

Institution: Liverpool John Moores University (LJMU)
Unit of Assessment: 11 - Computer Science and Informatics
<p>1. Unit context and structure, research and impact strategy</p> <p>1.1. Unit context and structure</p> <p>This UOA submission includes the Department of Computer Science, the Department of Applied Mathematics and the Department of Built Environment. The UOA research is structured into two research Centres:</p> <ul style="list-style-type: none"> • PROTECT - Centre for Critical Infrastructure Computer Technology & Protection (led by Shi) The research in PROTECT focuses on trustworthy computer technology for the functional enrichment and security protection of computing systems. The Centre comprises five research groups: Networking & Distributed Systems, Network & Information Security, e-Health Systems, Applied Computing, and Computer Games. • DSRC - Data Science Research Centre (led by Lisboa) The work in DSRC advances mathematical methodology and applications. The methodology focuses on the interpretation of machine learning models including interpretation by design. Applications cover specialist expertise in medical imaging, cancer research and mathematical biology, e.g., detection of glaucoma and NMR spectroscopy of brain tumours. <p>This UOA returns 42 FTE Category A staff, of which 31 FTEs are from the Department of Computer Science, 10 FTEs from the Department of Applied Mathematics, and 1 FTE from the Department of Built Environment. Each member of the staff can join more than one research Centre or Group to facilitate cross-discipline research collaborations. Among the staff returned, 26 are in PROTECT, 11 in DSRC, and 5 in both Centres. The Centres give the staff flexibility and support to pursue their own research interests while promoting and fostering a collaborative culture to jointly tackle multi/inter-disciplinary research challenges.</p> <p>In the rest of this document, the common information between the Centres or Departments will be presented at the UOA level without naming them, whereas details about a specific Centre or Department will refer to that Centre or Department.</p> <p>1.2. Research strategy</p> <p>1.2.1. UOA aims and strategy for period 2014-2020</p> <p>This UOA was guided by the University and Faculty strategies to deliver impactful research and scholarship during this REF period. Specifically, the UOA aimed to develop collaborative and targeted research of high quality, build critical mass in key existing research areas, and explore emerging topics in the areas for income and impact generation. To achieve this aim, our strategy was to consolidate and significantly expand our research base by nurturing existing academic staff and recruiting research-excellent new staff to increase the quality, volume and impact of our research. This strategy was implemented through the following mechanisms:</p> <ul style="list-style-type: none"> • Encouragement and support for excellent research work enhanced through staff recruitment and aligned with high priority areas, e.g., those identified by the EPSRC and EU, and publishable in good journals and conferences, • Inclusion of more academic staff in collaborative high-quality research led by well-established research-active staff, • Provision of incentives and support for collaborative funding applications, enterprise activities and impact creation, • Promotion of external collaborations and public engagement to widen the scope and identification of research opportunities and dissemination pathways, and • Scholarly enrichment of our degree programmes and teaching to keep up with the development of technology. <p>Our research strategy, measures for its implementation and the progress made were reviewed regularly to improve their suitability for the delivery of the UOA research aims. For instance,</p>

PROTECT successfully retained the Research Centre status following a biennial review by the University Committee for Research and Knowledge Exchange in 02/2018.

1.2.2. Review of the UOA's REF2014 plan and progress for period 2014-2020

The research plan for 2014-2020 presented in our REF2014 submission consisted of two parts, one for PROTECT and the other for Neural Computing Research Group (NCRG, expanded to become DSRC in 09/2016). PROTECT aimed to research underlying scientific theories, methods and mechanisms to support the development of trustworthy computing systems, which resulted in a significant number of high quality publications (e.g., in IEEE Transactions). It also planned to engage with users for impact generation, which led to wider realised impact from our research as demonstrated in the UOA's impact case studies (e.g., Smart Energy, Smart Care). Regarding the plan to attract funding from sources like the EU and EPSRC, a large growth in the amounts of funding awarded from these two bodies was achieved as detailed in Section 3.1.

NCRG maintained its focus on application-driven methodological research, particularly in the interpretation of machine learning systems and its impact on application areas, detailed in Section 1.2.4. This benefited from an increase in critical mass with the appointment of 5 new staff (Ortega - formerly an EU Marie Curie Research Fellow here, Olier, Correa, Siekmann, Czanner-G - formerly a scientist at Liverpool's St Paul's Eye Unit).

Further evidence of progress is highlighted by the following achievements:

- **Greatly increased REF-able staff:** **42 staff** including 24 recruited during this REF period are returned in this UOA, representing an **increase of 320%** over 10 staff for REF2014, which provides critical mass for the research areas covered by the UOA. The increase is the result of fulfilling the University strategy for the significant growth of both excellence and volume in impactful research as well as a consequence of an altered framework for REF2021.
- **Significantly increased research outputs in high-quality journals:** 105 peer-reviewed outputs are included in this UOA submission, while only 34 outputs were submitted to REF2014. 104 out of the 105 outputs are published in journals with the remaining one presented at a top conference (ACM-SIAM SODA), which shows a slight increase of the journal percentage from 97% for REF2014 to 99% for the current submission. The **average impact factor** of the journals publishing these 104 outputs is **4.76** that is 28% higher than 3.73 for REF2014. Here, the impact factors were checked using the 2019 Journal Citation Reports published by Clarivate Analytics, five of our REF2021 journal outputs were excluded from the calculation as their related journals (i.e., IEEE TCSS, IEEE T-SUSC and IEEE TETCI) started publishing recently with no impact factors available, and also one of our REF2014 journal outputs had no impact factor. The new average of impact factors indicates that the significant increase of our output quantity is achieved with an increase in quality.
- **Strong research income growth:** **£4.4m** was generated from funding sources such as EPSRC and the EU during this REF period, **rising by 300%** over £1.1m for REF2014, which was boosted by the considerable expansion of the UOA staff base.
- **Increased PhD awards:** **71.5 PhD completions** are reported in this UOA submission, showing an **increase of 218%** over 22.5 for REF2014, which is partly due to our Faculty and University investment in **60 PhD studentships** to attract bright students for research.
- **Continued investment in research facilities:** **£1.1m** was spent on the improvement and expansion of research facilities for the UOA research during this REF period, **rising by 59%** compared to REF2014.

The above facts point to an accelerated growth of the UOA research achievements since REF2014, thanks to a culture change with 68% of our academic staff being returned in this REF submission compared with 23% previously. Further details on the UOA research progress are presented below for PROTECT and DSRC.

