

**Institution:**

University of Essex

**Unit of Assessment:**

11 – Computer Science and Informatics

**1. Unit context and structure, research and impact strategy****a) Overview**

Significant University investment over the 2014-20 REF period has led to **exciting transformative growth**, with 73 Category-A FTEs submitted to REF2021 (**up 110%**, from 34.9 in REF2014), making the School of Computer Science and Electronic Engineering (CSEE) one of the largest UoA11 submissions in the UK.

We have a **dynamic and vibrant** research community, with more than 45% of academics being Early Career Researchers (ECRs; 33 staff, up from 3 in REF2014), 57 fixed-term research staff (up from 36 in REF2014), and 106 PhD students. The growth in academic staff has been coupled with a **50% increase in the per annum value of external research awards** compared to REF2014 (Section 3.a; Figure 1). Note: throughout the document, financial figures refer to CSEE-only awards and/or the CSEE components of joint awards, unless clear from the context.

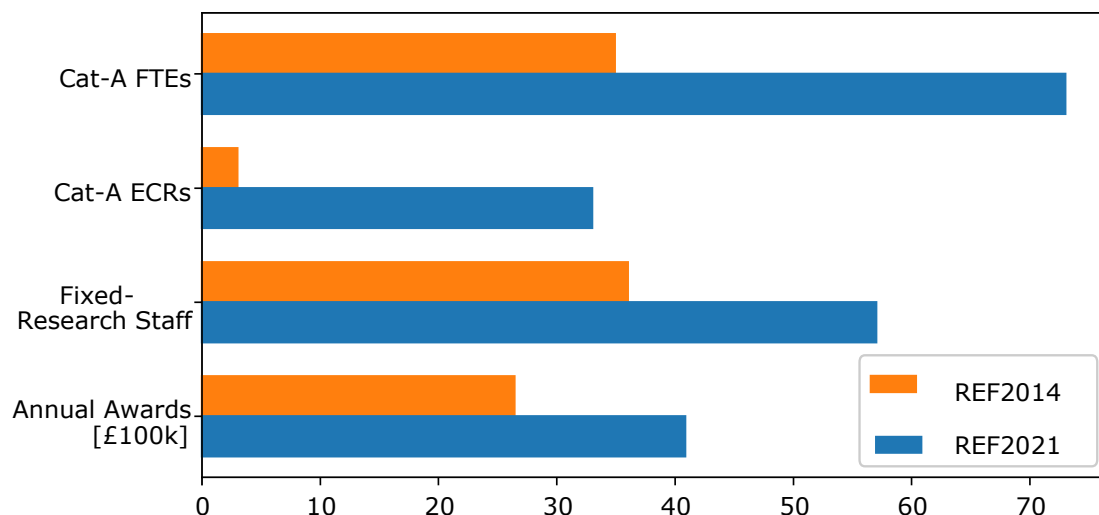


Figure 1. CSEE's growth at a glance.

The strategic vision of CSEE is to play a distinct role in the development of the international research agenda in both computer science and electronic engineering. Key focus is on excellence in fundamental research and the translation of innovation to solve real-world problems, while reaching out to other disciplines. The continuing improvement in the quality of our research environment is evidenced by:

- **Prestigious Publications:** The vast majority of our submitted REF outputs were published in **Top 10 journal percentiles** (based on source-normalised impact, SNIP), including high profile interdisciplinary research in *Science* and *Nature*.
- **Increased Research funding:** Research funding per annum increased over the REF period both in terms of **income** and **awards (by over 50%)** as evidenced in Section 3a.
- **Non-academic impact:** Research within CSEE addresses **key challenges faced by industry** and **wider society** (see Section 4c). Quantifiable evidence for the scale of our research impact can be shown on our submitted impact cases. CSEE ranked **2<sup>nd</sup> nationally** in terms of number of active Innovate UK **Knowledge Transfer Partnership (KTP)** projects. CSEE has established a multi-disciplinary Centre of Excellence in Artificial Intelligence with TWI (<https://www.twi-global.com>), Cambridge and a strategic research partnership with BT (<https://www.bt.com>).

- **Interdisciplinary Research centres:** CSEE is a **founding member of two major UKRI research centres:** the EPSRC National Centre for Nuclear Robotics (NCNR) and the ESRC Business and Local Government Data Research Centre. We, also, established the Institute for Analytics and Data Science (IADS), host the Centre for Computational Finance and Economic Agents (CCFEA) and the Computational Intelligence centre (CIC), and are part of the Essex Plant Innovation Centre (EPIC) and the Human Rights Centre (HRC). These Centres and Institutes facilitate **interdisciplinary collaborative research** and provide the means for **engaging with stakeholders and user communities to promote research impact**.
- **Training the Next Generation of Researchers:** We have **expanded the number of fixed-term research staff by 58%** (57, up from 36 in REF2014). During the REF period, 145 PhDs have been completed, while 67 full studentships were offered within the School from a number of sources (see Section 2b). **Our PhD students organise CEEC, the only IEEE-sponsored international conference organised by postgraduate students, providing unique training for the research leaders of tomorrow.**
- **Attracting and Developing Leaders:** We are able to recruit and retain international academics of the highest calibre who are regarded as world-class research leaders in their domains (see Section 4d). A focus on recruiting and supporting ECRs also ensures succession for future research leaders within the School.
- **Vibrant Research Environment:** During the REF period, 231 national and international academics and industrial research scientists from multiple disciplines visited CSEE and actively contribute to our dynamic research atmosphere, as detailed in Section 2a. We have world-class research facilities and **have expanded our research space by nearly 70%** (Section 3b).

## b) History and Structure

Essex has a long-standing tradition of research in **Artificial Intelligence** and **Communications**. It was one of the first UK universities to house a central research activity in Artificial Intelligence (AI), in the Department of Computer Science (CS), while the Department of Electronic Systems Engineering (ESE) pioneered a systems approach to telecommunications. The changing character and increasing pervasiveness of ICT led the University in 2007 to merge the CS and ESE departments into the School of Computer Science and Electronic Engineering. Since REF2014, CSEE has pursued an ambitious programme of development and expansion beyond its historic origins in Artificial Intelligence and Communications. As part of this expansion, long-standing research activities carried out within the AI group in the areas of Robotics, Embedded Systems as well as Brain Computer Interfaces and Neural Engineering gained critical mass and have branched out into separate newly formed groups. As a result, CSEE now has four Research Groups with members, in many cases, straddling more than one group. The groups are as follows (primary-group membership, underlined = group head, asterisk = emeritus professors):

### AI — Artificial Intelligence

(Amorim, Andreu, Barakat, Bourazeri, Chamberlain, De Feo, Doctor, Doran\*, Fairbank, Fasli, Fox, Garcia, Hagras, Jameel, Jindal, Kampouridis, Kanellopoulos, Kyropoulou, Lavington\*, Long, Luo, O'Hara, Papanastasiou, Richerby, Samothrakis, Turner\*, Voudouris)

The AI group includes two professors, one reader, eight senior lecturers, and thirteen lecturers. The group's mission is building systems and conducting theoretical research which model and support decision-making of autonomous entities. The group encompasses five special interest groups, each coordinated by a lead academic: Data Science; Computational Finance; Natural Language and Information Processing; Games & AI; and Health AI.

### BCI-NE — Brain Computer Interfaces & Neural Engineering

(Ali, Chowdhury, Cinel, Citi, Daly, Gan, Halder, Li(Ju), Matran, Perdakis, Poli, Raza, Scherer, Sepulveda)

The BCI-NE group includes five professors and nine lecturers and is one of the largest groups of its kind in the world. BCI-NE's mission is conducting theoretical research that expands understanding of the brain and neural systems. The group has produced internationally leading research and frequent media presence, with prestigious international and national collaborations (Section 4).

#### COMNET — Communications & Networking

(Abolghasemi, Adams\*, Al-Naday, Barros, Bebbington, Bourtsoulatz, Ghanbari\*, Hawksford\*, He, Henning\*, Liu, Loudon FRS\*, Mirshekar, Musavian, Newton, Rassouli, Reed, Ridley FRS\*, Sangwine, Thakur, Thomos, Varasteh, Walker, Yang, Zakleniuk, Zhang)

The COMNET group includes five professors, three readers, three senior lecturers, and nine lecturers. The group's mission is the design of next generation wireless communication, network architectures and systems. COMNET has a long history of collaborating with other research institutions and industries including almost all the Tier-1 operators in Europe such as BT and major telecom vendors such as Ericsson. Impactful patents and proposals to standardisation bodies have been generated out of these collaborations

#### RES — Robotics & Embedded Systems

(Anisi, Callaghan\*, Clark, Ehsan, Gu, Hoshier, Hu(H), Hu(L), Jarchi, Kolozali, Li(Ji), Massara\*, McDonald-Maier, Mohan, Ognibene, Singh, Su, Zhai)

The RES group includes three professors, one reader, one senior lecturer, ten lecturers, and one senior research fellow. The group's mission is to solve fundamental problems in robotics and embedded systems particularly in the 'perception-action, continuous learning, decision making, social intelligence' loop, localisation as well as embedded systems and System-on-Chip design and processor architectures targeted for cyber physical systems, automotive/industrial systems, computer vision, data analytics, Internet of Things and real-time critical systems. The research outputs benefit and impact a range of end users and stakeholders in Agricultural robotics, Assistive robotics for Social Care, Manufacturing, Electronic Products, Automotive and Nuclear Robotics.

