Measuring impact of academic research in computer and information science on society

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ABSTRACT
Academic research in computer & information science (CIS) has contributed immensely to all aspects of society. As academic research today is substantially supported by various government sources, recent political changes have created ambivalence amongst academics about the future of research funding. With uncertainty looming, it is important to develop a framework to extract and measure the information relating to impact of CIS research on society to justify public funding, and demonstrate the actual contribution and impact of CIS research outside academia. A new method combining discourse analysis and text mining of a collection of over 1000 pages of impact case study documents written in free-text format for the Research Excellence Framework (REF) 2014 was developed in order to identify the most commonly used categories or headings for reporting impact of CIS research by UK Universities (UKU). According to the research reported in REF2014, UKU acquired 83 patents in various areas of CIS, created 64 spin-offs, generated £857.5 million in different financial forms, created substantial employment, reached over 6 billion users worldwide and has helped save over £1 billion Pounds due to improved processes etc. to various sectors internationally, between 2008 and 2013.

CCS Concepts
CCS → Social and professional topics → Computing/ technology policy → Government technology policy → Governmental regulations

Keywords
research impact; research funding; computer science; information science

1. INTRODUCTION
Public education and research is generally supported by governments with tax-payers' money and different types of funding agencies for the welfare of modern society. Welfare includes economic benefits in the form of revenue and jobs, societal benefits in the form of improved quality of life and knowledge creation.

Additionally, academic impact is demonstrated in the form of advancing scientific research resulting from research support. Recently, there has been an increased interest in measuring the impact of scientific research at higher education institutions (HEIs), resulting in various metrics and methodologies. Metrics such as the h-index measures an individual academic's impact based on the number of publications and citations, the journal impact factor rates the quality of a journal, hence helps researchers in deciding their medium of research communication. Whole new areas of study i.e. Scientometrics and Bibliometrics have resulted from the yearning to measuring scientific impact. Additionally, these metrics are now known to be used to decide tenure and research funding etc. [1, 2, 4, 5, 7, 26, 43]. Impact assessment of academic research is now in operation in countries i.e. the United Kingdom, the Netherlands, the USA and Australia [11, 31, 39]. Impact assessment involves both qualitative and quantitative assessment. Qualitative assessment involves a panel of experts evaluating documented evidence from HEIs and quantitative assessment involves numerically analysing metrics indicating several impact possibilities and scientific outputs as a result of research [41]. The results of this impact evaluation lead to the award of performance based funding allocations to HEIs. As measuring impact is relatively a new measure, without definite guidelines [24, 40], the universities were free to describe any kind of impact generated as a result of their research, hence, leading to large amounts of unstructured text data, as seen in the REF 2014. This research aims to answer the following questions through a combination of discourse analysis and text mining of the impact case studies submitted by UKU to the REF 2014: (a) what are the key measures of impact of CIS research outside academia and how can these be assessed? (b) How to extract information relating to the key areas of impact from a large volume of unstructured text which has been written in free text form by various universities? (c) What is the impact of CIS research in the UK as reported through the impact case studies in REF2014 to justify public funding?

1.1 Impact of academic research
The nature of research is a rigorous time-consuming process consisting of identifying the problem, a detailed review of literature surrounding the topic, defining aims and objectives, develop a precise methodology, finally, collecting, analysing and interpreting the data. Measuring the impact of academic research began with the Science Citation Index and became academically prominent with the launch of various citations measuring applications i.e. Web of Science, Scopus and Scholar, in addition to the h-index, which measures an individual academic's contribution to in the form of research output citations [3, 20, 27].

However, there is a general debate about the effectiveness of such metrics-based systems [15], and researchers suggest several methods of alternative measures in the form of Altmetrics, readership, web impact, and recommendation based metrics etc. to counter the unfavourable comments on the metric based research measurement [14, 22, 23, 28]. The Leiden Manifesto states the ten principles of best practices in the assessment of research based on metrics, for the development of science in general and how it justifies its role in society [18]. Measuring the societal impact of academic research basic to justifying funding for research and there is a need to qualitatively and quantitatively simplify the measuring process for decision makers [4]. Consequently, governments and organisations began to argue for demonstrating the societal contributions of academic research, which is evident from the inclusion of measuring the social impact of research in research assessment exercises in various countries i.e. REF, STAR Metrics, RAE and ERA [2, 4, 10, 11, 13, 16, 25].

