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| <b>Institution:</b> University of Kent   |
| <b>Unit of Assessment:</b> 12: Engineering   |
| <p><b>1. Unit context and structure, research and impact strategy</b></p> <p><b>Context and Structure</b></p> <p>The University of Kent's School of Engineering and Digital Arts (EDA), located in the Division of Computing, Engineering, and Mathematical Sciences (CEMS), comprises three well-established and highly regarded research groups: Communications; Instrumentation and Control; and Intelligent Interactions. In addition to these established groups, since 2019 the School took the strategic decision to expand into the field of Mechanical Engineering, recruiting two new staff and the development of new laboratory space costing over £3 million. The overarching strategic aim of EDA over the REF2021 period has been to engage in research of the highest quality that will have a beneficial impact on industry and society, through fulfilling the three core objectives set out in our REF2014 submission: (1) growing core capability in our three established areas of research excellence; (2) expanding multi-disciplinary research through external and internal collaborations; and (3) impacting positively through our unique combination of technological and design expertise.</p> <p>We are proud of our achievements since 2014 with respect to all three objectives. We have grown core capability by increasing the number of Category A staff to 29 FTE (up from 24 FTE) across our three established research groups, and we have doubled our externally funded research awards from £1.5 million in REF2014 to £3.1 million in REF2021. We have also increased multi-disciplinary research through enhanced collaborations with industry and the private sector, public sector organisations, other universities nationally and internationally, as well as with Kent researchers beyond EDA (see Section 4). The impact of our research has been demonstrated in the areas of cyber security, process instrumentation, and mobile communications, as shown in our impact case studies and the further examples provided below. Much of this impact has been driven by our unique blend of design-informed technology.</p> <p>Underpinning our three strategic objectives has been a strong commitment to sustainability and the development of researchers at all career levels. This is reflected by the fact that four of the eight new staff appointed in this REF period were former PhD students and researchers in the School.</p> <p>The activities of the three groups are overseen by the School Research and Innovation Committee, chaired by the School Director of Research. Working closely with staff, this committee sets the groups' research priorities and identifies new opportunities.</p> <p><b>Communications.</b> This group comprises 10 staff: J. Wang (Chair), Assimakopoulos, Batchelor, Gao, Gomes, Horne, Sanz-Izquierdo, C. Wang, Young, and Zhu. It explores the theory, design, and manufacture of advanced communications technologies and systems for high-frequency and/or high-data-rate wireless systems operating from radio frequency (RF) to Terahertz (THz) frequencies to support new and emerging applications. The group has established collaborations with industries and academic institutes globally (see Section 4), and plays a leading international role in the fields of mobile communication systems, microwave photonics, RFID antennas, low-cost smart antennas, and space antennas.</p> <p>Since 2014, the Communications group has been actively involved in a number of national and international projects, cementing its international reputation. Recent projects reflect the areas stated in the group's objectives in REF2014, involving work on high-data-rate, 'fifth-generation (5G) and beyond' mobile communications; microwave photonics and fibre-wireless convergence; RF/microwave/mm-wave circuit design; RF identification (RFID) antenna and frequency selective surface (FSS); and smart antennas, microwave, millimetre-wave and sub-THz phased arrays and space antennas. In the REF2021 period, the group's achievements in the field of 5G (and beyond) mobile communications have included:</p> |

- Proposing a novel beam allocation algorithm in massive multiuser MIMO systems to achieve maximum throughput, (Zhu, Gomes, J. Wang, 2018).
- For the first time, proposing a user-centric optimisation algorithm in cloud radio access networks by dividing the optimisation problem into two stages (Zhu, Gomes, J. Wang, 2017).
- Presenting a new performance evaluation method for emerging mobile multiuser device-to-device (D2D) communications to mitigate interference between cellular and D2D users (Zhu, J. Wang, 2019).
- Leading a European project for the use of Ethernet optical fibre transport for the support of future mobile/wireless networks (Gomes, Assimakopoulos, 2014-17).
- Demonstrating the first millimetre-wave frequency distributed MIMO system using radio over fibre transport (Gomes, 2017).
- Proposing and demonstrating novel digital signal processing to support analogue radio over fibre (Gomes, Assimakopoulos, 2018).
- Proposing and demonstrating novel analogue all-optical signal processing for microwave photonic systems that tackle bandwidth and data challenges (C. Wang, 2018).
- Performing 5G harmonised research and trials for service evolution between EU and China (Zhu, Gomes, Assimakopoulos, J. Wang, 2018-21).

In the field of antennas and RF devices for mobile and satellite communications, IoT, biomonitoring, and space-borne remote sensing, the group's achievements in this REF period include:

- Proposing new techniques for the design of ultra-wideband reflectarray antennas and transmitarrays for satellite communications, demonstrating a printed reflectarray with the widest bandwidth reported (Gao, 2017).
- Pioneering the development of planar duplex filtering antennas (Gao, 2016).
- Proposing and demonstrating a wide range of low-cost electronically beam-scanning smart antennas using technology from our patent filing on active FSS (Sanz-Izquierdo, Gao, Batchelor, 2017).
- Proposing novel printed FSS for 5G and THz frequencies (Sanz-Izquierdo, Gao; 2020) and developing 3D printed wearable antennas (Batchelor, 2019).
- Developing nanowire transistor devices for beam-steerable antennas and, subsequently, smart printable surfaces for the control of radio waves inside buildings, with application in RF energy harvesting and signal strength improvement (Young, 2017).
- Demonstrating skin mountable sensing technologies with battery-free communications (Batchelor, 2020).

