Institution: University of Bradford

Unit of Assessment: B11 Computer Science and Informatics

1. Unit context and structure, research and impact strategy

Context and Structure of the Unit

Research in UoA B11 is based in the Faculty of Engineering and Informatics, with our academics drawn from the Department of Computer Science and the Department of Media, Design and Technology. The current horizontal Faculty structure, including six departments, with no hard-disciplinary borders, underpins a fundamentally interdisciplinary approach to research, while at the same time preserving the core identity of each department profile. This results in robust research interconnections across the computer science, media and engineering disciplines which emerge from fundamental research developed in each of them. The UoA B11 research is organised through three Research Units (RUs), which are listed below.

Artificial Intelligence and Visual Computing Research Unit

This RU focuses on developing Artificial Intelligence (AI) and Visual Computing (VC) fundamental and applied research. Members of this RU have an established track record in the development of knowledge and technologies in Artificial Intelligence, Visual Computing, Data Mining, Machine Learning, Image and Signal Processing, Big Data, Data Analytics, Digital Health and medical imaging/diagnostics. Staff members are Abdullatif, Elshehaly, Mehmood, Neagu, Qahwaji, Trundle, Ugail, Wan and Zhang

Computational Modelling Research Unit

The RU contributes to theoretical aspects of (unconventional) computational models, quantum and membrane systems, formal verification and testing, and dynamic system safety analysis, with a proven strong international track record, publishing in high-impact journals and top conferences. The RU members have developed applications spanning qualitative and quantitative analyses of complex, concurrent and stochastic systems in high-performance computing environments, the use of computational models in manufacturing, as well as practical software engineering solutions to industrial problems and cross-disciplinary applications. Staff members are Gheorghe, Konur, Lefticaru, Lei and Vourdes.

Internet of Things, Cyber Security and Networks Research Unit

This RU contributes to cutting edge research in the development of knowledge and technologies in smart cities, citizen science, semantic stream processing, semantic deep learning, intrusion detection systems (IDSs), malware analysis, network traffic modelling, performance optimisation, mobile, wireless and satellite communication, and vehicular communications networks including aircraft and trains. The RU has strong interdisciplinary national and international collaborations through funded projects, research labs working on smart cities and Internet of Things (IoT) challenges such as Amsterdam Data Science, and organisations such as Digital Catapult, and West Yorkshire Combined Authority. Staff members comprise Awan, Connolly, Ghafir, Hu and Thakker.

This organisational structure encourages fundamental research in core computer science areas and multi-disciplinary applications. New research facilities supporting multi-disciplinary research have been developed, such as the Centre for Visual Computing, the Advanced Automotive Analytics Lab, the IoT Innovation Lab, Cybersecurity Lab, the Computing Enterprise Centre and the Multimodal Biometrics Lab. More details are provided in Section 3.

Research in the three RUs is managed by the Department Research Committee (DRC), which develops, monitors, nurtures and reviews research plans and decisions in accordance with the University's strategy, evaluates research impact, sets priorities, allocates necessary resources

and provides consistent communication, and also supports and mentors research staff (in particular recently employed and junior staff).

Research and Impact Strategy

The Department's post REF2014 strategic plan was based on the vision of developing high-quality fundamental and applied research, whereby personal research interests and genuine curiosity are merged with the University research strategy and growing sustainably through identifying and nurturing relevant research areas. This vision is supported by the following research objectives and an action plan.

Research Objectives

1. *Improving the quality and quantity of research produced.*

2. *Exploring and identifying emerging and futuristic research areas and key challenges.*

3. *Developing strong and sustainable research infrastructure and organisation.*

Action plan

The research objectives have been agreed with the Faculty Research Committee (FRC) and the DRC, and are implemented through a set of coherent actions, A1 to A5, leading to research outcomes.

A1: *Continuous improvement of the research outcomes* [supporting objective 1]

A list of highly regarded journals and conferences and research grant opportunities has been identified by DRC and staff members are encouraged to prioritise publishing and apply for projects, respectively. Both the FRC and the DRC have supported staff members by organising scientific seminars and establishing a Faculty-wide Early Career Research Forum (ECRF). The submitted research outputs and the volume of research and knowledge transfer grants (Section 3) demonstrate the quality of our research outcomes.

A2: *Fostering new collaborations* [supporting objective 1]

A broad spectrum of collaborations, including projects, research seminars, visits and organizing joint events, with other high-profile national and international University research units (e.g. UK: Sheffield, Newcastle, Warwick, Nottingham; Europe: Genoa, Seville, Vienna; Other countries: UAE, Japan, India, China) and professional societies (e.g. British Computer Society (BCS), Institution of Engineering and Technology (IET), IEEE) are encouraged and supported in the UoA by the Department, Faculty and University. Joint seminars and talks, sandpit events and workshops are organised on regular basis, benefitting from our active representation with BCS, IET, Digital Catapult and funding through the successful Erasmus+ networks managed by the University and funded H2020 RISE projects.

A3: *RKT grants* [supporting objective 1]

The FRC actively monitors this activity and provides support to early-career staff members and peer-review of grant applications for all staff.

A4: *Identify and invest in strategic research areas* [supporting objective 2]

Our staff are involved in core and multi-disciplinary strategic research activities, such as Digital Health, AI, Multimodal Biometrics, Remote Sensing, Aeronautical Communications, 5G Wireless Communication and Systems, Networks, Smart Technologies, IoT, Cyber-Security, Automotive Analytics, Modelling and Formal Verification, Membrane Computing, Quantum Computing and Systems, High-Performance Computing, and Computational Biology. All staff members recruited during the REF period work in these areas. RUs are encouraged to strengthen their research in

these areas by applying for internal and external research funding, advertising new multi-disciplinary PhD projects on FindaPhD, organising specialist events, publishing in high impact research avenues (as illustrated by the research outputs submitted), developing new external and internal, academic and industrial collaborations.

