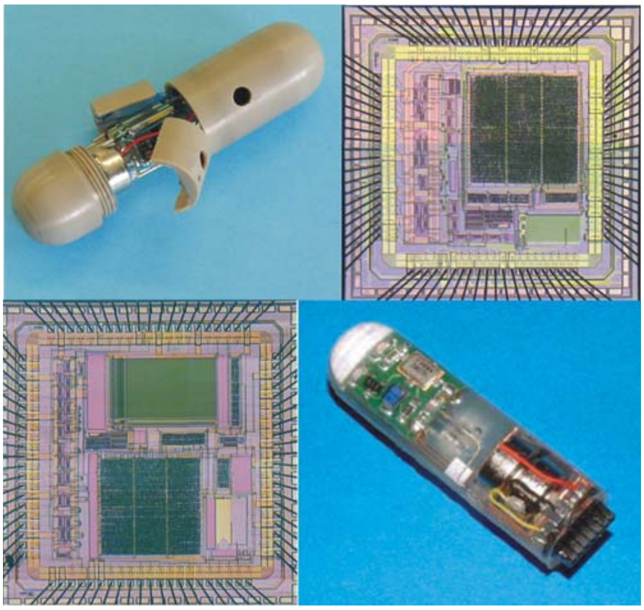
IDEAS

Integrated Diagnostics for Environmental and Analytical Systems



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University of Glasgow
University of Edinburgh
University of Strathclyde
Institute for System Level Integration

Contents

Introduction

The aim of the IDEAS project was to build a research platform that would demonstrate the possibility and the application of combining the previously disparate technologies of system-on-chip integration and laboratory-on-a-chip. From this platform it has been possible to build a significant new research activity in the collaborating universities supported by the expertise of the Institute for System Level Integration. The IDEAS project was led by David Cumming of the University of Glasgow.

Significant practical progress has been made by making a range of fully functional prototypes (see frontispiece) that have enabled the research team to initiate new activity that they would not previously have had. This is most clearly demonstrated by generating 56 publications and presentations, the appointment of new academics into the field and the award of an EPSRC Advanced Research Fellowship. A total of 24 people received training support from the project as RAs, Ph.D. or M.Sc. students, or as undergraduates.

New research funding from a range of sources has been raised and the current value of new grants is more than £5.4M. More is expected in the future due to a number of initiatives being pursued by the universities and the ISLI. The research field that we have been able to pioneer in IDEAS has become one of the most important to modern electronic engineering and the research programme we have launched can be expected to run for at least the next ten years.

Research assistants and students enjoying a break at a workshop in Perthshire. From left to right: Lei Wang, Tong Boon Tang, Mansour Ahmadian, Alex Astaras, Kevin Chai, Mark Milgrew and Geoff Irvine.

Overview of the IDEAS Project

Fundamental to IDEAS were the technologies surrounding system-on-chip (SoC) and laboratory-on-a-chip (LOAC). SoC is an essential microelectronics technology whereby many components of an electronic product are integrated on to a single integrated circuit. In practice this means that a single chip may have many so-called IP blocks on it that would traditionally have been sold as products in their own right including, for example, microprocessors, digital signal processors and data conversion devices. The communications market in particular has benefited from SoC for applications such as mobile telephones and internet routing. However, the practice and methodologies of SoC lend themselves exceptionally well to integrated sensor applications where it is a requirement to have complex electronic instrumentation. It was therefore part of the IDEAS project to use SoC technology to build single chip instruments.

LOAC is one of several terms used to describe devices that are built to enable chemical and biological processes to be carried out in a microscale format. In some regards it is the analytical analogue of SoC and a single LOAC device will have many components such as reservoirs, microfluidic channels, mixers, reactors and sensors all integrated on to a single substrate. New applications are still being found today but the technology has become relatively mature for applications such as drug discovery and genomics. Despite the availability of LOAC it was recognised at the beginning of the IDEAS project that although LOAC was small, the supporting electronic instrumentation was based around traditional component-based electronic design that was large and cumbersome. To some extent this was an inversion of the normal state of affairs where electronics would “out-miniaturise” the analytical tools.