The group's research over the next five years will focus on theory, techniques, and technologies to underpin next-generation, high-data-rate wireless communication systems, which, owing to spectral congestion, will increasingly be required to operate at higher frequencies with greater spectral efficiency. The systems will also need to efficiently and dynamically adapt and support end-user applications with vastly different service requirements and traffic characteristics. The group's strategic objectives in the forthcoming period include:

- Enhancing our work in radio resource allocation, ultra-massive MIMO, and multiple access for high-data-rate wireless communications by applying artificial intelligence technologies. This work will be undertaken at a critical and opportune phase, with the emergence of new international standards for 6G mobile communications.
- Extending our work on the use of analogue and digital fronthaul transport by integrating with software-defined networking, network slicing, and orchestration functions, important for future networks, and with the use of distributed deep learning algorithms.
- Developing further our microwave photonics research, particularly in on-chip photonic signal processing, and exploring interdisciplinary applications of microwave photonics.

- Translating our flexible skin-mounted wireless sensing platforms to millimetre-wavebands offering multiple channel access for sensors and monitored individuals.
- Continuing our innovation of manufacturing processes for lifecycle engineering with the development and incorporation of transient materials to our sensing platforms and batteries.
- Developing miniaturised wideband/multi-band beam-scanning intelligent antenna and circuits at microwave, millimetre-wave and THz frequencies for terrestrial (5G/6G mobile communications, smart sensors for self-driving cars) and space applications (satellite communications, Internet of Space).

**Instrumentation and Control (IC).** This research group comprises nine staff: Y. Yan (Chair), Hussain, Lu, Marcelli, Oven, Sakhaei, Shafiee, L. Wang, X. Yan. Formerly known as the Instrumentation, Control, and Embedded Systems group, it changed its name in 2018 to reflect a more concentrated focus on applied instrumentation and control. The group has had considerable success in solving challenging measurement, monitoring, and control problems through applied research programmes, with support from a range of funding bodies and industry. It has established long-term partnerships with power generation and manufacturing industries such as EDF Energy, RJM International, and KROHNE Ltd (see Section 4). The IC group's expertise lies primarily in industrial process sensors, intelligent instrumentation, smart condition monitoring, digital image processing, data fusion, data modelling, and robust control and estimation. Since 2014, the group has published more than 100 research papers in leading journals and over 130 refereed conference papers in the field of instrumentation and control. In addition to a well-equipped Instrumentation Laboratory on the University's Canterbury campus, the group has regular access to industrial-scale test facilities and full-scale power plants for demonstration trials.

The IC group has made significant advances in a number of externally funded projects with industrial and international partners, sustaining its international reputation in its field. Its achievements in this REF period include:

- Flame imaging technology capable of providing the quantitative measurement of flame characteristics such as temperature distribution, free radical concentration, and stability under a diverse range of combustion conditions (biomass flame, coal flame, oxy-biomass flames, gas turbine flames, etc.). This area of work (Y. Yan, Lu, 2014-20; Hossain, 2018-20) has been supported by Doosan Babcock, British Sugar, EDF Energy, RJM International, Walsn Energy Limited, and the UK Carbon Capture and Storage Research Centre (UKCCSRC).
- New solutions to mass flow metering and online particle sizing of pulverised fuel (coal and biomass) by combining piezoelectric sensing techniques and electrostatic sensor arrays. On-plant demonstration trials have been conducted on three coal-fired power stations in China in collaboration with Walsn Energy Limited and North China Electric Power University (Y. Yan, 2017-20). The pulverised fuel flow metering technology has resulted in the installation of full-scale systems in operation at over 20 power stations across China (Y. Yan, 2014-20), as detailed in the impact case study (Y. Yan et al.) in this submission.
- The development of Coriolis flow metering technology for the measurement of multiphase flow. The Coriolis technology, though well established for single-phase flow measurement, has been extended to measure gas-liquid flows by incorporating multi-modal sensing and soft computing models (Y. Yan, L. Wang, 2018-20). It has been successfully deployed for the measurement of CO<sub>2</sub> under both static and dynamic CCS conditions. This area of research is supported by KROHNE Ltd and North China Electric Power University.
- Advances in fundamental theoretical research in relation to robust decentralised control and fault diagnosis. A systematic methodology has been developed for robust control of nonlinear systems using limited measurement information (X. Yan, 2014-17). Significant achievements have been made in dealing with nonlinear interconnections under complex surroundings. Sliding mode technique-based fault diagnosis has been developed to enhance the system performance and safety (X. Yan, 2016-20). These methods have been deployed in real systems such as robots, high-speed trains, and industrial processes in

collaboration with Nanjing University of Aeronautics and Astronautics and China University of Petroleum.

- Computational modelling applied to understand physical properties of biological cells to identify differences between normal and diseased bloods. This area of work was funded by an EPSRC grant and in collaboration with University of Exeter and King's College London (Marcelli, 2015-19).
- Development of electronic devices to achieve diagnosis of medical conditions in speech-swallowing therapy with support from RoseMedical (Marcelli, 2017-20).

Post-REF2021, a subset of the IC team will lead the future Mechanical Engineering group (see Section 3). The remaining IC group members will continue to focus on Instrumentation and Control, sustaining research that is beneficial to the power-generation, renewable-energy, manufacturing, and healthcare industries. The IC group will continue with its applied research programmes in sensing, instrumentation, imaging, robust control and estimation, and plans to further develop its research in the following core areas:

- Multiphase flow metering, in particular, coal/air and biomass/air two-phase and coal/biomass/air three-phase flow metering and online sizing of coal and biomass particles.
- Mass flow rate and gas fraction measurement and leak detection of carbon dioxide under Carbon Capture and Storage (CCS) conditions.
- Monitoring and characterisation of burner flames in the power-generation and other industries.
- Structural health monitoring of mechanical systems such as wind turbines.
- Automated quality inspection of recycled plastic waste bales.
- Fundamental nonlinear control paradigms with intelligence consideration applicable to networked systems and multi-agent systems, with a focus on control mechanisms in engineering applications.
- Deep learning techniques to perform image-based cell profiling to enable the quantification of phenotypic differences on large-scale biological systems, to automate the process of discrimination between cell lines with the same genetic origin, and to perform functional and mechanistic investigations.