A5: *Organising the research and building infrastructure* [supporting objective 3]

The process of re-organising the research started by clustering RUs around three main research themes, encompassing the strategic research areas (mentioned above). These RUs represent the backbone of our research environment. Research at every level is supported by a nurturing environment that encourages cutting-edge and impactful research.

As shown in Section 2, this UoA went through a major process of staff recruitment, since 2015 we have appointed an anniversary chair (Gheorghe) and ten lecturers (Abdullatif, Connolly, Elshehaly, Ghafir, Konur, Lefticaru, Lei, Mehmood, Thakker, and Zhang).

Our research environment enabled the production of significant impact in many disciplines: automated solar activity prediction (Qahwaji with NASA, Impact Case Study (ICS) B11-1 "ASAP system makes prediction of solar activity faster, automated and more accurate"), and advanced face recognition (Ugail, ICS B11-2, "Deep face recognition accurately identifies suspects in international criminal investigations").

Our staff continue to make significant contributions supporting the University's key research themes of Advanced Health Care, Innovative Engineering and Sustainable Societies. We have strategically targeted fundamental research contributions and applications in the UoA relevant interdisciplinary areas to these themes, as illustrated by projects mentioned in Section 3.

Open Access and Ethical Policies

The University has implemented a series of initiatives that encourage and incentivise staff to meet, not just the basic open access (OA) requirements of the REF process, but that go beyond these. Within UoA B11 DRC members have adopted the following practices:

1. We actively promote OA and open research. OA promotion activities include presentations to faculty assemblies, checking open access compliance of publications and data, and advising academics on all aspects of OA.

2. We operate a system of mandatory peer review of all grant applications. This process includes an element where OA considerations must be addressed. We ensure that we implement stringent data management plans for all data arising which may include, but is not limited to:

    - Simulation results and experimental data are shared for use in validation or reproduction of the work undertaken. Readme files are included alongside all core data sets clarifying file naming conventions, units, acronyms and any other relevant information.

    - Source codes are archived using the GitHub version control system, usually with an interface allowing non-specialists to gather data for their work.

    - All public data sets could be given a DOI to aid discovery and linking e.g., by the promotion of data sets on academic social media and the study website.

3. The peer-review process also requires reviewers to consider the extent to which applications have OA activities and funds embedded within them (where permitted by the funding agency). For example, funds may be requested to store data in national or international

database(s). Staff from the central Research and Innovation Services (RaIS) team will also check for the inclusion of OA activities when reviewing applications before submission.

4. The University holds an annual open research day at which delegates can learn from experts about a variety of OA issues, such as optimisation of social media exposure, OA success stories from within the University, and guest speakers from external organisations such as the Patent Agency and 'The Conversation UK'. Alongside the Open Research Day, the University holds pop-ups in key locations across the campus throughout the week.

5. We actively encourage our staff to apply for the University's Research Development Fund (RDF), offering funds for gold OA publication of non-UKRI funded outputs and a monthly publication award, a requirement of which is that the output is available via OA, so incentivising OA compliance. Furthermore, access to any element of the RDF (e.g. pump-priming funds or conference attendance) is only available to staff whose outputs are OA compliant.

6. We take the necessary steps (via the RUs) to make sure staff adhere to the University and funders' publication policies, requiring that staff check with repository staff regarding OA compliance of their chosen journal.

7. Social media workshops form part of the diet of training available to researchers. These workshops focus on the use of social media to open up the process of research, from ideation, to launch, to progress updates, to outputs and data beyond the researchers' usual ambit. In addition, the OA team offers presentations at research away days, research group meetings, and research committees.

The University of Bradford has its own Ethics Policy based on the UUK Concordat for Research Integrity. We rigorously ensure that those of our projects that involve healthcare aspects (e.g. gestational diabetes) or collection of personal data (e.g. H2020 eBORDER project) have the necessary ethical approval. We recognise that all researchers have an obligation to ensure that their research is conducted with honesty, integrity, openness, minimal possible risk to participants and themselves, and respect for other people, their values and their cultures. Our policy makes it clear that conducting research with integrity requires embracing intellectual honesty and accepting personal responsibility for one's own actions. Researchers are expected to consider the ethical implications of their research and, depending on its nature, the cultural, economic, and social consequences of it. Researchers are also required to consider issues related to Trust and Privacy especially when processing personal data in line with the GDPR.

Our researchers are required to consider their research from the perspective(s) of the participants and any other people who may be affected by it and are encouraged to undertake the University's unconscious bias e-learning training module to assist with this.

Research misconduct is monitored via the University's management structure or the University's whistleblowing procedures. Both routes require reporting the misconduct to the Chair of the Committee for Ethics in Research and via that body, to the University's Ethics Committee. An annual research misconduct report is produced by the Chair of the Committee for Ethics in Research. This is presented to University Council and made publicly available via the University website, in accordance with the concordat for research integrity to which the University is a signatory.

Comprehensive training in the application of research ethics is available at the University. There is mandatory training for newly appointed researchers as part of their induction process. All researchers are required to undertake a training session, which is available twice a year.

2. People

Our staffing strategy aims to create critical mass in research activities by supporting research groups' activities while giving individuals the freedom to pursue new opportunities. Our staffing strategy starts with initial recruitment and includes the management and retention of competent and motivated staff carrying out the right roles at the right time to meet their personal, departmental and wider university goals. We have clear leadership roles, to create sustainable and vibrant teams able to work in a supportive environment while working across discipline boundaries to deliver our vision.

