Institution: Loughborough University

Unit of Assessment: B11 Computer Science and Informatics

a. Overview

The research work submitted to this Unit comprises both theoretical and applied elements, and is undertaken in four research groups. Three of these groups were returned for assessment in RAE2008 and received a rating of 55% of 3* and above. A strategic decision was made to form the Theoretical Computer Science group to provide underpinning research for the three applied groups.

1. Interactive and Intelligent Systems (IIS) (Chung, Fatima, Hinde and Meng): The specialised knowledge of the members include: adaptive and cross-organisation workflow technologies; techniques for improving safety-related systems; fuzzy logics and evolutionary problem solving systems; resource allocation in multi-agent systems; electronic trading of goods and services.

2. Networks, Communications and Control Systems (NCCS) (Guan, Maennel, Phillips, S.Yang, and H.Yang): The group's research considers all aspects of networking and communication systems, and address specific issues related to Internet and control, wireless sensor networks, network performance modelling, measurement and evaluation. The work ranges from underlying mathematical theory to practical creation and operation of networked systems.

3. Vision, Imaging and Autonomous Systems (VIAS) (Bez, Edirisinghe, Glencross, Meng and Schaefer): The main research focus of this group is the development of advanced machine learning, graphics, image processing, analysis, representation and coding technologies that can be used to implement a range of applications which include video surveillance and forensic systems, medical imaging, robotics, multimedia representation and coding, imaging displays, digital cinema, computer graphics and animations.

4. Theoretical Computer Science (TCS) (Bell, Bez, Hussak, Reidenbach, Salagean and Yousif): The research of the group covers a relatively wide range of established and emerging fields in Theoretical Computer Science, including mathematical logic, formal languages, computability and complexity theory, numerical analysis, cryptography, geometric computation, algorithmic learning theory and energy-efficient scheduling.

b. Research strategy

Vision and strategy since 2008:

The Unit's vision has been to extend its presence in core areas of the discipline and further develop its activities in strategic areas of application, and to create an environment in which both basic and applied research can thrive.

The Unit's research strategy has had three strands:

1. Create a Theoretical Computer Science research group to underpin applied research.
2. Expand collaboration with industry and other academic units to sustain significance and relevance of the Unit's research.
3. Increase the Unit's research student population to further enhance the vitality of the research environment.

1. Create a Theoretical Computer Science research group

The Unit's RAE 2008 submission stated a commitment to both theoretical and applied research. As a consequence a Theoretical Computer Science group was formed with four existing and two newly appointed staff to ensure critical mass. Whilst engaging in research in theoretical computer science, the group has since supported other applied research groups in the mathematical and theoretical foundations of computing. For example, the group's research in geometrical computation and illumination modelling has contributed significantly towards the work of the Vision, Imaging & Autonomous Systems (VIAS) group.

2. Expand collaboration with industry and other academic units
The Unit has invested in strengthening collaboration with industry and other academic units. This was implemented within the research groups as described below.

Interactive & Intelligent Systems (IIS): Using Artificial Intelligence methods and systems, members of the IIS group have played a key role in working across all research groups and with other departments in the University (e.g. Sports Science, Aeronautical Engineering, Chemical Engineering, Loughborough Design School and Information Science), supporting multidisciplinary research projects.

In collaboration with the Aeronautical Engineering Department of the University, Chung and Meng are co-investigators of an EPSRC grant (EP/J011525/1) worth £1m: *Towards More Autonomy for Unmanned Vehicles: Situational Awareness and Decision Making under Uncertainty*. A previous grant, ASTRAEA, on unmanned vehicles (Chung) in collaboration with BAE was shortlisted for a 2009 IET Innovation Award.

Networks, Communications & Control Systems (NCCS): The Networks, Communications & Control Systems Group has been further extended by appointing two lecturers, Maennel and H.Yang. The group has been successful in attracting research grants from EPRSC, The Royal Society, TSB and industry.