**Intelligent Interactions (II).** This research group comprises 10 staff: Howells (Chair), Ang, Covaci, Deravi, De Wilde, Efstratiou, Guest, Hoque, Sirlantzis, and Von Jungendorf. The group's research focus encompasses all aspects of information engineering, digital media, and human-machine interactions, and successfully blends these themes to address fundamental current issues in how artificial intelligence, robotic systems, and digital media can be efficiently exploited within the engineering and security domains. The group has an international reputation for its work in a number of key application areas in pattern recognition, interaction design, social, ubiquitous and mobile computing, device authentication, security and biometrics, healthcare, e-learning, computer games, interactive media environments, digital film, and animation. The group's principal achievements in the REF2021 period have included:

- Biometric verification technologies (Guest, Deravi, 2014-20; see impact case study), which has impacted the algorithmic performance of biometric implementations, increasing rates of accuracy in recognition and protection against attacks, thereby ultimately enhancing the experience and convenience for end users. This work has also provided multiple worldwide standards since 2007 for the interchange of data, directly used by implementers of systems worldwide, and also contributed to understanding the use of these systems in novel implementations, in particular on mobile devices, increasing the security of devices for the general public and service providers.
- Device authentication which has led to the development of ICMetrics (Howells 2014-20; see impact case study), a highly novel technology for deriving secure, uniquely identifying encryption keys from the properties of digital systems, which enables the establishment of trust and provenance in the identity and integrity of electronic devices via their inherent



physical and behavioural characteristics. This research has led to the creation of a spin-out company, Metrarc Ltd.

- Health-related robotics where the group developed and tested the UK's first and only (currently) fully actuated wheelchair-driving virtual-reality-enabled simulation platform. This work focuses on the fusion of computer vision, pattern recognition, artificial intelligence, and robotic control for assistive technology (AT) systems. The team also successfully developed and trialled with wheelchair users technology for autonomous and semi-autonomous navigation of wheelchairs able to provide environment contextual information (e.g. avoiding obstacles, and semantically characterising objects in the environment such as door-handle types and electric switches, as well as potholes in the road). This represents a fundamental requirement for patients to practically employ such systems (Sirlantzis, Hoque, Howells, 2014-20).
- Human-centred healthcare innovations where the group has pioneered the design of virtual reality (VR) in dementia care over the past seven years. This work has led to a pilot trial in a psychiatric hospital (St Andrew's Healthcare). The team has also designed the first multi-user remote VR system for eating-disorder therapy.
- The group also has a strong interest in the use of artificial intelligence for art creation, and for this research it has received the BCS AI Award at the Lumen Prize (Von Jungfeld, 2019).

Over the next five years, the II group plans to build on its strong knowledge base and the increasing successes of our industrial collaborations, maximising the impact from existing research themes. The focus of II will be to:

- Extend its work linking the areas of biometrics and forensics, including interdisciplinary studies of interpretation and use, connect work in the security domain to new analyses of user interaction, and explore new applications in extended realities and social networks.
- Extend its work on device authentication into the development of practical exploitable systems.
- Increase the reach and visibility of its work on assistive robotics and other healthcare technologies, with a focus on usability and functionality, aiming to achieve large-scale practical uptake of the technology. This work will be augmented via a collaboration with the new Mechanical Engineering research group.
- Link technologies that understand and generate new 'art' with healthcare-centred applications, making use of sensors and machine learning.

### Supporting Interdisciplinary Research

Our three research groups work flexibly together and with other Schools at Kent, with interdisciplinary research strongly encouraged. There has been a strategic emphasis throughout the REF2021 period at both School and institutional level on supporting a wider engineering provision than the traditional electronic-based disciplines at Kent, and on nurturing increased interdisciplinary activity by encouraging participation in University initiatives and joint studentships. As well as fully integrating within the initiatives outlined in REF5a, our disciplinary base has been enhanced throughout the REF period by involvement with a number of research centres operating at both Faculty (now Divisional) and institutional level, including the Institute of Biotechnology and Molecular Medicine (iBaMM), the Signature Research Themes 'Future Human' and 'Migration and Movement', and the Kent Interdisciplinary Research Centre in Cyber Security (KirCCS), which has been recognised by the EPSRC and NCSC as an Academic Centre of Excellence in Cyber Security Research (ACE-CSR). Following on from the success of KirCCS, the School has played a leading role in the University's plan to establish an Institute of Cyber Security for Society (iCSS), which is being launched in 2020-21. This Institute, one of only four at the University, involves interdisciplinary research with disciplines such as Computing, Sociology, Law, Business, Politics, and Psychology.

We have a strong research track record in new wireless communications sensing through Manufacturing the Future, sensing and instrumentation technologies, and autonomous and robotic

platforms, as exemplified by our wheelchair research. For further interdisciplinary collaboration, we will strengthen research links with the Materials for Energy and Electronics group in the School of Physical Sciences, and grow our longstanding activities in healthcare technologies in collaboration with the new Kent and Medway Medical School (KMMS). The interdisciplinary growth areas that we will be prioritising are all included in the UK Industrial Strategy and the Research Council priority themes for a Prosperous Nation.

### **Impact Strategy**

Impact has always been a core strand in EDA's research and innovation strategy. Each of our research groups has strong and well-established links with industry (see Section 4), and impact is an essential part of the annual Individual Research Planning (IRP) meetings with our staff. We actively involve industry and other stakeholders from the early stages of our research activities, and the benefits of these close relations are demonstrated in our impact case studies and in the project examples provided in Section 1 above. Collaborations with industries are exploited through internationally funded projects, KTPs, and industry-funded studentships. Spin-out companies and consultancy work are also actively encouraged and supported. Research planning in the School is geared towards the translation of research outputs to achieve a strong impact across the spectrum, in particular the generation of new industrial products and services, as evidenced in our impact case studies.