Our priority has been to recruit high-quality academics with an international reputation and excellent research promise. Each member of the staff is part of one or more of the three RUs. Since 2014, a significant number of new staff members have been appointed who each enhance the research portfolio of every RU. An Anniversary Chair (Gheorghe), and ten Lecturers (three in 2014-2015 and the rest in 2019) joined one or more of our three RUs as core or associate members. The ten lecturers are Konur, Thakker, Lei (all in 2014-15), Mehmood, Ghafir, Abdullatif, Lefticaru, Zhang, Elshehaly, and Connolly (in 2019). They have received University and Faculty support for their research development and expansion of their grant portfolios - all staff members recruited in 2014-2015 have secured considerable grant income as Principal Investigators, as demonstrated in Section 3. Among these new staff, there has been one promotion to Reader (Konur) and two to Senior Lecturer (Thakker and Lei).

Each RU comprises a dynamic blend of senior staff, providing research leadership, and high-calibre early career researchers (ECR) working together in a highly collaborative environment. Career development is a priority for the UoA and is addressed via an annual performance review. Academic staff workload is managed by allocating credits for publication of research outputs, research project management, proposal writing, postgraduate researcher (PGR) supervision, scholarship activities and conference attendance as well as research-related management and academic citizenship roles. Performance of staff is monitored regularly and reviewed annually, where staff development, goals and mechanisms for support are discussed, and individual action plans developed. Academic staff are actively encouraged to take leadership courses offered by the University and other organisations regionally and nationally. Examples of these leadership courses include the Bradford Leader programme (nine days residential) and the Bradford:Fellowships programme.

Each ECR is assigned an experienced staff member, who is not their line manager, as a mentor to support their academic career development, including support for professional development and qualifications. The mentor gives appropriate guidance in all aspects of their roles, including research activity planning, publication targets, grant applications, collaborative developments in academia and industry, recruitment of PGRs and RAs, and attendance at relevant conferences. ECRs have a reduced or minimum teaching load and no administrative duties for their first three years, providing them with more time and freedom to focus on their research activities and development. They are supported by the Faculty to attend conferences and networking events. ECRs are required to complete the Bradford:Fellowships programme, which provides training in teaching and knowledge transfer skills. ECRs prepare a research development plan, supported by their mentors and in line with the Faculty's strategy and plans, highlighting their career development opportunities and setting personal development goals aimed at enhancing their research profiles. ECRs are encouraged and supported to progress to principal PhD supervisor status through initial involvement as Associate Supervisors. The intention is that, by the end of the planned period, the new members will have developed the required skills and competencies for research. Newly appointed ECRs review and discuss with mentors their research plan annually, over three years.

Early career academics in the UoA are part of the faculty-wide ECRF, which aims to provide a supportive and vibrant environment for ECRs to interact in an interdisciplinary forum, conducive to the achievement of personal and Faculty strategic goals. The forum participants meet monthly and receive support in the development of their research, including finding collaborations, advice

and help on research funding and grant writing, and overall research matters. In the last few years, the ECRF has organised events on topics such as grant applications (EPSRC New Investigator Grant, writing your proposal step-by-step), industry-focused R&KT funding, Intellectual Property (IP) development, the Researcher Development Concordat, and the Research Information System.

Support capability for the UoA is complemented by the central RaIS team who support staff training in IP protection, business development, grant development and submission, industrial partnerships, and local business engagement, amongst other activities. RaIS helps with identifying appropriate research funding and developing and submitting applications. A wide range of training events is available for all staff members to develop and enhance various research competencies, including finding research funding, writing successful grant applications, effective research supervision, research ethics, and using social media for supporting research activities. Also, RaIS circulates regular research bulletins and newsletters by email. Our staff are supported in preparing high-quality research applications by rigorous internal peer review by two senior colleagues and by our dedicated Faculty Research & Knowledge Transfer Business Development Manager and RaIS.

Post-Doctoral Research Assistants (PDRAs) & Visiting Research Fellows

The nature of our research has facilitated a high number of externally funded PDRAs and visiting research fellows working alongside our research-active staff. Over the REF period, we have had 20 externally funded PDRAs and visiting researchers (mainly from overseas research institutions). All these PDRAs and visiting researchers have contributed significantly to our research environment, providing a comprehensive global view and additional maturity of thought and practice to support our research culture, in particular our PGR progression. All the PDRAs working with us have improved their academic and technical skills and progressed with their careers. Some examples include:

- Dr Saeed Sharif who worked on NHS Funded project with Qahwaji went on to become Senior Lecturer at the University of East London

- Dr Raluca Lefticaru worked with Gheorghe (2016-2018) and then joined the University of Sheffield as PDRA until Sept 2019, then joined the University of Bradford as a lecturer.

- Dr Longzhi Yang worked with Neagu as PDRA and now is an Associate Professor at Northumbria University

- Dr Moi Hoon Yap worked with Ugail as a postdoctoral researcher is now a Reader at Manchester Metropolitan University

- Peter Lowry worked with Ugail as a KTP associate now is a full-time forensic scientist at Acume' Forensics

- Dr Cheng Yong Qiang with Hu as a PDRA (2013-2015) and went on to become a Senior Lecturer in the University of Hull

- Dr Adeel Ahmed with Hu as a RA (2017-2018) and now a Data Engineering Manager at the Adecco Group

- Dr Fouad Benamrane with Hu as a PDRA (2018-2019) and now a NPI Nuage/SDN Consultant in Nokia, Morocco

- Dr Doanh Kim Luong with Hu as a PDRA (2018-2021) and now a software developer at SAP, Belfast.