1.2.3. PROTECT aims and achievements

After REF2014, PROTECT was expanded due to the internal restructuring of our Faculty in 2015 to include more staff with a wider range of research interests. This allowed the Centre to broaden its research scope from the previous specific area of critical infrastructure systems to

the more general area of trustworthy computing systems with the aims stated in the previous section. To manage the research, PROTECT was organised into the five research groups as mentioned in Section 1.1. These groups allowed PROTECT to pool a wide range of expertise to collaboratively address increasingly multi/inter-disciplinary research challenges while accommodating flexibilities for individual groups to pursue their own research interests. This tactical arrangement enabled PROTECT to contribute significantly to the UOA outputs and secure over £3m external funding in this REF period. The following highlights exemplar achievements involving joint efforts by different research groups:

- **Smart network connectivity:** Our research in this area focused on building algorithms and frameworks for mobile/wireless networks and systems. For example, the EU H2020 funded Wi-5 project (01/2015-06/2018, [link](#)) provided support to this research, resulting in a platform for optimised and automatic connections to improve the efficiency of Wi-Fi services in congested environments (Bouhafs, Mackay, Raschella, Shi). The project results were then extended and evaluated in practical 5G settings (Mackay, Bouhafs, Waraich) through the DCMS (Department for Digital, Culture, Media & Sport) funded interdisciplinary Liverpool 5G Testbed project (03/2018-01/2020, [link](#)) for using 5G technologies to improve health and social care services, as reported in the UOA's ICS3 (Impact Case Study 3 listed in Section 1.3.3). The promising benefits demonstrated from the testbed led to a successful funding application to DCMS in 05/2020 for the Liverpool 5G Create project to further develop and widen these benefits (08/2020-03/2022, [link](#)).
- **Intelligent systems:** Our work in this area was centred on developing machine learning based interdisciplinary techniques to support technology-assisted social care services and wildlife conservation. For instance, our work produced an intelligent technique that uses smart meters to support dementia patients living alone, partly supported by an EPSRC grant (06/2018-07/2019, EP/R020922/1), with a successful clinical trial by Mersey Care NHS Foundation Trust in 2016-2017 (Chalmers, Fergus, Hurst, Mackay). This work won the 3rd prize of the London Innovation Awards in 2015 and attracted wide interests with 11 national press articles and 4 government policy documents as detailed in the UOA's ICS1. Our research also generated a machine learning based platform for animal identification and classification using camera traps and drones (Fergus, Chalmers), which is the first one made available for wildlife conservation organisations to use via conservationai.co.uk. This work was partly supported by an EPSRC GCRF grant (10/2019-03/2021, EP/T015403/1).
- **Trustworthy services:** Our research in this area developed efficient and effective solutions to address trust and security challenges. For example, the EU FP7 funded Aniketos project (08/2010-05/2014, [link](#)) supported our work on generating solutions for modelling, composing and validating trustworthy composite services (Shi, Zhou). The modelling results were then used to create a unique 3D security requirements modelling platform (Zhou, Tang, Shi), partly funded by DCMS and Innovate UK (2017), which won the 2nd and 3rd prizes at the UK round and grand final of the China-UK Innovation & Entrepreneurship Competition in 2017, respectively. In addition, the EU H2020 funded Wise-IoT project (06/2016-05/2018, [link](#)) and Korea IITP funded TII project (06/2015-05/2018) advanced our research in IoT-based trust models with the results successfully tested in the Spanish city of Santander in 2018 (Lee). The software produced by the TII project was also certified by TTA (Telecommunications Technology Association supported by the Korean government) for commercial use. The models were then extended based on blockchain to address GDPR compliance (Lee) through another Korea IITP funded project GDPR-PIIM (04/2018-12/2020).

1.2.4. DSRC aims and achievements

The overarching aim of DSRC remained on interpretation of machine learning, through complementary research in novel methodology and practical application to real-world data. The Centre secured £1.5m grants for research and enterprise. Its research was at the interface between statistics and machine learning, achieving high performance with models understood by end-users. Evidence for this approach is the award for winning a datathon to predict unexplained behaviour in a complex chemical plant (see Section 4.2). Real-world impact extended also to support for SMEs including job creation through the LCR (Liverpool City Region) Activate

programme (see Section 4.2). Much of the research was closely aligned with external collaborations, including:

- **Novel methodology:** This covered three areas. First, we focused on machine learning models that are interpretable by design, relevant for high stakes applications, e.g., in medicine. Nomograms were frequently used in conventional medical statistics and we developed them for SVMs and with so-called Self-Explaining Neural Networks (Lisboa, Olier, Ortega, Jarman). Secondly, through a long-standing collaboration on brain tumour spectroscopy with Carlos Arús at the Universitat Autònoma de Barcelona (08/2013-07/2020), we predicted response to chemotherapy for the first time with this non-invasive method and saw the predictions validated with murine models (Ortega, Olier, Lisboa). Thirdly, a collaboration on drug discovery with Ross King (Alan Turing Institute and University of Cambridge, 10/2013-07/2020) and AstraZeneca (AZ, 10/2015-02/2019) led to novel approaches for QSARs (Olier), which AZ is using to find drug candidates to be repurposed to treat conditions different from those originally approved, potentially shortening the discovery time for new drugs.
- **Clinical decision support:** The research aimed to i) optimise the design of ophthalmic studies by improving the sample size calculation, ii) model the noise in measurements from retina and cornea and propose how instruments should be used for diagnosis, and iii) build multivariate biostatistical methods for more accurate and explainable diagnosis (Czanner-G, Siekmann). We improved precision, so minimising patients being wrongly sent for a cross-linking operation (partly funded by the Clinical Eye Research Centre, Royal Liverpool University Hospital NHS Trust, 03/2014-08/2018). In diabetic retinopathy, we developed methods that underpin the decision support system for a national screening programme in China. We also developed a highly accurate interpretable algorithm to detect glaucoma (funded by EPSRC Mathematics in Healthcare Centre, Liverpool University, 11/2015-07/2019) in collaboration with Harvard/MIT. This led to the joint work on early glaucoma diagnosis with Aravind Eye Care System in India, University of Ulster and Lancaster University, featured in “Coming to terms with AI” in Eye News 26(2), Aug/Sep 2019.
- **Drug quantitative systems pharmacology:** Our research was to develop innovative methods for pharmaceutical development (Webb, Kelly). We produced computational 3-D spheroid models of liver, backed by a novel experimental rig, which were used by AZ at their drug discovery phase to screen 5000 compounds for hepatic safety, impacting the choice of molecules to progress (see ICS4 for details).

1.2.5. Interdisciplinary research and achievements

The above achievements show that UOA staff actively engaged in multi/inter-disciplinary research through internal collaborations among staff in different disciplines and external partnerships. In particular, the nature of the research in DSRC as well as the health and conservation related work in PROTECT is inherently interdisciplinary. The research committees at Centre, Faculty and University levels actively encouraged and facilitated interdisciplinary collaborations, e.g., through joint PhD studentships and grant applications. The technology centres such as Sensor City (a global hub for the development of sensor and IoT technologies) and MTC (Manufacturing Technology Centre) affiliated with the University keenly brought the academic staff and business users together to forge interdisciplinary research partnerships.

The above support enabled the UOA to deliver a sizable amount of interdisciplinary work covering various disciplines such as healthcare, conservation, psychology, astrophysics, biology and manufacturing. 39% of the outputs submitted and 60% of our grants include interdisciplinary work. For instance, 12 papers were co-authored by our math staff (e.g., Lisboa) and those (e.g., Burniston, Robinson, UOA24) in the Research Institute for Sport and Exercise Sciences at LJMU, and an EPSRC funded project (08/2015-09/2016, EP/M029484/1) involved computing (Dobbins) and psychophysiology (Fairclough, UOA04) staff to jointly develop a mobile lifelogging platform.

