) unless noted otherwise

Key Publications

- [1] **T.F.Cootes**, G.J. Edwards and **C.J.Taylor**. "Active Appearance Models", IEEE Pattern Analysis and Machine Intelligence (PAMI), Vol.23, No.6, pp.681-685, 2001.
[DOI: 10.1109/34.927467](https://doi.org/10.1109/34.927467). [2972 citations].
- [2] **T.F. Cootes**, G. Wheeler, K. Walker, and **C. J. Taylor**, "View-based active appearance models," Image and Vision Computing, Vol. 20, pp. 657-664, 2002.
[DOI: 10.1016/S0262-8856\(02\)00055-0](https://doi.org/10.1016/S0262-8856(02)00055-0). [152 citations].
- [3] K.N. Walker, **T.F. Cootes**, and **C J. Taylor**, "Determining correspondences for statistical models of appearance," Proc. European Conference on Computer Vision, pp.829-843, 2000. [DOI: 10.1007/3-540-45054-8_54](https://doi.org/10.1007/3-540-45054-8_54). [not indexed by WoS, 9 Google Scholar citations]
- [4] I.M. Scott, **T.F. Cootes**, and **C.J. Taylor** "Improving Appearance Model Matching Using Local Image Structure", Proc. Information Processing in Medical Imaging, pp. 258-269, 2003. [DOI: 10.1007/978-3-540-45087-0_22](https://doi.org/10.1007/978-3-540-45087-0_22). [52 citations]
- [5] **D. Cristinacce** and **T.F.Cootes**, "Feature Detection and Tracking with Constrained Local Models", Proc. British Machine Vision Conference, Vol. 3, pp.929-938, 2006.
[DOI: 10.5244/C.20.95](https://doi.org/10.5244/C.20.95). [not indexed by WoS, 883 Google Scholar citations]
- [6] **T.F. Cootes**, **C.J. Twining**, **V.S. Petrovic**, **K.O. Babalola**, and **C.J. Taylor**, "Computing Accurate Correspondences across Groups of Images," IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 32, No. 11, pp. 1994-2005, 2010.
[DOI: 10.1109/TPAMI.2009.193](https://doi.org/10.1109/TPAMI.2009.193) [47 citations]

4. Details of the impact

Context

The new generic approach to image interpretation, established by the research, has achieved significant impact reaching across multiple domains. In face image analysis, the approach has proved highly influential – in awarding an IEEE Face and Gesture Conference Test of Time

award in 2015, the citation described the work as having '*Inspired many (if not all) subsequent work on deformable models for face analysis*' [A].

Pathways to impact

There have been many commercial applications of technology based on the published research. We focus on two where the evidence is clear-cut. **Image Metrics** was founded in September 2000 by team members Gareth Edwards and Kevin Walker. Building on the body of research, to which they had made a significant contribution, they developed software for facial motion capture for use in film and high-end video game production. Having left Image Metrics, Gareth Edwards founded **Cubic Motion** in 2009, to bring performance-driven facial animation to the computer games market, again developing facial motion capture software that built on the research. In both cases, the **facial motion capture technology is core to the company's success** [B, C]. As well as Gareth and Kevin, seven other members of Taylor and Cootes' Lab have worked for the two companies, including four who currently occupy senior positions. Five of these moved from the University of Manchester in the period 2000-2010, and one in 2016. Taylor also acted as Scientific Advisor to Cubic Motion from 2009-2020.

Reach and significance of impact

Image Metrics and Cubic Motion are direct beneficiaries of the research, between them achieving turnover exceeding [text removed for publication] in the assessment period, with over [text removed for publication] current employees. Significant indirect beneficiaries are film, game and app developers who have delivered both economic and cultural impact.

Image Metrics

During the previous REF assessment period, Image Metrics achieved significant success providing facial animation for major movies and games. From 2012 it repurposed the technology, becoming a world-leading provider of Augmented Reality and hyper accurate facial detection solutions. The Makeup Genius virtual makeover app, developed in collaboration with L'Oreal Paris and launched in 2013, has had [text removed for publication] downloads in the assessment period. In 2015, it won eight Cannes Lion Awards and a Golden Clio Award. Other notable developments include the Turned Zombie, HOOYA, and Die Hard Fan face-painting apps. Die Hard Fan, which targets sports fans, won Silver Clio and Cannes Bronze Lion awards in 2016, and was adopted by the Rio Olympics, Baltimore Ravens, and Chicago Bears. In 2018, Image Metrics licenced its augmented reality technology to Chinese social media giant, Baidu, who have used the technology to implement social face AR filters in its applications.