PGR Recruitment, Supervision and Submission

During the REF period, we revised PGR processes to encourage the recruitment of quality PhD students. The PGR processes include competitive advertisement of PhD applications on platforms such as FindAPhD, with staff competing for advertisement slots; reaching out to various strategically important geographical areas for recruitment through marketing and outreach activities; a three-step verification process for selection of the candidates including interviewing every candidate; the encouragement of cross-disciplinary supervisory team formation and inclusion of relevant ECRs; and documenting the process of selection. Staff are encouraged to bid for studentships to provide fully-funded PhD positions available through research bid funding and industrial partnerships – a proportion of our PGR community over the period of this REF period has resulted from such scholarship (notable funders include Commonwealth Scholarship, EU, PTDF Nigeria, and EPSRC). The supervision and PGR progresses are strictly monitored by the PGR office – monthly, annually, and at three other milestones of the PhD (transfer to PhD, transfer to write-up, and viva voce thesis defence).

During the census period, our research groups have supervised to graduation 79 PGRs, which includes a significant number of students holding prestigious Research Council awards, and international government funding (from Iraq, Libya, Nigeria, Oman, Egypt, Jordan, Pakistan, Japan).

Our PGRs benefit from studying in an interdisciplinary academic environment with access to an excellent range of well-equipped research and office facilities. All PGRs are provided with a desktop computer, access to our laboratory facilities, technician support and funds for travel and conference attendance. PGRs receive an annual subvention of £500 towards research expenses, to cover the costs of laboratory work, field research and conference attendance. For seminars, we have a monthly 'best presentation' award. The Faculty holds an annual PGR conference (Annual Innovative Engineering Research Conference (AIERC)) for postgraduate students, who are all encouraged to participate. This gives opportunities for PGRs to present their research, discuss new research ideas, and get feedback. It is also a good opportunity to gain valuable experience in presentation and communication skills. At this conference we have a number of awards including 'best paper', 'best-published work', 'best presentation', and 'best poster' - all these awards monetarily contribute to research and training expenses for PGRs. We also run a PGR research seminar series where the students present their work weekly to an audience of fellow PGRs, staff, and members of the public. These seminars have continued virtually during the pandemic. One PGR is selected each month for a 'Monthly Best Presentation Award' – decided by a panel of three reviewers. In addition, our researchers (PhD, PDRA, visiting research fellows and full-time staff) are encouraged to work together to share ideas and to generate lively discussion through seminars and workshops. In 2020 we established a new "IET on Campus" PGR society which is managed and led entirely by our PGR students under the mentorship of a senior staff member (Qahwaji). This PGR society will organise events and activities which will be funded and sponsored by IET.

All PGRs have a support committee, with a Principal Supervisor and one or two Associate Supervisors. PGR progress monitoring, in ensuring support for students to timely completion, is a high priority for the PhD supervisors. All PGRs are required to agree a Personal Development Plan with their supervisors at the beginning of their study, and there is a rigorously enforced system for recording both PGR progress and regular formal meetings between PGRs and their supervisors. In addition to the monthly monitoring process, an annual monitoring report is formally completed by the PGR and main supervisor, allowing for progress issues or skill development needs to be identified and tackled by the supervision team and PGR director.

We place great emphasis on PGR training and support, integrating students into the research community, supporting them to fulfil their development plans and providing them high quality personal, professional and career development opportunities. The University is a signatory to the Researcher Development Concordat and fully committed to implementing its principles for the career development of researchers. In addition to the technical skills and development training

programmes provided by the Faculty, the University library and staff development provide a comprehensive programme of research and transferable skills training (including employability skills).

Towards the end of their first year PGRs are required to prepare and submit a Transfer Report that is read by two assessors, not involved in the supervision of the student. There is then a viva voce assessment at which a decision is made to recommend the student's transfer to full PhD registration status or to propose additional work that is required before this recommendation can be made. This supporting environment has helped boost our PGR completion rates. During this REF period, there were 79 PhD completions.

Equality and Diversity

All staff involved in the recruitment and selection process are trained on equality, diversity and unconscious bias by completing an e-learning modules, followed by one day of directed training. We are proud that our staff come from diverse backgrounds, which enables us to build a more inclusive culture for supporting staff and students.

For both staff and students, there is explicit information in our recruitment literature to encourage applications from minority backgrounds and female computer scientist/engineers, to widen access to computer science. Three new female members of staff (Lefticaru, Elshehaly, and Connolly) were recruited recently and a number of female PDRAs are contributing significantly to the delivery of our funded projects (Sadaf, Palczewska, Kotiyal).

All our 19 staff are permanent staff with no known disabilities. There are 15 male and 4 female staff members.

The ethnic status of staff is shown below.

Ethnic Status	Headcount	Percentage
Arab	2	10.5%
Asian or Asian British - Indian	1	5.3%
Asian or Asian British - Pakistani	2	10.5%
Chinese	4	21.0%
Other Asian Background	1	5.3%
Other Ethnic Background	4	21.0%
Other White Background	1	5.3%
White	4	21.0%

Contract levels are shown below:

Contract levels (HESA Codes)	Headcount	Percentage
F1 (Professor)	7	36.8%
I0 (Reader, Senior Lecturer)	2	10.5%
J0 (Lecturer B)	6	31.6%
K0 (Lecturer A)	4	21.1%

3. Income, infrastructure and facilities

Computer Science Funding Profile

Our grant applications and awards are diverse and the funder base for our UoA has three main components. Firstly, RKT applications and awards with industrial partners targeting Innovate UK or Access Innovation funding schemes. Secondly, a solid profile of EPSRC and European Union grant applications and awards schemes and calls. Thirdly, industry funding, including multi-disciplinary collaborations with other University departments (e.g. Automotive Engineering, Wolfson Centre for Applied Health Research, DVC (Research, Innovation & Engagement) HEIF grants) and organizations such as the NHS National Innovation Centre, Digital Catapult and Translate Medical Technologies.