Research within CSEE is supported through world-leading **Research Facilities** (see Section 3b), that provide the required infrastructure and testbeds to undertake our internationally leading experimental research.

### **c) Strategy, Goals and Achievements (2014-2020)**

Our **strategy**, outlined in REF2014, included the following **core research goals**:

- G1) maintain our leading position in foundational and applied research in the fields of **Artificial Intelligence** and **Communications Systems**;
- G2) expand and consolidate research in the thematic areas of **intelligent infrastructures** and **assisted living technologies** that cut across current research themes;
- G3) increase the level of **external research income** per FTE in the next period;
- G4) increase the number of **high-quality research outputs**;
- G5) increase the **non-academic impact** of our work.

These strategic goals have been achieved, evidenced as follows:

**G1) Fundamental and ground-breaking research** continued to be produced in our **key areas of existing strength (AI and Communications)** and two further groups have emerged to strengthen our work in areas of Robotics and Embedded Systems as well as Brain Computer Interfaces and Neural Engineering. Our research is well aligned with UKRI priorities (connecting the nation, future intelligent technologies, innovation in health and social care, transforming food

production, etc.), whilst responding to emerging major research themes and societal challenges.

#### Artificial Intelligence (AI)

- The group attracted **awards worth £12.8M** in the REF period from EPSRC, ESRC, EU, Innovate UK and has strategic partnerships with industry and international organisations such as UNESCO, BT, BAE Systems, local governments and others
- We are part of IGGI (Intelligent Games and Game Intelligence) EPSRC Centre for Doctoral Training (CDT).
- In the field of Explainable AI and applications, the work of Hagrais with BT was **awarded the 2015 and 2017 Global Telecom Business Awards** and best paper awards in major international conferences.
- In the field of Natural Language Processing (NLP), theoretical work on information retrieval in large data spaces led to the development and success of London-based start-up Signal AI, **winning the 2015 National Best KTP Partnership Award**, and enabling the company to raise in excess of **£50M venture capital funding and grow to 150 staff** (see Impact Case Study).
- Fox and Chamberlain co-developed an NLP-based platform for monitoring civilian-led human rights abuses which **forms part of the evidence base of the United Nations and other organisations including the Minority Rights Group and Ceasefire** (see Impact Case Study).
- Chamberlain, Clark and Garcia developed a computer vision system for 3D marine surveying that increased surveying speed 10-fold, revolutionising the UK's capabilities in precision habitat monitoring with Natural England and citizen science organisation Seasearch. The project won **Defra's 2020 Breaking the Mould Award**.
- Theoretical work investigating disagreement and ambiguity in human language was given a significant boost by the **€2.5M DALI EU project** (Chamberlain and Bartle, Cols) to develop novel algorithms for consolidating multiple interpretations of text.
- The AI group is at the **core of the ESRC Business and Local Government Data Research Centre (ESRC BLG, £5M, CSEE £1.2M)** and contributes via IADS to the **ESRC Research Centre on Micro-Social Change (MiSoC, £5M across 4 Essex departments)**.
- **A multi-disciplinary Centre of Excellence was launched in 2018 with TWI** to expand our applied AI research to heavy industries and construction.
- Fasli was **appointed the first UNESCO Chair in Analytics and Data Science**.

#### Brain Computer Interfaces & Neural Engineering (BCI-NE)

- The group attracted **awards worth £4.6M** in the REF period, mainly from EPSRC, EU, and MoD.
- Perdakis presented **the first BCI-based therapy for stroke rehabilitation** shown to deliver clinically significant and lasting outcome.
- Scherer made significant contributions to gaining a **deeper understanding of mechanisms of brain rhythms and their interpretation** in the context of motor behaviour.
- Within the areas of neuroergonomics and adaptive neuro-technologies, Scherer is **among the few researchers world-wide studying online man-machine co-adaptation**.
- Poli, Citi and Cinel developed novel approaches in the area of BCIs for assisting decision-making (a form of cognitive augmentation). These integrate neural, physiological and behavioural data to improve individual and group performance in decision-making, including groups where one or more participants are machines. In this area, they **obtained £2.35M from the EPSRC and the UK Ministry of Defence including two US/UK ongoing projects** (MURI and BARI).
- Matran-Fernandez and Sepulveda participated in the international Cybathlon 2016, the first international BCI competition for people with disabilities, and **attained third place**.
- The group has also done significant work in **neuromuscular control of robotic prostheses** (Citi, Matran-Fernandez, Sepulveda, Poli) in **collaboration with world-leading partners within the DeTOP (£420k) and SenseBack (£220k) projects**.

- Citi was part of the research team **showing for the first time that an amputee could touch and feel with a sensory-enhanced prosthetic hand surgically wired to nerves** in his upper arm. The pioneering experiment was published in *Science Translational Medicine* and widely reported in the world media including the BBC, *The Guardian*, *The Independent*, and *New Scientist*.

#### Communications & Networks (COMNET)

- The group attracted **awards worth £4.1M** in the REF period from the EPSRC, EU and Innovate UK.
- Reed and Al-Naday's IP-over-ICN work has been **included in the 5G standards** (3GPP Release 16, Technical Specification Group Services and System Aspects; 3GPP TS 23.501 V16.1.0 2019-06).
- Walker's pioneering research resulted in **the world's first 10GbE backbone link for trains achieving bandwidth capacity previously considered impossible** (see Impact Case Study).
- The group has rich testbeds which served within the networking hubs of many EU projects including H2020 POINT (£380k), a collaborative project proposing **a radically new IP-over-ICN architecture to shape future Internet**, and H2020 SerIoT (£300k), a collaborative project proposing **intelligent approaches to perform anomaly detection using SDN and Blockchain technologies in IoT networks**.
- The IP-over-ICN testbed developed by the group was **demonstrated at two Mobile World Congresses (Barcelona)**, which is the premier showcase for the mobile industry.
- **COMNET's network testbed**, together with its cloud and edge computing facilities, are also **an essential part of a global testbed initiative IEEE InterCloud**, where Yang was a founding member and one of the six executive committee members.

#### Robotics & Embedded Systems (RES)

- The group has attracted **awards worth £7.1M** in the REF period, mostly from the EPSRC, ESRC, EU and Innovate UK.
- The group expanded its research in resilient embedded and intelligent systems in extreme environments (nuclear and space robotics), led by McDonald-Maier as a part of **the £42M** (£11.6M from EPSRC of which £1.4M to CSEE) **EPSRC National Centre for Nuclear Robotics (NCNR)** in collaboration **with NASA Jet Propulsion Lab, BAE Systems, Kuka, Toshiba, Rolls-Royce** and other world leaders.
- Research on embedded systems and Systems-on-Chip diagnostics and analytics through EPSRC and EU projects has contributed **unique outputs and IP, where spin-out company UltraSoC Technologies**, co-founded by McDonald-Maier, attracted some **£20M investment**, introduced disruptive technology into the market place and successfully **exited to Siemens** in an acquisition that delivered high return for all the stakeholders (see Impact Case Study).
- McDonald-Maier and Ehsan's computer vision work **detecting human rights violation in images, researched as part of the £4.75M** (across 5 Essex departments) **ESRC Human Rights and Big Data Technology (HRBDT) project, has been adopted by the United Nations** (OHCHR – Office of the High Commissioner for Human Rights and UNHCR – High Commissioner for Refugees).
- Essex's AgriRobotics research **featured in the influential 'Future of Food 2040' report of the National Farmers Union** and plays an active role in further evolution of EPIC (see also Section 4b).
- Mohan and Woods lead an Innovate UK project (£231k) on adaptive motion control of cutting machines and predictive maintenance with the UK's Leading CNC machine manufacturers Blackman & White.

**G2)** Strategic investment in world leading research facilities for **intelligent infrastructures** and **assisted living** (Section 3b) has allowed expansion of the RES and BCI-NE research units into top-level research groups. We have further expanded our world-leading expertise in embedded



systems and robotics to deliver unique **intelligent infrastructure** as part of the EPSRC NCNR (McDonald-Maier and Ehsan). Our role in this national centre is to increase the resilience and robustness of embedded and robotic systems in extreme environments and contribute new computer vision-based localisation methods. This work is carried with our long-term collaborator **NASA JPL**.

Walker has pioneered novel intelligent infrastructure enabling, for the first time, complete 10GbE backbone connectivity in railway trains, transforming on-train communications and internet connectivity used in the majority of new UK train rolling stock.

Additional expansion has also been undertaken in intelligent systems for **ambient assisted living** and healthcare (Hagras and Clark) where our pioneering 3D intelligent vision systems (developed in cooperation with Leonardo, a global leader in Aerospace, Defence and Security) are due to be deployed in houses of the elderly and disabled. Mohan collaborates with Provide (reaching 4.5M people across Essex and Cambridge) to train robotic companions for a range of assistive services in their care homes. Furthermore, the BCI-NE group did realise various cutting-edge assisted living technologies as mentioned above

**G3) Increased our external research funding:** CSEE has been awarded grants worth £28.6M (up 50% from REF2014, after accounting for the longer duration of REF2021) **with an average value per FTE per annum** which is **above the Russell Group median** for UoA11 (see Section 3a). This can be partly attributed to the long-term staffing and staff development strategy detailed in Section 2a.

