Institution: 10007140 Birmingham City University

Unit of Assessment: UoA11. Computer Science and Informatics

Title of case study:
Augmented Reality and Virtual Reality interaction and quality of experience for industry and healthcare

Period when the underpinning research was undertaken: 2011 - 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:
Dr Ian Williams [IW]	**Associate Professor in Digital Media Technology and Head of the digital Media Technology Lab (DMT Lab)**	**2008 – present**
Dr Maite Frutos-Pascual [MFP]	**Senior Lecturer in Digital Media Technology**	**2015 – present**
Dr Andrew Wilson [AW]	**Associate Professor**	**2003 – present**

Period when the claimed impact occurred: 2014-present

Is this case study continued from a case study submitted in 2014? Y/N
N

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

The Digital Media Technology (DMT) Lab at Birmingham City University has developed world-leading research to improve the quality of experience and interaction capabilities of Augmented and Virtual Reality systems (AR/VR). This research has been adopted by industry internationally, including Glaxo Smith Kline (GSK), and in two NHS Trusts. The impact has been in product analysis, consumer environment design, new tool development and new product evaluation, resulting in new projects, tools, practices and cost savings. Furthermore, a series of AR/VR events have informed, educated and inspired traction in industry awareness. A range of clinical medical simulations including a world first inexpensive VR ophthalmology training application which has significantly improved trainee doctors' confidence and ability to perform this procedure in patients in the future. Finally, the design of an AR platform for delivering radiotherapy training and treatment has been formally agreed with a major NHS cancer centre.

2. Underpinning research (indicative maximum 500 words)

DMT Lab's research in AR/VR overcomes barriers to AR/VR use in real-world situations, specifically focusing on improving realistic barehand (without controllers/devices) based virtual object interaction (grasping, lifting and using) **[R1-R6]**. This research has been disseminated in world leading academic events and venues of significant status, winning best paper awards and nominations **[R6]** and invited submissions into leading journals **[R1]**. Events include IEEE ISMAR **[R2**], IEEE TVCG **[R1]**, IFIP Interact **[R6]** and ACM CHI **[R5]**.

One of the first studies into barehand based interaction in AR/VR was presented in **[R1]**. This quantified the magnitude of errors in user interactions across a range of tasks (e.g. lifting, moving), object sizes and interaction constraints (e.g. speed, direction). Findings showed that the interaction errors could be modelled and are dependent on the size of the virtual object and the user's hand placement. Furthermore, two novel objective interaction metrics were presented giving a framework for improving the user experience **[R1]**. Expanding on the work defined in **[R1]** the first evaluation of barehand grasping for virtual objects in AR was presented in **[R2]**. This explored the accuracy of grasping virtual objects and the influence of shape, size and location. Recommendations for a more accurate object interaction were presented based on speed and location accuracy (i.e. how close users are to the virtual object when interacting). Continuing the objective interaction metrics resulted in **[R1]** two new interaction accuracy metrics which contribute to the field of objective interaction analysis **[R2]**.

Visual presentation of virtual objects in AR/VR was also addressed in the research of **[R3]** which explored different object rendering techniques (i.e. drop shadows) on barehand interaction. The results illustrated that drop shadows reduce completion times and also significantly improved user's estimation of virtual object position. Further research into the visualisation methods is presented in **[R4]** which evaluated multiple viewing angles. Results found that significant improvements for object location accuracy using the dual view technique are achievable, and alongside the findings from **[R3]**, improve the longstanding issue with visual convergence and divergence problems in AR interaction.

Virtual object contextual information (task, temperature, and appearance) has been explored in the research **[R5]**. Differences in grasping patterns in VR compared to real object interaction were presented objectively. Results showed that visual contextual information on the object properties (temperature, weight, size, shape and function) influence a user's grasp choice and accuracy. Furthermore, that a smaller set of grasp choices are applied when grasping virtual objects compared to real objects **[R5]** leading to design recommendations for AR/VR.