Image Metrics' technology is also licensed, for applications in the visual effects, gaming, feature film, and animation industries, to sister company Faceware Technologies. Their products have been used on hundreds of titles, including Oscar-winning feature films, 7 of the top 10 AAA games from 2016-2020, and by over 2,000 studios and institutions in 75 countries on 6 continents [B].

Image Metrics and Faceware currently employ more than [text removed for publication] staff, with locations in Manchester, Los Angeles, Las Vegas, Austin and Puerto Rico, and have generated income in the assessment period in excess of [text removed for publication] [B].

Chief Technical Officer of Image Metrics, Kevin Walker, is on record as saying "*Without the foundation laid by the University of Manchester research, Image Metrics would not have achieved the success it has.*" [D]

Cubic Motion

During the REF assessment period, Cubic Motion has grown to become the leading provider of automated performance-driven facial animation to the global video games market, with Triple-A clients including: Epic Games, Electronic Arts, Supermassive Games, Sony and Sledgehammer Games. During the assessment period, Cubic Motion have provided the facial animation for titles with more than 50,000,000 Sony PS4 sales [E] and 10 BAFTAs [F], including: Marvel's Spider-Man; Call of Duty: WWII; God of War; Horizon Zero Dawn; Hellblade: Senua's Sacrifice; The

Dark Pictures Anthology: Man of Medan; Westworld Awakening; Blood and Truth; Metro Exodus; and Hidden Agenda.

The following quotations give a measure of the company's standing in the industry:

CEO of Epic Games: "*Cubic Motion's real-time facial performance capture is awe-inspiring*" [C];

Co-founder Rocksteady Studios: "*Cubic Motion's facial animation service stands alone ... It enables the creation of completely credible digital characters*" [C];

Founder and CEO, Cloud Imperium Games: "*Cubic's facial animation technology is ... the best facial animation technology we've seen*"[C];

GamesBeat: "*the characters are stunningly realistic, as if you're looking at the real actors and actresses*" [G].

The turnover of the company has risen rapidly over the REF assessment period, starting at below GBP1,000,000 and rising to more than GBP10,000,000 for the year ending 30 June 2020 (from GBP4,200,000 the previous year), with the total for the period in excess of GBP20,000,000. The number of employees has grown over the same period from 55 in 2016/17 to 104 in 2019/20. In March 2020, Cubic Motion was acquired by market leader Epic Games for an undisclosed sum [C].

Director of R&D for Cubic Motion, Gareth Edwards, is on record as saying "*The University of Manchester research, in which I played a part, was game-changing, and, along with subsequent work from Taylor and Cootes' group, laid the foundations for the success of Cubic Motion*" [C].

5. Sources to corroborate the impact

- [A] Letter from Chair of IEEE Face and Gesture conference 2015 confirming Enduring Impact Award and citation.
- [B] Letter from the Chief Technical Officer of Image Metrics, including confirmation of: key role of the research, company achievements, financial and staffing details. (February 2021)
- [C] Letter from the Research and Development Director of Epic Games Animation Ltd (Cubic Motion), including confirmation of: key role of the research, company achievements, financial and staffing data, use of quotations from industry experts, personal quotation for use in the case study, sale to Epic Games. (February 2021)
- [D] Email from Chief Technical Officer of Image Metrics, agreeing quotation for use in the case study. (February 2021)
- [E] List of best-selling PS4 games captured from https://en.wikipedia.org/wiki/List_of_best-selling_PlayStation_4_video_games 11/02/2021
- [F] British Academy Games Awards 2018 and 2019 captured from <https://www.bafta.org/media-centre/press-releases/games-awards-winners-announced-2018> and <https://www.bafta.org/media-centre/press-releases/winners-announced-british-academy-games-awards-in-2019> 11/02/2021
- [G] Gamesbeat review commenting on Cubic Motion technology captured from <https://venturebeat.com/2015/08/24/until-dawn-is-a-scary-and-riveting-interactive-horror-movie/> 11/02/2021