**G4) Increase the number of high-quality research outputs:** Our strategy has been to encourage and support staff to perform high-calibre fundamental and experimental research. To achieve this goal, strategic investment in academic staff has maintained our leading position in long-standing research areas and allowed expansion into new areas by recruiting rising stars (ECRs) and established leaders. This has been further supported by investment in creating world-leading experimental facilities, mechanisms to cover publication fees of new academics and supporting staff in-between grants (see Section 2.c). This was made possible by our **significant increase in external funding** that further boosted collaborations with top-tier universities. As a result, CSEE staff have published in the internationally leading journals (*Science*, *Nature*, *IEEE Transactions*, and others) and in top international conferences (IJCAI, DAC, INFOCOM, NER and others). In the REF period, CSEE staff have deposited in the University Institutional Repository 1074 journal papers (of which 51% as Green and 26% as Gold open access), 531 conference papers, 34 book chapters and co-edited 10 books. Of the REF outputs that our Category-A academics submitted, **the vast majority were in Top 10 Journal Percentiles (SNIP)**.

**G5) Increase the non-academic impact of our work** (see also Section 4c): CSEE encourages research activities which result in high non-academic impact. Research income from UK Government and UK Industry had a spectacular continuous growth from 2013/14 to 2019/20 (Table REF4b). We are **2<sup>nd</sup> in UK in terms of number of active Innovate UK funded KTPs (Innovate UK statistics, 31/05/2020)**. Furthermore, we have established **strategic partnerships with large industrial partners (BT, Microsoft, Dolby), borough councils, NHS and world-leading organisations like TWI**. During the COVID-19 pandemic, the CSEE4COVID team of academics **rapidly reprioritised workload to work with several regional NHS trusts** to improve epidemiological models for predicting hospital needs and strategically allocating resources. **CSEE (through IADS) has worked extensively with local governments and businesses** (e.g. BAE Systems, BT, Leonardo, Microsoft, Oracle, Orbital Media and Preqin) and has helped them setup or expand their data science departments. Furthermore, the University and CSEE encourage members of staff to commercialise their research for example via spin-out companies as was the case with **UltraSoC Technologies, which was successfully acquired by Siemens in 2020**. All the above-mentioned activities allowed CSEE to transfer our research expertise to big sectors of major importance to the international, national or local economies and organisations like the **United Nations (UN)**. Three impact cases stemmed from strategic relationships with industrial partners and world-leading organisation like BT, Dolby, Microsoft and the UN, while two case

studies resulted from our partnerships with SMEs through KTPs and a case study stemmed from commercialisation of research.

#### d) Open Research and Integrity

CSEE is **committed to open research** in its broadest sense. Opportunities to discuss the department research strategy and policies are available to all staff at quarterly departmental meetings, research away days, and at monthly Research Committee for those involved. Minutes and recommendations from these meetings are circulated freely to ensure an open research environment. Open access publishing (of both outputs and data) is promoted and encouraged leading to 26% of CSEE outputs deposited in the Institutional Repository in the REF2021 period being Gold Open Access and further 51% as Green Open Access. The department also follows the UKRI Concordat on Open Research Data; 18 datasets have been published alongside or in parallel to journal outputs over this REF period. Open publishing of software and code is also encouraged; within this REF period 27 pieces of software or code were published in open-source form in other external repositories.

The University and School conform to the Concordat to Support Research Integrity, and has developed the *University Code of Good Research Practice*, which is provided to all staff as part of training and induction. This includes explicit reference to the Committee on Publication Ethics (COPE) recommendations on publication and authorship; the department is committed to ensuring all contributors, including PhD students, gain appropriate recognition and are included in research outputs. Overall oversight of research integrity is provided by REO's Research Governance and Planning Manager, who ensures compliance with the code as well as other external legislation and funders' requirements across all projects within the department. The department has a robust ethics procedure managed by the departmental Ethics Officer and by the University Ethics Committee and its three Ethics Sub-Committees (ESC).

#### e) Strategy and Vision (2021 onwards)

CSEE's vision for 2021 onwards builds on the foundations and successes of the 2014-20 strategy and aspires to expand into new and currently emerging areas. Our **core strategic research goals (SRG)** are to:

- SRG1) Maintain our leading position in fundamental and applied research in the fields of Artificial Intelligence, Brain Computer Interfaces, Neural Engineering, Embedded Systems, Robotics, Communication and Networks.
- SRG2) Expand and consolidate research in thematic areas identified by the government as posing societal challenges such as Healthcare Informatics, Bioengineering and Mechatronics. We have begun recruiting in these areas in 2019 and the COVID-19 pandemic has accelerated our plans for expansion.
- SRG3) Expand and consolidate research in interdisciplinary areas which align with the UKRI priorities such as health and human sciences, agriculture and food manufacturing, psychology, life sciences, social sciences, human rights and finance.
- SRG4) Further increase the number of high-quality research outputs.
- SRG5) Further increase the level of external research income per FTE.
- SRG6) Further increase the non-academic impact of our work.

These strategic research goals will be achieved through the following means:

- Monitor and **shape the research** of CSEE through its Research Advisory Group (RAG) in order **to maintain alignment and relevance to international scientific priorities as well as user communities' and societal needs** (SRG1).
- Maintain a **strategic staffing policy** that ensures we recruit **high-calibre** researchers who can strengthen our existing and future research areas (SRG1/2/3).
- **Invest in healthcare informatics research and create strong links with NHS clinicians, like GPs, specialists, mental health clinicians, and psychotherapists** (SRG2/3). The

research will be focused on the application of electronic engineering, informatics, mixed reality, robotics/mechatronics and AI to health.

- Invest in **maintaining and creating new world-class research testbeds** (SRG1/4/5/6).
- Continue to **invest in PhD studentships** which can strengthen new research areas, especially those related to **interdisciplinary areas** across the faculty of sciences and across the University (SRG2/3/4).
- **Foster cross-thematic, multi- and inter-disciplinary research and engagement** with industrial forums, local communities (SRG2/3).
- **Strengthen our existing system of incentives and mechanisms promoting the submission of high calibre research outputs** while holding firm to our full **commitment to research integrity** and **open research** (SRG4).
- **Manage staff loads** to ensure that sufficient time is provided to staff to conduct research and in parallel maintain current research leave arrangements (SRG4/5).
- **Nurture innovation** and provide strong support by senior academics and CSEE's Research Advisory Group (RAG) for individual researchers in writing proposals for external funding agencies (SRG5).
- Continue the proactive approach adopted for the dissemination of funding opportunities and keep organising **brainstorming sessions** to incubate ideas and promote collaboration (SRG3/4/5).
- Support **research generating high levels of non-academic impact** through regular engagement with companies at our annual joint workshop with industry, through our industrial liaison committee and through strategic initiatives such as the new Artificial Intelligence Innovation Centre with TWI, which aims to disseminate our AI expertise to manufacturing industries (SRG6).
- **Support and mentor early career staff** in their professional development through the assignment of a senior mentor and through the annual appraisal and review process (SRG4/5/6).
- Reinforce our commitment to fostering a **diverse and inclusive** environment where everyone has **equal opportunity to develop their full potential** (SRG1/2/3).
- **Sustain a vibrant multi-disciplinary research culture** including research students through weekly thematic seminars, interdisciplinary seminars, workshops, and the student-led IEEE CEEC conference, which allows our students to grow their academic and organisation skills (SRG3).

## 2. People

### a) Staffing strategy and staff development

#### Staffing strategy and its links to research strategy

Our staffing strategy is guided by the needs and strategic direction of CSEE. We aim to appoint the best possible candidates internationally to ensure the **continuity** of our existing research in **areas of excellence** and to **expand** the scope of our research to new areas (as prioritised by RAG, see Section 3c), taking into account emerging research challenges, societal needs and opportunities.

RAG oversees the research strategy and management within CSEE. It includes the Head of School, Directors of Research and Impact, Deputy Directors of Research, a representative of CSEE's Athena SWAN committee, and the Research group heads, who represent their group within RAG and play a major part in the School's research management. Group heads have a pivotal role in the definition of person specifications for new academic positions within each group and participate in the corresponding recruitment panels.

Since 2014, we have appointed 60 early career researchers to their first Lectureships, as well as 4 new Senior Lecturers / Readers and 2 Professors. The appointments made during this period directly align with CSEE's strategy to support existing areas and expand in new areas in the themes of Communications and Networking (Abolghasemi, Al Naday, Barros, Bourtsoulatzé, He, Li, Liu, Musavian, Rassouli, Thakur, Varasteh, Zhang); BCIs/Neural Engineering (Ali, Chowdhury,



Halder, Li, Matran-Fernandez, Perdakis, Raza, Scherer), Robotics and Embedded Systems (Anisi, Hoshier, Hu, Jarchi, Li, Mohan, Ognibene, Singh, Su, Zhai) and Artificial Intelligence (Amorim, Andreu-Perez, Barakat, Bourazeri, Chamberlain, Doctor, Garcia, Jameel, Karapetyan, Kolozali, Samothrakis, Kyropoulou, Kanellopoulos, Kampouridis, Long, Papanastasiou, Voudouris). In recognition of their excellence in research, 8 members of staff were promoted to Senior Lecturer, 2 to Reader and 6 to Professor since August 2013. Overall, CSEE's research active academic staff now accounts for 73 FTEs (**up 110% from RAE 2014**) as a result of the strategic expansion outlined above. All of our Category-A staff are on open-ended (long-term) contracts or fixed-term contracts with a guarantee of a permanent standard academic contract in due course (for IADS and AI Industry Fellows).