1.2 Contribution of Computer and Information Sciences

Every aspect of everyday modern human life constitutes of some application of CIS, be it occupation, family, leisure, health and communication etc. CIS is evolving into a computationally intensive field implementing large quantities of data feeding from diverse networks to perform various tasks. Improving data-driven services fetches £5.40 for every £1 spent according to UK government, yielded £796 billion against an investment of £3.8 billion within US Human Genome Project, an additional $1 trillion return for the $9.1 billion investment in the genomics research, increased reliance on data helpful in making fundamental discoveries in science and encourages an open data platform for public use [30]. Governments around the world have noticed the shift in technological paradigm and are allocating necessary resources right from the grassroots level. For example, in 2016 the US government launched the *Computer Science For All* initiative, consisting of $4 billion for the 50 states, $100 million to school districts and $135 million to the National Science Foundation (NSF) to future-proof the country's human computational skill competencies [38], in addition to the 3.5% increase in the NSF's general allocation for CIS to $954 million [36]. The UK Government recently pledged £17 million to the AI sector as it was estimated to feedback £650 billion to the UK's economy by 2035 [9]. Similarly, various countries around the world are following suit with the projection of more than 50% of all Science, Technology, Engineering and Mathematics (STEM) jobs will be within the CIS realm [37, 38]. Despite the assurance, recent political events and, a looming funding crisis have created an environment of uncertainty for researchers with regards to the availability of research funding, especially in the UK [8, 12, 21, 34, 35]. Hence, there is a need to firmly establish the contributions made by CIS researchers at UKU to UK society. The recent REF, which concluded in 2014, offers a small yet focussed perspective.

1.3 UK Universities and REF 2014

Like in any other countries, HEIs play an essential role in UK society. According to a latest Universities UK report, the UK HE sector contributed £39.9 billion, equivalent to 2.8% of the UK's gross domestic product (GDP), and employed 757, 268 individuals in 2011 (Universities UK, 2015). According to the Higher Education Statistics Agency [17], a typical UK HEI's revenue break-down is as follows: 35% tuition fee, 30% funding council grants, 16% research grants and contracts, 1% from endowments/ investment income, and 18% from other sources i.e. alumni donations etc. [17]. Visibly, a large portion of revenue for the HEIs come from the funding councils, which generally award the funding based on performance, thus making research evaluation and the financial returns of research conducted an important question for academia to inquire. The REF is the UK's national research assessment exercise which awards funding to UK's HEIs based on their quality of research, jointly conducted by Higher Education Funding Council of England (HEFCE) and Wales (HEFCW), the Scottish Funding Council (SFC) and the Department for Employment and Learning (DEL) of Northern Ireland [31]. An HEI's REF ratings are known affect funding acquisition capabilities, league table scores, reputation and attracting talent [42]. The recent REF exercise assisted in the yearly disbursal of £1.6 billion per year of performance based research funding to UK based higher education and research institutions until the next such exercise, possibly commissioned for 2021. The submission process involved HEIs choosing the fields of research (called Units of Assessment/ UoAs) out of the available 36 UoAs, which they wished to be evaluated upon and prepare their submission in a prescribed format. Subsequently, the submissions were evaluated by 1052 individuals, out of which 77% were academics and 23% were users (individuals who apply HEI research and collaborators outside academia), under the guidance of 36 expert sub-panel chairs, additionally supported by four main panel chairs to evaluate and determine the quality of research [31].

Research was adjudged into five categories; 4* (world leading), 3* (internationally excellent), 2* (recognised internationally), 1* (recognised nationally) and unclassified [31]. The overall quality of research was assessed through a combination of quality of research outputs (65% weightage) in terms of rigour, originality and significance; 'impact' of research (20% weightage), a new factor introduced in REF evaluation, assessing the 'reach and significance' of research on multiple societal factors; and research environment (15% weightage), in terms of 'vitality and sustainability' i.e. PhD completions, laboratory facilities and wider disciplinary contributions [31]. Assessment of impact costed the UK government £55 million out of the total £212 million expenditure on the REF and led to the disbursal of £320 million to UK HEIs [6, 40]. CIS chiefly came under UoA 11, and 89 HEIs submitted 280 impact case studies for the REF, A recent report which has utilised REF's CIS impact case study submissions as a case study, indicates that research at UKU in the 2008-2013 period had resulted in creation of spin-offs, patents, employment and a generated income of approximately £470 million [19]. However, the report does not state the research methods used, nor does it comprehensively state areas of impact, human reach, income from all the possible streams and saved expenditure etc. As it has become vital to comprehensively inform the public and the government regarding the impact of CIS research in academia, a text mining operation was performed on the impact case studies, leading to a larger picture than initially revealed.