In collaboration with other departments in the University, S.Yang is co-investigator of an EPSRC grant worth £1.4M (EP/I000267/1): Low Effort Energy Demand Reduction. Another two R&D competition grants of S.Yang on wireless home networks have resulted in a UK patent (GB0921008.9). The research outcomes of these grants were demonstrated at the 2011 Ecobuild in ExCel, London, and won the 2010 Honeywell Prize from the InstMC. Phillips has received support from the University's EPSRC Feasibility Account funds culminating in joint projects with Loughborough Design School and the School of Civil and Building Engineering. Maennel and Phillips work closely with Internet Service Providers and Vendors (Sky, IIJ, Cisco, Juniper) in investigating secure internet routing and have secured £65K from CISCO to upgrade research infrastructure. Guan has secured over £300K funding from BAE Systems and the EPSRC Knowledge Transfer Account (KTA) of the University to investigate Quality of Service monitoring and congestion control of computer networks.

Vision Imaging & Autonomous Systems (VIAS): The membership of the VIAS group has been extended by appointing Glencross and Schaefer, thus broadening its scope to cover two strategic areas: Computer Graphics and Medical Imaging. Strategically this group has focused on cutting-edge applied research, attracting funding from UK/EU industry supported by new state-of-the-art research laboratory facilities (see section d).

Glencross has been successful in attracting funding from industry (KiSP, The Foundry, BMW) for her work in reflectance modelling for realistic graphics object/scene creation. Schaefer has recently secured an EC FP7 grant (£160K) for collaboration in the area of Medical Imaging. Edirisinghe's successful research has led to his existing collaboration and knowledge transfer activity with Apical Ltd, winning the 2013 Loughborough University Enterprise Award. He has also secured grants from EPSRC and TSB to collaborate with industry in areas of video analytics and forensics.

Theoretical Computer Science (TCS): The newly formed TCS group has links with other academic units worldwide. These have led to many collaborative initiatives, funded in various ways including the LMS and the host institutes.

Bell worked on complexity problems for algebraic structures with Harju and Karhumaki at the University of Turku and Blondel at the Université catholique de Louvain. Reidenbach hosted visitors from the Universities of Kaiserslautern and Frankfurt investigating combinatorics on words and was invited by the University of Singapore to work with Jain and Stephan in automata theory. Yousif works with Martins and Santos at the University of Coimbra on numerical methods.

3. Increase the research student population
The Unit has formed strategic partnerships with overseas institutions and UK industry to obtain funding and recruit high quality PhD students. Collaborations with other academic units within the University have secured University studentships with joint supervisions. Compared with 2008, the current research student population is 20% larger. The research students are actively involved in seminars, competitions and international conferences (see details in Section c).

Research Strategy (Future)
The Unit's aim for the future is to build on existing excellence to shape and advance academic research in the Unit's chosen research areas and to create impact in society. The Unit's programme for future research includes the following:

1. Alignment with University research strategy
2. Creation of a research centre
3. Further blue-sky research
4. Responsiveness to change

1. Alignment with University research strategy
The University has identified six cross-cutting research themes to address significant research challenges. Where possible the Unit will align its research along these themes, to create large scale projects in collaboration with other units within the University. The themes the Unit will contribute towards include: Enabling Future Technologies; Energy; Health and Wellbeing; Secure and Resilient Societies.

2. Creation of a research centre
Building on externally funded research studentships (e.g. from the Omani Government and Apical Ltd.) and successful collaboration with industrial partners, the University has approved the forming of a Centre for Doctoral Training (CDT) in image processing and intelligent systems in the Unit. Capitalising on this, a research centre incorporating the VIAS and IIS research groups is being planned. The research centre will carry out research in embedded algorithms to support future mobile technologies and video analytics, and in applying AI techniques to different application domains in collaboration with other units across the whole University.

3. Further blue-sky research
Recognising the importance of curiosity-driven research in advancing science, the Unit will continue to provide resources for activities that are not motivated primarily by specific applications, but have the potential to make a significant contribution to the discipline.