### **Research Integrity**

EDA nurtures a strong culture of research integrity. The fundamentals of research ethics are reinforced annually through information sessions for all staff, together with dedicated training sessions for PGR students. EDA's Research Ethics and Governance Officer is responsible for providing advice and guidance for academic staff as they develop research projects. The School has a robust ethics approval process that guarantees rigorous and timely review. The School is a member of the Research Ethics and Governance Committee. Alongside a formal reporting and accountability function, this Committee is an important venue for sharing best practice and addressing difficult cases, while also providing external ethics reviews for large grant applications. The University's Research Ethics and Governance Manager works within this framework to provide advice and to share knowledge on emerging best practice. We have also developed a legally compliant infrastructure for collecting and sharing research data, including data that contains personal information as defined in GDPR. Together, these procedures drive a proactive culture of research integrity that combines a strong knowledge base with a rigorous, timely, and well-supported administrative process.

### **Open Research**

EDA is fully committed to open research, and is supported by the University to achieve Gold rather than Green Open Access (for further information, see REF5a). Through the University's Research and Innovation Services team, as well as the Office for Scholarly Communication, all members of staff in EDA have benefited in the REF2021 period from dedicated training opportunities on Open Access, research metrics, dissemination planning, and copyright.

## **2. People**

### **Staffing Strategy**

Our staffing strategy is to recruit, develop, and retain high-quality researchers, focusing on areas where we can build critical mass and increase visibility, and appointing early career researchers (ECRs) whenever possible in order to support the next generation of research leaders in Engineering. Over the REF2021 period, we have strengthened established areas of research excellence and invested in emerging areas (in particular, Mechanical Engineering), while maintaining strong succession planning. We have sought to: maintain appropriate growth and balance in our staff numbers; focus on recruiting and nurturing highly skilled ECRs; support and develop the potential and capabilities of all our staff; and ensure our environment is conducive to international quality research. During the REF period, we have appointed six new staff to existing

groups and two additional staff to our new Mechanical Engineering research group. Additionally, two new technical posts have been created to support Mechanical Engineering. We have focused on building a strong network of talented ECRs in order to recognise new talent and ensure a vibrant and sustainable research culture. Of the eight new staff appointed during the REF2021 period, six had not previously held established academic positions.

While our academic recruitment strategy focuses on building our strength in the School's research groups, we also seek to enable multidisciplinary connections. For example, the appointment of Hossain (2018) and L. Wang (2018) aligned with our succession planning strategy for the IC group, while their work on sensors, computer vision, and deep learning helped to strengthen connections across all the research groups. The II group recruited Von Jungfeld (2016) and Covaci (2018) to build links between research on human-machine interaction, AI, and mechanical engineering. The appointments of Assimakopoulos (2019) and Horne (2020) complemented the strengths of the Communications group through their expertise on smart antenna technologies for wireless communications.

### Staff Development

The EDA staff development process is designed to create an open, inclusive, and supportive working environment. We look to develop the potential and capabilities of all our staff through a range of development opportunities, including:

- A supportive and rigorous probation procedure.
- One-to-one mentoring for new staff. Annual individual research planning (IRP) and performance development ('Reflect, Plan, Develop') reviews.
- Transparent and equitable time management through our work allocation model (WAM).
- A supportive peer-review system.
- Inclusive platforms and events for knowledge sharing.
- Internal funding for travel and conference attendance.
- Flexible and family-friendly working patterns.

The School is a vibrant and supportive workplace with a strong culture of celebrating successes. We actively seek 'good news' stories about our staff and students, and we publicise achievements through the School website, social media, and on public display screens within the School.

*Probation and support for ECRs.* All new staff are required to undertake a rigorous and supportive three-year probation process. ECRs are assigned a mentor from among the senior staff for the duration of their probationary period and are actively supported to plan their short- and long-term career, with a view to achieving promotion within five years of appointment. New staff are given a reduced teaching load (a 50% reduction in year 1; 25% in year 2), as well as significantly reduced administrative duties. Additional support is provided to our ECRs through the integration of the various training development mechanisms with opportunities to network and share best practice across the institution. ECRs have priority for the allocation of internally and externally funded PhD studentships, and at least one studentship has been allocated to each of our ECR in recent years. ECRs who are new to PhD supervision are mentored by more experienced supervisors and are encouraged to join PhD supervisory teams to help with their development as independent research supervisors. The School also supports ECRs by funding six additional months of PDRA time for New Investigator Award winners, attaching PhD studentships to most successful funding proposals and providing additional travel support for attending conferences and other networking activities.

*Appraisal and career development.* The School undertakes an annual appraisal process with each staff member, conducted by a senior academic and complementing the School's Individual Research Planning (IRP) process (see below), and the University's 'Reflect, Plan, Develop' (RPD) process. The RPD serves the purpose of identifying the needs of each member of staff, including training, pathways to promotion, and career development. For staff at an early stage of their academic careers, the School has fully embraced the Concordat to Support the Career

Development of Researchers to ensure holistic support for our ECRs. The RPD and IRP processes provide staff with mentoring and support to help disseminate research and maximise impact, and ensure that resources are targeted appropriately and effectively. The career development needs of more established academic staff are also identified through the annual appraisal and IRP processes. These annual reviews are monitored by the Head of School and the Heads of the research groups, to ensure that individual staff are supported and encouraged, and that their research fits the strategic direction of the unit. Staff development needs, career guidance, and training are also supported at University level through its Staff Development Policy (see REF5a).

*Promotion and reward.* The School Promotions Committee takes a proactive approach to the career development of our staff, identifying potential candidates early in the annual promotion cycle and encouraging and assisting them in their applications. This has resulted in considerable success in career development for our staff since REF2014, with five promotions to Senior Lecturer, three to Reader, and four to Professor. Promotion to Reader and Professor requires evidence of international research reputation, supported by objective criteria and external support. Final decisions on promotions are made by the University Promotions Committee, chaired by the Vice-Chancellor, with supportive written feedback provided to all applicants. Since 2014, a number of our research students and Research Associates have secured academic positions, either within the School (four) or elsewhere (eight). The School has also attracted a large number of highly qualified overseas Visiting Scholars and research students over the REF period, and we will continue to make use of the advice and input of our Visiting Scholars in the development of high-quality outputs.