1.3. Impact strategy

1.3.1. UOA strategy, plans and impact for period 2014-2020

Guided by the University and Faculty strategies to deliver impactful research, our UOA strategy for achieving research impact during this REF period was to exploit existing collaborations with known user organisations for impact realisation, encourage the wide dissemination of research results to end users to seek other impact generation opportunities, and provide incentive support to the staff for impact activities. We planned four measures to implement this strategy:

- a) Identifying and focusing more effort on research areas of impact potential, in which we have strong expertise and existing user connections. This resulted in e-health systems, networking technology and data analytics flagged up as our focal areas.
- b) Expanding our external engagements by energising research dissemination via multiple means such as conferences and events to seek new collaborators and joint grant applications to widen our impact generation.
- c) Providing strong staff support, e.g., teaching and administrative workload reduction, funded external conference and event attendances, and promotion rewards, to incentivise and facilitate wider staff participation in impact activities.
- d) Enhancing our cooperation with enterprise services within the Faculty and University as well as technology centres (e.g., Sensor City and MTC) to take advantage of their large user networks to explore other channels for wider impact opportunity identification.

The progress of the above activities was reviewed annually to identify necessary actions to take to ensure the expected growth of the UOA impact that is summarised below:

- *Economic benefits:* Our research produced better techniques for solving real-world problems, which were mostly the results of joint projects with users. For example, a user partner of the Wi-5 project mentioned in Section 1.2.3, AirTies in Turkey with over 30 million homes worldwide powered by their technology, adopted the project results to improve their customers' quality of experience (see ICS3 for details).
- *Enhanced public services:* Our work on data analytics generated methods for better risk identification and prediction. The UOA's ICS1 and ICS2 provide detailed examples for the impact generated. For example, ICS2 shows that our joint work with Merseyside Fire and Rescue Service led to reduced fire risks to lives and properties.
- *Technology-assisted wildlife conservation:* Our research in this area used machine learning and drone technologies to develop smart animal identification and monitoring services for wildlife conservation. Eight organisations (see Section 4.1 for details) engaged in the research and field trials.
- *Policy and standard engagement:* The UOA research generated impactful results. By engaging with government and standardisation bodies as well as the media, the results informed relevant policy making and technical standardisation. The UOA's ICS1 and ICS3 provide examples. For instance, the work in ICS1 led to 4 government policy documents.

1.3.2. Approach to impact

Our research impacts were achieved by exploiting a range of pathways to implement the abovementioned measures a) – d). The impact approaches described in our REF2014 submission were adapted and extended to widen our impact activities in this REF period, as detailed below.

1. Targeted impact exploitation through existing user connections: To take measure a) forward, we put particular efforts into advancing our research in two of the identified areas, e-health systems and data analytics, while consolidating our connections with user organisations such as Mersey Care NHS Trust and Merseyside Fire & Rescue Service. The results of the efforts are reported in our ICS1, ICS2 and ICS4.

2. Wider external engagement and collaboration: To implement measure b), we explored the following ways for impact generation:

- i. *Targeted research dissemination:* The staff were encouraged and funded for research dissemination via targeted conferences, journals, and public/trade events to seek collaborations. For example, a member of our staff (Merabti) met an attendee at the Wireless Days conference in November 2013. Their conversation led to the conception of an initial

research idea for collaboration and the subsequent formation of a consortium to successfully bid for the Wi-5 project with user partners to exploit the project impact (see ICS3).

- ii. *Funding applications to work with users:* Relevant calls for proposals were disseminated to the staff regularly to encourage them to apply, and the progress and success in funding applications were reviewed and shared with the staff on a bimonthly basis to motivate more applications. These measures enabled user participation in 77% of our external grants.
- iii. *Public engagement:* The staff were encouraged to participate in public events and other outreach activities for raising the awareness of issues related to their research. This helped to widen the research impact. For example, our smart meter based work was presented at the IBM think event in 2018 with over 40,000 delegates to promote its importance and potential ([link](#)).
- iv. *Influence on public policy and technical standardisation:* The staff were motivated to use their research to inform and shape relevant policymaking and technical standardisation to increase the research impact. For example, a standard recommendation (Y.3055) by the GDPR-PIIM project mentioned in Section 1.2.3 was accepted by ITU-T that coordinates international standards for telecommunications and ICT.
- v. *Direct engagement with companies:* This allowed the staff to directly interact with users for research dissemination and exploitation. In particular, we placed over 80 second year undergraduates on average per year. This gave the staff opportunities to directly engage with the placement organisations for impact exploitation. For example, the work in our ICS2 was initiated and developed through such engagement.
- vi. *Open source software:* The UOA research produced a number of software prototypes. Making them freely accessible helps with their further development for wider impact. For example, the Korea IITP funded GDPR-PIIM project stated in Section 1.2.3 published its software code on GitHub (<https://github.com/nguyentb/Personal-data-management>).

3. Staff support and reward: Regarding measure c), the staff support mentioned was implemented, which will be detailed in Section 2.1.

4. Enterprise services: To deliver measure d), we worked closely with the University and Faculty for the use of their research and innovation services (see Section 2.1 for details). For instance, we used the services to file a worldwide patent application about our smart meter based work (see ICS1) and carry out an ongoing negotiation with interested parties for joint commercialisation. Moreover, we utilised the technology centres to reach out for wider collaborations. Notably, through Sensor City, we secured our participation in the two Liverpool 5G projects mentioned in Section 1.2.3.

1.3.3. Relationship to case studies

This UOA includes the following 4 impact case studies built on the approaches in Section 1.3.2, where a reference like '(2.i, 3)' indicates the use of approaches 2.i and 3 for the related impact:

- *ICS1 Smart Energy, Smart Care:* This demonstrates the impact in one of our focused areas in collaboration with Mersey Care NHS Trust (1, 3), wide engagement with the media and government (2.i, 2.iii, 2.iv), and commercialisation efforts (4).
- *ICS2 Fire Prevention and Community Safety:* Its impact shows the collaboration with Merseyside Fire and Rescue Service in another focused area (1, 2.v, 3) and the dissemination of fire risk profiles in fire safety communities (2.i, 2.iii).
- *ICS3 Wi-5:* It presents the impact generated from projects Wi-5 and Liverpool 5G Testbed (2.i, 2.ii, 3, 4), dissemination and standardisation activities (2.iii, 2.iv), and project open source software (2.vi).
- *ICS4 Improving Drug Safety Screening: 3D – Liver Spheroid Toxicity Model:* This illustrates the research impact exploitation with AstraZeneca in another focused areas (1, 2.ii, 2.v, 3) and the dissemination of the results produced (2.i).

1.4. Future research and impact strategy

The UOA research and impact strategies and their implementation mechanisms stated in Sections 1.2 and 1.3 will be consolidated to guide our future research and impact planning,

management and delivery. We will advance the UOA research and impact aims by broadening our collaborative culture for excellent impactful research, extending the critical mass for higher research productivity and capability to tackle complex multi/inter-disciplinary research issues, and fostering research agility to embrace emerging research challenges and impact opportunities within our expertise areas. More specifically, we will continue our research and impact approaches for developing fundamental solutions and integrating them into impactful applications. Particularly, we will invest more research efforts in the areas of secure technology for 5G and beyond, intelligent and trustworthy e-healthcare systems, and big data analytics in conservation and medicine. These areas fit well with this UOA's research expertise and interests, still pose significant research challenges, and possess great potentials for wide research impacts. We will also encourage adaptability in our research to embrace new funding opportunities, which will be discussed in Section 3.1. In addition, the research results produced will be used to enrich our degree curriculums for the delivery of cutting-edge and exciting education to our students.