The technical programme of the IDEAS project was therefore focused on demonstrating that integrating SoC and LOAC was not only possible, but an essential technology for delivering a new capability to medicine, agriculture, process industries, engineering and a whole host of other applications. In order to demonstrate the new capability we needed a potent symbol and driver that would be easily recognised and understood by a broad range of potential end users. For this purpose we invented the concept of the “Laboratory-in-a-Pill” or LIAP that could be used as a diagnostic tool for gastro-intestinal dysfunction.

The LIAP has several properties that made it an ideal driver for the IDEAS project. It was essential that the device be small, consume very small amounts of power, operate wirelessly, and be capable of making a broad range of measurements. In the course of the project we developed several systems with increasing functionality, complexity and utility as time went by.

The concept behind the IDEAS project was not so one-dimensional to preclude a range of other related activities that needed to be pursued. Off-shoot research projects were carried out by many students who worked with us over the course of the project. The student research allowed us to study aspects of the IDEAS technology such as neural data processing, sensor fusion, wireless propagation, single chip sensor systems, and sensor-system-on-a-chip (SSOC). All this additional activity added to our publication output and helped build up the overall research profile of the IDEAS project.

Clearly the technical programme was not the sole function of the IDEAS project, and the most important aspect was the development of a new capability and generating new research activity that the universities would not previously have been able to demonstrate. The IDEAS project has been very successful in this regard enabling Glasgow University to establish a new research group around microsystem technology and microelectronics, and both Glasgow and Edinburgh Universities to attract significant new funding from Government and industrial sources.

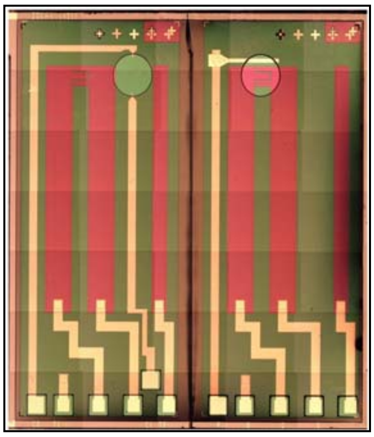
The Technical Achievements of the IDEAS Project

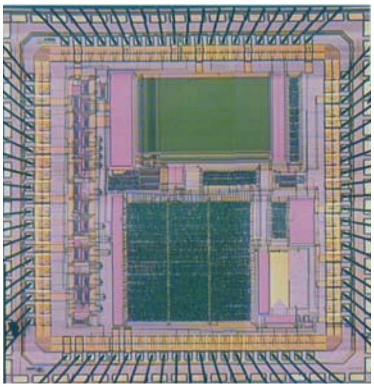
The technical programme for IDEAS was driven by the development of a LIAP device to meet a number of more generic objectives targeted at creating a research platform.

Here we present the spread of technologies that were investigated in depth during the IDEAS project.

Sensors

An essential ingredient of any IDEAS devices, such as the LIAP, is the sensor interface. The sensors we used were fabricated by the project team to give bespoke performance in challenging conditions. An important factor in optimising sensor design was biocompatibility and robustness against biofouling. The sensors that we made were shown by *in situ* testing to have an operational life-time in excess of 40 hours.



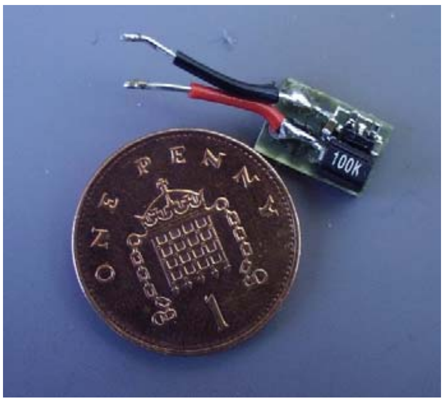


SoC Design

The project went through several iterations of chip design of increasing complexity. The micrograph shows a chip with a microprocessor, RAM, sensor instrumentation, data conversion, data compression and encoding, and a small wireless transmitter with a range of 10 cm.