4. Responsiveness to change
The Unit's research income has been mainly generated via grants funded by the EPSRC, TSB and UK industry. The funding profile will be extended and diversified to cover funding from international organisations. An annual strategic research budget of £20,000 will be used to pump prime such activities. In anticipating continuing changes in HE funding and advances in technology developed by industry, the Unit will seek to strengthen current links with industry by forming strategic partnerships with key collaborators.

c. People, including:
i. Staffing strategy and staff development
The sustainability of the Unit's research groups is paramount to the staffing strategy. Therefore the Unit's policy has been to appoint strong researchers at an early stage of their careers. Furthermore, the Unit's strategy has been to maintain a high quality team of technical and administrative staff supporting research.

Following the Unit's research strategy, two appointments have been made to each of the following research groups, TCS, VIAS and NCCS. A new appointment to the IIS group is underway.

The Unit has a good track record of retaining staff and developing staff for promotion. Since 2008 eight promotions have taken place, two to Chair positions, one to a Readership and five to Senior

Lecturer positions. Three staff (Guan, S.Yang and Phillips) have taken Sabbatical Leave and secondments to consolidate their research in collaboration with other academic institutions and industry.

Academic staff development involves the completion of an annual Personal Research Plan (PRP) for the purpose of monitoring and development of an individual's research. Further, an annual Professional Development Review (PDR) is used to identify training needs in discussion with line managers. In addition, a comprehensive staff development programme is available to all staff through the University's Staff Development Centre. The Research Office provides one-to-one support for staff writing grant proposals.

To support research, academic staff on probation are assigned significantly reduced teaching and administration loads, e.g. year one is a third of the normal load. During the probationary period staff are supported by a mentor, a fully-funded PhD studentship, and travel fund for conferences. Since 2008 further funds to the value of approximately £100K have been allocated by the Unit, HEFCE and the University to support staff on probation with small equipment purchase for research.

The University's implementation of the Concordat to support the Career Development of Researchers received the EC's HR Excellence in Research Award. Specific outcomes include a continuing commitment to a University-wide Research Staff mentoring scheme, a revised Code of Practice for the Employment of Researchers, and establishment of the Loughborough University Research Staff Association. Research staff in the Unit continue to be active participants of the University's staff development programme.

Loughborough University is committed to achieving equality and diversity and provides training in recruitment and selection. The geographic origin of staff in the Unit includes: Africa, China, Europe, India, South East Asia and the Middle East. The University holds the Athena Swan Bronze Award, and the Unit is working towards gaining Silver Award status.

ii. Research students

The aim within the REF period was to grow the Unit's PGR student number whilst ensuring quality and successful outcomes.

PhD student recruitment:

To encourage high quality UK/EU undergraduate students to consider PGR study, approximately 4 summer studentships (10 weeks duration) have been annually awarded based on an open competition since 2011. Another source of quality students is the Unit's MSc programmes that are coupled to the Unit's research specialisms.

A total of 24 research studentships have been funded since 2008 from the Unit's budgets, EPSRC DTA, the University and industry. Studentships are awarded on academic merit and in areas strategic to the Unit (see Section b).

The Unit has been successful in recruiting fully funded international PGR students, e.g. 12 from Oman and 6 from Brunei.

The current PGR population is 60, indicating a 20% increase as compared to 2008.

PhD student progress monitoring:

A Director of Research Degree Programmes oversees the process of annual progress reviews of students, and offers pastoral support. Each research student is required to write an annual progress report and have a viva. Progression is dependent on a successful outcome. In the case of unsatisfactory progress after an action plan, transfer from PhD to MPhil or termination of studies are considered by a review panel. Any exceptional situations are dealt with by the Associate Dean Research (ADR) of the School of Science.

PhD student support:
The Unit provides a vibrant and supportive research environment for its 60+ research students including: workstation, research facilities, IT support, weekly seminars, conference travel funds and prizes.

Students are provided support to disseminate their work through conferences, workshops and academic journals. Students rehearse their presentations for conferences in a supportive environment within the Unit's seminar series. During their period of study, each student receives funding to attend up to two conferences. This represents an annual total spend of £15,000 from the Unit plus additional funds provided by the University. The School of Science holds annual poster competitions for research students. Industry-sponsored prizes are awarded to the best papers. Each year the Unit selects a publication for the best student paper award of £1,000.

The Unit has a Research Student-Staff Committee to review, maintain and improve the research student academic experience.