Finally, interaction methods for object manipulation (selection, rotation, translation and scale) were reported in the research **[R6]**. Evaluations of metaphoric interaction (indirect to object) and isomorphic interaction (direct to object) were researched. Results showed the isomorphic interaction was more accurate (time, location and usability) with tasks that required the movement and position of virtual objects. This research led to improved interaction and addressed the lack of guidelines and standard interaction paradigms between AR/VR devices.

In addition to products designed through lab experimentation, Dr Andrew Wilson's research into enhancing engagement, satisfaction and improved adoption of emerging technologies in healthcare has resulted in the development of a heuristic framework for the development of game-based simulations **[R7]**. This research has been applied in the collaborative development of several clinical simulations including a world first VR app that uses gamification to teach medical students how to correctly perform an examination of the back of the eye **[R8]**. This study was the first to look at alternative and more timely assessment approaches to the gold standard randomised controlled trial that is routinely used in medicine. It is the first study ever to report on the use of the Technology Acceptance Model for the evaluation of medical education software in working clinical settings. It was successfully used to measure students' self-efficacy given that self-confidence and perseverance are extremely important for clinical competency. Dr Wilson's research provides a strong evidence-base that specifies many human factors that software engineers need to consider when developing medical simulations

Our work in AR/VR has been awarded several funded projects (**RG1, RG2, RG3, RG4, RG5**).

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

[R1] G. Hough, I. Williams, C. Athwal, (2015)Fidelity and plausibility of bimanual interaction in mixed reality, IEEE transactions on visualization and computer graphics 21 (12), 1377-1389,. Available at: https://www.open-access.bcu.ac.uk/561/

[R2] Al-Kalbani, M., Williams, I., & Frutos-Pascual, M. (2016, September). Analysis of Medium Wrap Freehand Virtual Object Grasping in Exocentric Mixed Reality. In *15th IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, 2016. Available at: https://www.open-access.bcu.ac.uk/4109/

[R3] Al-Kalbani, M., Frutos-Pascual, M., and Williams, I. (2020) "Evaluation of Drop Shadows for Virtual Object Grasping in Augmented Reality," in IEEE Computer Graphics and Applications, vol. 40, no. 4, pp. 10-25, 2020. IF 1.627. Available at: https://www.open-access.bcu.ac.uk/9216/

[R4] Al-Kalbani, M., Frutos-Pascual, M. and Williams, I. (2016. November). Improving Freehand Placement for Grasping Virtual Objects via Dual View Visual Feedback in Mixed Reality. In *22nd ACM Symposium on Virtual Reality Software and Technology (VRST)*, 2016. ACM, pp. 279- 282. Core A. Available at: https://www.open-access.bcu.ac.uk/4106/
[R5] Blaga, A., Frutos-Pascual, M., Creed, C., Williams, I. (2020) "Too Hot to Handle: An Evaluation of the Effect of Thermal Visual Representation on User Grasping Interaction in Virtual Reality". ACM CHI Conference on Human Factors in Computing Systems 2020, pp. 1-16. Core A*. Available at: https://www.open-access.bcu.ac.uk/9213/
[R6] Frutos-Pascual, M., Creed, C. and Williams, I. (2019) "Head Mounted Display Interaction Evaluation: Manipulating Virtual Objects in Augmented Reality". IFIP Conference on Human-Computer Interaction, pp. 287-308 Core A. Best Paper Winner, Reviewer's Choice. Available at: https://www.open-access.bcu.ac.uk/7755/
[R7] Wilson AS, Broadbent C, McGrath B and Prescott J. (2017). Factors associated with player satisfaction and educational value of serious games IN M. Ma and A. Oikonomou (eds) Serious Games and Edutainment Volume II. Springer International Publishing pp513-535. Available at: https://www.open-access.bcu.ac.uk/4123/
[R8] Wilson A.S., O'Connor, J., Taylor, L. and Carruthers, D. (2017) "A 3D Virtual Reality Ophthalmoscopy Trainer". Clinical Teacher (Wiley Online). 14(2). Available at: https://www.open-access.bcu.ac.uk/4837

The following grants (to the value of GBP350,000) were awarded following rigorous peer review processes: **RG1** Grant # 132812 (Innovate UK), **RG2** Grant #AH/T001348/1 (AHRC), **RG3** Grant #KTP011503 (Innovate UK), **RG4** Grant #KTP011890 (Innovate UK), **RG5** Grant #MID-A3 (Innovate UK)

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

Our research has been applied into multiple industries, departments, practices and procedures and has been adopted internationally.