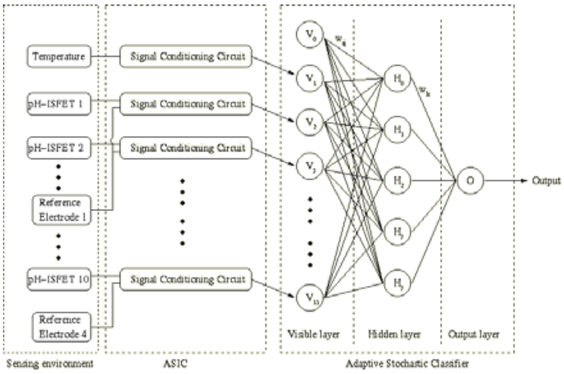
Wireless Communications

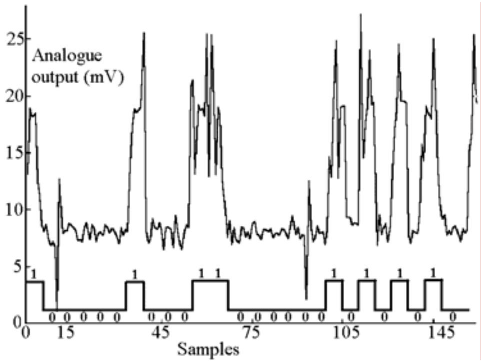
Wireless communication was essential to IDEAS and the LIAP concept. During the project we experimented with a variety of wireless technologies. One of the most interesting of these was the low frequency inductive transmitter that could be made to be very small and transmit data through animal tissue with high efficiency. This technology made it possible to reduce the overall power consumption of the LIAP.



Sensory Signal Processing

Sensor drift is inevitable in a wide variety of sensors and could have a great impact on the use of IDEAS devices installed over long operating periods. We have developed an adaptive stochastic classifier that is hardware-amenable to enable local sensor data fusion. It is an efficient architecture that enables drift compensation and calibration with a small hardware overhead.



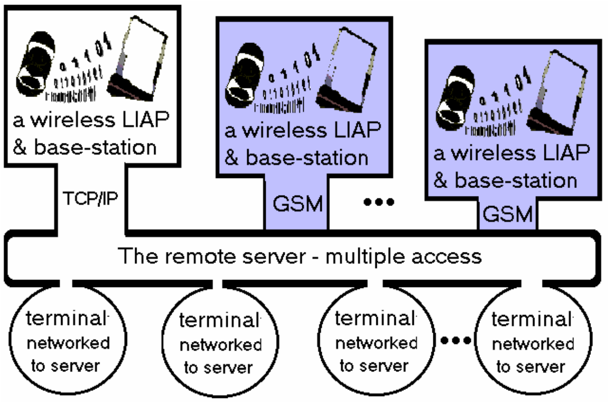


Digital Signal Processing

The IDEAS capsule was designed to work in conditions that are not conducive to obtaining the best performance from an electronic system. In order to retrieve information out of the transmitted data from the device it was necessary to use state-of-the-art-signal processing techniques. The figure on the left shows the detected raw signal and the correctly processed digital signal below.

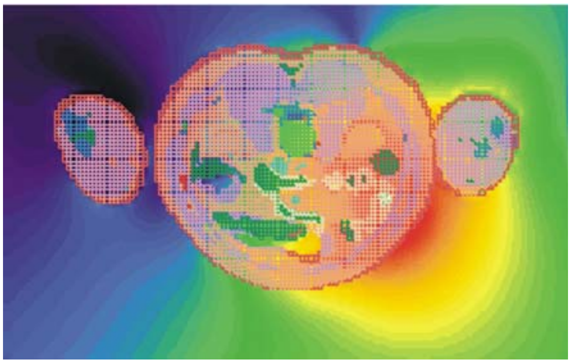
Internet Access

There is a growing trend in wireless technology for devices to be accessible by the internet at any time. This is an important aspect of LIAP technology since by making the pill communicate with a wirelessly networked "base station" device, worn by the patient, it is possible for a remote client (e.g. a clinician) to observe a patient's condition from virtually anywhere. In IDEAS we developed a TCP/IP based system that could be modified to work with GSM or 3G mobile networks.