1.4 Challenge of finding impact in the impact case studies

Each impact case study was between 4 to 5 pages and each UKU had to follow the template as shown in Table 1. In total, there were over 1000 pages of unstructured textual data (roughly 37.2 megabytes) that had to be analysed to retrieve impact data. The real challenge the dataset posed was the unstructured nature and various standards in the use of language and impact descriptions written by UKU. As the REF 2014 was the first time that impact of research at UKU was evaluated, the universities did not possess sufficient experience and guidance to communicate impact. Evidently from table 1, specific measures of impact were not provided as part of the template, so it was up to the submitting institutions to decide what to include in the impact case studies. Consequently, several UKU went to the extent of hiring specialist writers to write their impact case studies, additionally, the UKU had a free reign to describe whatsoever they felt their research had an impact on, with reasonable evidence. Reviews of the REF 2014 has indicated this as an area of improvement and suggested the Higher Education Funding Councils in the UK to provide better guidance to UKU [24, 40]. The unstructured nature of language and varying standards of writing in the impact case studies led to the third question; (c) How to effectively identify impact elements in large quantities of text? A combination of manual and automated processing of the impact case studies, further described in the Methodology was applied to overcome the challenge of making sense of various impact elements and further text mining of the identified keywords led to giving an overview of various contributions made by CIS research at UKU.

Table 1. Template of impact case studies

1. Institution
2. Unit of assessment
3. Title of case study
4. Summary of impact (indicative max. 100 words)
5. Underpinning research (indicative max. 500 words)
6. References to research (indicative max. of six references)
7. Details of impact (indicative max. 750 words)
8. Sources to corroborate impact (indicative max. of 10 references)

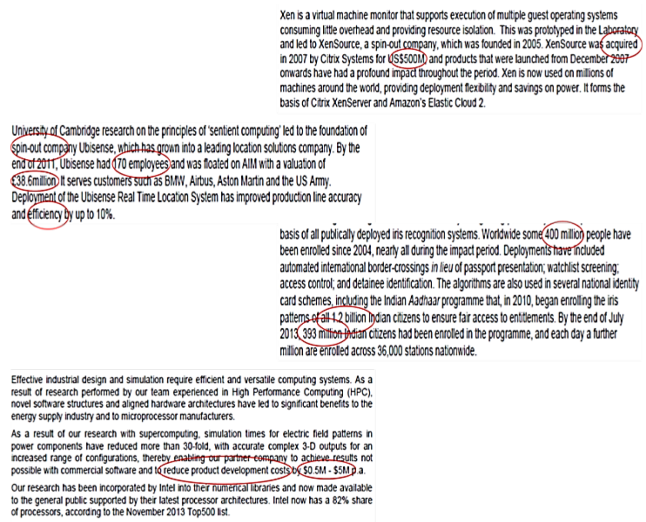
2. Methodology

All the impact case studies submitted under the UoA 11 were downloaded from the REF 2014 website, which are publicly available here. Only 248 impact case studies were available out of the 280 submitted and it is believed that the 32 impact case studies are censored due to confidentiality issues, as the REF permits confidential submissions [31]. Additionally, it is important to inform that library and information management was separately allocated under UoA 36 (Communication, Cultural and Media Studies, Library and Information Management). Hence it was difficult to establish the exact field which they contributed towards. Therefore the impact case studies submitted under UoA 36 were not considered for the analysis. It is also important to note that the number of impact case study submissions was restricted to number of staff submitted for the REF evaluation under a specific unit of assessment as listed in Figure 1. Therefore, it is important to keep in mind that the contributions listed in the REF are limited, but in reality the impact could have been much more than what was reported in the REF. UKU chose the best impact case studies for REF submission which demonstrated a wider social and economic impact from a pool of impact case studies originally created.