#### Career development support and the implementation of the Concordat

Our policies aim to enable staff to maximise research potential, to reward and sustain high performance, and to instil high staff morale and promote a vibrant research environment. Career development support and advice is provided at all career stages and the Head of School, Director of Research and research group heads are responsible for overseeing the implementation and compliance with the *Concordat to Support the Career Development of Researchers* (<https://www.vitae.ac.uk/policy/concordat>). To develop leadership skills for academics at different levels, the School nominates promising academics to attend the 'Future Leaders' and 'Strategic leaders' University-run training programmes.

**Annual appraisals** held with all staff ensure continuous monitoring of performance and the prompt identification of development needs. In addition to reviewing teaching and administration loads, these meetings consider the quality and volume of research outputs, research grant activity, knowledge transfer, and other achievements. In discussions with staff, quantifiable objectives for research, teaching and administration as well as further development for the coming year are set. These are also opportunities for the line manager to offer wider support and recognition of diverse needs, ideas and ambitions.

**Probationary lecturers** have reduced teaching and administration loads and are assigned senior mentors who provide individual guidance on career planning, research profile development and effective grant proposal writing. Within 6 months from appointment, the new academic, their mentor and the Head of School, draw up and sign a 'Pathway to Permanency' agreement which sets the targets and performance expectations for successful completion of the probationary period. Essex has a standard three-year probation period but academic staff can apply for early permanency if the agreed targets are met earlier (ten of the current ECRs achieved it). We provide the following support to probationary colleagues:

- £2,000 each year to support their research (conferences, equipment, consumables, etc);
- Support and feedback for funding applications through internal peer review;
- Priority when accessing PhD studentship schemes (for example departmental, industry or faculty-funded cross-disciplinary studentships): our aim is that each probationary lecturer will supervise at least one PhD student, ideally from their first year with us;
- Teaching allocation is aligned to the academic's research topic whenever possible;
- 40% more research time than permanent staff in the workload allocation model.

In addition to an induction programme that all new staff must attend, the Organisation Development team and the Research and Enterprise Office (REO) offer a wide range of training courses, including PhD supervision, teaching and learning approaches, leadership, and writing grant proposals. These are also offered to senior staff who are encouraged to engage in continuous professional development. Established academics also receive support in writing proposals for external funding agencies and are encouraged to submit their drafts for internal peer review.

**Research leave** (one term's paid research leave for every six terms' service) further supports CSEE members in their continuing development (including ECRs and part-time staff, pro-rated).

The leave is available to all staff including permanent research fellows with priority given to ECRs.

**Research officers** also undergo an annual appraisal process to assist them in their career development. They work with their supervisor to identify suitable **professional development**; advanced subject-specific scientific training is provided via participation in specialist external courses funded by CSEE. Research officers are encouraged and supported to participate in all CSEE activities, from contributing to seminars and workshops to networking. They are also given the opportunity to engage with limited teaching duties (e.g. occasional lectures/seminars to UG/PG students) and they are encouraged to work towards becoming fellows of the Higher Education Academy, which improves their career prospects within academia.

#### Stimulation of exchanges between academia and industry, public and third sector bodies

- CSEE established strategic relationships with major organisations like BT, TWI, NHS, etc as well as other SMEs which allowed secondment of staff (e.g. Walker is Essex/BT liaison, Westcott from Filament Ltd is entrepreneur in residence with CSEE), funded research projects and dissemination of research impact (as evidenced by 5 of the submitted impact cases). The relationship with TWI allowed the exchanges of staff, 7 studentships, major research funding and dissemination of our research to heavy industries and civil engineering.
- CSEE is 2<sup>nd</sup> nationally in the number of active KTP projects, which provides sustainable opportunities for research and impact with industry and public/third bodies.
- CSEE holds an annual workshop with industry and public/third sector bodies (attended by 80-100 delegates) which aims to disseminate our research achievements and stimulate and facilitate exchanges and collaborations between academia and industry on projects with impact on local economy and society.
- CSEE has an industrial liaison committee which helps shape CSEE's impact and applied research strategies.

#### Recognition/support for staff carrying out research and impact activities

- CSEE has a Director of Impact who develops and oversees the strategy for supporting and enabling staff to achieve impact from their research via the various mechanisms detailed in the previous subsection.
- CSEE implements a Work Allocation Model which rewards time for various research and impact activities (e.g. research projects, PhD supervision, impact activities)
- The University awards 20% grant indirect costs to research incentive accounts of grant holders, which can be used for research purposes or salary enhancement.
- CSEE awards £800 to the research incentive account of staff for each accepted paper in prestigious research outlets.
- The University holds annual awards to recognise the best internationally leading research and impact activities.

**Mentoring** and advice are also provided by **Emeritus Professors** (Adams, Callaghan, Doran, Ghanbari, Hawksford, Henning, Lavington, Loudon FRS, Massara, Ridley FRS, Turner) who continue to play an active role and contribute to enriching the research environment of the UoA.

**Vibrant Research Community:** Seminars are organised in CSEE in collaboration with other departments to exchange ideas and facilitate collaborations across the University. These provide a forum for members of staff to present research ideas and findings while also bringing in leading external researchers and practitioners. The weekly **seminar series**, now in its 45<sup>th</sup> year of continuous existence, is aligned with CSEE's research groups and is open for all staff and students. The seminar series is complemented by the IADS Seminar Series, the Health and Social Care Research Seminar Series, the monthly BCI-NE seminars, the Language and Computation weekly seminar and the Annual Language and Computation Research Day (now in its 19<sup>th</sup> year). In addition, a well-attended summer school in Analytics and Data Science has been organised on an annual basis for the past 4 years (attended by over 700 participants).

International staff, visiting scholars and research fellowships

CSEE's vibrant research community encompasses a wide network of visitors made up of visiting scholars, visiting students, research collaborators, industrial contacts, and ex-staff who still actively collaborate with the School. In the current census period, 231 visitors collaborated with members of CSEE through visits ranging from short stays to one or more years. In addition, to attracting world leading academics, we host the 'Essex International Visiting Fellowships', a generous programme that provides the recipients with return airfare, exclusive use of a University-owned house and a small weekly stipend for visits lasting between two weeks and four months. Since its inception in 2016, the programme has funded 8 Visiting Fellows hosted by CSEE. We have also established the Northwest University (NWU) China TTP program where staff from NWU visit with mentors from CSEE. CSEE is one of 10 research intensive UK universities participating in an agreement with the National Institute of Informatics (NII) Tokyo, one of the top research institutes in the world.

This is complemented by our funded collaborative research projects that also enable regular long-term collaborative exchange visits to take place, e.g. with NASA JPL and the Australian Centre for Robotic Vision.

**b) Research students**

CSEE has a thriving **research student community** with 106 PhD students at the census date, and 145 PhDs awarded during the REF period. Students are funded from a variety of sources, including competitive scholarships from **EPSRC (through the IGGI CDT), University postgraduate scholarships, Faculty of Science and Health interdisciplinary studentships and departmental studentships**. Overall, these mechanisms funded **67 scholarships**, of which 8 were through the IGGI CDT. Students are also funded through research grants (e.g. **H2020 covering stipend** and CSEE providing a fee waiver) or overseas national level government scholarships, such as the **agreement with China Scholarship Council (CSC)**.

**Research students are an integral part of CSEE's research culture** and are treated as the colleagues and scholars we expect them to become. They are supported and mentored to become independent researchers and are funded to present their work at conferences through a dedicated research student fund. They are actively involved in CSEE's activities such as contributing to and participating in seminars and workshops. **PGR recruitment** is overseen by the **Graduate Director for Research Students** and applications are handled by dedicated **Research Admissions Tutors** with **responsibility for ensuring the quality and academic standards of the students recruited, safeguarding an open and transparent recruitment process** which is not discriminating against individuals based on protected characteristics, and matching applicants' research interests with suitable supervisors. Research students need a first degree as a minimum in Computer Science, Electronic Engineering or related discipline or a Masters level qualification. We support applicants from ethnic and sexual/gender minorities and we have a strong commitment on diversity and inclusivity.

Every student is provided with desk space and a state-of-the-art new personal computer whilst further specialist facilities and access to laboratories are provided based on the research topic. Each research student has a named **individual supervisor**, and often also a co-supervisor, who they meet on a weekly basis. Progress is formally assessed twice a year through **Supervisory Board Meetings** that involve the student, the supervisor(s), and two additional academics. The **Research Students Progress and Monitoring Committee** is responsible for overseeing progress and reporting on all students to the **Graduate School (GS)**. All research students aiming for a PhD are admitted as MPhil/PhD students and their PhD status is only confirmed in the first (or second) Supervisory Board of Year 2.

CSEE and University **training provided for research students is extensive**. Training needs are identified by the student and supervisor and then reviewed at each Supervisory Board meeting to

monitor the training completed and what needs have emerged. The GS works with academic departments to set and monitor research student strategy and provide access to high-quality **cohort skills training and career coaching**. Training in discipline-specific skills is provided through advanced subject courses, while generic skills courses such as project management, effective communication and team working are offered through the University's **Proficio programme**. **All incoming doctoral students are given the equivalent of £2,000** each to spend on advanced training courses, conferences, or summer schools of their choice in consultation with supervisors. In addition, they are **allocated £1,000** each to present a paper in a major international conference. Research students' culture and networking are encouraged in a number of ways, including research group meetings, departmental seminars and GS-run events, such as the Doctoral Welcome Conference and the annual GradSchool. Students also have the opportunity to undertake limited teaching duties for their own career development (as graduate teaching assistants) and, through the University's *Cadenza* program, they are **encouraged to work towards Associate Fellowship of the HEA**.

