**Institution: King's College London**

**Unit of Assessment: B11: Computer Science and Informatics**

## a. Context

### Background

Department of Informatics research includes theoretical and application-led work in the fields of telecommunications, robotics, AI, software engineering, security, management of complexity, algorithms and bioinformatics. Impact is sought through the application of these areas within the framework of **Future Intelligent Systems**. Links with industry are nurtured through contributions to standards and through collaborative projects, consultancy and public engagement. Informatics benefits from a strongly industry-facing research activity in the Centre for Telecommunications Research, although industry-linked research is carried out throughout the department. Informatics is part of a university with world-leading Schools of Medicine, Law, Arts and Humanities and Biomedical Sciences, supporting creation of close links with health practitioners at Guy's and St Thomas' hospitals. Informatics is situated in the Strand Campus, in the heart of central London, facilitating access to business and industry, policy makers and health organisations.

### Main non-academic user groups, beneficiaries and audiences for research

Informatics research targets: mobile communications and telecommunications industries, the medical professions (surgery, pharmaceuticals and heath informatics); the energy industry; automation industries (robotic manufacturing industries, intelligent sensing, autonomous robotics); standards bodies and software industries (internet and social media, security, software development and testing). Examples of companies with whom we have built links include: Alcatel-Lucent, BBC, BT, France Telecom, Schlumberger, AstraZeneca, BAE Systems, Scisys, Daimler Chrysler, CSC, Oracle, Samsung, Nokia, Vodafone and Motorola.

### Main types of impact relevant to the research

**Impact on Communications Infrastructure:** effective and efficient wireless communications and communications infrastructure, mobile systems, green communications, multimedia over internet, standards and security.

**Impact on Health:** autonomous robotic medical devices, secure clinical record management and privacy protection, authentication of pharmaceutical products, decision support, microwave imaging and biomedical signal processing.

**Impact on Autonomous Intelligent Robotics and Systems**: robotic manipulators, sensors, efficiency of production and decision processes, planning and energy-efficient computation.

**Impact on National Security**: cyber security, hazard detection, identification and tracking (including software viruses and other attacks) and data security.

## b. Approach to impact

Informatics forms links with relevant industries and practitioners, driving work in partnership with them, working in close collaboration through projects and consultancy relationships, and engages beneficiaries through technical and academic training. Research also contributes directly to standards, shaping the practice and pursuit of the discipline.

### Specific staff support for engagement in impact

The College **Business and Innovation** group supports the protection of IP through an IP and licensing manager associated with the School of Natural and Mathematical Sciences. The College also appointed an **Innovations Fellow** within the Department, tasked with the promotion of innovations and commercialisation of research within Informatics. The fellow has organised industry days and workshops on industry interfaces, spin-outs and IP protection. A **joint lectureship** is held between Informatics and the medical school with the goal of bridging the research of the two departments and seeking impact of informatics research in health. This appointment has led to five current funded projects in Health Informatics, collaborating with industries and health practitioners, and medical decision-making, bringing in over £3M to the College and supporting 6 cross-departmental RAs. The appointment, and the projects following from it, have given Informatics direct access to leading healthcare industries.

### Department support activity

Financial support is provided using pump-priming funds administered through the Departmental Research Committee: these funds facilitated the [RWL] case study. EU projects are a key means

to form links with industrial partners, so support is available to attend consortium-forming meetings in Europe, contributing to 15 successful applications for EU project funds over the REF period.

**Examples of engagement with key beneficiaries**

The following examples illustrate how the departmental approach leads to opportunities that can be exploited to achieve impact. These examples are at different stages of maturity, but represent a cross-section of examples of the progression of research to impact.

**Communications Infrastructure and Applications:** Researchers, particularly in the Centre for Telecommunications Research (CTR), have directly engaged with telecommunications industries such as Alcatel-Lucent, BAE, BBC, BT, France-Telecom/Orange, Nokia and Vodafone, to achieve impact. An example is research, working with the BBC, on iPlayer traffic which has the prospect of reducing heavy user traffic by up to 97% and energy usage by 74% using a novel high-gain algorithm. Impact of research activity is sought by participation in industry-led research bodies, such as the Wireless World Research Forum, in which Aghvami is one of only 15 global fellows, and Mobile Virtual Centre for Excellence (Mobile VCE), which is an academic and industrial collaboration. Further engagement is achieved through organisation of major international meetings between research and industry participants, such as the International Symposium on Personal Indoor and Mobile Radio Communications, founded by Aghvami and now in its 24th year. Placement of PhD graduates in key industries (eg Ericsson, Huawei, NEC, Orange and Thales since 2008), and provision of industry training courses, offers direct influence on industry practice.

This work has led to significant impacts in economic terms, including the formation of successful spin-outs described in the [WTC] case study and patents in communications technologies (15 patents within the REF period, 9 of which have been assigned to Alcatel-Lucent, in a partnership arrangement, with an estimated value of £3-4 million).

