Institution: University of Surrey

Unit of Assessment: UOA 13 Electrical and Electronic Engineering, Metallurgy and Materials

Title of case study: Computer Vision for Stereo 3D Film Production

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

The introduction of computer vision algorithms that allow creation of stereo 3D content in film and broadcast using conventional 2D monocular video cameras has permitted fundamental advances in the 3D reconstruction of complex real-world dynamic scenes from video, enabling the rendering of stereo views from a single camera view. Technology introduced by Surrey has been used for 3D scene analysis by the UK company, The Foundry, in their film post-production for major Hollywood 3D film productions (Avatar, Harry Potter, Planet of the Apes, Tron, The Hobbit). Since 2007, The Foundry has transformed to become the leading provider of 3D stereo production software tools to the global visual effects industry, growing from 20 to over 200 employees.

2. Underpinning research (indicative maximum 500 words)

Stereo 3D production requires the use of a high-precision camera rig to align a pair of moving and zooming cameras. This introduces a number of significant limitations:

(1) all stereo parameters (inter-ocular distance, convergence, zoom) are fixed at the time of acquisition;

(2) distortion between the stereo views occurs due to zoom and colour differences;

(3) camera movement is restricted due to the stereo rig. Correction of distortion and adjustment of stereo parameters in post-production is highly labour intensive and restricted to the captured camera views.

Research conducted at Surrey in collaboration with The Foundry (www.thefoundry.co.uk) a world-leader in film post-production tools and the BBC, supported by Royal Society, TSB and EU funded projects (2007-11), has introduced a number of significant advances in robust through-the-lens 3D scene analysis. The advances greatly increasing the flexibility in stereo 3D production and allow stereo image pairs to be produced from monocular camera views. The fundamental research advance at the University of Surrey underpinning this technology is the introduction of robust computer vision algorithms for 3D reconstruction from video of complex natural scenes [1,2]. The foundations for this technology are based on early research [5-6] which pioneered the use of multiple view images and video to capture 3D shape, and introduced the use of this technology for content production.

A significant research challenge faced by Surrey researchers has been the reconstruction of highly dynamic elements, such as people, whilst maintaining video-quality stereo rendering. This has been achieved by pioneering research introducing a framework for joint segmentation and reconstruction from multiple view video [2] which robustly solves two classical problems in computer vision. Information across views is exploited to overcome the inherent ambiguity in single view video analysis. This framework provides the basis for both manipulation of stereo 3D acquisition in post-production and creation of stereo image pairs from a single moving monocular cameras as used in conventional production. This research has recently been extended [3,4] to introduce the first integrated pipeline for 3D reconstruction of both background scene and

foreground live action. This pipeline was used by film production company BUF in EU project i3Dpost and demonstrated in the productionof The Midas Touch (2011).

This research was led by Prof. Adrian Hilton in Surrey's Centre for Vision, Speech and Signal Processing (CVSSP) working with post-doctoral researchers Dr. Jean-Yves Guillemaut (appointed Lecturer in 3D Computer Vision, April 2012). Early research at Surrey [4] was conducted by Dr. Jonathan Starck as a PhD and post-doctoral research before he joined The Foundry to lead their research team. The Foundry has exploited Surrey research advances in 3D video analysis to extend their software tools (NUKE) from 2D compositing to full 3D video editing. This has led to NUKE becoming the industry leading 3D stereo production tool widely used through the global film industry.

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

1. Hilton, A., Guillemaut, J.-Y., Kilner, J.J., Grau, O. and Thomas, G., 3D-TV Production from Conventional Cameras for Sports Broadcast, IEEE Transactions Broadcasting, 57(2): 462-476, 2011 (Grau, Thomas are co-authors from BBC Research)

2. Guillemaut, J.-Y. and Hilton, A., Joint Multi-layer Segmentation and Reconstruction for Free-Viewpoint Video Applications, International Journal of Computer Vision, 93(1):73-100, 2011

3. Kim, H., Guillemaut, J.-Y., Takai, T. and Hilton, A. Dynamic 3D Scene Capture and Reconstruction for Outdoor Production in IEEE Transactions on Circuits and Systems for Video Technology, 22(11): 1611----1622, 2012

4. Kim,H. and Hilton,A. 3D Scene Reconstruction from Multiple Spherical Stereo Pairs in International Journal of Computer Vision (accepted for publication January 2013) http://link.springer.com/article/10.1007%2Fs11263-013-0616-1

5. Starck, J., Nobuhara, S., Maki, A., Hilton, A. and Matsuyama, T. The Multiple Camera 3D Production Studio, IEEE Transactions on Circuits and Systems for Video Technology 19(6):856-869, 2009 (with international collaborators Nobuhara, Maki, Matsuyama from Univ. of Kyoto, Japan)

6. J. Starck and A. Hilton. Surface Capture for Performance-Based Animation. IEEE Computer Graphics and Applications, 27(3):21—31, 2007.