Given the growing visibility of and interest in digital technologies (including AI and Big Data), Computer Science funded projects cover all three of the University's main research themes: Advanced Healthcare, Innovative Engineering, and Sustainable Societies. Some relevant examples are shown below, demonstrated by externally funded RKT projects:

Advanced Healthcare:

Some examples include:

- *"Efficient 3D Corneal Modelling",* Oct 2013 – Oct 2017, value GBP250,000, externally funded by NHS National Innovation Centre.

- FP7 SEURAT-1 COSMOS project *"In Silico Models for the Prediction of Human Repeated Dose Toxicity of Cosmetics to Optimise Safety",* Jan 2011-Dec 2015, value EUR572,000 for Bradford from EUR6,790,000 project.

- Three Small Grants funded by the Digital Catapult on 5G and Healthcare, 2018, value GBP10,000.

- Digital Health Projects funded by Translate, 14 funded student summer projects, GBP2,500 each, 2017-2020.

- HEIF projects funded through internal PVC Research Office call on COVID-19 impact in 2020, total GBP60,000.

- HEIF projects funded through internal grant schemes on Air Quality monitoring in 2020-2021, total GBP50,000.

Innovative Engineering:

Some examples include:

- EU H2020 SESAR JU SINAPSE – "*SDN Architecture with AI to improve aeronautical communictions, performance, security and efficiency"*, 2020-2022, total value EUR853,000, Bradford EUR284,000.

- EU H2020 Cleansky2 JU COMET – "*Future Cockpit Network Communications Environment Testing"*, 2018-2022, total value EUR9,600,000, Bradford EUR907,000.

- Innovate UK SINCBAC: "*Secure Integrated Network Communications for Broadband and ATM Connectivity"*, 2012-2014, total value GBP1,000,000; Bradford GBP588,000.

- Innovate UK "*HARNet Harmonised Antenna, Radio and Networks"*, 2014-2015, total value GBP11,500,000; Bradford GBP766,000.

- EPSRC project: "Light-weight Verification of Synthetic Biology", 2018-2021, GBP352,000.

- H2020 project funded by European Commission Research and Innovation call: H2020-MSCA-ITN-2016 (Marie Skłodowska-Curie Innovative Training Networks), *"SECRET: SEcure Network Coding for Reduced Energy nexT generation Mobile Small cells"*, November 2016-November 2020, EUR3,300,000.

- FP7 project *"First European Comprehensive SOLar Irradiance Data exploitation"*, EUR2,000,000.

- Jaguar Land Rover AAA project Advanced Powertrain Reliability R&D - *Intelligent Personalised Powertrain Health Care (InPowerCare)*, in excess of GBP500,000.

- European Space Agency (ESA) funded project: *"Solar Events Prediction system For Space Launch Risk Estimation",* In collaboration with the Technical University of Catalonia and the University of Malaga (Spain), Sep 2014-2016, EUR100,000.

- Marie Skłodowska-Curie Actions, Research and Innovation Staff Exchange (RISE), Call: H2020-MSCA-RISE-2019, *"Secure and Wireless Multimodal Biometric Scanning Device for Passenger Verification Targeting Land and Sea Border Control"*, EUR1,000,000, between five European partners.

- Six Innovate UK KTP and EU Access Innovation projects with industry (e.g. Intelligent Manufacturing for Rakusen's Ltd., 2017-2019, Smart Network Traffic Monitoring with Xalient Ltd., 2020-2022).

- InnovateUK funded KTP project with Hebe Works Limited, Leeds, 18-month project, 2015-2016, GBP104,000.

- KTP with Exa Networks, *"Classification of Web contents using Machine Learning"*, GBP140,000, Funded by Innovate UK and Exa Networks Ltd, June 2018-May 2020.

- *MotiVar: Motivating weight loss through a personalised avatar* - with collaborators from School of Health, University of Bradford, King's College London, University of Leeds and Mid Yorkshire Hospitals, funded by NIHR, value GBP252,000, April 2017 – September 2020.

- *'Fragmented Heritage' From the Kilometre to the Nanometre: Automated 3D Technology to Revolutionise Landscape, Site, and Artefact* Analyses, AHRC Digital Transformations Programme Theme Large Grant awarded– with Dr Andrew Wilson and Dr Adrian Evans (School of Archaeological and Forensic Sciences), and external/international collaborators such as Dr Nicholas Ashton (British Museum) and Dr Louise Leakey (East Africa), value

GBP1,900,000, July 2013 – December 2020; joint award with the School of Archaeological and Forensic Sciences.

- Development of the HALO Biometric Custody Suite - with Acume' Forensics, KTP funded by Innovate UK, GBP153,000, June 2016 – January 2018.

Sustainable Societies:

Some examples include:

- European Council (ERDF Interreg North Sea) funded project on *Smart Cities and Open Data REuse: SCORE*, 2017-2021, grant value: EUR2,800,000.

- British Council SITARA project on sustainable smart grids, 2016-2018, GBP150,000.

- Innovate UK funded KTP project on *Artificial Intelligence in Immigration Law* with A, Y & J Solicitors, London. 24-month project, 2020-2022, funded for GBP175,000.

- Innovate UK and direct industry-funded projects, such as KTP *"Decision Support System for Sustainable Housing"* with Incommunities, 2015-2017, GBP120,000;

- KTP *"Open Data for Smart Cities"* with HebeWorks Leeds, Innovate UK Urban Living: Integrated Products and Services competition: Binnovation - Using IoT technology for household waste, 2015-2017, value GBP104,000.

- Connected Placed Catapult project on Horizon Scanning of Integrated Urban Planning for Net Zero Carbon Emissions, GBP15,000.

- GCRF funded PhD studentship on the use of drones for undiscovered landmines in archaeological sites, GBP73,000.