Students are given many training opportunities provided by the University Staff Development Centre and the Library. Training undertaken is monitored as part of the annual progress review. The University's Mathematics Learning Support Centre provides mathematics and statistics support to research students. The opportunity to gain teaching experience, in tutorials, problem classes and laboratory sessions, is offered to research students.

Student achievements:
Since 2008, six students have won best paper awards at international conferences. Average completions per year in the REF 14 period is 12 compared with 6 in the last RAE period, an increase of 100%.

d. Income, infrastructure and facilities
Funding portfolio
Within the current assessment period the Unit's 'research spend' has been £3.5M, an average increase of 61% per annum, compared to the assessment period of RAE2008.

Example grants for research in intelligent systems: A web-based semi-automatic assessment tool for a conceptual database model, TSB – £167K; Designing mechanisms for automated resource allocation, EPSRC – £243K; Intelligent business transaction agents for cross organization workflow definition and execution, EPSRC – £72K; Towards more autonomy of unmanned vehicles: Situational awareness and decision making under uncertainty, EPSRC – £246K.

Example grants for research in networks and control systems: Framework for distributed development and integration, MoD – £201K; Modeling of network performance for large scale systems with QoS constraints, The Royal Society – £92K; LEEDR: Low effort energy demand reduction, EPSRC – £135K; Low cost wireless tracking system for motor manufacturing, storage and delivery, ERDF – £45K; QoS negotiations for improved dependability in distributed systems, EPSRC – £48K; Towards a higher level configuration specification language, CISCO – £66K

Example grants for research in image processing systems: AllCast, viewing subjectively optimized video in mobile handsets tailored to ambient lighting, TSB – £162K; Development of an image signal processor, Apical Ltd. + EPSRC – £121K; Recovering outdoor sets for movie post production, Foundry + EPSRC (KTA) – £78K; Intelligent CCTV video forensic tool, TSB + EPSRC + Visimetrics Ltd. – £121K; Reflecting the reflectance, KiSP (an international SME) – £73K; Design and implementation of an end-to-end HDR video delivery system, Apical Ltd + TSB – £80K

Future plans for funding
In addition to EPSRC, TSB and industry funding, the Unit aims to generate funding via the Horizons 2020 programme. A strategic research support fund of £20,000 p.a. has been created in 2012 to pump prime new research initiatives and enable staff to travel to funding related meetings

worldwide. Seven members of staff have already benefited from this fund. For example, an EC FP7 project (2.3M Euro) on water consumption monitoring and intervention has recently been awarded to the NCCS group and is due to start in Feb 2014.

The Unit aims to extend the industry funding portfolio by encouraging academic staff to form new partnerships with UK and international companies. Industry is regularly invited to attend research events and open days organised by the Unit, and a new industry brochure has been produced for circulation detailing different ways to work with the Unit. The Unit's links with overseas governments (China, Oman, Qatar, Saudi Arabia, Brunei) are providing opportunities to approach their academia and industry for collaborative research projects and PhD student sponsorship. For example, the Unit will build on its successful partnership with the Omani Government.

Formal R&D arrangements are being negotiated with industry partners, e.g. the relocation of Apical Ltd. to Loughborough University Enterprise Park in 2014 to facilitate closer collaboration.

Infrastructure
In 2011/12 the Unit moved all its staff, research students, research labs and teaching facilities to a single refurbished building at a cost of over £5M. Research facilities include the newly established (2012) **Dark Room** equipped with a Reflectance Acquisition Rig worth £25K, which is used for studying the problem of better quality material reflectance acquisition of fabrics in collaboration with The Foundry.

The **Usability Laboratory** created at a cost of £50K in 2010, which consists of video/audio recording facilities in a controlled environment, eye tracker devices and large multi-touch screens. The lab is being used by the IIS group for user behaviour analysis which can lead to the creation of better interactive systems for different application domains.

The **Robotics Laboratory** equipped at a cost of £30K in 2010/11 consists of 23 mobile robots of different types, a number of unmanned flying objects and various simulation environments. This is presently used by the IIS research group on projects related to autonomous vehicles.