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

"Surrey, collaborating closely with The Foundry across two funded research projects, have made advances in 3D computer vision which have greatly assisted us in the development of our industry-leading tools for stereo-3D film production."
Founder and Chief Scientist, The Foundry.

Introduction of a computer vision framework allowing robust reconstruction and analysis of real-world scenes has had a direct impact on stereo 3D production in film and broadcast. Significant contributions include:

- Pioneering computer vision technology allowing stereo 3D production from a single moving camera. This allows stereo production from the principal film camera view without the need for a stereo camera rig.

- Full control of stereo parameters in post-production for film and broadcast allowing correct rendering for different screen formats and avoiding the need for manual correction of visual distortion. This greatly increases the flexibility of stereo production for both film and broadcast.

- Stereo production of stadium sports using conventional broadcast cameras avoiding the need for expensive stereo camera rigs and making possible simultaneous stereo 3D production alongside conventional broadcast. Prototypes of this technology have been used in conjunction with the BBC for a variety of stadium sports (football, rugby, ski-jump).

- Integration with The Foundry of robust visual analysis in industry leading film post-production software to increase flexibility in stereo production (Ocula) and video editing for visual-effects (NUKE).

- Stereo 3D film production and post-production through integration of computer vision technologies in The Foundry's NUKE product which has been used on major stereo film productions (Avatar, Harry Potter, Pirates of the Caribbean, Batman)

Advances in robust visual reconstruction have been directly exploited by UK industry collaborations in broadcast (BBC), film post-production tools (The Foundry) and film post-production (Framestore, DoubleNegative). Framestore and DoubleNegative are the two largest UK film post-production companies with 500-1000 employees working on visual-effects for major film releases (Avatar, Harry Potter, Batman) and have both received Academy Awards (Oscars) for their work.

Exploitation of the robust visual reconstruction and stereo 3D rendering in film post-production has been realized though The Foundry's NUKE software. This research has extended NUKE functionality from a 2D compositing package to a 3D post-production tool which is established as the market leader in stereo post-production. This is evidenced by use of NUKE as the major tool in the recent wave of blockbuster stereo 3D films (Avatar for example) and recognition of The Foundry as one of the fastest growing UK technology companies.

The Foundry has expanded from c. 20 people in 2007 to >200 in 2013. Dr. Jonathan Starck who transferred across to The Foundry in 2008 from the University of Surrey to work on NUKE is now their Lead Researcher heading up the company's research team. The Foundry has been listed in the Sunday Times Microsoft Tech Track top 100 each year from 2010-13 as one of the UK's fastest growing technology companies.

The technology introduced in collaborative projects is licensed to The Foundry and BBC under the terms of the i3Dlive and i3Dpost collaborative agreements. The IP is primarily realized as mathematical methods, software and know-how and therefore not directly applicable for patent protection.

Following the success of NUKE for stereo 3D production, The Foundry has become one of the leading software providers to the global visual effects industry; their revenue increased from £6.1M in 2009 to £14.9M in 2010 with a tripling of personnel from 35 to more than 100. The Foundry was acquired in March 2012 by the Carlyle Group for an undisclosed sum and ranked 10th in the 2012 Sunday Times Deloitte Buyout 100.

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

- **C1.** Founder and Chief Scientist, The Foundry. Contact details provided.

- **C2.** BBC Lead Researcher. Contact details provided.

- **C3.** BBC Blue Peter, broadcast February 2011, use of 3D reconstruction technology for ski-jump Guinness book of records attempt
http://www.bbc.co.uk/blogs/researchanddevelopment/2011/03/rd-and-blue-peter--ski-rossend.shtml

- **C4.** Ocular product launched by The Foundry in 2008 now a leading film industry tool for stereo post-production http://www.thefoundry.co.uk/products/ocula/

- **C5.** The Foundry were listed in the Sunday Times Tech Track 100 from 2010-13 as one of the UK's fastest growing technology companies:
http://www.thefoundry.co.uk/articles/2012/09/18/411/the-foundry-places-in-tech-track-100/
http://www.thefoundry.co.uk/articles/2012/03/23/330/the-foundry-ranks-10th-in-the-sunday-times-buyout-track-100/