Number of Category A staff submitted (FTE)	Required number of case studies
Up to 14.99	2
15 – 24.99	3
25 – 34.99	4
35 – 44.99	5
45 or more	6 plus 1 further case study per additional 10 FTE

Figure 1. No. of impact case studies required in REF 2014 [40]

The 248 impact case studies were classified by the submitting HEI and were separately uploaded to Nvivo 10, a qualitative data analysis software widely used by researchers. Initially, all the case studies were manually read to understand the format of writing as the impact case studies were written by various HEIs and it was found that the writing standard varied greatly, hence various keywords indicating the a specific impact area were chosen for text mining as listed in table 2. An example of the variations in writing is shown in Figure 2.


Xen is a virtual machine monitor that supports execution of multiple guest operating systems consuming little overhead and providing resource isolation. This was prototyped in the Laboratory and led to XenSource, a spin-out company, which was founded in 2005. XenSource was acquired in 2007 by Citrix Systems for US$500M and products that were launched from December 2007 onwards have had a profound impact throughout the period. Xen is now used on millions of machines around the world, providing deployment flexibility and savings on power. It forms the basis of Citrix XenServer and Amazon's Elastic Cloud 2.

University of Cambridge research on the principles of 'sentient computing' led to the foundation of spin-out company Ubisense, which has grown into a leading location solutions company. By the end of 2011, Ubisense had 170 employees and was floated on AIM with a valuation of £38.6million. It serves customers such as BMW, Airbus, Aston Martin and the US Army. Deployment of the Ubisense Real Time Location System has improved production line accuracy and efficiency by up to 10%.

basis of all publically deployed iris recognition systems. Worldwide some 400 million people have been enrolled since 2004, nearly all during the impact period. Deployments have included automated international border-crossings *in lieu* of passport presentation; watchlist screening; access control; and detainee identification. The algorithms are also used in several national identity card schemes, including the Indian *Aadhaar* programme that, in 2010, began enrolling the iris patterns of all 1.2 billion Indian citizens to ensure fair access to entitlements. By the end of July 2013, 393 million Indian citizens had been enrolled in the programme, and each day a further million are enrolled across 36,000 stations nationwide.

Effective industrial design and simulation require efficient and versatile computing systems. As a result of research performed by our team experienced in High Performance Computing (HPC), novel software structures and aligned hardware architectures have led to significant benefits to the energy supply industry and to microprocessor manufacturers.

As a result of our research with supercomputing, simulation times for electric field patterns in power components have reduced more than 30-fold, with accurate complex 3-D outputs for an increased range of configurations, thereby ~~enabling our partner company~~ to achieve results not possible with commercial software and to reduce product development costs by $0.5M - $5M p.a.

Our research has been incorporated by Intel into their numerical libraries and now made available to the general public supported by their latest processor architectures. Intel now has a 82% share of processors, according to the November 2013 Top500 list.

Figure 2. Variations in writing the impact case studies

UKU chiefly reported regarding the commercialisation of their research, patents filed, economic benefits in the form of income and social benefits in the form of user reach, employment and reach etc. as impacts as a result of their result. Additionally, the initial reading greatly helped in understanding the various themes of impact generated by the HEIs in various forms. Next, a text search query built into Nvivo 10 was run using each keyword in table 2 on each of the uploaded impact case studies and the retrieved results were based on the generalisability of the keywords. For example, searching for the word sport will retrieve words which hold a more general meaning i.e. sport, sporting, play, recreation etc [29]. The process was repeated for each keyword. All the retrieved references to the keywords were manually analysed and corresponding information was entered into MS Excel for aggregation. The aggregated data was subsequently computed to attain the findings. A detailed description of the methodology is described in figure 3.

Table 2. Impact area and chosen keywords for text mining

Impact area	Keywords
Patent	Patent, patents
Economic and Social	Pounds, dollars, euros £, $, €, hundred, thousand, million, billion, 0k (zero k), save, reduce, grant, users, subscriber, page hits, viewers, licence(s), engagement, employment, reach, jobs, customer, created, invent, efficient, discover, developed, patients, code
Commercialisation	Spin-out, spin-off, spinout, spinoff

As no specific categories of themes of impact were suggested in the guidelines, the submitting UKU had the freedom to mention what they thought had had an impact. Hence, the research also aims to identify commonly mentioned themes. Additionally, the information retrieved was verified manually for duplication, ensuring that the impact elements were computed just once. Income stated in different currencies in the impact case studies was standardised to GBP (£) using XE Currency Converter.