*Supporting funding applications.* In line with University policy, the School has a strongly supportive internal peer-review process to help our staff produce high-quality grant proposals, with particular mentoring and reviewing assigned to UKRI New Investigator awards. Additionally, frequent internal workshops and staff forums are organised on the preparation of high-quality applications by senior academics with extensive experience of success in funding applications. The University's Graduate and Researcher College also runs a regular Grants Factory programme for staff applying for research funding, and this includes regular mock panels to provide feedback to less-experienced staff on how to write strong applications. The University also provides funding to pump-prime research and innovation projects on a competitive basis, the allocation of these funds prioritising ECRs. In the REF2021 period, staff in EDA were successful in obtaining these funds on several occasions; for example, Von Jungenfeld's work on interactive projections on the Gulbenkian façade (£5,350) and Covaci's work on multisensory stimulation for masking quality degradation (£3,867).

*Workload allocation.* The School workload allocation model (WAM) is designed to provide support for research, with an additional 10% of research time over and above the time allocated to the project to any project investigator. This serves to both reward any successful proposal investigator and to release time for them to devote to the preparation of further project proposals.

### **Equality, Diversity, and Inclusivity**

EDA is committed to incorporating the principles of equality and diversity in every aspect of our recruitment and promotion processes, working patterns, teaching, and research. All our staff are required to undertake equality and diversity training on, for example, unconscious bias awareness and diversity and inclusion in Higher Education. The School is actively engaged in the University's Equality Diversity and Inclusivity (EDI) Network, and is represented on the forum by our EDI representative (Deravi). The School has established its own EDI Committee to ensure that EDI principles are embedded in all of our activities. We were particularly proud to have won the Workplace of the Year award at the Times Higher Education Leadership and Management Awards (THELMAs) in 2018. The award recognised the creation of a bespoke EDI participatory calendar focused on the theme of identity, culture, and celebration to recognise numerous important issues and events such as International Women's Day, LGBT History Month, Chinese New Year, and Mental Health Awareness.



*Gender equality.* In recognition of its achievements in working towards gender equality, EDA secured an Athena SWAN Bronze Award in 2015, and this was renewed in 2018. We are now preparing an application for a Silver Award. The School takes proactive steps to ensure that female colleagues are represented in all areas of School governance, including appointment and promotion panels.

*Working patterns.* The School prides itself on being an open, fair, and democratic workplace. Workloads are allocated on a transparent basis, with a WAM that includes credit for a range of activities, including leadership roles and PGR supervision. We very much appreciate that staff need to balance often conflicting demands with regards to teaching, research, and personal lives, and we look to ensure a good work/life balance for all our staff. We embrace family-friendly policies, including flexible working and the potential for job sharing. We follow the University's policies concerning support for staff and research students returning from periods of leave (including parental leave) or ill health, or with caring responsibilities.

In preparing our submission to REF2021, all staff directly involved in the submission, including the Unit's REF Working Group members and the REF Coordinator, were required to undertake additional EDI training as part of Kent's Code of Practice. Furthermore, we ensured that all staff were able to participate in the process of output selection, encouraging staff to propose which outputs they would like to have considered for submission and ensuring as fair a balance as possible in the final selection.

### **Research Students**

*Recruitment.* Our PhD programmes attract high-quality applicants that reflect and enhance the School's research environment. We have been successful in our strategy to grow our postgraduate research student (PGR) population, with an increase in student numbers of 25% over the REF2021 assessment period, our current cohort being 50 PGRs. To support more PGR scholarships, our focus has been to work with industry in order to explore new partnerships and funding (see Section 4). Academic staff are encouraged to apply for large external funding (e.g., EU/EPSRC), making it possible for the School to support PhD scholarships either as part of the award or through School funds. Awards which have been supported by PhD studentships include 5G-DRIVE, AMBER and PriMa (EU), and Multisense (EPSRC). To enable for the creation of more studentships, external funds have, on occasion, been combined with internal match-funding through University scholarships. School and University policy is to offer 50% funding for studentships that are match-funded by industry, together with several fully funded industrial studentships.

*Training and supervision.* The training and management of our PGRs is led by the School Director of Graduate Studies and our School Graduate Studies Committee. Support for research students is well resourced, and includes both personal direction and group support. The Graduate and Researcher College (formerly the Graduate School) provides a formal Researcher Development Programme for all PGRs and RAs. This is delivered partly at University level (transferable skills) and partly through the School's specialist training programme. Each PGR is supervised by a supervisory panel consisting of first and second supervisors and a supervisory chair. Newly appointed early career staff are trained in research supervision and associated student care. All PGRs attend regular research seminars organised by each research group, give internal seminars at least once a year, and attend the biennial School research conferences. Each student is financially supported by the School to participate in at least one major international conference over their registration period. Students benefit greatly from increasing numbers of international visitors to the School, broadening their horizons and enhancing opportunities for cross-topic discussion.

The University has implemented a robust progress monitoring system. Each student must have an induction review at the end of the first month of their registration, a probation review by the end of the tenth month of registration, and a review at the end of years two and three. In the writing-up year, students may request an extension from a few months to one year. Only under exceptional circumstances is an extension given for more than one year. Progress is monitored

with assistance from the institutional Student Data System, which sends email reminders to students and supervisors of deadlines for submission of reports and outcomes of assessments. This high-quality support, combined with a rigorous first-year evaluation, helps to ensure excellent progress for the great majority of our PGRs, and our completion rates are excellent.