REO offers additional distinct services to research students, including a **postgraduate consultancy** service allowing students to gain or extend engagement with employers, a business incubation hub and advice on securing start-up funding and patents.

A major success of CSEE has been the **Computer Science and Electronic Engineering Conference (CEEC)** which has been led and organised annually since 2009 by CSEE research students with central support provided by the School. CEEC has grown from an internal event to an international conference being **the only one of its kind in the UK that is run by research students with the proceedings published by IEEE**. It attracts an increasing number of international submissions and presentations (in 2019, 100 delegates from 20 countries of 5 continents with over 40% of the submitted papers from non-UK based authors). CSEE supports the conference by providing funding to each research group to invite world-leading researchers as keynote speakers. CEEC provides training and experience to future research leaders on how to review papers and how to organise an international conference (including writing the call for papers, organising tutorials, inviting keynote speakers, balancing a strong technical programme with a fun social programme and allowing for networking between students and established researchers).

### c) Equality and diversity

The University and CSEE recognise the value of diversity and are committed to equality of opportunities. The University has a very clear policy supporting equality and diversity for all staff and students, which includes flexible working arrangements, a dedicated team of harassment advisers, and training for all staff in equality and diversity issues. The **University's commitment to equality and diversity is also seen in the long-established groups for protected characteristics** (e.g. the LGBT+ Forum, the Access Forum for staff and students with disabilities, whose co-chair is a member of CSEE, etc.) and the high management profile of our **University-wide inclusivity champions** (e.g. the Registrar is our disability champion, the PVC-Research is our LGBT+ champion, etc.). Furthermore, the **University leads the One-Essex Inclusivity Network** involving members from the University as well as from various county-wide inclusivity bodies, both from local government and private institutions. Essex is a member of the **Stonewall's Diversity Champions programme**, became a **Disability Confident** (formerly 'Two ticks') **employer** in 2008 and received its **Athena SWAN Bronze Award** in September 2013, which was successfully renewed in November 2017.

We have a departmental **Inclusivity and Disability (I&D) Officer** supporting staff and students with protected characteristics to ensure everyone has **equal opportunity to conduct research productively**. The I&D Officer also gives inclusivity-centred talks at all induction events (for both staff and students) and liaises with the University on behalf of our students and staff with protected characteristics. Every new member of CSEE staff is required to complete training on equality and diversity within six months of starting their roles.



Within CSEE, staff come from diverse cultural backgrounds from over 19 countries (up from 12 in REF2014). Policies to improve gender equality have led to CSEE being awarded a **Departmental Athena SWAN Bronze Award** in 2019 and an **increase in the number of research active female academics (from 3 in REF2014 to 12 in REF2021)**. CSEE's commitment to equality is reinforced by the appointment of Fasli as UNESCO Chair in Analytics and Data Science to highlight the critical role data plays in promoting equality and sustainable development.

**Equal opportunities** in career path and promotions, submission of funding applications, access to internal funds, recruitment for research-related leadership roles, conference attendance, sabbaticals and training are given to all staff including part-time and fixed term staff. **We monitor gender and full- vs part-time distributions in different staff and student bodies, in staff committees and outreach activities, to ensure representativeness and equality of workload.** During the REF period, female academics have held important roles within CSEE and beyond: as Head of School and then Dean of the Faculty of Science and Health (Fasli), and Deputy Pro-Vice-Chancellor Research and the incoming Head of School (effective August 2021) (Musavian). During recruitment of new staff, marketing materials always explicitly **encourage people with protected characteristics to apply** (especially from groups that are underrepresented in IT & engineering) and every effort is made to have diversity as one of the criteria for appointing interview and selection panels.

CSEE offers £2,000 research budget for each staff in-between grants and staff **returning from periods of leave (including parental leave) or ill health, managing long-term illness, or with caring responsibilities**. We have an **open and transparent workload allocation model** which can be adjusted to support returning staff. Also, the unique needs of staff with disabilities, medical issues, and/or caring roles are taken into account throughout the process, e.g. by reducing administrative load where needed. We provide extra funding to support conference attendance or other research necessary travel for staff and research students with caring responsibilities, ill health etc.

CSEE provides suitable computing and lab facilities as assessed by the I&D Officer to support staff with protected characteristics (e.g. disabilities) to enable them to research productively.

RAG (which includes a representative of CSEE's Athena SWAN committee) and the I&D Officer have scrutinised the preparation of REF submission to ensure that due regard to equality and diversity issues was paid at all stages. The selection of the output portfolio is balanced across all research groups and to ensure adherence to the equality and diversity policies as set out in the University Code of Practice.

### 3. Income, infrastructure and facilities

#### a) Income

Following the research strategy detailed in REF2014 (G1-G3 above), CSEE increased its external research income (i.e. the amount of money received in respect of externally sponsored research), from £13.5M in REF2014 to £20.2M spend in this REF period. The increase is even more significant in terms of grants awarded (i.e. the value of competitive grants that have been won in the period and contribute to research spend during and after the census period). During the REF period, CSEE has **been awarded grants worth £28.6M** from a diverse range of funding agencies, including the EPSRC, ESRC, MoD, EU, ERDF, Innovate UK, as well as many industrial companies such as BT, Leonardo and others. Members of CSEE have also collaborated in projects based at other host institutions funded by Marie Skłodowska-Curie Actions-RISE, FP7-PEOPLE, national research councils-USA, Newton institutional links, Wellcome Trust and many others. **This is an increase of 50%** (after accounting for the longer duration of REF2021) on REF2014 when CSEE's equivalent research awards amounted to £13.2M. These grants also provided opportunities for cross-fertilisation, change in culture, growth and expansion in new research areas.

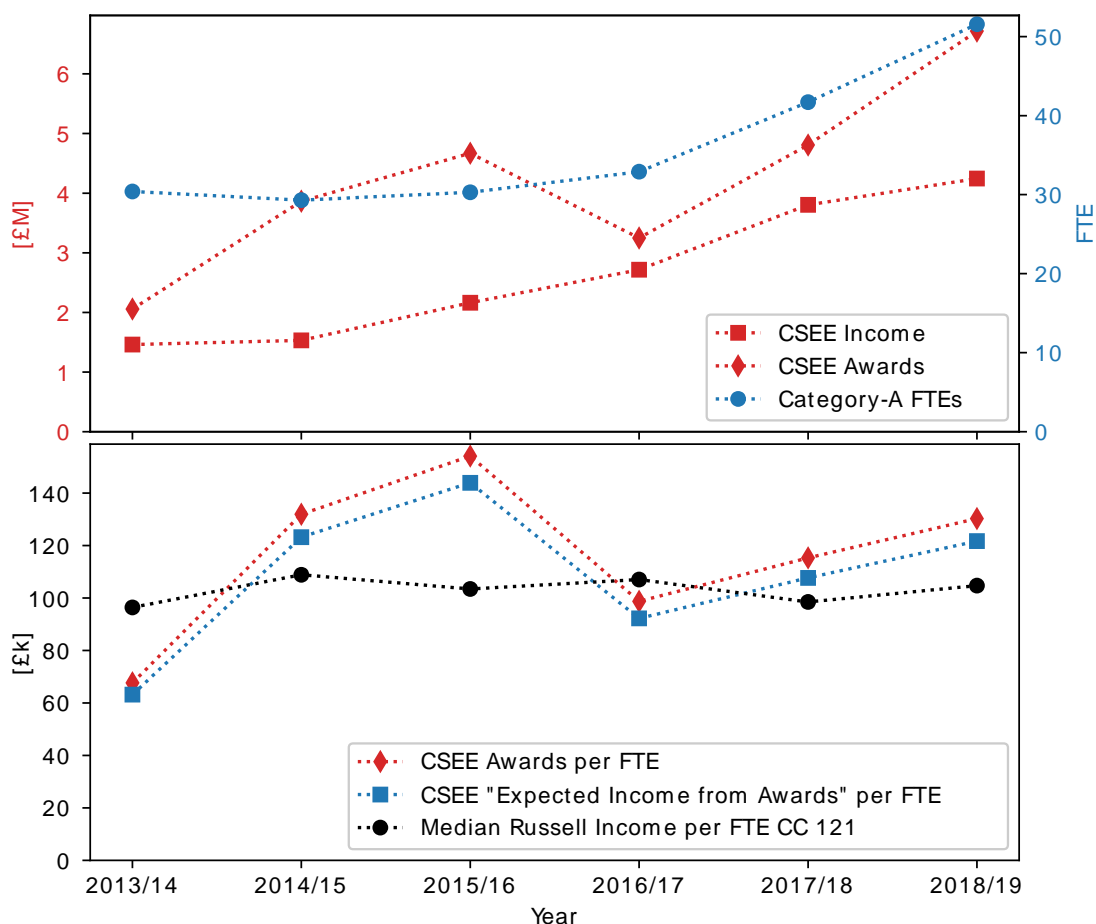


Figure 2. Top: Yearly trend of the research income, total value of the awards and FTEs; Bottom: Yearly trend of the value of the awards per FTE won by CSEE academics.