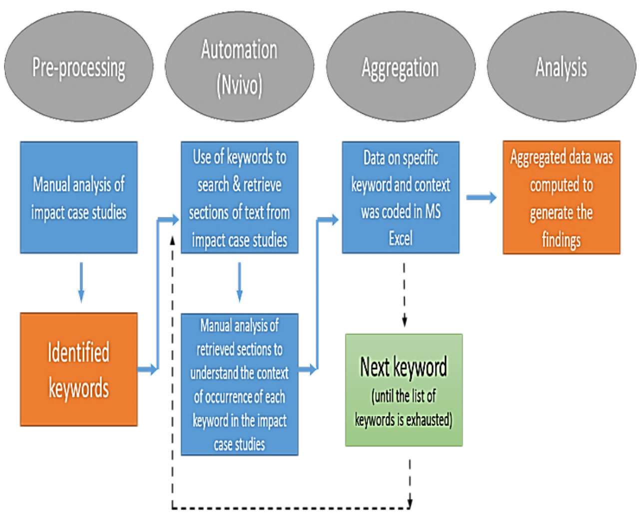


Figure 3. Methodology adopted to identify impact

3. Findings and discussion

3.1 Framework to measure impact

Although various funding bodies persuaded researchers and institutions to demonstrate the wider social impact of research beyond academia, no specific framework or template has been proposed for capturing data on such impact, which means, there is a need for the framework. In the absence of an agreed framework, it becomes difficult for institutions and researchers to demonstrate impact of their research. The REF 2014 panel summary reports of UoA 11 and UoA 36 indicated that the impact of CIS research underpins all human activity, particularly in creating economic impact, influencing policy, preservation and conservation, creating novel technologies, improving public engagement and services etc [32, 33]. The panels had generally favourable reviews for the quality of CIS research at UKU. However, when reviewing the impact case studies, the panels indicated the difficulty in understanding impact created on society by a particular research due to underreporting, especially in provision of information relating to evidence, user benefits, impact, and knowledge transfer [32, 33]. Therefore, an impact capturing mechanism to comprehensively capture research impact should be established due to the role of the captured information as an informant to funding.

Bringing together all the findings, this research was primarily able to identify the different themes of impact created by CIS research at UKU, namely; patents, economic impact, social impact and commercialisation. Under each theme there were several types of contributions made, chiefly under economic and social impact i.e. employment, income and reach of research as suggested by UKU. As the findings indicate the exact contributions made by CIS research at UKU, it is beneficial to build a framework through which one can measure impact of any CIS research. As stated earlier, the inadequacy of guidelines regarding communication of impact led to misunderstandings and under-reporting of impact. Additionally, administering the impact element of the REF 2014 costed the tax-payer £55million. This research suggests a framework which can comprehensively capture the impact in CIS and simplifies administration. Table 3 is an example of such a template, which comprehensively captures all the impact information created by CIS research, which could potentially be adapted and utilised in other disciplines. Table 4 consists of an example to describe the impact of a particular research. The first column describes the title of research and the second column consists of the general themes of impact. Recording the patents can be done under 'No. of patents', against which the universities will have the opportunity to describe which area of CIS is the patent contributing, in addition to the field of application. The template describes two patents being created as a result of research and the patents fell under the area of AI and information retrieval, additionally finding application in education and astronomy. Similarly the universities will describe if their research had led to creation of spin-offs, subsequently giving information on contributing areas.

The template gives an example of context 1 leading to the creation of a spin-off in the AI and finding application in education. The first two sections capture the inter-disciplinary nature of CIS research. Further, the template captures information on the income generated by the research in the forms of income from various places, grants, capital raised (by spin-off or any other source) and sales generated by the sale of any software created. The template gives an example of context 1 leading to the creation of a product whose sales fetched the university £10000. Further, the template records information about how development of any processes led to saving in expenditure. The template gives an example of the both the contexts saving £108 for the public and private sector. Finally, the template captures information with regards to social impact. In this example, context 1 had created 14 jobs, trained 500 school children for free on a specific software and sold 1008 licences; and context 2 had created 1 million lines of code which was used by the astronomy community leading to the discovery of a planet. Finally, researchers are also requested to provide additional information regarding their research in the sections provided. Hence, the template captures all the impact information which academics think is a result of their result, outside academia.