Impact on consumer healthcare: shopper analysis and product packaging

GlaxoSmithKline (GSK), the global pharmaceutical company, used the research to develop novel insights, practices and policies for adopting AR/VR into the GSK consumer healthcare (CH) business. "Working with the expert team at BCU gives us the opportunity to use the latest technological developments to understand factors influencing consumers' decisions about how best to take care of themselves and their families." UK & Ireland General Manager for GSK Consumer Healthcare **[S01]**.

The research **[R1- R5]** has enabled GSK's Shopper Science Lab (SSL) to grow via a "significant uptake in the technology" **[S01]** leading to a growth in the number of their AR/VR projects undertaken from 2016 to 2019 and increased value. From the research "the total number of Virtual Reality projects applied by GSK's SSL has grown from 6 per annum in 2015 to 33 per annum by 2019" **[S01],** via "significantly reduced turnaround time, cost and improved quality for each project" **[S01]**. Furthermore, "when benchmarked against standard agency fees to develop comparable projects at [removed for publication] per day, GSK save approximately [removed for publication] per project" **[S01]**; therefore, the research resulted in a saving of [removed for publication] in 2019 alone. These projects have covered products, shops and clients over a large geographic area, notably across the five market regions of Europe, Middle East, Africa, America and Asia-Pacific.
Furthermore, the research of Dr Williams and Dr Frutos-Pascual **[R1- R5]** has resulted in tools being applied in GSK SSL to "expand the range of services the Shopper Science Lab provides across GSK, [removed for publication] **[S01]**. These tools are embedded into the "AR platform called Shopper Toolkit (STAR) that allows sales reps to demonstrate our latest marketing materials" **[S01]**. [removed for publication] The tools in STAR embed the teams

research from AR and VR interaction and include an interactive AR store layout configurator which allows designers and sales representatives to quickly mock up and review CH store designs in a novel and engaging way; an interactive AR packaging designer for CH products which allows for the rapid changing, presentation and assessment of alternative designs of product packaging during shopper trials; and also an AR virtual pharmacist which can interact with and assist users in real-time.

The research has also impacted GSK company understanding, learning and participation via a series of webinars and events **[S01]**. These attracted a "total of 546 attendees across the business" **[S01]** from a range of geographic markets in North America (USA, Canada), Europe (UK, Ireland, Switzerland, Belgium, Portugal, Italy, Spain, Cyprus), East Asia (Pakistan, India, Singapore) and Africa (Egypt)–**[S01]**, as well as 1575 companywide interactions **[S01]**. These have produced three new projects for GSK **[S01]**, two with [removed for publication], and one with [removed for publication] **[S01]**.
[removed for publication] deployed a product trial, based on our research, for consumer education of healthcare using STAR. Following positive feedback, [removed for publication] have developed a schedule for rollout of the work during 2021. "We actually can have it rolled out in 2021!" [removed for publication] **[S01]**.
In additional to tools and platforms, the team's research **[R1- R5]** also enabled GSK to develop the AR Playbook, an AR/VR document detailing results, tools, and applications for CH change. The playbook "has been used across GSK to communicate the potential of Augmented Reality technology and guide stakeholders as they execute projects" **[S01]**. This is impacting company policy leading to increased business education, awareness and traction for AR and VR technology throughout all divisions GSK worldwide **[S01]** and has gained 1,388 interactions (views, likes, shares and comments) for two VR/AR meet-ups on GSK's Facebook page, Workplace **[S01]**.