**Health:** Researchers have exploited the opportunities to engage with health professionals associated with KCL, particularly in the areas of robotics and intelligent sensing, pharmaceuticals authentication and health informatics. This area illustrates the use of EU projects as a vehicle to interact with relevant industries and practitioners. For example:

1. Althoefer has worked on Nuclear Quadropole Resonance (NQR) sensing for pharmaceuticals authentification with Wellcome Trust and Astra Zeneca.
2. The EHR4CR (Electronic Health Records for Clinical Research) project, led by AstraZeneca, exploits work on data provenance – see [DPS] study – and the joint Informatics-Medical Schools lectureship.
3. The EU project TRANSFoRm (Translational Research and Patient Safety) coordinated by the KCL medical school, links Informatics in collaboration with Custodix, Quintiles and CSC. This work exploits agent systems and cross-disciplinary skills in the joint lectureship appointment.
4. Flexible manipulators developed in the EU FP7 STIFF-FLOP project, for surgical use, in collaboration with the Shadow Robot Company, the Foundation for Cardiac Surgery Development and the European Association for Endoscopic Surgery.
5. DIET4Elders, funded by Ambient Assisted Living (AAL), partnered with Tunstall Healthcare.

Direct interaction with health professionals, particularly at Guy's and St Thomas' Hospitals, has led to development of novel signal processing techniques and also a *sensitive fingertip* sensor designed for use with automated techniques during key-hole surgery, to probe tumours.

**Autonomous Intelligent Robotics and Systems:** This area is strategically important within the departmental focus on Future Intelligent Systems. Through collaborative projects, industry partnerships have been formed, influencing research activity in this area. Examples include:

1. Intelligent sensing and signal processing developed for the [RWL] case study.
2. Persistently autonomous behaviour, being developed in EU projects featuring collaboration with Subsea 7, Seebyte, BP (EU Project PANDORA), who, through the Industrial Steering Committee, are participating in directing the project to confront industry problems.
3. Space science exploration work in collaboration with GMV, CSEM and Scisys (EU Project PRoViScout), which has had impact in the SciSys design of on-board software for the ESA ExoMars mission, to include hooks for on-board planning of autonomous science acquisition.
4. Novel mechanisms and sensors for advanced robotics have been developed in TOMSY, HANDLE and DARWIN, EU FP7 projects that address different aspects of dexterous manipulation and object-handling, including both advanced control and the design of next-

generation hardware to achieve future concepts of motion and control. These projects are in collaboration with the French Atomic Energy Commission (CEA), Shadow Robotics, Profactor and Novocaptis, the latter three representing key links to the growing intelligent robotics industry. This work has led to multiple patent applications.

5. Collaboration initiated with IdMind, Festo and the Fraunhofer Institute (EU Project SQUIRREL) to include planning, world-modelling, learning and control.

**National Security**: Researchers have collaborated with industries in several areas related to security. Cross-disciplinary research with the War Studies Department, which considered applications of multi-agent software systems to problems in cyber security and work on cyber-weapons, was presented at Whitehall and published in the Royal United Services Institute Journal, and is influencing policy makers. Other examples of direct collaborations in this area include:

1. Development of NQR hardware and intelligent classification software for the detection and identification of explosive materials hidden in luggage, vehicles or buried underground, as part of funded projects, including CONTEST (Home Office funding), a dstl-funded PhD study on modelling of NQR signals from explosives and funding from MoD and NATO.
2. Algorithmic and theoretical products including the specification of financial computing applications, with Holistic Risk Solutions.
3. Planning for target-tracking, with BAE Systems: an initial prototype system led to subsequently funded research within the EPSRC/Industry cross-funded programme on Autonomous and Intelligent Systems.
4. The Digital Forensic Advisor, is a decision support system for the 2010 UK Equality Act, developed with the Institute of Psychiatry and Monad Solutions, licensed to Intellas UK.

**Standards and Impact on Practitioners**

Standards are central to achieving impact by shaping the work of industries and practitioners. Informatics researchers have contributed to a wide range of standards in different areas, all of which are either having immediate impact (eg data provenance – see [DPS] case study, software modelling standards – see [SMS] case study, wireless communications standards – see [3GS] case study), or are placed to have impact in the short term. Other examples include:

1. The recently published ETSI standard “Architectural Reference Model for Autonomic Networking, Cognitive Networking and Self-Management” incorporating KCL contributions on future networking.
2. Continuing work on the standard Planning Domain Description Language, PDDL, which is increasingly influencing applications of automated planning, such as a superfast printer designed at Xerox and space operations planning at SIFT Ltd.