Table 3. Suggested template to measure impact of research in academia

<table>
<tr><td rowspan="17">Title of research</td><td>No. of Patents</td><td>CIS area?</td><td>Application area?</td><td colspan="3" rowspan="6"><u>Additional notes:</u></td></tr>
<tr><td>1</td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td></tr>
<tr><td>No. of Spin-off</td><td>CIS area?</td><td>Application area?</td></tr>
<tr><td>1</td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td></tr>
<tr><td>Income generated</td><td>Total domestic income</td><td>Total international income</td><td>Grants received</td><td>Capital raised/ acquisition</td><td>Sales</td></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Expenditure saved</td><td>Public expenditure</td><td>Private expenditure</td><td colspan="3" rowspan="3"><u>Additional Notes:</u></td></tr>
<tr><td>Context 1</td><td></td><td></td></tr>
<tr><td>Context 2</td><td></td><td></td></tr>
<tr><td>Social impact</td><td>No. of jobs created</td><td>No. of lives benefitted in any form (training, saving lives, environment etc)</td><td>Code contribution (GitHub uploads etc)</td><td>Licences sold</td><td>Leading to discoveries</td></tr>
<tr><td>Context 1</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Context 2</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table 4. Example template to measure impact of research in academia

<table>
<tr><td rowspan="17">Title of research</td><td>No. of Patents</td><td>CIS area?</td><td>Application area?</td><td colspan="3" rowspan="6"><u>Additional notes:</u></td></tr>
<tr><td>Context 1</td><td>Artificial intelligence</td><td>Education</td></tr>
<tr><td>Context 2</td><td>Information retrieval</td><td>Astronomy</td></tr>
<tr><td>No. of Spin-off</td><td>CIS area?</td><td>Application area?</td></tr>
<tr><td>1</td><td>Artificial intelligence</td><td>Education</td></tr>
<tr><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Income generated</td><td>Total domestic income</td><td>Total international income</td><td>Grants received</td><td>Capital raised/ acquisition</td><td>Sales</td></tr>
<tr><td>Context 1</td><td></td><td></td><td></td><td></td><td>£10000</td></tr>
<tr><td>Context 2</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Expenditure saved</td><td>Public expenditure</td><td>Private expenditure</td><td colspan="3" rowspan="3"><u>Additional Notes:</u></td></tr>
<tr><td>Context 1</td><td>£108</td><td></td></tr>
<tr><td>Context 2</td><td></td><td>£108</td></tr>
<tr><td>Social impact</td><td>No. of jobs created</td><td>No. of lives benefitted in any form (training, saving lives, environment etc)</td><td>Code contribution (GitHub uploads etc)</td><td>Licences sold</td><td>Leading to discoveries</td></tr>
<tr><td>Context 1</td><td>14</td><td>500 school children trained</td><td>-</td><td>1008</td><td></td></tr>
<tr><td>Context 2</td><td>-</td><td>150 astronomers used the code</td><td>1 million lines of code</td><td></td><td>1 planet found.</td></tr>
</table>

3.2 Impact of CIS research as reported in REF2014

3.2.1 Patents

In the 2008-2013 period, UKU acquired 83 patents in different areas of CIS and found application in various fields as graphically presented in Figure 4. The highest numbers of patents were acquired in the field of designing algorithms for the purpose of drug discovery and database querying to analyse large data sources. Similarly, the findings also indicate that patents being acquired for novel methods in computing for security surveillance, digital imaging, machine learning, soft/hardware design and digital communities.

Additionally, patents were also acquired by the creation of novel computing concepts, query languages, network optimisation and security, augmented reality and assistive technologies. Also considering that the 248 case studies are only a handful selected by the UKU for submission and discounting of UoA 36 for the current analysis, the number of patents acquired could potentially be higher than found by this research.