1.5. Open research environment

To increase the visibility and impact of our research, the University offers institutional repository services, LJMU Research Online and LJMU Data Repository, for green open access to published research material and data. A designated officer (Dishman) produces a quarterly open access compliance report for each UOA. The reports help the UOA coordinator to monitor the open access status of accepted outputs and take necessary actions to ensure their open access compliance if needed. This resulted in 97% of our in-scope outputs being available in the University's repository and compliant with the REF open access policy.

The University and Faculty also provided funds for gold open access to outputs published in journals such as IEEE Access and PLOS One to widen their dissemination and impact. 10% of our outputs benefited from such open access.

Moreover, projects typically create their own websites (e.g., <http://wise-iot.eu/en/home/>) to disseminate research findings, e.g., through project reports for open access, and share non-private data to encourage further research. Another platform for research sharing is open source repositories such as GitHub for program and data sharing as described in Section 1.3.2.

1.6. Research integrity

The University's Code of Practice for Research specifies the principles, responsibilities and values for research integrity, which the UOA staff are expected to follow. The Code is important for building trust, confidence and accountability in the research conducted in terms of the methods developed, data used and findings derived, while meeting all legal, ethical and professional requirements related to the research. These were embedded into our research output generation and impact exploitation to meet the standards defined in the Code. The support for this included the Code being part of the new staff induction and subsequent further training (see Section 2.1). The staff research conduct was also monitored and reviewed according to the Code as part of the annual PDPR (Personal Development and Performance Review) to promote good practice and address related issues. These facilitated the UOA's research outputs and impact case studies in compliance with the Code.

2. People

2.1. Staffing strategy and staff development

Our **staffing strategy** is to recruit academic staff based on their ability to meet specific requirements relating to both teaching and research. All candidates are required to outline their potential contribution to research related activity and assessed on their capacity to strengthen our impactful research. A total of 24 new academic staff appointed by the two Departments (Computer Science and Applied Mathematics) during this REF period have been returned in this UOA submission, and 6 of them have participated in funded projects as either PIs or CoIs. 9 of the staff appointments were for the gradual replacement of 9 Category B staff who left due to personal reasons (2) and promotion opportunities (7).

The Departments are committed to employ the best available academic staff on an equal opportunity basis regardless of their personal background such as gender and nationality. This has created a diverse international community that helps the Departments to forge international collaborations (see Section 4.1). Currently, 45% of the staff are from other countries across four continents, 12% of them are women, and the average staff age is 45 with 33% of them under 40 years old, which provides a reasonable age balance. The Departments also have a succession plan to maintain the age balance in future staff recruitment and give opportunities to mid-career academics to gain knowledge and experience in senior research roles (e.g., research group leaders and centre directors) based on a 3-year rotation. These roles help the staff to progress their careers, while providing stability for the research management of the Departments.

The strategy for staff development is to provide a wide range of personal and community-based support mechanisms to meet staff needs at different stages of their careers. These include **training support** at *University level*, e.g., an award-winning ACTivator programme provided by the University for staff development, which is an important part of the University's Strategic Plan. On average, the programme delivers 12 workshops annually, covering a wide range of topics from research integrity and leadership, through funding and impact generation, to IP management. There were around 60 attendances to the workshops by the UOA staff between 01/2016 and 07/2020. At *Faculty level*, experience sharing workshops are organised 3 or 4 times a year for experienced staff to share their good practice and lessons learnt with other staff in terms of successful grant applications to funding bodies like the EU, EPSRC and Innovate UK. All the UOA staff have benefited from the workshops, e.g., the training helped three ECRs (Dobbins, Tso, Hurst) to successfully obtain and complete their first EPSRC grants. At *Department level*, two staff away days per year provide skill training, share good experience and promote communication and collaboration for both research and teaching. Also 3 extra staff away days have helped the staff to develop their action plans to raise the quality of their research outputs and impacts.

Funding support is also available. This includes covering costs for the staff to attend conferences and networking events to present their research results and seek collaboration and funding opportunities. An annual average of £30k is budgeted for this purpose. Moreover, pump-priming grants are offered at University, Faculty and Department levels for the staff to bid for facilities needed to support their research and teaching. A total of £280k was awarded to the UOA staff in this REF period. To accelerate the staff's research, both the Faculty and University offer research scholarships to attract excellent students. 60 of our PGR students obtained scholarships during this REF period. To support research impact development, funding is available at University and Department levels for targeted external engagement, which helped the UOA to develop its impact case studies.

Additionally, **personal support** is in place to facilitate the staff in their career development. An annual PDPR exercise provides an opportunity for the staff to work with their line managers to review and plan their academic activities. The research-active staff are recognised by an average reduction of 17% in teaching and administrative workloads. The allowance is even higher for the staff with external funding based on their budgeted time, and also a further reduction of 10% is given to the staff leading impact case studies. These enable the staff to pursue their research and impact agenda often supported by PGR students and/or RAs. There is an internal annual quality review of research outputs and impact case studies, and the feedback from the review is provided to individual staff for quality improvement. To support funding applications, the University's Research & Innovation Services (RIS) together with the Finance and Faculty support offices helps individual staff to prepare applications and provide post-award support if funded, which are assisted by a Grants and Projects (GaP) system. RIS also runs a biweekly drop-in session onsite before the COVID-19 pandemic and online during the pandemic to advise staff on funding issues. Their services have benefited all our staff with external funding. The information on the grant applications is circulated bimonthly within the Faculty to acknowledge the staff's effort and encourage more funding applications.

To recognise the staff's achievements and motivate them for more success, **award support** is offered by the University under its annual Professorship and Readership Conferment scheme to promote those staff with excellent contributions to the University's research, impact and

scholarship activities. During this REF period, 7 staff returned in this UOA were conferred as professors (Al-Jumeily and Hussain) and readers (Fergus, Hurst, Lee, Shamsa and Zhou). Along with this scheme, the University runs a biennial professorial performance review to reward good performers and help others for on-going improvements. In addition, there is an annual staff event for the LJMU Vice-Chancellor's Awards for Excellence in Research, Scholarship & Knowledge Transfer to showcase that such excellence is high on the University's agenda. For example, Lee received a Vice-Chancellor's Award for his research achievements, and Hurst an Early Career Researcher Award for Impact, in 2017.

To foster a collaborative culture for increasingly multi/inter-disciplinary research in the UOA's subject areas, **community support** is essential. This includes a biweekly research seminar programme combining talks in different Departments within the Faculty to allow the staff and PGR students to learn emerging research topics, share research findings, stimulate further studies and promote collaborations. Also, the PROTECT (via its research groups) and DSRC centres organise regular meetings to discuss specific research challenges and gather joint efforts to address them through co-authored research publications and collaborative projects. Moreover, the University affiliated technology centres such as Sensor City and MTC host regular industrial events that provide networking opportunities for the staff to directly engage with companies to exploit collaboration potential. These efforts led to 41% of our submitted outputs with internal co-authors and 80% of our research income involving internal collaborations.