The Vision, Imaging & Autonomous Systems (**VIAS**) **Laboratory** has been refurbished and equipped at a cost of over £100K. Some of the research equipment has been provided by industrial sponsors. The laboratory is being used by the VIAS research group on projects related to CCTV forensics, image enhancement, medical imaging and multimedia coding.

The **Networks Laboratory** was refurbished in 2010/11 at a cost of £180K, with a £100K contribution from CISCO. The laboratory is used by the NCCS members to support their research in Wireless Sensor Networks, QoS, Mobile Ad Hoc Networks, congestion monitoring and control, network measurements, design, protocols.

Planned Infrastructure & Investment
Recent investment by the University of approximately £5.5M in infrastructure and equipment means that the Unit's present need for research facilities has been met. There is a further plan to equip the VIAS lab with embedded systems development kits for hardware testing of software implementations. Commitment for sponsorship for the VIAS laboratory has already been made by Apical Ltd. CISCO pledges for equipment support will be used to upgrade and maintain the Networks Laboratory, providing a quality research facility for NCCS members.

Loughborough's cloud-based data centre and the 3000 node supercomputing facility provided by HPC Midlands situated within the University campus is available for use by the Unit.

Facilities & Services
Three staff have provided consultancy services to industry and public sector organizations: energy forecast visualization and data mining for ETI (Edirisinghe), software development for the English Institute of Sport (Chung), requirements capture for on365 (Phillips), software system integration & installation for Quanta (Phillips), detection of metal whiskers for JSC (Edirisinghe).

The Dark Room facility is being used by Apical and BMW for evaluating colour constancy algorithms and for studying ambient illumination and material reflectance, respectively. The Usability Lab is used by researchers from the School of Business and Economics and the Marketing and Communications Office of the University. A major high street retailer is currently negotiating the use of the lab.

e. Collaboration or contribution to the discipline or research base

1. Information on support for and exemplars of research collaborations including national or international collaboration

Collaborations are supported by small travel grants awarded by the Unit, the University, or from awards and grants from external bodies. All members of the Unit have a wide national and international network of collaborators across the world. For example,

- Bell collaborates with Blondel (Universite catholique de Louvain, Belgium) and Halava, Hirvensalo, Harju, Karhumaki (Turku University, Finland) leading to joint publications and ongoing research.
- Chung collaborates with Sao Paulo University, Brazil and Victoria University, Australia. The work has resulted in joint publications.
- Maennel has collaborations, with published outputs, with University of Adelaide, Cambridge University, Universidad Carlos III de Madrid and funded research collaboration with Cisco.
- Meng conducts work on "Developmental Robotic Writing Control Driven by Enhanced Constraint-lifting Algorithms" funded by the National Natural Science Foundation of China.

The scale of the Unit's collaborations is further evidenced by its joint publications with international collaborators.

2. Information on and support for and exemplars of interdisciplinary research

The University supports interdisciplinary research through fully-funded PhD studentships and the Unit has been awarded 5 since 2008, e.g., Chung with Sports Science, Bell with Aeronautical Engineering, Salagean with Electrical Engineering, Edirisinghe with Chemistry. In addition, a further 8 students funded from other sources are jointly supervised with staff from other Units within the University.

The Unit's staff are co-investigators on two interdisciplinary EPSRC-funded research projects of over £1M each, one joint with Aeronautical Engineering to investigate autonomous decision making of UAVs and the other with Civil Engineering in the application of remote controlled energy saving devices in buildings. Other joint work with Aeronautical Engineering on UAVs was shortlisted for a 2009 IET Innovation Award.

Bez collaborates with the Mathematics Department at Birmingham University on the Interface of Mathematics and Computer Science. The work is partially funded by the LMS and has led to joint publications.

The VIAS group have published extensively in the medical imaging and bioinformatics literature.