Figure 2 provides a more detailed analysis of our funding trajectory based on our financial data as well as HESA data (available for the period 2013/14 - 2018/19). More specifically, Figure 2-top shows how **CSEE's annual income has more than doubled over this period while the annual value of the awards is following an even steeper trajectory, which will likely translate into additional income in coming years** (due to the delay between funds being awarded and spent). Figure 2-bottom shows the value of the awards per FTE won by CSEE academics as well as the expected income resulting from these awards, which takes into account the fact that some of these will be reimbursed at 80% FEC. For comparison, we also report the median income of Russell Group universities submitting to HESA cost centre 121 (which corresponds to UoA11). Over the period considered, CSEE's academics were awarded **£117.3k/year/FTE**, with an expected resulting income of **£109.6k/year/FTE**, which is **above the Russell Group median income** of **£99.8k/year/FTE**.

The **equality and diversity policies** in Section 2c extend to the **support provided for acquiring research funding**. As a result of these policies, our data show **no significant gender differences** (two-sample Kolmogorov-Smirnov test) in terms of value of awards obtained nor in terms of number and conversion rate of grant applications.

## b) Facilities

CSEE has a diverse set of **specialist laboratories** featuring state-of-the-art equipment funded by strategic infrastructure investments, research grants and donations from industry. As research undertaken by CSEE requires extensive infrastructure, support for new activities as well as continuous support and periodic replacement of existing equipment, the University has specific provisions (Strategic University Infrastructure Funds) for the renewal and development of

infrastructure required to undertake research in the sciences. **We have expanded our research space by nearly 70% and invested more than £6M in creating and maintaining internationally leading research facilities** including the newly refurbished intelligent flat (iSpace) and the new BCI-NE, embedded and intelligent systems (EIS@Essex) and mechatronics labs. Continuous updates and additions to the Essex robotics arena and communications and networks labs retain them as world-leading testing facilities. **This unique infrastructure also helped to develop systems which are close to market, facilitating our research dissemination and impact activities.**

The **Robotics Laboratory** offers dedicated space for indoor robots. The University has invested over £3M to equip this state-of-the-art laboratory for robotics research. The laboratory accommodates over 50 robotic systems, including wheeled, flying, humanoid, and wheelchair robots, as well as various robotic arms and hands. In addition, through a £80k Strategic equipment award (2018) a new agricultural robot has been built at Essex comprising a Husky UGV carrying two UR3 arms, customised cutter/gripper, soft multi-fingered hand, and vacuum gripper. The facilities have been deployed in research projects funded by the EPSRC, including the NCNR, the EPSRC Robust Remote Sensing project and the EPSRC RoBoSaS, as well as Innovate UK and Industry.

The **Embedded and Intelligent Systems Laboratory (EIS@Essex)** has state-of-the-art design and prototyping facilities for advanced embedded systems design and system-processing architectures. Additionally, the EIS@Essex NCNR Lab has been expanded with dedicated embedded systems, FPGA/GPU units and sensors for extreme environments and autonomous systems (£120k investment by University and EPSRC/EU project funds). The Laboratory was crucial in conducting our research as part of the EPSRC funded RoBoSaS collaboration with NASA JPL, the Robust Remote Sensing, the NCNR, the ESPACENET, and RESIP EPSRC grants and the SYSIASS and COALAS EU ERDF grants. EIS@Essex encompasses the iSpace (intelligent flat) testbed for Internet of Things established from a University investment of £240k. EIS@Essex also includes £1.4M RCIF-funded facilities encompassing 3D projectors and high-resolution audio equipment which have been used in projects funded by DSTL and Innovate UK.

The Essex **Brain Computer Interfaces and Neural Engineering laboratory** is **one of the best in the world for non-invasive BCIs and cognitive augmentation**. With funding from the University and CSEE, it has recently acquired a new home spanning 190m<sup>2</sup>, three large Faraday cages (£150k), a robotic transcranial magnetic stimulation system (£140k), three mobile EEG (£90K), and a mobile VR kit (£60k). These have complemented our existing state-of-the-art EEG systems, high-density sEMG, fNIRS systems, transcranial current/functional/magnetic stimulators, eye trackers, motorised wheelchairs, robotic arms, electrophysiological sensors, computer cluster and backup storage, bringing the total equipment value to over £1M. These have also been acquired via grants from UK Ministry of Defence (MoD), US Department of Defense (DoD), EPSRC, EU, etc. including one under the DoD/MoD Multidisciplinary University Research Initiative and one under the DoD/MoD Bilateral Academic Research Initiative.

The **RF & Microwave Research Laboratory** houses modern equipment for developing devices and systems up to 67 GHz, including several scalar and vector network analysers, signal sources, spectrum analysers, an atomic-force microscope, mm-wave antenna radiation pattern measurement, as well as design workstations with ADS and CST software. The equipment (which cost in excess of £500k) was mainly obtained through EPSRC grants and SRIF funding and has been used in research projects such as the EPSRC grant on Liquid Crystal Based Beam Steerable Planar Antennas for 60 GHz Wireless Networks and Full duplex radios. The Laboratory has also a refurbished clean room and micro-fabrication facility through a £500k University investment.

The **Access Networks Laboratory (ANL)** has state-of-the-art wireless and system measurement tools with approximate total value £500k. The equipment has been funded in part from EU grants and in part by University infrastructure funds and was used in several grants and consultancies, including two from the EU commission (iCIRRUS and CHARISMA), an EPSRC (NIRVANA) and six KTPs.

The **Network Convergence Laboratory (NCL)** maintains a well-equipped research network test bed that consists of electrical and optical core networking technologies and heterogeneous wireless access networking technologies across the University campus and surrounding areas. In addition to hosting several planetLab nodes, NCL is also connected to GENI in USA via openFlow switches, and is the host to an enterprise SAN, a blade cluster of 70+ CPUs. The testbed is also a home to an edge computing cluster. These facilities have been used in various EU and EPSRC projects, such as EPSRC NIRVANA and TANGO and EU H2020 POINT, iCIRRUS and SerIoT.

The **Natural Language and Information Processing (NLIP) Laboratory** has two high performance servers (£60k) specifically for text and image processing and a number of large-scale multi-lingual commercial datasets.

Staff also make use of **other infrastructure available across the University** such as the UK Data Archive, which houses the UK's largest collection of datasets in social sciences and humanities. Such datasets are important for CSEE's work in machine learning and data analysis as well as growing research in the area of **big data and text analytics**. IADS houses multiple research-focused desktops having direct access to GPUs, alongside two ESRC BLG associated high-performance GPU-focused machines (£20k each). CSEE academics also have access to the University's High-Performance Computing cluster 'CERES', which has 1008 processing cores (1870 with hyperthreading) provided by servers with a mix of Intel E5-2698 and Intel Gold 5115 processors, and between 512Gb & 1.5Tb RAM each. There are also 24 NVidia GTX & RTX Series GPU cards attached for research purposes.

### c) Operational and Organisational Infrastructure

**RAG formulates and implements CSEE's research strategy** and acts as a formal link between CSEE, the University's Research Committee and the REO. RAG follows CSEE and University equality and diversity codes of practice. Its role is to:

- (i) Decide CSEE's overall short- and long-term research strategies;
- (ii) Critically appraise the research undertaken within CSEE;
- (iii) Track external drivers such as UKRI priorities, society needs, national and international research agendas, long-term trends, emerging areas and challenges to steer and position CSEE to respond to these changes;
- (iv) Distribute resources and devise incentives to realise CSEE's research strategy;
- (v) Provide critical support in the preparation of research proposals and initiatives, e.g. by providing seed money;
- (vi) Allocate PhD studentships and funds to purchase or upgrade equipment on a competitive basis according to CSEE's research strategy.

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

### a) Cross-institutional collaboration

The University and School have a wide range of mechanisms in place to support and encourage collaborative research, including the previously mentioned 'Essex International Visiting Fellowships', research leave, and financial support for research-related travel. Additional support includes a dedicated 'Research Development Manager (EU/International)' within REO to help CSEE academics develop Horizon 2020 proposals by organising training events, selecting and informing CSEE academics of H2020 calls in their areas, and providing feedback on draft applications. The University is also part of YERUN (Young European Research Universities Network), which aims to strengthen and develop cooperation among a cluster of highly-ranked, young research universities in Europe.

During this period, members have engaged in extensive collaborative activities with national and international partners in academia, research institutions and industry. **According to SciVal, 78%**



of all our papers (2014-2020) involved co-authors from another institution and 64% involved international co-authors.

Using as a criterion individuals with whom papers were co-authored or grants worth over £50k were won during the period, staff in CSEE collaborated with 34 UK universities (including Cambridge, Imperial, Oxford, UCL, etc.) and 203 overseas universities and research institutes (including UC Berkley, Princeton, ETH, EPFL, Harvard, USC, MIT, NASA JPL, etc.).