For research sustainability, **ECR support** is important, particularly for helping new staff to quickly settle down in new working environments, integrate themselves into existing research groups/centres, and develop essential academic skills. In addition to all the aforementioned support applicable to ECRs, each new ECR receives initial inductions and handbooks given at both University and Department levels and is assigned a line manager and a senior colleague (a professor or reader) as a research mentor, who offer regular guidance on academic activities and standards expected. The research mentor also helps the ECR to join a research centre(s) and PGR supervisory teams, and participate in collaborative projects, which enable them to gain wider experience in research activities. Normally, ECRs are given higher priorities for pump-priming grants and research scholarship awards, and a special upskilling funding scheme operated annually by the University in recent years allows senior staff to mentor ECRs for raising their competence in REF-able output generation. For example, during this REF period, each ECR returned in this submission received at least one pump-priming grant, 13 of them got scholarships, and 2 secured upskilling grants.

Furthermore, new staff enjoy lighter workloads. They are normally assigned only one third of the normal workload in the first year, two thirds in the second year and the normal workload from the third year onwards, which allows them to gradually take on teaching duties while enabling the continuation of their research. A one-year (3 hours per week) postgraduate certificate course on teaching and learning as well as a PhD supervision workshop are delivered by the University to assist them in gaining relevant academic skills, which forms an important part of their career development. Also, the support provided to and the performance delivered by ECRs are routinely monitored for additional assistance if needed. These are considered by probation reviews toward the end of the 3-year probationary period to determine those staff's suitability for their jobs. All the academic staff apart from one recruited in this REF period successfully passed the probationary period after 3-years employment, and 3 of them obtained funding under the EPSRC First Grant or New Investigator Award scheme.

The **Research Concordat** is also implemented to support the career development of researchers. It operates a robust action plan delivered through a Concordat Task Group and overseen by the University Research, Scholarship & Knowledge Transfer Committee. The Group used a Careers in Research Online Survey (CROS) before 2018, which has been replaced by the Culture, Employment and Development in Academic Research Survey (CEDARS), to identify areas for improvement and take necessary actions to fulfil it. The good performance of this plan was recognised by the EU HR Excellence in Research Award in 2012 that was successfully retained following biennial reviews in 2014, 2016 and 2018. The UOA staff actively participated in and benefited from the scheme, e.g., through the ACTivator programme mentioned earlier.

2.2. PGR students

PGR student recruitment is crucial to the UOA for the delivery of its research and impact strategies, and is managed by a support team at Faculty level. To recruit qualified students, we advertise PhD opportunities widely through external websites such as www.findaphd.com, the University's own website, graduate career events and our own undergraduate and masters programmes. Each application received is reviewed by potential supervisors to check the applicant's qualifications. If qualified, an interview with at least two academic staff is carried out before a place can be offered. On average, the UOA recruits 14 PGR students per year.

During this REF period, both the University and Faculty invested significantly in **PhD studentships** in order to attract high calibre candidates for PhD research. The funding was provided via a number of means from fully funded University and Faculty scholarships, through fee paying only at Faculty level, to match-funded studentships at University and Faculty levels with financial contributions from outside organisations. 60 of our PGR students were funded by some of these schemes.

A number of monitoring and support mechanisms are in place to guide PGR students through their study process. For **initial support** to new students, the University's Doctoral Academy (DA) runs an induction about PhD research, and the Faculty provides another induction about local research environments and codes of conduct. Each student is then assigned to a supervisory team normally consisting of three supervisors including one experienced supervisor and one ECR for training purposes or a business/industrial partner for practical expertise. They set up a weekly meeting to discuss the research. All the supervisors must complete the supervisor training delivered by the DA. The student is also allocated an office space with a high specification PC and has access to our networking, cyber security and AR/VR research laboratories if needed and the well-stocked University library services including IEEE Xplore.

The **progress monitoring** of PGR students involves several stages, supported by an online progression system (eDoc). Every student submits a registration application approved by the supervisors within the first 3-month enrolment, which is assessed by the Faculty Research Degree Committee (FRDC) including one senior member of the staff from each department. After the registration is approved by the FRDC and then DA, the supervisors undertake a review with the student within the first 6-month enrolment to discuss their research progress and first-year goals. The student then submits a report on their progress and further research plan within the first 12-month enrolment for the first-year review. A review panel including at least two supervisors and an independent assessor appointed by the FRDC holds an interview with the student to examine the quality of the reported work. If the work is considered inappropriate, the student could change the registration to MPhil or terminate the studies. Otherwise, the student remains registered for PhD. During this REF period, 96% of our PGR students successfully passed their first-year reviews.

For those students who continue for PhD, there is a subsequent monitoring exercise organised annually by the DA. Each student completes a progress monitoring form with comments from the supervisors, which the FRDC reviews and recommends necessary actions if needed, before passing the form to the DA for further consideration. The arrangement of a PhD viva by the supervisors needs to be reviewed and approved by both the FRDC and DA.

Communication support is also available for students to voice their needs. Supervisors normally have regular dialogues with their students in terms of the support needed, which are recorded in the annual progress monitoring forms. There is an elected PGR student representative in each Department, who sits in FRDC meetings and liaises regularly with the research centres' directors and a designated support officer to discuss the students' needs. The University runs a biennial Postgraduate Research Experience Survey to collect students' views on research and support at Faculty level, e.g., with an overall satisfaction of 79% for our Faculty in the 2019 survey. These mechanisms allow students' voices on their needed support to be heard at different levels for necessary actions to be taken.

Community support is an important part of PhD studies. Our Faculty manages a series of biweekly seminars given by PGR students with each presenting a couple of talks within their study period to allow them to share research findings, gather feedback for further investigation

and practise presentation skills. The Faculty also organises an annual research student conference including invited keynote speeches, selected student presentations, lively poster sessions and prizes for the best papers and PhD theses to recognise and celebrate the students' successes and encourage better quality research. For example, 6 of our PGR students won the best PhD thesis prizes between 2018 and 2020. Coupled with this conference, the University runs a DA Conference to widen the dissemination of students' research achievements.

To provide **bespoke technical support** to students' research, there is a team of 8 technicians who maintain our research labs and assist individual students in using the lab facilities to conduct their research. The students are encouraged to publish their research findings. The University and Faculty offer travel funds for attending at least one conference by each PGR student during their study period, and extra funding may be available for more conference attendances if their research is related to funded projects. Moreover, the Faculty provides a free English proof reading service to help international students improve the English quality of their theses.

Training support for generic skills development is delivered via several mechanisms. The DA runs a Researcher Development Programme covering a wide range of training topics, e.g., systematic literature reviews, research ethics, technical writing, presentation skills, impact engagement, job application and interview skills. The DA also delivers a training course on teaching and learning, which is compulsory to take by those PGR students who want to support teaching labs and student tutorials. Their departments then make arrangements for them to gain practical experience, which is particularly valuable if the students want to seek academic careers.