### 3. Income, infrastructure and facilities

#### Income

Since REF2014, the School has been very successful in increasing the income it has received from its research activity, income having almost doubled: from £1,135,993 in 2013-14 to £1,943,171 in 2019-20. This has been achieved through an increase in the cumulative value of both grant applications and awards since 2013-14. In 2016-17, the value of the School's share of awards from externally funded competitive sources reached £3.1 million – the highest annual figure on record for the School. The awards we received throughout the REF2021 period have come from a varied portfolio of funding sources, ranging from standard research funders – research councils (EPSRC, ESRC, AHRC), EU, Innovate UK, DSTL, and Newton Fund – to direct industrial funding, including Huawei, Leonardo, and KROHNE Ltd. We have set ourselves new and ambitious income targets for the next five years, with a view to achieving £3 million per annum by 2023, with incremental increases thereafter. These targets will help to ensure the sustainability of our research, as well as our standing in the field.

The School also has a good record of innovation grant applications and awards from a portfolio of industrial and business contacts. Since 2014, we have worked with more than 50 regional, national, and international industrial organisations in consultancy, postgraduate studentships, KTPs, and other forms of collaborative projects (see Section 4). The School will continue to actively engage with industry-linked high-impact funding streams such as KTPs via Innovate UK and Keep+, as well as encouraging consultancy work.

#### Infrastructure and Facilities

EDA resources a well-founded laboratory infrastructure across its three established research groups, concentrating investment in both its leading and its niche experimental areas. During the REF2021 period, the Communications group significantly enhanced its experimental laboratories. Benefiting from a combination of EU funding (5G-DRIVE) and University support, we have invested £55k in a new SDR-based MIMO testbed to assist our theoretical work on massive, multi-user, and distributed MIMO schemes. An Ethernet fronthaul testbed, with high-performance FPGAs, switches, servers, precision time measurement, hardware and virtual probes, to a total value of £100k, has been built using EU/UK funding (iCIRRUS, NIRVANA, 5G-DRIVE), University funds, and in-kind support from VIAVI (£34k). Our microwave photonics work has benefited from a new optical wireless transmission testbed, including new laser sources, spatial light modulator, high-speed photodetector, and free-space optics, which has been supported by EU/UK funding (Marie Curie CIG, Royal Society, Catapult RiR). In our antennas laboratory, in-house 3D printing equipment for the manufacture of antennas and frequency selective surfaces has been developed through Royal Society funding (£15k), and a £20k upgraded RFID system was developed in 2017.

For the Instrumentation and Control group, a state-of-the-art slurry flow test-rig was constructed with support from industrial partners KROHNE Ltd. During the REF period, the instrumentation laboratory has seen an investment of £22k in a high-speed camera and fibre-optic imaging for its flame research activities, including a significant portion directly from the University. The IC group also maintains a long-term working relationship with power-generation organisations, which provide access to industrial-scale combustion test facilities and full-scale power plants. For the Intelligent Interactions group, a new virtual reality laboratory funded by Santander (£10k) was established in 2020. To support biometrics usability research, the group benefited from a flexible image and data acquisition and processing facility, supported directly from University QR funds (£10k) in 2018.

In the REF2021 period, the University committed to a £3 million modernisation programme to develop a new Engineering and Design Hub, providing a multi-purpose design studio, heavy and light machinery workshops, maker space/skills centre, and modern production facilities. State-of-the-art facilities include material testing machines, CNC and 3D printing machines, wind tunnel, collaborative robots, and a dedicated makerspace. The Hub provides extensive technical support facilities and also enables complementary activities that will enhance research activity across all of our research groups.

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

##### Research Collaborations, Networks, and Partnerships

EDA has a well-established track record of successfully collaborations with industrial partners regionally, nationally, and internationally, as well as with a range of academic institutions worldwide. We are well-connected to multiple European academic and industrial communities, and we also maintain strong connections in China and the US, which will help to minimise the impact of Brexit on our research income. There has been a significant increase in KTP awards since 2017, and we are now collaborating in projects with Dyrhoff Ltd, KROHNE Ltd, PlanSnap Ltd, and Shearwater Systems Ltd. Since 2014, our staff have undertaken consultancy work for a range of companies, including Applied Nanodetectors Ltd, Centre for Process Innovation Ltd, Cobham CTS Ltd, Doosan Babcock Ltd, Emmerich Ltd, Givaudan UK Ltd, Haag-Streit UK Ltd, Megger Instruments Ltd, Smilepass Ltd, Vislink PLC, and Worldwide Fruit Ltd. The School is linked to three active spin-out companies: Metrarc Ltd (Howells); GreenTech Automation Ltd (Y. Yan and Lu); and Evidentia Ltd (Batchelor and Horne).

In the field of 5G and beyond mobile networks, the Communications group has collaborated with a number of overseas universities, including Southeast University, Xidian University, and City University of Hong Kong, producing four joint research projects funded by the Royal Society, EU Horizon 2020, and the Chinese Government, and 36 joint papers, including four outputs included in this REF submission. The group participated in the EU 5G-DRIVE project, which focused on early 5G trials and the lessons that can be learnt, and is twinned with a China Mobile-led trials project. This has resulted in joint publications with partners from both projects, including the University of Surrey, VTT, OTE, Orange (PL), China Mobile, and Eurescom.

The group has pioneered the proposal for the use of Ethernet in the fronthaul of future mobile networks in Europe, with Gomes leading two projects: iCIRRUS (Orange [France], ADVA, VIAVI, Interdigital, Telekom Slovenije, Primetel, Wellness Telecom, IAF GmbH, Fraunhofer-HHI, University of Essex); and NIRVANA (Kent/Essex, with industry support from BT, EE, VIAVI, NEC, among others). The iCIRRUS project liaised with other EU projects, and one of the results was a contribution on Ethernet fronthaul to the Wiley book on 5G, led by the EU 5G PPP projects.

The Communications group is heavily involved in the integrated microwave photonics COST network, with Gomes being one of the two UK general committee members. Our participation in the EU-Japan RAPID-5G project on radio over fibre for millimetre-wave 5G resulted in joint work and publications with University Duisburg-Essen, Siklu, Exatel, Corning, and the Japan partners Hitachi, ENRI, Koden, and Osaka University. New international collaborations with the Chinese Academy of Sciences, Tianjin University (China), National Tsing Hua University (Taiwan), and McGill University (USA) were supported by three Royal Society International Exchange grants, leading to joint work and publications.