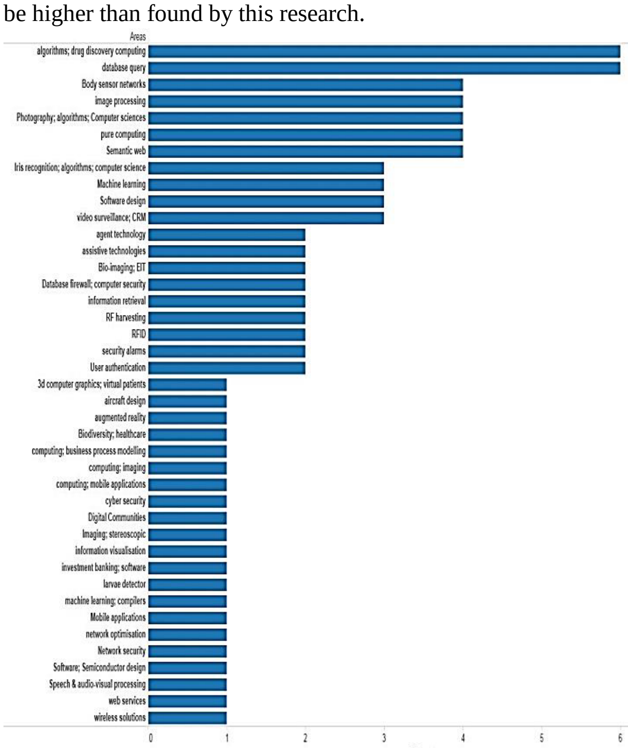


Figure 4. The number of patents in different fields acquired by UK Universities as a result of CIS research in the 2008-2013 period

3.2.2 Spin-offs

Most UKU are encouraging the commercialisation of knowledge acquired through academic research and build strong connections with industry. The findings suggest that UKU were had created 64 spin-offs as a direct result of their result and some of the spin-offs are a direct result of the patents acquired by the institutions. In fourteen cases, the acquisition of patents led to the creation of 40 spin-offs in different fields of CIS, having a wide range of applications in medical imaging to investment banking. The spin-offs also resulted in large amounts of income in several forms i.e. grants, acquisition of spin-offs, sale of products/ licenses, contracts and consulting activities. The highest number of spin-offs were created in the image processing area, which saw health, manufacturing and agricultural applications.

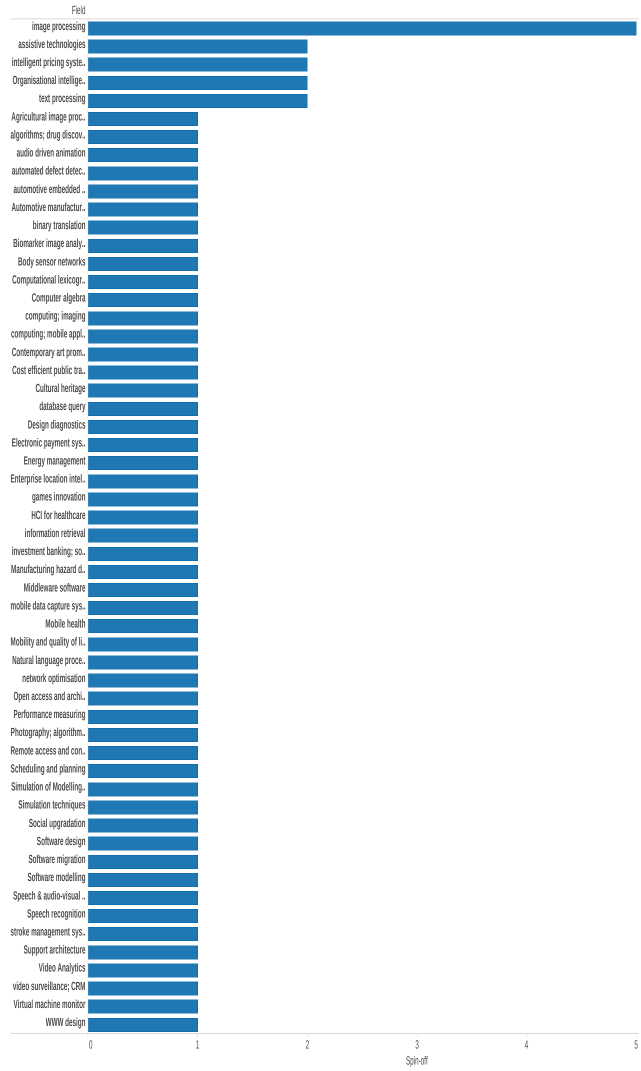


Figure 5. Different fields where spin-offs were created by CIS research at UK Universities in the 2008-2013 period

Spin-offs also led to the creation of significant employment in multiple industries, however, the exact figure was difficult to attain due to complexity in the processes of take-overs. Employment creation was estimated by a chartered institute at 1900 [19]. A complete list of spin-offs created in different fields of CIS is available in Figure 5. Also considering that the 248 case studies are only a handful selected by the UKU for submission and discounting of UoA 36 for the current analysis, the number of spin-offs incorporated could potentially be higher than found by this research.