The above monitoring and support measures led to a significant increase of our PhD completions in this REF period by an annual average of 172% over those for REF2014.

2.3. Equality and diversity

The University sets out its commitment and policy to promote an environment where everyone is treated equally and with dignity and respect. It holds an institutional Athena SWAN Bronze award. To raise the awareness and compliance of the policy, the University delivers a series of training workshops and events every year (e.g., 4 in academic year 2020-2021). Each member of the staff is required to complete an online training course on the issues of equality and diversity annually, and the issues also form part of the PDPR exercise. In addition, the Departments operate an open and fair staff recruitment process with at least one female academic in each recruitment panel. These measures have resulted in a diverse staff profile as stated in Section 2.1. Among 42 Category A staff returned to this UOA, 5 are women, reflecting the on-going challenges in female staff recruitment for STEM subjects. One of the 5 women is a professor, representing a higher percentage (i.e. 20%) of professorial promotion than 11% for the male staff. The average numbers of outputs submitted by the female staff and ECRs are 2.2 and 2.3 that are 12% and 18% higher than those for the male and non-ECR staff, respectively.

3. Income, infrastructure and facilities

3.1. Income portfolio

The UOA **strategy** for income generation is to align our research with the priority areas of funding bodies and increase our efforts in funding applications. As mentioned in Section 2.1, the UOA staff are well supported and advised by the research and innovation services at both University and Faculty levels to produce funding applications and deliver the ones that are successfully funded. These led to a significant increase of the UOA research income in this REF period with a total of £4.4m up from £1.1m for REF2014, which was achieved by a 200% rise of staff participation in the funded projects.

Figure 1 below illustrates a **breakdown of our income** from different sources for this REF period in comparison with our REF2014 figures. Clearly, the largest income comes from the EU, rising to nearly 8 times higher than our REF2014 figure. The second largest income is from the UK government with nearly 4 times over our REF2014 amount. Also the biggest growth of our income comes from UKRI, showing nearly 47 times higher than our REF2014 figure. However,

the increase of our income from other sources is much lower with 19%, and the incomes from industry and charities are 4% and 35% less than the REF2014 figures, respectively. This is because funding opportunities from our engagement with these sectors were limited, partly due to the economic uncertainty caused by Brexit.

Examples of our **main funded collaborative projects** with a total budget of over £1m for each include: ANIKETOS: Secure and Trustworthy Composite Services (EU FP7, €9.6m, 08/2010-05/2014); Wi-5: What to do With the Wi-Fi Wild West (EU H2020, €2.1m, 01/2015-06/2018); Wise-IoT: Worldwide Interoperability for SEMantics IoT (EU H2020, €1.5m, 06/2016-05/2018); Liverpool 5G Testbed (DCMS, £3.5m, 03/2018-01/2020); Liverpool 5G Create (DCMS, £4.3m, 08/2020-03/2022); LCR Activate - Digital Accelerator (ERDF - European Regional Development Fund, £2.1m, 2017-2020, [link](#)); TII (Trusted Information Infrastructure): S/W Framework for Realizing Trustworthy IoT Eco-system (Korea IITP: £5m, 06/2015-05/2018, converted based on 1 GBP = 1,489 KRW on 23/09/2020); and GDPR-PIIM: GDPR Compliant Personally Identifiable Information Management Technology for IoT Environment (Korea IITP, £1.6m, 04/2018-12/2020). In addition, examples of our EPSRC-funded projects include 'Using Drones to Protect Biodiversity and Spur Economic Growth in Madagascar' (£574k, 10/2019-03/2021) and three awards to our ECRs (Dobbins, Tso, Hurst) under the First Grant or New Investigator Award scheme (£100k per project).

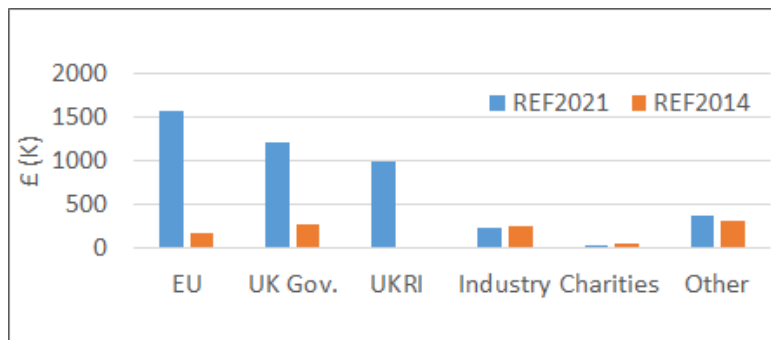


Figure 1: Research income and sources

The above grants helped to advance the UOA research with significant outcomes in terms of **high-quality outputs and impact**. These include publications in high-quality academic journals, e.g., IEEE TMC, IEEE TIFS and IEEE TNSM, as evidenced by the UOA's submitted outputs. The project results were also exploited to create impacts as shown in our impact case studies.

It is evident from Figure 1 that we will need to extend our funding sources for **future income and impact** generation. While endeavouring to sustain and even increase our income from the EU, UK government and UKRI, it is imperative for the UOA to extend its engagement with other available funding bodies. In particular, we will seek further collaborations with charity and industry organisations as only 1% and 6% of the UOA research income come from these two sectors, respectively. As our research is grounded on practical solutions to tackle real-world problems, we will invest more efforts in exploring collaboration opportunities in these two sectors to expand the income and impact of our research.

3.2. Infrastructure and facilities

The research infrastructure and facilities supporting this UOA are invested and operated at University, Faculty and Department levels. At **University level**, LJMU's document REF5a presents the details of the support provided by the University. The support most relevant to the UOA includes the provision of office space and standard IT services, digital resources like IEEE Xplore and the institutional repositories for open access, and research support (e.g., by RIS and DA) to assist the staff in funding applications and offer administrative support to PGR students. As stated in Section 2, the UOA staff have benefited significantly from the University's support. In addition, the University invested in Sensor City in partnership with the University of Liverpool, supported by a £10m grant from the Department for Business, Energy and Industrial Strategy and the England ERDF, to create a global innovation hub for sensor technology in 2017. It

provides the UOA staff with a venue for user engagement and a platform for the joint exploitation of sensor-related applications.

At **Faculty level**, the University allows its QR funding together with other research income and office/lab improvement budgets to be dispersed to faculties. This enabled our Faculty to invest in infrastructure and facilities over this REF period. The main investment relevant to this UOA is three-fold. First, office and lab space in the Departments involved in this UOA was improved and expanded with a spending total of £2.7m. The total space increased by 20% in comparison with that in the previous REF period. Notably, the space for two new labs, LIVE Lab and Machine Learning, was allocated to meet increasing needs for research, impact generation and teaching in usability studies and intelligent systems. Also, the yearly average number of our PGR students in this REF period increased by 32% over the previous REF period. To meet the growing office space demand, the Faculty acquired extra offices and moved all the PGR students there, which in effect added further space to improve the condition of the UOA staff's offices.