As explained in Section 2, we have appointed new staff members (with a mixture of experienced staff and ECRs joining across all our RUs). They are starting to contribute significantly to our research bidding activities, also bringing their own industry and network opportunities. Today the largest rise in grant bidding in this UoA comes from joint funding applications submitted by ECRs and senior staff working together. This is a direct result of the implementation of the support mechanisms described above to support all staff, in particular ECRs.

The UoA has maintained its strong industrial links over the REF period, undertaking research and knowledge transfer contracts with industrial funders (such as Jaguar Land Rover: over GBP£500,000 in the AAA Lab). Examples also include knowledge transfer with SMEs, for example, Exa Networks, A Y & J Solicitors, Xalient Ltd, with a value exceeding GBP600,000.

Looking forward we are committed to continue our engagement with EPSRC, EU and Innovate UK, and enlarge our international collaborations and funding (e.g. in direct-funding calls with Canada, Brasil, China, India, Japan, and EU countries). Our research groups and research directions are aligned with the priority areas of these funding bodies. All research groups are also encouraged to diversify their funding portfolio and apply for grants from, for example, the Royal Society, MRC, NIHR, Wellcome Trust and ESA.

Infrastructure and facilities

Our physical infrastructure is based around specialised spaces housing offices and specialist labs for individual research units. The highly-specialised labs support the depth and breadth of experimental and computational activities required to develop the quality output and impact delivered within the research themes:

- **The Centre for Visual Computing (CVC)** brings together computational, physiological and psychological expertise to undertake world-class research and development in digital

imaging, visualisation, human visual perception, computer-based simulations and machine learning. Research within CVC utilises a suite of modern 3D non-contact scanning and 3D printing devices, visible and thermal imaging systems, eye trackers, an industry standard 21 camera motion capture system and a state-of-the-art digital arts centre.

- **The Advanced Automotive Analytics (AAA) Laboratory** is an interdisciplinary collaboration between researchers in Computer Science and the Automotive Engineering Research Centre, focused on research and development of big data science methods and solutions to enhance vehicle reliability throughout the lifecycle – from design to service and reuse. The AAA Lab provides a set of world-class computational and analytics research expertise and facilities (internal and cloud big data storage, access to the UoB High Performance Computing (HPC) Cluster, big data analytics processing GPGPU hardware and software). These are used for knowledge discovery from complex automotive engineering challenges with fresh innovative machine learning techniques, funded by renowned industry partners and organisations (Jaguar Land Rover, the SAFI consortium original SAFI Consortium Partners: Airbus, Renault, PSA and Valeo, IAV) and University competitive HEIF calls.

- **Bradford Computing Enterprise Centre (CEC)** is a software development unit providing knowledge transfer and custom software solutions to clients using a combination of academic researchers and students' problem-solving expertise and skills. The beneficiaries of short-term projects are local SMEs, funded through a variety of sources including Access Innovation, the former European Commission Erasmus+ programme, Innovate UK and industry funded projects. Expertise is provided by academic staff supported by a full-time R&KT Development expert and R&KT Business Development Manager, with teams of undergraduate second and final year, Masters and PhD students. Facilities include a dedicated specialist CEC computing lab, meeting and interview facilities with a variety of hardware equipment (data servers, workstations, laptops, EPOC+, R-Pi etc) and access to online storage and processing equipment.

- **Interdisciplinary Research Centre in Cyber Security (IRC Cyber Security)** brings together academics from Computer Science, Engineering, Peace Studies, Social Sciences, Management, and Law to work on cybersecurity and cloud computing-related research projects in a lab with a variety of state-of-the-art computing facilities. This research centre has strong links with members of the West Yorkshire Police Counter Terrorism unit and works on joint projects.

- **The CS Arrack lab** was recently built to facilitate various testing methodologies for developing effective techniques to detect and/or prevent various sophisticated current and potential future cyber-attacks. The test laboratory includes state-of-the-art computing facilities and powerful switches to analyse high volumes of traffic.

- **The IoT Innovation Lab** provides physical and collaboration infrastructure to support research in IoT and Smart Cities. The lab has state-of-the-art equipment, including sensors, drones, network traffic monitors, high-performance computing, and dedicated datasets, for supporting research, development, and teaching. The lab's facilities were part of our expertise/offerings in six successful research proposals (combined value for UoB share of over GBP700,000 from European Union, Innovate UK, Digital Catapult, and HEFCE).

- **The Future Ubiquitous Networks Research Lab** with state-of-the-art facilities including a high-performance computer for data-intensive AI training, an ADS-B radio transceiver set for anti-jamming trials, an inhouse flight simulator, a CISCO switch and a Software Defined Networking software platform.

- **The Multimodal Biometrics Lab**, which is the newest lab in CS, fully funded by the H2020 project eBORDER, to establish biometric data capturing suite for capturing 3D facial images and videos and other biometric data (e.g. fingerprints, iris, etc). The lab contains a variety of

3D cameras, infrared cameras, iris scanners, fingerprint scanners, powerful workstations, and secure data storage facilities. The lab focuses on the development of cutting-edge imaging and machine learning technologies coupled with data fusion techniques for delivering real-time automated person identification technologies.

Computer Science researchers also have access to several university research facilities such as:

The High-Performance Computing (HPC) Cluster facility, which provides a powerful platform to accommodate large memory and parallel processing applications. The HPC provides over 10 times the capacity available on a typical desktop workstation, allowing otherwise impossible calculations to be carried out. With a diverse range of benefits, the HPC is providing solutions in processing real-life big data using advanced deep learning technologies.