The diversity of our international dimension is exemplified by collaborations with top researchers in all our areas of research, including: Friston at UCL (Ognibene) and Thakor at NUS (Li(Ju)) in BCI and neural engineering; Nelson at ETH (Hoshier), Milford at Queensland (McDonald-Maier and Ehsan), Sandini at IIT (Mohan) and Henkel at Karlsruhe (Singh) in robotics and embedded systems; Poor at Princeton (Musavian), Hanzo at Southampton (Zhang, Yang, Liu), Frossard at EPFL (Bourtsoulatzé and Thomos) and Van der Schaar at Cambridge (Thomos) in communications; Mendel at UCLA (Hagras), Jordan at UCB (Citi), Xie at Microsoft Research (Jameel), Alon at Princeton (Kanellopoulos) and Tardos at Cornell (Kyropoulou) in AI.

Exemplars of specific cross-institutional collaborations include the following:

In 2014, the AI group was awarded EPSRC funding for a **Centre for Doctoral Training** (IGGI: Intelligent Games and Game Intelligence) together with York, Goldsmith and QMUL.

CSEE joined forces with the Human Rights Centre of the University of Essex in the **HRBDT Project** with human rights researchers at Harvard and Cambridge University, as well as human rights organisations such as the WHO and the UN. Funded by a £4.75M large grant from the ESRC, the Essex-based project considers the challenges and opportunities presented by AI, big data and associated technology from a human rights perspective. In this project, **AI group** academics Fox, McDonald-Maier, Poesio and Kruschwitz collaborate with a multidisciplinary team of professionals in criminology, economy, law, philosophy, political science and sociology to tackle challenges like algorithmic accountability to protect human rights, understanding how AI can also threaten the right to equality and privacy, exploring the use of NLP to detect mis- and dis-information and investigate how these affect human rights and use modern computer-vision technology to empower human rights organisations and the UN.

In the **BCI-NE group**, Poli is the Coordinator of a prestigious 3-year (2018-2022) \$5M grant under the US DoD's inaugural Bilateral Academic Research Initiative (**BARI**), for a project on the use of neural, physiological and behavioural data to improve hybrid human-machine group performance in decision-making, in partnership with the USC, UCB, Harvard, UMASS Medical School and Oxford. He is also UK coordinator of the prestigious 5-year (2016-2021) \$11.5M grant under the US DoD Multidisciplinary University Research Initiative (**MURI**), for a project on the use of neural, physiological and behavioural data to improve performance in decision-making, in partnership with USC, UCB, Harvard, NYU, UCLA, Imperial, and UCL. Citi and Cinel are Co-Is in these projects.

In the **COMNET group**, Walker and Yang were Essex PIs of the European commission funded iCIRRUS (overall budget €3.8M) in a project in partnership with ORANGE SA (France), PRIMETEL PLC (Cyprus), WELLNESS TELECOM SL (Spain), Fraunhofer (Germany), Interdigital Ltd (UK), among others. Reed, Thomos, and Yang were Essex PIs of the EU-funded project POINT (overall budget €3.5M) in a project in partnership with Interdigital Ltd (UK), Primetel (Cyprus), RTWH Aachen (Germany), Aalto University (Finland), among others. Reed and Thomos were Essex PIs in another EU-funded project involving DT-sys (Germany), DT (Germany), ATOS (Spain), CERTH/ITI (Greece), among others. Academics from the group also participate in EU-funded actions aiming at building/strengthening collaborations between EU and Chinese research institutions such as CROWN (FP7-PEOPLE-2013-IRSES - Marie Curie Action) and CLIMBER (FP7-PEOPLE) and across Europe such as RECENT (H2020 MCSA-RISE), involving partners from UK, Portugal, Finland, and Turkey.

In the **RES group**, McDonald-Maier and Ehsan are key Co-I in the NCNR, a £42M (EPSRC £11.6M) collaborative project involving international experts from 8 UK universities and 30+ partners from the nuclear industry and the research base, including NASA JPL, BAE Systems, EDF Energy, Japan Atomic Energy Agency, National Nuclear and Physical Laboratories, Rolls-Royce, Thales and Toshiba. The project is researching and developing cutting-edge technology to solve the problem of nuclear waste. McDonald-Maier leads the research strand on the development of resilient electronic systems that can function in areas of high radioactivity where robots are prone to failure and using computer vision in such extreme environments for localisation.

#### b) Major strands of interdisciplinary research

Members of CSEE collaborate extensively with scholars from other disciplines both within and outside the University. CSEE plays a major role in interdisciplinary areas, mediated by its Research Centres and Institutes that often act as contact points for reaching potential collaborators and effectively facilitating cross- and interdisciplinary work.

To foster collaborative and multidisciplinary work, the Faculty of Science and Health has introduced competitive Faculty-funded PhD studentships awarded to projects proposed and supervised by academics from different departments. So far, CSEE has been awarded 30 of these PhD studentships spanning a wide range of topics, from the application of AI to improve DNAzyme design to the study of social cognition development in infants and robots.

Our **research strategy is well aligned with UKRI priorities** (e.g. future intelligent technologies, transforming food production, innovation in health and social care, among others) and emerging major research themes and societal challenges specifically after the COVID pandemic.

**Interdisciplinary work has enabled us to increase our research funding and well as publish in high-quality research outlets.** Our major interdisciplinary research strands are:

- **Assisted Living Technologies**, a focus area where many members of CSEE work with staff from Life Sciences, Psychology, and Health and Human Sciences on a series of challenges that are directed to improving assisted living technologies and care with the users' needs in mind. For example, Mohan collaborates with Provide (reaching 4.5M people across Essex and Cambridge) to train robotic companions for a range of assistive services in their care homes. Hagraas and Clark are pioneering 3D intelligent vision systems (developed in cooperation with Leonardo) that are due to be deployed in houses of the elderly and disabled.
- The **Brain-Computer Interfaces and Neural Engineering** research group is interdisciplinary by definition as it explores systems integrating computer and electronic devices with human central and peripheral nervous systems for the purpose of enhancing, replacing or recovering function. The group is the UK lead for a \$11.5M US/UK Multidisciplinary University Research Initiative (on BCI-enhanced human decision-making, as part of an international team whose diverse expertise spans from machine learning to neural engineering to neuroscience), leading the first \$5M US/UK Bilateral Academic Research Initiative (on human-machine teaming, collaborating closely with experimental psychology in Oxford and Harvard Medical School), and is a key partner in EU projects like DeTOP (working closely with neurophysiologists, hand-surgeons and bioengineers), NEVERMIND (with bioengineers, psychologists, psychiatrists and three clinical centres) and POTION (with chemical engineers and clinical psychologists).
- **Trust in emerging AI, Systems and Robotics** technologies addresses the need for such systems to work as expected for their purpose, to be designed and tested to ensure that they work consistently and safely, and that they are appropriately developed within a legal, ethical and social context. This integrates and extends our technical research with social sciences and humanities research in a multi-disciplinary approach as part of IADS, HRBDT and the HRC.
- **Human Language Understanding and Technology** sits at the intersection of Computer Science, Language and Linguistics, Philosophy and Logic. CSEE academics work closely

with the UK Data Archive on information extraction, text mining to support visualisation and automated analysis of query logs. Our research in this area resulted in the DALI and HRBDT project and the impact cases with Signal and Minority Rights Group.

- **Computational Finance and Economic Agents**, where AI group members work as part of CCFEA, closely with members of other academic departments such as Mathematical Sciences, the Essex Business School and Economics. Recently emerging work in **complex socio-cognitive systems** and **global systems science** is done in collaboration with Sociology, Economics and Government. For example, Samothrakis is a Co-I in the **ESRC Research Centre on Micro-Social Change (MiSoC)**, a multidisciplinary centre promoting collaboration between economists, sociologists and other social scientists, and using quantitative social science to provide evidence with which to address key societal challenges.
- **Transforming Food Production**: Our work with Life Sciences in the EPIC resulted in **agritech** for plant imaging and soft fruit picking/packing using computer vision, soft manipulation, mobile robotics, drones and human robot collaboration. This also resulted in building the world's **first prototype of a mobile bimanual collaborative robot for agricultural applications**, with trials conducted in the **country's first vertical growing system for soft fruit (NGS)** located at one of the world's leading jam producers (Wilkin and Sons, Tiptree, Essex). This research paved the way for securing funds from the Industrial Strategy Challenge Fund in the next REF period (overall budget £1.3M, CSEE-led).
- **Marine technology** brings together the work done in machine vision and robotics with marine ecology and conservation and has resulted in award-winning (Defra's 2020 Breaking the Mould Award) 3D visualisation systems which were used for monitoring change in reef structures in Indonesia and the Caribbean. This research, in collaboration with Natural England and the Eastern Inshore Fisheries and Conservation Authority (EIFCA), has facilitated fisheries policy change through a co-produced investigation into human impacts on the UK's only chalk reef in East Anglia.
- **Policy and government**. The **ESRC Business and Local Government Data Research Centre (ESRC BLG) (PI: Fasli, CoIs: Matran-Fernandez, Raza)** at the heart of IADS, collaborates with private sector, public sector and non-profit organisations who can wield the transformative power of data to benefit their communities. By supporting them in implementing best practice, **we create real-world impact, influencing policy and informing practice**. BLG's aim is to be the UK's centre of choice for data research.

### c) Contribution to the economy and society.

Research at CSEE addresses **key challenges faced by industry**, as well as those concerning **wider society**, such as ageing and assisted living, food production and environmental protection but also military and security. In order to realise the potential of our research, staff actively engage with a range of users and beneficiaries, including: companies in the computer hardware, software and engineering sectors; computing and telecoms network providers and operators; IT based services; computer games; international standardisation bodies for emerging technologies; patient groups and healthcare providers (through NHS trusts and Provide); the MoD; and utilities companies and public authorities.