Secondly, in addition to the standard IT facilities operated by the University, the Department of Computer Science runs more specialist computing labs with the facilities upgraded normally every 5 years. Similarly, the UOA staff and PGR students have computer facilities in their offices with an upgrade cycle of 5 years. The cost of such facility upgrades amounted to a total of over £1.1m in this REF period. Also, the two new labs have cutting-edge facilities for the development and delivery of immersive, virtual, mixed and augmented reality technologies as well as high performance computers and large data storages for machine learning based data analytics, which costed a total of over £250k. To support individual staff or groups' research, the Faculty offers pump-priming and capital equipment grants for the staff to apply in order to acquire specialist facilities needed for their research and impact generation. A total of £280k was awarded to the UOA staff over this REF period, e.g., for purchasing cloud servers and mobile devices.

Moreover, all the faculty-funded **facilities are shared** among different departments and research centres to promote cross-subject research collaborations. Notably, the Faculty invested £700k in a much more powerful high-performance computing facility between 2018 and 2019. It comprises 1,280 AMD Rome processing cores in 20 high-density HPE Apollo compute nodes, networked with the high-bandwidth, low-latency HDR Infiniband fabric and supported by a parallel BeeGFS file system with a total memory footprint of 10TB and a long-term storage capacity of 1.5PB. The facility offers excellent capabilities for our UOA staff to conduct computationally intensive data processing experiments.

Thirdly, in this REF period, the Faculty invested in setting up a dedicated team of 5 admin staff to support research-active staff in external funding applications, funded project management, staff training and PGR administration. The team liaises between the Faculty academic staff and the University's RIS and DA to reduce the staff's administrative workload on funding and PGR related activities and thus give them more time to focus on research matters. The team also works closely with senior research-active staff to review and advise on funding applications. This UOA benefited significantly from the team's support during this REF period, evidenced by the increased research income and PhD completions as discussed earlier.

At **Department level**, the infrastructure and facilities provided by the University and Faculty were complemented by further pump-priming funding with around £20k per year from our Departments in the last three years of this REF period. This allowed the UOA staff to upgrade facilities in the existing research labs such as those for information security, networking and gaming in order to engage in up-to-date research and impact activities. For example, the facilities provide an integrated environment involving IoT devices, cloud servers and GPU-based computers for research experiments on smart and secure IoT systems, and a 5G testbed for the simulation and evaluation of wireless resource optimisation techniques. There is a team of 8 technicians in the Department of Computer Science to provide the operational support and maintenance of all the computing facilities accessible by the UOA staff and PGR students. In addition, there is an annual budget of £30k provided by our Departments for other financial support, e.g., research consumables and travel.

The aforementioned infrastructure and facilities underpinned the UOA's **impact activities** during this REF period. This is because they allowed the UOA staff to develop new expertise through the implementation and evaluation of research findings and then disseminate the successfully validated results to interested research users for impact exploitation. The UOA's impact case studies demonstrate such links from infrastructure and facility utilisation to impact generation.

For fair funding distribution, applications to each funding scheme mentioned earlier are normally assessed by a group of senior staff who have completed the **equality and diversity** training delivered by the University and form a balanced representation of the applicants. The assessment takes into account factors such as application merits, staff personal circumstances and ECR support for decision making to ensure fair funding allocation and equal opportunities for all. This is then followed by a feedback process to resolve any concerns raised by the staff. To access funded facilities shared by a few users (e.g., the 5G testbed), the sharing is often agreed and arranged among the users themselves. For facilities in high demand (e.g., high performance computers), a set of criteria and a booking system are normally used to ensure fairness in the facility sharing.

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

4.1. Collaborations

The UOA staff have long recognised the growing trend of technological convergence and the important value of collaboration to address multi/inter-disciplinary research challenges brought about as a result of this. Such recognition has been reflected in the UOA research strategy in Section 1.2.1 with a focus on collaboration. During this REF period, a number of measures were taken to facilitate and support collaboration as described in the previous sections. These measures led to successful collaborations at local, national and international levels, which were built on concerted effort and complementary expertise to make more significant research findings and impact as shown in the UOA's submitted outputs and impact case studies and generate more research income as discussed in Section 3.1. Specifically, these collaborations include:

- **Funded research collaborations:** The UOA staff were active in seeking external funding for collaborative research and successful in delivering funded projects, which enabled the staff to collaborate internally and with academic and research institutions worldwide for joint research. 80% and 83% of the UOA income involve internal and external collaborations, respectively. For example, our funded international collaborations include:
 - 4 European (e.g., University of Cantabria in Spain, and Institut Mines-Télécom in France) and 5 Korean (e.g., Korea Advanced Institute of Science and Technology, and Kyungpook National University) institutions as project partners on the EU and Korea joint Wise-IoT project to build federated and interoperable platforms for secure IoT applications (Lee).
 - 7 institutions (e.g., SINTEF in Norway, University of Salzburg in Austria, Waterford Institute of Technology in Ireland, and University of Trento in Italy) as project partners on the EU FP7 Aniketos project to develop trustworthy service composition techniques (Shi, Zhou).
 - 1 institution Universitat Autònoma de Barcelona (UAB) in Spain, supported by projects including EU FP7-PEOPLE TRANSACT (03/2013-02/2017), to investigate novel ways of data representation, e.g., for medical images (Lisboa, Ortega, Olier).
 - 1 institution Le Quy Don Technical University (LQDTU) in Vietnam through Royal Academy of Engineering and Vietnamese Government funded projects (03/2017-06/2019) to design new intrusion detection methods (Shi, Shone, Askwith, Zhou, Mac Dermott).

These funded projects successfully delivered novel techniques and tools and generated research publications to disseminate them. For example, the collaboration with UAB resulted in 12 journal articles (e.g., in PLOS ONE), 8 conference papers (e.g., in IEEE IJCNN) and one book chapter. The collaboration with LQDTU led to a journal publication ("A Deep Learning Approach to Network Intrusion Detection Computational Intelligence for Cloud

Computing”, IEEE TETCI, Vol. 2, No. 1, 2018) with 8,900+ views and 130+ citations ([link](#)).