Digital Health Enterprise Zone (DHEZ) programme is a GBP13,000,000 partnership led by the University of Bradford and backed by investment from the City of Bradford Metropolitan District Council and the UK government. The DHEZ facilities include business incubation space, a lecture theatre with Tech-Living Lab observatory space, Exhibition space, a Healthcare Analytics lab and a Technology House/Living Lab. The Technology House is a two bedroom house, built within the campus, containing advanced sensor technology designed to monitor and capture data on movement and daily living activities. The property utilises state-of-the-art technologies including embedded electronics, mobile, wireless and satellite communications, biosensors and biomaterials, and big data analytics.

The Wolfson Centre for Applied Health Research (CAHR) brings together researchers from the Universities of Leeds and Bradford with clinicians from Bradford Teaching Hospitals NHS Foundation Trust to do research on three UK health priorities, which are Healthy Childhood, Healthy Ageing and High Quality and Safe Care.

Staff and PGRs in the UoA have access to extensive general and dedicated computing facilities within the Faculty and across the university. Each researcher is provided with hi-spec desktop PCs suitable for the level of their computational investigation, installed with generic research software (e.g. MATLAB, visual studio, AutoDesk, others). The Faculty annually renew the license of specialised software for research purposes, for example, MATLAB. Both the faculty and the university provide dedicated IT support teams to provided professional and technical service to all staff and students. Grant holders are provided with virtual machines for hosting project web pages and code repositories.

Technical support is provided by 14 Technicians plus two apprentices. We have signed up to the Technician Commitment which provides development opportunities via the National Technicians Development Centre (https://nationaltechnicianscentre.ac.uk).

4. Collaboration and contribution to the research base, economy and society

Overview

Most of our research is multidisciplinary and our staff are highly collaborative. Since 2014 we have worked on funded projects with around 20 companies and more than 50 universities; examples are given below. During the same period, we have published with over 250 co-authors that are external to this UoA, including more than 130 international collaborators, over 100 outside Computer Science and over 20 industrial/clinical. These collaborations are vital for our research strategy and successes. The great majority of our funded research projects involve substantive collaboration with internal and external researchers, businesses, or medical partners.

We have strong research links with Bradford Council, Bradford Royal Infirmary, Leeds Institute of Health Sciences, Leeds General Infirmary (Neurology Dept), Bradford Institute for Health Research (BIHR), the Wolfson CAHR, and tens of SMEs. The collaborations include publishing

joint papers, joint supervision of PhD students, access to specialised datasets for analytics purposes, and joint applications for research funding. For example, our collaboration with Biomedical and Electronics Engineering resulted in many H2020 projects (e.g. eBORDER, SECRET, SESAR, Cleansky2), a funded PhD project with LGI (Ramzi Jaber) and a new pending KTP application with Vision Surgery Ltd. Working with colleagues from other disciplines and other research units is a common practice for staff in our UoA. This is evidenced by the tremendous breadth of disciplines and processes, such as synthetic biology (funded through EPSRC research grants), optimising industrial processes (Innovate UK KTP projects), creating cloud-based data analytics environments for monitoring computer networking activities (Access Innovation funding), multimodal biometrics (H2020 eBORDER), 5G technologies (H2020 SECRET), EU project Smart Cities and Open Data REuse (SCORE), two Digital Catapult funded projects on 5G and Urban Planning, 3D modelling of the Cornea (NHS-funded 3D Cornea project), the prediction of Solar Energetic Particles (ESA-funded project).

Our researchers are also involved in cutting edge research and the development of technology, in collaboration with prestigious national and international collaborators. Some examples are shown below:

The development of the Communication Management Platform (CMP), which is fundamental in the modernisation of air traffic management (ATM) systems in Europe and was also integral to the realisation of the EU Single European Sky ATM Research (SESAR) vision to progressively increase the level of automation support, the implementation of virtualisation technologies and the use of standardised and interoperable systems.

The development of Data and Model Governance for Predictive Toxicology, an integral part of the COSMOS Space platform, which has been taken to industry level by partner R&D companies.

The development of a smart production control system for Rakusen's Ltd (UK-based food manufacturer) to improve the production of quality products based on real-time data-driven decision-making models. The project has been shortlisted for KTP Best of Best 2020. The success of the project has been in several media outlets, including The Manufacturer and Food Manufacture.

The development of an automated content classification system for optimal web content filtering performance. The system is developed in collaboration with Exa Networks, one of the key Internet Service Providers for Schools across the UK, where web filtering solutions have a major impact on end-users (primary and secondary school children).

Development of a technology-centric Citizen Science as a Service (CSaaS) framework for event monitoring - used in real-world flood monitoring use cases with two large communities in England and Scotland.

Development of an UrbaN observatory for Indoor air Quality monitoring (UNIQ) using low-cost IoT devices and used to support Bradford's Clean Air Zone.

Other examples include an advanced communication management platform (Hu with Thales), monitoring network traffics (Konur with Xalient), intelligent monitoring of web contents (Lei with Exa Networks), AI-based decision support system for UK Immigration Law (Thakker with A Y & J Solicitors) and extracting patterns from automotive powertrain health care data (Neagu with Jaguar Land Rover).

Involvement with Professional Societies

The UoA strategy to actively engage and facilitate innovation bridges to sister disciplines has promoted active staff memberships in professional bodies' (IET, BCS) events. Some of our staff are fellows of BCS (Awan), IET (Qahwaji), Institute of Physics (Vourdas), IEEE (Zhang -Senior Member), founding members of the IET executive committee on Healthcare (Qahwaji), the IET

Engineering Safety Policy Panel (Qahwaji), IET Technical Assessors (Qahwaji), and members of the International Membrane Computing Society (Gheorghe, Konur).

Our staff are also serving on the boards of Digital Catapult, West Yorkshire Combined Authority, Industrial Centres of Excellence (ICE), Bradford District & Craven Digital Programme Board, IET Executive Committee on Healthcare. Additional benefits of our interdisciplinary research include collaborations with industry and colleagues in research-informed teaching, industry participation in showcases and the Industry Advisory Board and participation in knowledge transfer for SMEs through schemes such as Access Innovation and direct funding.