3. Information on how research collaborations with research users, including industrial users, have informed research activity and strategy

Edirisinghe's and Bez's research collaboration with Apical Ltd has led to three recently funded R&D projects (EPSRC, TSB/KTP) and five funded PhD projects, creating a new area of research activity in perceptual enhancement of images and video. This expansion of research activity, coupled with the forming of a CDT, has led to the strategic plan to create a research centre in imaging and intelligent systems. Edirisinghe's collaboration with Visimetrics Ltd has identified a new research area in CCTV forensics. The joint ideas have resulted in two recent grants (EPSRC/TSB funded R&D grant, TSB funded KTP grant) and 5 publications. Glencross' research collaboration with the Foundry Ltd in reflectance modelling has resulted in the creation of the Dark Room laboratory facility. This work has led to subsequent funding from KiSP and BMW.

4. Exemplars of leadership in the academic community

National/international advisory board membership: Chung is an Executive Member of UK Deans of Science; Phillips is Chair of the Council of Professors and Heads of Computing.

Leadership roles in industry, commerce, Research Councils, learned societies, professional bodies: Glencross was Vice Chair of ACM SIGGRAPH Professional and Student Chapters Committee, and now serves on the ACM Europe Council; three members of the Unit (Chung, Hinde and S.Yang) belong to the EPSRC Peer Review College; Maennel is an Advisor to NATO Cooperative Cyber Defence Centre of Excellence (CCD COE) in the preparation of their "Locked Shield 13" exercise.

Staff in the Unit were involved in a large number of conference programme committees. Conference programme chairs include:

- Bell and Reidenbach are organising and hosting the British Colloquium for Theoretical Computer Science (BCTCS) in 2014.
- Guan was the founding Chair of the International Workshop on Performance Modelling and Evaluation in Computer and Telecommunication Networks (PMECT'2007-2013) in conjunction with IEEE ICCCN (07-13); and was Program Co-Chair, International Symposium on Pervasive Grid (PGrid08), Sao Paulo, Brazil, 2008.
- Schaefer was Programme Co-Chair for: the 7th Int. Conference on Signal Image Technology and Internet Based Systems (SITIS) 2011, and the International Conference on Visual Information Systems (VISUAL) 2008.
- S.Yang, was Programme Chair for 2013 IEEE IoT Conference, Beijing; Programme Co-Chair for UKACC Control 2012, Cardiff, UK and IEEE Int. Conference on Networking, Sensing, and Control, 2009, Japan.

Invited keynote lectures:

- Chung delivered keynotes at: First International Symposium on Socially and Technically Symbiotic System, Okayama, Japan, 2012; 3rd IEEE International Conference on Broadband Network & Multimedia Technology (IC-BNMT), Beijing, 2010; European Conference on Intelligent Management Systems in Operations, Salford, 2009.
- Schaefer delivered a number keynotes at international events including: 5th Int. Conference on Emerging Trends in Engineering and Technology (ICETET) 2012; 6th Int. Conference on Computer Vision and Graphics (ICCVG) 2012; Symposium on Neural Network Applications in Electrical Engineering (NEUREL) 2012; 16th IEEE Mediterranean Electrotechnical Conference (MELECON) 2012.
- S.Yang, was keynote speaker at: Wireless Sensor Networks & RTLS Europe, Munich, Germany, 2011; 17th Annual Conference of The International Emergency Management Society, Beijing, 2010.

Journal editorships:

- Guan acted as Guest Co-Editor for a number of special issues: Journal of Computer and System Sciences (JCSS), 2009; Journal of Telecommunication Systems: Modelling, Analysis, Design and Management, 2009; Journal of Simulation, Modeling, Practice and Theory, 2008; Journal of Multimedia and Ubiquitous Engineering, 2008.
- S.Yang, was/is Associate Editor of: International Journal of Systems Science (2005-2012); International Journal of Automation and Computing, 2007-present; Journal of the Institute of Measurement and Control, 2006-present.
- Chung is on the Editorial Board of the journal Applied Artificial Intelligence.

Awards, prizes and research fellowships: S.Yang, won the 2010 Honeywell Prize of the Institute of Measurement and Control; six best student paper awards were won at international conferences; Chung was awarded a JSPS (Japan Society for the Promotion of Science) Invitation Fellowship (2012); Guan held a Royal Society Industry Fellowship (2009-11); S.Yang, held a Royal Academy of Engineering Industrial Fellowship (2010).