**Responsiveness**

In general, the department acknowledges the need to recognise and respond to opportunities to achieve impact from its research. The engagement of industry in small projects has led to prototypes and longer-term collaborations. For example, Tratt received research funding from Oracle which then led to an EPSRC project featuring Oracle as a collaborator.

Algorithm developments achieved in Informatics also led to an energy-efficient task scheduling system for Nokia and a case study of the “Next Release” problem for Motorola. Crochemore’s work on the Factor Oracle algorithm underpinned the automated Jazz improvisation machine, OMax and string-indexing algorithms for efficient database querying, in collaboration with IRCAM (*Institut de Recherche et Coordination Acoustique/Musique*).

Cooper and Radzik were successful in obtaining a competitive Samsung GRO award in 2012, one of only 5 UK universities to do so. A similar responsiveness led to Fox and Long achieving funding for 2 separate projects under the EPSRC/industry co-funded Autonomous Intelligent Systems programme, initiated by industry to advance autonomous systems activity in the UK.

**c. Strategy and plans**

The Department plan is to pursue impact within the theme of Future Intelligent Systems, which defines its research strategy. Areas of synergy have been identified, cross-cutting the activities of research groups and exploiting the strengths within the Informatics. These are:

1. **Smart Infrastructure** which combines mobile communications, the Internet of Things, intelligent sensing and the infrastructure supporting Smart City and Smart Grid technologies to have impact on future technologies. Green communications, intelligent autonomous resource management, such as of communications resources and energy and distributed sensor

networks fall within this research theme, combining skills from CTR, Planning, CoRE and AIS. It also includes Massive Data analysis (managing and supporting the collection, storage and mining of data in a massively interconnected communications infrastructure supporting interoperability) and sophisticated software systems.
2. **Autonomous Intelligent Robotics and Systems** addressing mechanisms and sensing, advanced control, goal-directed reasoning, multi-agent coordination and software security. The research aims for impact in sectors including communications, health, robot exploration, automated manufacturing and cyber-defence.
3. **Health Informatics** exploiting work on combinatorial algorithms for bioinformatics (genome analysis) and work on data provenance and communications in health care. It includes exploitation of distributed smart sensing, communications and robust and secure data management for health care professionals.
4. **Software Modelling and Development Infrastructure** tackling the development of novel software engineering tools and environments and the problem of guaranteeing behaviours of complex software systems. Its impact is in the software industry, including Borland, IBM and Oracle, and users such as NASA, Samsung and BAE Systems.

The Department is already nurturing several areas of significant potential impact, at varying levels of development, including, for example, intelligent sensing using Nuclear Quadropole Resonance techniques, which is being applied to pharmaceutical authentification and explosives detection; intelligent control for drilling operations, being pursued with Schlumberger and Dohler's ongoing collaboration with WorldSensing, to develop and deploy smart wireless sensing technology.

The Department has a pool of considerable successful experience in working directly with industrial and business partners and also in forming and managing successful spin-out companies. This pool is being used to provide technical advisory streams to transmit the lessons and strategic insights from the experienced staff to newer staff, supporting and mentoring their engagement in the process of translation of research as it progresses through successive Technology Readiness Levels towards exploitation. It is planned to strengthen this activity and to actively monitor research activity to identify potentially commercially valuable IP.

To achieve impact in these sectors Informatics plans to address the following **generic goals**:

1. target new academic appointments to enhance the identified areas of strength;
2. build and maintain strong PhD student cohorts focussed on the strategic themes, seeking to partner with relevant industries in tying PhD research projects to business and industry themes;
3. continue efforts to grow a sustainable portfolio of funded collaborative research with industry and the public sector;
4. exploit IP via licensing agreements (using College-led expertise and departmental experience).

Informatics will also capitalise on its own **unique situation** to:

1. build on existing cross-disciplinary relationships within the College, to route innovations through the world-class research centres that King's has in health and the social sciences;
2. continue to contribute to standards, where KCL has had particularly successful impact roles in the past, and is already involved in further standards development;
3. exploit the cultivated synergy between research groups to tackle emerging social and economic challenges, using smart technologies, mobile communications, automation and data management to confront the future problems of intelligent resource management.

**d. Relationship to case studies**

Six cases have been submitted: two involving contributions in wireless communications technology [WTC] and [3GS], which illustrate the deep links between the Centre for Telecommunications Research and industrial partners. These cases group together multiple elements (three spin-out companies form [WTC] and contributions to three standards underlie [3GS]), but doing so offered an opportunity to showcase some of the other impact research in Informatics is achieving: impact in software standards in both [SMS] (a well-established and widely used standard in UML) and [DPS] (a more recent standard, rapidly gaining users); impact in software development [PEX] and impact in intelligent sensing [RWL].

These cases demonstrate the breadth and generality of the contributions of KCL Informatics' research beyond the academic world and the illustrate how the aspiration to achieve impact through research is being realised.