Antennas work concerning the integration into printed and scaled-up manufacturing processes is carried out in collaboration with the High Value Manufacturing Catapult for Printed Electronics and CPI, making available roll-to-roll integration tools to create batch and roll-to-roll scaled-up demonstrators of wireless passive-sensing labels integrated with printable flexible polymer batteries at UHF and mmWave bands. The work is in partnership with the University of Manchester, Northwestern University Chicago, University Roma tor Vergata, Great Ormond Street Children's Hospital, AgeUK, PragmatlC printing, Givaudan Ltd, NeuDrive, and DSTL. In the areas of space antennas and smart antennas, the group has collaborated with over 30 institutes and

companies across Europe, including Airbus UK, Airbus France, German Aerospace Agency, IHP Microelectronics, Germany, University of Calabria, Italy, Institute of Telecommunications, Portugal, KU Leuven, Belgium, TU Graz Austria, University of Warwick, University of Southampton, and University of Sheffield. The collaboration has been centred around several multi-disciplinary projects funded by the EU and EPSRC (GaNSat, DIFFERENT, WISDOM, LN Tunable, LPUWB). The projects led to many innovative concepts and the development of antennas for applications in space and terrestrial mobile communications, partly summarised in an invited paper in the *Proceedings of the IEEE* (March 2018). For example, the WISDOM project led to the first 3D-printed high-gain wideband Fabry-Perot antenna at 140 GHz. The DIFFERENT project led to the development of the first Ka/X dual-band digital beamforming synthetic aperture radar for space-borne earth observation. Results of DIFFERENT have been exploited by DLR Germany for the development of a new radar demonstrator for future missions, including NASA's NISAR Mission and ESA's Rose-L Mission. The group has also collaborated with ESIGELEC, GreenSysTech, Intrinsic materials and the University of Surrey on two EU-funded Interreg projects (HOMES and SURFAS), both on printed electronics for smart antennas and surfaces for future mm-wave systems. This has resulted in a number of joint publications. A novel calibration technique for mmWave and THz measurements has been developed and published with the UK's National Physical Laboratory. The group has recently been awarded funds from the Royal Society International Exchanges cost share scheme to collaborate with the Beijing University of Post and Telecommunications on the development of 3D printed dielectric resonator antennas (DRA) for 5G millimetre wave applications and beyond.

The IC group has established strong partnerships with leading power-generation and associate service organisations, including EDF Energy, British Sugar, Doosan Babcock, RJM International, Moneypoint Power Station (Ireland), Enlanda Instrumentation, and Walsn Energy Ltd, through projects funded by Innovate UK, BF2RA (Biomass and Fossil Fuel Research Alliance), and UKCCSRC, as well as industrial consultancy and studentships. Close interactions with industrial partners have influenced the IC group's research direction and strategy, as evidenced in our impact case study (Y. Yan et al.). Other examples of this include our collaboration with EDF Energy and British Sugar to develop a smart technology for the flexible operation of biomass/fossil fuel-fired power plants since 2015. We also work closely with industrial firms locally and nationally through KTP programmes funded by Innovate UK. For example, as a result of a recently completed KTP project with KROHNE Ltd, the IC group developed a new series of smart multiphase flow meters, using Coriolis flow meters incorporating soft computing algorithms. In an ongoing KTP project, the IC group is working with DYRHOFF Ltd to achieve smart condition monitoring of large-scale inflatable rubber dams for hydraulic power and other industries. The IC Group has also been working with RoseMedical in the development of electronic devices for medical diagnosis in speech-swallowing therapy. Collaboration with Haag-Streit UK, a manufacturer of medical instruments, has led to the development of a digital version of their tonometer – an instrument that measures internal eye pressure.

The II group has developed excellent collaborative project teams with institutions nationally and internationally. Ongoing contacts include BT, threeUK, GlobalSign, KeyTalk, Ericsson, TrendMicro, BAEsystems, Chelmsford, Apurba Inc., and Ames Grid Services. There is also a strong research relationship with the East Kent Hospitals University Foundation Trust (EKHUFT), which has directly collaborated with us on several research projects. The group's biometric privacy work is carried out in partnership with the universities of Twente (Netherlands), Oslo (Norway), Würzburg (Germany), and Leuven (Belgium), whilst our mobile biometric work is a direct collaboration with UAM (Spain), UniRoma3 (Italy), University of Magdeburg (Germany), and WUT (Poland). In the area of human/computer interaction, we continue to collaborate with the University of Southampton and IBM. In the area of human/computer decision making, there has also been significant work with collaborators in Georgia Tech to push the boundary of wearable technology. New skin-like flexible sensors have been developed, powered by machine learning, for Dysphagia therapy, brain-machine interaction for wheelchair control, and VR eye-tracking for ocular disorder therapy. The group has benefited from PhD studentship funding from CallSign Ltd and GCHQ/NCSC in the areas of novel swipe interaction authentication and performance evaluation, respectively. We have also undertaken mobile device work on forensic knuckle identification with



Purdue (US) and Lancaster universities. Through our role in the European Association for Biometrics, we have delivered training courses to over 70 organisations, including police forces, border agencies, industry, and other academic organisations. We continue to work with Ingenium Biometrics Labs (a team of consultants to the Cabinet Office), with whom we plan to develop Europe's first FIDO Alliance-certified biometrics testing facility with Ingenium biometrics by 2021.

The Mechanical Engineering team, which is currently in the process of being established, already benefits from strong research collaboration with Rolls-Royce, London Array, Network Rail, EDF, Babcock International, TWI, Siemens, and Vattenfall.

To build and support all of these relationships and networks over the REF2021 period, 18 members of the School have either chaired or been programme committee members for over 60 conferences or events, of which 32 were IEEE.