3.2.3 Income

As stated earlier, income was generated by the UKU through several forms totalling up to £857.5 million against different forms of private and public investment between 2008 and 2013. The income standard with regards to currency stated by UKU in the impact case studies varied significantly, and a closer look demonstrated that the income had come from various parts of the world, indicating global reach of UKU research. Income was chiefly generated by the creation of algorithms/software for investment banking, assistive technologies, image/speech/audio-visual processing, sale of licenced softwares in scientific computing, 3d computer graphics, simulation and modelling, and drug discovery. Additionally, it is important to note that the total income stated is only from 28 impact case studies out of the 248. This is due to the various impact case studies demonstrating impact in different ways, however, in reality a financial element is definitely attached to any type of impact. Also considering that the 248 case studies are only a handful selected by the UKU for submission and discounting of UoA 36 for the current analysis, the generated income could potentially be higher than found by this research.

3.2.4 Saving expenditure

The findings indicate that CIS research at UKU had helped to save over £1 billion in expenditure for general public, government and private organisations. The main beneficiary in this segment was the UK's National Health Service (NHS), which reportedly saved £513.5 million as a result of implementation of an efficient spending tracking system, implementation of a clinical management system for stroke patients and optimisation of paired kidney tracking. These implementations are a result of creating optimised algorithms in AI to track potential donors, clinical management and a clinical finance management tool. Other notable mentions are: (a) saving £230 million for the UK rail industry by the creation and application of an optimised scheduling system (b) £25 million for UK's automobile users through reduced manufacturing costs as the result of modelling a visual manufacturing process and (c) $2.52 million for the Ford Motor Company by implementing an automated design analysis and diagnostic method. Additionally, a few of the institutions stated that they had several millions of Pounds for the oil & gas industry, and partner organisations, however the figures were not explicitly mentioned apparently due to privacy concerns. Also considering that the 248 case studies are only a handful selected by the UKU for submission and discounting of UoA 36 for the current analysis, the expenditure saved for the public, government and private organisations as a result of UKU's CIS research could potentially be higher than found by this investigation.

3.2.5 Reach

CIS research at UKU had a reach of over 6 billion individuals worldwide in the form of page hits, TV viewership, licenses, users of specific softwares/digital services for various purposes, creation of middleware, policy changes and enrolment etc. Page hits concentrated in the communication of process architecture, provision of world's species conservation data and provision of healthcare information. Additionally, considerable efforts were made in digitising cultural heritage through the Europeana project, digitally linking 1 million archaeological archives, teaching computer programming for approximately a million students worldwide, persuading the UK government to invest £35 million in the robotics sector, citizens enrolling in national ID programs through iris recognition, accurate diagnosis of specific medical conditions, worldwide adoption of asynchronous circuits for improved process modelling and shaping the air traffic policy of Europe for safer flights etc. The reach is projected to be considerably larger when other case studies written by UKU and UoA 36.

3.2.6 Code Contribution

CIS research at UKU had also been instrumental in the contribution of 268 million lines of code for various applications. Notably, (a) 250 million lines of code was contributed towards the general automation software design and verification process, (b) 15 million lines of assembler code was contributed for software migration processes, and (c) 2 million sequence lines of code was contributed towards the management and integration of larger scale life science data. Again, the miscellaneous contributions could be higher when UoA 36 and unelected impact case studies from UKU are considered.

4. Conclusion

This study has shown that it is possible to develop a framework to measure and communicate the impact of research in CIS. Pending any framework or template reporting impact in the REF 2014, a new methodology had to be developed, combining discourse analysis and text mining. Our findings indicate that it is possible to develop a template to report the impact. Additionally, the study (a) a future direction in the documentation for measuring impact of CIS research in the UK, (b) can also lead to a similar study in other disciplines, using the methodology developed here that may give rise to a different framework for measuring impact in different disciplines, and (c) has identified the categories and extent of contribution of CIS research at UKU including, 83 patents, 64 spin-offs, over £850 million in income, in addition to saving the public and private sector over £1 billion and reaching out to over 6 billion individuals around the world. The findings will provide a positive perspective towards CIS research in public view.

5. Further statements

This research did not require any ethics approval and did not receive any funding. The authors declare no competing interests.

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