- **Research user engagement:** The majority of the UOA’s projects involved research users as project partners or advisers to ensure that the project outcomes address their needs and have lasting impact on the improvements of their products or services. This led to collaborations with a wide range of user organisations including large international companies such as NEC, SAP and Samsung. Examples of the user involvement in the UOA’s projects include:
 - 15 telecommunication operators (e.g., Orange in France, EE in the UK, and Ziggo in Netherlands) as project advisory board members and 3 industrial partners (e.g., Telefónica in Spain and AirTies in Turkey) on the EU Wi-5 project to develop optimised connectivity for Wi-Fi services, adopted by AirTies to improve their services as detailed in ICS3 (Mackay, Bouhafs, Raschella, Shi).
 - 7 companies (e.g., Blu Wireless, and eHealth Cluster) and 2 public organisations (Liverpool City Council, and Royal Liverpool & Broadgreen University Hospital Trust) as project partners on the Liverpool 5G Testbed project for improving people’s health and wellbeing, with extra funding to further exploit the project impact through Liverpool 5G Create (Mackay, Bouhafs, Waraich, Raschella, Fergus, Chalmers, Zhou).
 - 8 wildlife conservation related organisations (e.g., Durrell Wildlife Conservation Trust, BBC Natural History Unit, and Endangered Wildlife Trust in South Africa) engaging with our work on animal detection for wildlife conservation, but unfortunately several scheduled field trials with some of these organisations had to be halted due to the COVID-19 pandemic (Fergus, Chalmers).
- **Interdisciplinary research collaborations:** As stated in Section 1.2.5, interdisciplinary research relies on collaborations and forms a significant part of the UOA submission. The last two projects above clearly show interdisciplinary nature, e.g., the work on wildlife conservation involves collaborations among staff in the Department of Computer Science, Astrophysics Research Institute, and the School of Biological & Environmental Sciences at LJMU.
- **Other research collaborations:** In addition to internal collaborations, the UOA staff actively reached out to establish collaborations with individual researchers in other institutions worldwide (e.g., in France, China, Korea and Australia) for joint research. This helped to increase the significance of their research findings and thus lead to high quality research outputs and grant awards. For example, 89% and 41% of the UOA’s submitted outputs have external and internal co-authors respectively, and grants such as Wise-IoT involve prior external research collaborations.
- **International research visits:** An important measure for promoting fruitful research collaborations is to host research visitors and send staff to visit other institutions to accelerate the generation of joint research publications or funding applications. During this REF period, the UOA staff received 28 research visitors from other countries, e.g., Prof J.D.M. Guerrero from the University of Valencia in Spain (05-10/2013, 05-09/2016), Dr T. Shinagawa from the University of Tokyo in Japan (09/2017), and Dr F. den Hartog from UNSW Canberra in Australia (11/2019). The UOA staff also made 30 visits to foreign institutions, e.g., Kelly to the University of Michigan in the USA (09/2015), Zhou to Zhejiang University in China (07/2018), and Czanner-G to Aravind Eye Care System in India (07/2019).

4.2. Contributions

Sections 1 and 4.1 have highlighted the UOA’s research and impact contributions to various disciplines, including national and international priority areas identified by the EU and EPSRC, in terms of advancing state-of-the-art technologies and setting further agendas for sustainable research. **Wider contributions** were also made during this REF period to benefit different communities and publics from the UOA research. These are illustrated through the following examples:

- Supported 150 SMEs in the LCR for the technology-assisted improvement of their products and services through the LCR Activate - Digital Accelerator project (Lisboa) mentioned in

Section 3.1, which created 70 gross jobs and generated £2.7m in GVA for the local economy based on a beneficiary survey ([link](#)).

- Organised a British Council funded Newton Researcher Links Workshop on Health and Well-being through VR and AR in China on 27-30/06/2018 (El Rhalibi, Kolivand, Shen) to help ECRs to explore research collaboration opportunities, with 20 participants from each of the UK and China ([link](#)).
- Produced a VR proton beam therapy unit in collaboration with Interserve and Christie Hospital Manchester (Hurst, Shone, Tully), which was partly supported by the Innovate UK ProAccel project (12/2017-05/2018, [link](#)) and played by the mayor of Manchester and 500+ visitors on the opening weekend (07/2018) of the hospital's new Proton Beam Therapy Centre ([link](#)).
- Applied the UOA's pedagogical research in network security to ease students' difficulty in studying the topic by producing and releasing a series of story-based animations about network security protocols (Kifayat, Shi, Shone) on YouTube ([link](#)), which was funded by the UK Higher Education Academy (11/2015-02/2017) and received a total of 44,000+ views (available on request due to changes to some view numbers) since 02/2017.
- Developed an AR application for life-science education in collaboration with Aberdeen University and Imagin3D (Hurst, Tully), which appeared on BBC News Scotland and a front cover of Physiology News Magazine ([link](#)), is now used for teaching first-year biology students at Aberdeen University and shown to school children ([link](#)).

In addition, the UOA staff actively contributed to a wide range of other academic activities in terms of **community engagement and leadership**. These include:

- **Advisory/standardisation boards:** 35 roles were contributed by the UOA staff. Examples include Vice-Chair for Marie Skłodowska-Curie Actions-Individual Fellowships (Lisboa, 2018-2020), Chair/Co-Chair of H2020 Expert Advisory Group for SC1: Health, Demographic Change and Wellbeing (Lisboa, 2014-2018), Vice Chair for H2020 FET-OPEN (Fergus, 2016-2020), and Chair of ITU-T Focus Group on Data Processing and Management (Lee, 2015-2020).
- **Prizes/awards:** 20 awards were given to the UOA staff, e.g., the best papers at IEEE ICME 2018 (Sheng) and IEEE iThings 2017 (Yang), one of the two winners of a datathon with a shared prize of €50k organised by national oil company Galp in Portugal in 11/2019 (Olier), and the 3rd prize of the London Innovation Awards in 2015 (Chalmers, Fergus).
- **Research fellowships:** 2 grants were awarded to the UOA staff. Ortega with the support of Lisboa secured an EU Marie Curie Research Fellowship (10/2013-03/2016, €231k). Kelly was awarded an early career mini fellowship by the In Vitro Toxicology Society (IVTS) (2015, £1,500).
- **Journal editorships:** 22 roles were held by the UOA staff. Examples include Academic Editors in PLOS ONE (Ortega and Olier, 2018-now), Associate Editor in BMJ Open Ophthalmology (Czanner-G, 2016-now), and Associate Editor (Yang) in IEEE JTEHM (2018-now) and IEEE Access (2018-now).
- **Conference/workshop chairs:** 58 chair positions were served by the UOA staff, including T6 Programme Chair of IEEE CCNC (El Rhalibi, 2017-2018), Programme Chair of IEEE-CIBD (Lisboa, 2015), Series Co-chairs of IEEE DeSE (Al-Jumeily and Hussain, 2007-now), and General Chair of TENAS (Pereira, 2014-now).
- **Keynotes/invited talks:** 142 speeches were given by our staff. For example, keynotes include IEEE ICCT 2015 (El Rhalibi), IEEE ICDM 2016 and IDEAL 2019 (Lisboa). Talks were given at Microsoft Research (Savoye, 02/2016) and MIT (Czanner-G, 09/2017, 06/2018) in the USA as well as Westminster Sustainable Business Forum (Chalmers, 07/2016).
- **Journal editorial boards:** 21 memberships were taken up by our staff, e.g., Applied Soft Computing (Lisboa, 2013-2015), Graefe's Archive for Clinical and Experimental Ophthalmology (Czanner-G, 2012-now), and Biosensors & Bioelectronics (Lee, 2018).

Unit-level environment template (REF5b)

- **Conference committees:** 60+ memberships were served by the UOA staff. Examples include SIGGRAPH 2016 (Savoye), CGI 2018-2020 (Sheng), IEEE FiCloud 2016 (Pereira), IEEE ICC 2019 (Raschella), and ISCC 2020 (Shi).
- **Paper/proposal referees:** 700+ research papers and funding applications were reviewed by the UOA staff, e.g., for IEEE TPDS, IEEE TMC, Neurocomputing, PLOS ONE, ACM TECS, GLOBECOM, IEEE VTC, and funding bodies such as the EU and EPSRC.