Staff in CSEE typically adopt **three distinct approaches to generate and increase non-academic impact from research** (see also G5 in Section 1c):

- **Interactive engagement**: by forming relationships with key individuals in relevant companies and standardisation bodies, staff develop a continuing dialogue about specific research needs. For instance, CSEE partnership with BT's main technical hub has led to research on intelligent and pervasive systems to guide workforce planning, to provide a mobile search engine, and to optimise protocols for network demand, scheduling and access (this resulted in two of our impact case studies). This approach is complemented by wide-ranging consultancy and advisory opportunities.

- **Collaboration:** most of the School's externally-funded research is inherently collaborative, and often involves industry and policy/standardisation bodies. Such collaborative relationships form a natural starting point for impact creation. For example, the spin-out UltraSoC (one of our impact case studies) arose from collaborative EPSRC research projects with Delphi and Infineon Technologies. In addition, collaboration within the ESRC-funded HRBDT led to another impact case study. Collaborations are also used to leverage significant in-kind support from industrial partners, for example, McDonald-Maier has secured approximately £10M+ in this way from organisations including Thales, Motorola and Rolls Royce. KTPs are used extensively in collaborating with industry. In the REF period, 25 KTPs (worth approximately £4M in funding) have been successfully completed (resulting in two impact case studies).
- **Dissemination:** research findings are actively shared with key user groups to inform them of developments of topical and strategic significance. This typically takes place at industry-facing conferences (covered by popular media). Social networks are used to disseminate new developments rapidly. CSEE organises an annual joint workshop with industry, which has a strong track record of leading to new collaborations, also enabling both research and industry to gain an insight into the latest priorities and capabilities within the sector.

As shown in Section 3a, our research portfolio has a healthy mix of fundamental and high-impact applied research, with important contributions to the economy and society. **Quantifiable evidence for the scale of our research impact on the local and national economy can be shown on our submitted impact cases.** Intellectual property created as part of our research has been extensively licenced and commercialised in spin-outs, such as key-less cybersecurity company Metrarc working with BT and the UK MoD in addition to UltraSoC, acquired by Siemens. Other evidence comes from KTP final reports submitted to Innovate UK. Considering all KTPs for which the majority of the grant duration falls in this REF period and where CSEE was the leading academic partner, our industrial partners reported a combined expected change of £24M in annual sales turnover in the three years following the end of the projects. Their testimonies illustrate the transformational impact of the joint work with CSEE academics: 'We are already seeing indications that the business value has increased from a few million, to somewhere in the many tens of millions. That is exciting and attributable to the KTP programme we have undertaken' (Peter Brady, CEO of Orbital Media Ltd); 'The impact of the KTP has been transformational for Mondaq's business. [...] We have brought new skills and people into the business in the form of data scientists which have impacted the entire corporate culture' (Andrew Partridge, co-founder of Mondaq Ltd).

#### **d) Contribution to the research base, evidence of peer esteem and research leadership.**

CSEE members made a substantial contribution to our discipline and others by editing key journals, chairing major conferences, delivering prestigious keynotes, organising the IADS summer school (attended by 700 participants over 4 years, of which about one third were PGR students, mostly external), serving in research councils' boards and producing landmark publications for which they won best paper awards.

Selected examples of leadership roles (which evidence the success of strategic goal G1) fulfilled by CSEE staff during the REF period include:

**Journal Editorial Board Memberships. 61 in total**, including: *IEEE Trans AI* (Hagras), *IEEE Access* (Anisi, Li, Liu, Yang, L.Hu), *IEEE Trans. Cybern.* (Gan), *IEEE Trans. Antennas Propag.* (Mirshekar), *IEEE Trans. Wireless Commun.* (Musavian), *IEEE Trans. Network Sci. Eng.* (Yang), *IEEE Trans. Fuzzy Syst.* (Hagras, Doctor), *Front. Neurorob.* (Gu), *Front. Neurosci.* (Scherer, Halder), *Brain Sci.* (Cinel), *Sci. Rep.* (Scherer), *Human Computation* (Chamberlain), *Evol. Comput.* (Poli).



**Guest Editorships. 39 in total.**

**Organisation of Conferences. 167 roles in total**, including. General Chair: IEEE Int. Conf. on Automation and Computing 2016 (Gu), NASA / ESA Conf. on Adaptive Hardware Systems 2019 (McDonald-Maier), Int. Conf. on Smart Grid and Innovative Frontiers in Telecommunications 2016 (Yang), IEEE Int. Conf. for Emerging Security Technologies 2017 and 2019 (McDonald-Maier) Program Chair: IEEE Int. Conf. on Automation and Computing 2015 (Gu), IEEE Int. Conf. on Fuzzy systems 2017 and 2021 (Hagras), IEEE Int. Symp. on Computer-Based Medical Systems 2020 (Garcia), IEEE Int. Conf. on Mechatronics and Automation 2014 and 2017 (H.Hu), IEEE Int. Conf. on Computer and. Information Technology 2018 (Thomos), IEEE Int. Conf. on Advanced Robotics and Mechatronics 2018 (Gu)

Special session/symposium/workshop Chair (selected): IEEE ICC 2021 Wireless Communications Symposium (Musavian), MECOMM workshop at ACM SIGCOM 2017 and 2018 (Reed), RTDPCC workshop at IEEE HPCC 2018 (Zhao), Games4NLP workshop at LREC 2020 (Chamberlain), CIFE symposium IEEE SSCI 2020 (Kampouridis).

**Keynote/Invited Talks.** (selected) Int. Conf. on Life System Modeling and Simulation LSMS & ICSEE 2014 (H.Hu), World Conf. on Complex Systems WCCS 2015 (Fasli), Int. Conf. on Cloud Computing and Artificial Intelligence CloudTech 2015,2020 (Fasli), Int. Conf. on the Theory and Practice of Natural Computing TPNC 2018 (Hagras), Int. Conf. on Intelligent Computing in Data Sciences ICDS 2018 (Hagras), Int. Conf. on Applied Human Factors and Ergonomics AHFE 2019 (Poli), Int. Conf. on Data Management, Analytics & Innovation ICDMAI 2020 (McDonald-Maier), Int. Conf. On Image Analysis and Recognition ICIAR 2020 (Hagras), SmartHort2019 Agriculture and Horticulture Development Board (Mohan),

**Best Paper Awards.** 25 in total, including: PhyCS 2014 (Gan), ICALP 2016 (Richerby), BCS SGAI Int. Conf. on AI 2016, FUZZ-IEEE 2014 (Hagras), KSEM 2017 (Long), Advances in Robotics 2017 (Chowdhury), ICT Express 2018 (Jarchi), UKRAS 2019 (Gu).

**Personal awards, fellowships, distinctions from major organisations.** IEEE Fellowship for contributions to electromagnetic modeling in 2014 (Mirshekar), Institute of Acoustics (IOA) Peter Barnett Memorial Award in 2014 (Hawksford), IEEE Computational Intelligence Society Distinguished Lecturer 2016-2018 (Hagras), U.S. National Library of Medicine Honour Award in 2017 (Garcia), IACAP's 2017 Covey Award (Turner), Gold Medal of the Audio Engineering Society in 2017 (Hawksford), IEEE Communication Society's Outstanding Young Researcher Award for the EMEA Region 2019 (Jindal), IEEE Communication Society Distinguished Lecturer 2020 (Yang), Fellowships of the BCS (McDonald-Maier and Yang).

**Membership of learned societies. 36** of our academics are members of the IEEE (of which 12 Senior Members, **2 Fellows**: Hagras and Mirshekar and **1 Life Fellow**: Ghanbari); 11 of the IET (of which **8 Fellows**: Adams, Hagras, Hawksford, Henning, H.Hu, McDonald-Maier, Vickers, Yang); 3 of the ACM; 3 of the Brain-Computer Interface Society; 3 of the BCS (of which **2 Fellows**: McDonald-Maier and Yang); 2 of the IOP (both Fellows: Henning, Zakhleniuk); and 1 of the IMA (**Fellow**: O'Hara).

**Membership of international standards committees and working groups:** Andreu-Perez is Chair of the IEEE CIS Task Force on the Extension of Type-1 Fuzzy Sets (Since 2018) and Chair of the IEEE CIS Task Force on Uncertainty and Fuzzy Modelling for Brain Analysis and Interfaces (Since 2018); Kampouridis is Chair of the IEEE CIS Technical Committee on Computational Finance and Economics (since 2020), Musavian is co-founder and co-Chair of IEEE UK and Ireland Future Networks Local group. Poli is a member of the Task Force on Hyper-heuristics within the IEEE CIS's Technical Committee of Intelligent Systems and Applications and of the IEEE CIS Task Force on Evolutionary Computer Vision and Image Processing.

**Membership of Research Councils and Funding Boards:** CSEE members have served in UK research funding bodies (including EPSRC, MRC, ESRC, NERC, UKIERI, Leverhulme Trust, the Royal Society) and served as chairs and members in Prioritisation Panels for the EPSRC (Clark, Musavian, Yang) and for the Royal Society (Cordero de Amorim). They have also served as reviewers for the European Research Council (McDonald-Maier, Mohan, Yang) and for national research councils from 22 countries, including DFG, DAAD, MIUR, NSF, NWO, IRCLA, SNSF, among others.