### **Contributions to, and Recognition by, the Research Base**

EDA staff play an important international disciplinary leadership role, demonstrated by the range of indicators of influence, contributions to, and recognition by, the research base. Over the REF2021 period, our staff have either organised or served as session chairs at 106 events. Nineteen members of staff have been invited to engage through 98 presentations and guest lectures, 53 of which were overseas. Six members have served on national and international committees (UK Government, EU, etc.), or given evidence as expert witnesses. For example, Guest was appointed by the Home Secretary (through a competitive process) as a member of the UK Home Office's Biometric and Forensics Ethics Group (BFEG), an independent group of 10 leading multidisciplinary experts providing advice to Government on issues of biometric and forensic data-use and systems implementation.

The following examples illustrate how members of the School have contributed to, and been recognised by, their research base over the REF2021 period:

*Expert panel member/witness.* J. Wang: Selection Committee, Royal Academy of Engineering; Gao: Panel member of Award Committee, IEEE Antennas and Propagation Society; Guest: evidence given to UK Parliamentary Science and Technology Select Committee, and member of UK Government Home Office Biometrics and Forensics Ethics Group; Deravi/Guest: Principal UK Expert to ISO/IEC JTC1 SC37 WG2/WG3; Gomes: expert on British Standards Institute committee EPL/103.

*Learned societies or professional bodies.* Y. Yan: Council Member of International Flame Research Foundation (IFRF), and member of the Executive Committee of the Fuel and Energy Research Forum (FERF); Guest: Chair of BSI IST/44 WG2; Shafiee: Institution of Mechanical Engineers (IMechE), UK Manufacturing Advisory Committee (MAC), RenewableUK, EERA JP Wind, and European Safety and Reliability Association (ESRA); Gao: UK Representative in European Association on Antennas and Propagation.

*Conference programme chairs.* Ang: Co-Chair, INTERACT 2019; C. Wang: Co-Chair of OGC 2019; Efstratiou: Chair of WristSense 2015, 2016, 2017; Batchelor: organiser, IET Symposium on Wideband Antennas; J. Wang: Executive Chair, and Gomes, TPC Chair: IEEE ICC 2015; Sirlantzis: Chair, CareTech, 2015; and Howells: Co-Chair, EST 2014, 2015, 2017.

*Invited keynote lectures.* Gao: ConTEL, 2019; Gomes: EEE MWP Topical Meeting workshop on MWP for 5G, Optical Fiber Communications conference, 2016; X. Yan: TCCT Workshop on Modelling, Control and Applications; Y. Yan: 3rd Clean Coal Technology (CCT), 2014, IEEE SCORed, 2016, IEEE CASS, 2017, IEEE ISCTE-IUL, 2018, 40th Annual Congress of China Instrument and Control Society, 2019, ISTM, 2019.

*Fellowships.* FREng (J. Wang, Y. Yan); FIEEE (Gao, J. Wang, Y. Yan); FIET (Batchelor, Deravi, Gao, Gomes, Howells, J. Wang, Y. Yan); FInstP (Y. Yan); FInstMC (Y. Yan); FBCS (Guest).

*Journal editorships. Measurement, Measurement: Sensors, Flow Measurement and Instrumentation, Industrial Combustion Journal, IEEE Transactions on Instrumentation and Measurement (Y. Yan); IEEE Photonics Technology Letters (C. Wang); IEEE Access (Hossain); IET Electronic Letters (Gao, Young); IEEE Transactions on Antennas and Propagation, Radio Science, Chinese Journal of Electronics, Chinese Journal of Radio Science (Gao); SCIENCE CHINA Information Sciences, IEEE Transactions on Vehicular Technology (Zhu); Research in Applied Mathematics (X. Yan); Journal of Advanced Intelligence Paradigms (Sirlantzis); Journal of Forensic Document Examination (Guest).*

*Awards, prizes, and other indications of recognition.* Ang: Best Paper, Georgia Tech BioEngineering 2020; Y. Yan: Gold Medal for the most published author of all time from the UK by IEEE Transactions on Instrumentation and Measurement 2020, Best Application Award at IEEE I2MTC2017, Best Paper Award at IEEE I2MTC 2016; Von Jungefeld: Lumen Prize BCS in AI 2019, Best Paper EvoMUSART 2015; Sans-Izquierdo: Best Contributions to the 4th IET Enterprise Workshop; Marcelli: Best Paper, 5th International Conference of the Financial Engineering and Banking Society, Banking, Financial Markets, Risk and Financial Vulnerability; Gao: Distinguished Lecturer of IEEE Antennas and Propagation Society, 2016, IET Premium Award for Best Paper in IET Microwave, Antennas and Propagation; Y. Yan: Distinguished Lecturer, IEEE Instrumentation and Measurement Society.

### **Contribution to the Wider Economy and Society**

Staff in EDA are outward-facing in approach and seek to engage the wider public in our research wherever possible. For example, several members of staff have undertaken media activities, including Batchelor, who has appeared on BBC Radio 4 *Costing the Earth*; Guest, who has been interviewed for *The Register*, the *Sunday Times*, BBC News and CityAM; and Ang, who has appeared on the BBC World Service and been interviewed in the *Telegraph*, together with numerous interviews in specialised trade publications.

The School prides itself on its responsiveness to national and international priorities, and to emerging engineering challenges. We seek to involve a variety of relevant stakeholders at the heart of our research activities. Many projects involve collaboration with stakeholders in the public sector, especially with the NHS, Government departments, and the European Commission, as well as extensive ongoing partnerships with industry and the private sector. Examples of our contributions to industry, society, and the economy, nationally and internationally, are demonstrated in our impact case studies, and in the examples described in Section 1 and 4 above. The significance and range of the impact of our research has been underpinned by a strong record of interdisciplinarity and collaboration, and by our outward-facing, responsive approach. It is demonstrated by our increasing success in grant applications and awards, and it reflects our ongoing investment in resources, infrastructure, and development opportunities, and the high international standing of our staff.