Supporting Academic Activities

Our staff serve as Associate Editors for journals such as IEEE Access, Expert Systems, Journal of Intelligent Manufacturing (JIMS); Simulation Modelling Practice and Theory (SIMPAT, Elsevier); PLOS ONE; PeerJ Computer Science; and Journal of Membrane Computing (Springer). They also serve as guest editors for established journals such as Expert Systems, Multimedia Tools and Applications (Springer), Multimedia Systems (Springer), IEEE Access, Future Generation Computer Systems (Elsevier), Computers, Materials and Continua (Tech Science Press), Mathematical Problems in Engineering (Hindawi), Concurrency and Computation: Practice and Experience (CCPE, Wiley), Neural Computing & Applications (Springer), Soft Computing (Esevier), Theoretical Computer Science (Elsevier), Natural Computing (Springer), and Biosystems (Elsevier).

Our researchers are heavily involved, as reviewers, in supporting the peer-review process for many leading journals such as: IEEE Access, IEEE Industrial Informatics, IEEE Transactions on Reliability, IEEE Transactions on Dependable and Secure Computing, IEEE Transactions on Control Systems Technology, IEEE Transactions on Fuzzy Systems, IEEE Transactions on Industrial Informatics, IEEE Transactions on Vehicular Technology, IEEE Systems, IEEE Internet of Things, Solar Physics, ACM Transactions on Autonomous and Adaptive Systems, Expert Systems, Artificial Intelligence, Microelectronics, Multimedia Tools and Applications, Future Generation Computer Systems, Journal of Supercomputing, Space Weather, Neural Computing and Applications, Reliability Engineering and System Safety, Fuzzy Sets and Systems, Defence Technology, Algorithms, Engineering Computations, Royal Society Open Science, Journal of Intelligent Systems, Journal of Software Engineering and Applications, Energy and Environment, Sustainable Cities and Society, Theoretical Computer Science, Information Systems, and more.

As further evidence of esteem, UoA staff have been invited to deliver many talks including Data Science in Spacecraft Missions & Space Research workshop (Royal Statistical Society-London 2016), IEEE ICSPIS 2018 (Dubai), Industry 4.0 HTU 2019 (Amman) United Nations Institute for Training and Research (UNITAR) Digital Policing Conference 2020, 1st and 2nd International Forum on Frontiers of Automation and Artificial Intelligence (FAAI 2019 & 2020), Cyberworlds 2020, UTM Distinguished Lecture, AI Tech North (2019, 2020), 35th Asian Bankers Association General Meeting and Conference, SKIMA 2017, ACIT2015 and ICIT2015. Our staff are also involved in the organisation of international conferences acting as conference chairs for many, such as IEEE FiCloud, MobiWis, CMC2019, CMC2017, SSBSE 2019, A-MOST 2020, A-MOST 2021, BDCloud-2020, DSS-2018, OBD 2015, UKCI2014, and EDMA 2019, EDMA 2020.

Our researchers (Neagu, Gheorghe, Hu, Ugail, Vourdas, Ugail, Qahwaji, Konur, Thakker) are recognised as experts and are members of the EPSRC Peer Review College or are frequently asked to review UKRI applications, evaluating proposals for funders including EPSRC, NERC, BBSRC, MRC, NIHR, Innovate UK, British Council, EC H2020 (expert evaluators), and Sêr Cymru II (Welsh Government fellowship programme). Our staff are also involved in the evaluation of international projects for international award funding bodies such as The Swiss National Science Foundation (SNSF), the Cyprus Research and Innovation Foundation, the King Fahd University of Petroleum & Minerals (KFUPM – KSA), MITACS Canada, and the Austrian Research Promotion Agency (FFG).

Engagement with research users and the public

Engagement with research users is an important aspect of our research strategy and culture. Our researchers are actively working with multidisciplinary partners delivering smart technologies to different users. The current users of our technologies include space agencies (NASA, ESA), various elements of the NHS (including Bradford and Craven Clinical Commissioning Group), local authorities (e.g. Bradford Council, Aberdeen City Council), charities (Well Bradford), and industry (from local SMEs to large multinationals (e.g. Thales). We have established different points of access to our experts and research to enable external interaction. During the REF period we have been delivering several IET sponsored events every year (e.g. seminars, workshops, public lectures) delivered by our experts and collaborators and usually attended by professionals and members of the public. These events have proven to be very successful for engaging both the public and professions, and for providing excellent networking opportunities. These events have continued online during the pandemic. Some of the topics covered in these events include 5G technologies, Digital Health, Space Weather Prediction, Smart Cities, Agile Techniques, IoT, AI and Big Data. The National Science and Media Museum hosts public nights, called Lates Nights, and we contributed to different Lates events on topics related to Space, Human Faces, and Games. These events are attended by several hundreds of members of the public. Our staff have also delivered public talks to different astronomical societies, such as the West Yorkshire Astronomical Society and Huddersfield Astronomical Society. Our experts were also involved in different events sponsored by the Digital Catapult and Satellite Applications Catapult. Our EU funded projects (SECRET, eBORDER, SCORE) run dedicated knowledge transfer events informing the public and interested professionals about our research and development activities in cutting edge topics such as AI, 5G, IoT, and Multimodal Biometrics. Our staff are frequently interviewed by media outlets and newspapers discussing news events such as the Khashoggi murder, solar storms, air quality, 5G developments, healthcare technologies, and women in STEM. In addition, our staff are actively engaged, through cross-sector and community-led programmes, in several initiatives to bridge the digital divide in Bradford and equipping secondary school students with the digital skills necessary for the post-pandemic recovery of the city.