Impact on manufacturing: product design and product promotion

Outside of CH the team's research **[R4, R5, R6]** has also made impact with Murray Uniforms and Holosphere UK. Murray, one of the UK's leading workwear manufacturers, are using the research in the Murray AR Visualisation and Design Tools platform to revolutionise workwear design **[S02]**. Based on DMT Lab's research, the AR Visualisation and Design Tools (ARVID) allows Murray Uniforms to *"help designers to showcase [their work] and create new patterns, while enabling clients to take an active role in the [creative] process,"* says Murray's Head of Design **[S02]**. ARVID is impacting the design workflow from conception through to design and development **[S02]**.
Holosphere UK used the research to develop a novel AR vehicle promotion system when they "quickly realised they [DMT Lab] would be perfect academic partners. Holosphere worked with the team to design, develop and evaluate a proprietary AR system for the automotive sales sector". Supporting growth in the company "Since then we have called upon the DMT Lab for input on a number of projects and potential funding opportunities and they have supported us with advice and expertise from academia and research in our field" **[S03]**.

Impact on medical education and care: VR/AR solutions for clinical training and treatment

Research led by Dr Andrew Wilson **[R7, R8]** has demonstrated effective processes when developing medical simulations. Since 2015, our VR ophthalmology application has been used to teach practitioners. Approximately 150 medical students per year at Sandwell and West Birmingham Hospitals NHS Trust (SWBH NHS Trust) can use this application in their ophthalmology training. The trust's director of medical education states this "emphasizes practice on real patients; however, obstacles arise due to time constraints in busy clinics and concerns relating to patient discomfort …. Therefore, it is extremely important to find alternative cost-effective approaches to train our new doctors." **[S04]**. With the help of medical students (25), 80% of them stated that the app had improved their understanding of how to correctly perform this diagnostic procedure with a significant improvement (25%) in

their answers to clinical aspects relating to this procedure. Importantly all medical students said they would be more confident in performing this procedure on patients in future. “The app enhances the students’ learning of this complex procedure thus improving their confidence in practising the skill on the ward-based patients they will be assessing. Previously they would not have had the confidence to undertake this skill independently.” (SWBH NHS Trust Clinical Teaching Fellow, 2020) **[S04]**. From 2015 to 2020 there have been over 1100 downloads of the application **[S05]**, with wider positive feedback from ophthalmologists and physicians (10 respondents) from the UK, USA, Singapore, France and Poland, saying they will use the app in their teaching **[S05]**. The successful adoption of this tool by the NHS has resulted in continued collaboration with them. New AR/VR training tools for visualisation of knee pathologies, examination of the ear, visualisation of the circulatory system of the heart and lung as well practice-based treatment of sepsis and management of medical conditions such as complex regional pain syndrome being implemented **[S04]**. Senior Occupational Therapist at Sandwell General Hospital, was struck by the potential of the app: “The concept of using virtual reality to treat complex pain conditions was exciting, appealing and showed a lot of potential. This software has the potential to be helpful in offering additional treatment options for people who suffer from CRPS.”

Wider adoption of our research **[R1, R6]** has also been embedded into the Northern Centre for Cancer Care at the Newcastle Upon Tyne NHS Foundation trust **[S06]**. The work has designed a platform for delivering radiotherapy training and treatment **[S06]**. This is supported by the Academic Health Science Network (AHSN), with a formal memorandum of understanding between BCU and the NHS covering the design, development and commercialisation of the AR in Radiotherapy product **[S06]**.

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

S01: Impact on consumer healthcare in *GlaxoSmithKline*
Press release, testimonial and figures showing the impact of the research on GSK.
[Named Corroborator 001]
S02: Impact on manufacturing: product design
Testimonial from Head of Design in Murray Uniforms
S03: Impact on manufacturing: product promotion
Testimonial from the Technical Director, Holosphere UK
[Named Corroborator 002]
S04: Impact on Medical Education and Care
Testimonials from Sandwell and West Birmingham Hospitals NHS Trust
[Named Corroborators 003 and 004]
S05: Feedback from Ophthalmologists and Physicians
Download figures and questionnaire showing feedback from Ophthalmologists and Physicians.
S06: Impact on Medical Education and Care
Testimonial and MoU with The Newcastle upon Tyne Hospitals NHS Foundation Trust
[Named Corroborator 005]