Radio Propagation

Getting data out of the human body is not a trivial matter. In order to optimise the design of a LIAP system it is essential to understand exactly how the radio environment of the human body behaves. We were able to do this using FDTD modelling using data from the visible human male project that was carried out by the NIH.

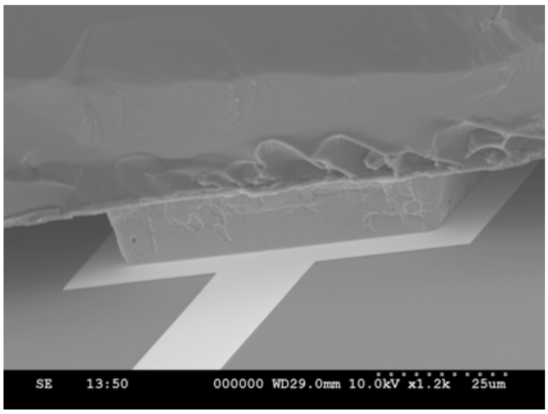


Capsule Integration

All the components that were realised in the IDEAS project had to ultimately fit into a small, robust, capsule that would be capable of withstanding the most stringent operating conditions. Several prototypes were developed in the course of the project to meet these requirements. The device shown to the left is only 35 mm long when sealed.

Packaging

Although the packaging of the capsule that was achieved in the project was remarkable we forsee that there will be a requirement to miniaturise IDEAS-like technology even further in the future. Extremely miniaturised technology such as SmartDust or SpeckNet motes will require the use of technology such as flip-chip or bump-bonding. This is a commercial technology that we felt it was vital to have access to in the universities. We therefore commissioned Kelvin Nanotechnology to develop this technology for us.



Staff and Training

Across the institutions a large number of academics and researchers have contributed to the success of the project.

The Academic Team

The academics who worked on the project were:

David Cumming, Jon Cooper, *Department Electronics and Electrical Engineering, University of Glasgow.*

Alan Murray, Anthony Walton, Tughrul Arslan, James Dripps, Brian Flynn, *School of Engineering and Electronics, University of Edinburgh*.

Peter Dickman, *Department of Computing Science, University of Glasgow*.

Philippa Yam, *Department of Veterinary Clinical Studies, University of Glasgow*.

Stuart Reid, *Department of Veterinary Clinical Studies, University of Glasgow, and Statistical and Modelling Sciences, Strathclyde University*.

Other Consortium Members

We were also supported by other partners who were not (at the time) working in a Scottish HEI.

Steve Beaumont, Director, *Institute for System Level Integration, Livingston* (now VP Research at *Glasgow University*)
Mr J. J. Casey, *Department of Surgery, Edinburgh Royal Infirmary.*

Research Assistants

The research assistants who worked on the project were:

Alex Astaras; Mansour Ahmadian; Nizzamettin Aydin; Lawrence Chirwa; Li Cui; Michael Dales; Imran Farooq; Paul Hammond; Matt Holgate; Erik Johannessen; Leena Patel; Tong Boon Tang; and Lei Wang.

A valuable outcome is that so many people were able to advance their careers both in Scotland and elsewhere by gaining experience with the consortium.

Student Training

Twelve students gained valuable training directly from the project through several mechanisms including work towards a Ph.D. or M.Sc. and summer internships. Many of the students are still in Scotland, either in academia or industry, and as with the RAs the project has disseminated its results and new skills to the community as a whole through the movement of people.

Infrastructural Development

The Capital Base

Using funding from the grant Glasgow University was able to build a modest test and measurement laboratory for integrated circuits and create a design laboratory. This entailed the refitting of laboratories and the acquisition of a wafer prober equipped with a laser cutting tool for chip test and repair. This proved to be a valuable item, although we were also required to use MIAC at Edinburgh University for the more complicated repairs. A range of high value test and measurement instruments were bought including: a parameter analyser; a spectrum analyser, a logic analyser; and a large memory depth oscilloscope. A range of smaller instruments and electronics tools were also bought. These and other items of equipment were heavily used by the project team.

As the LOAC and sensor work progressed in the project our need for high quality photolithography grew. IDEAS contributed to the purchase of a Suss Microtech MA6 mask aligner at Glasgow University. This tool proved invaluable to IDEAS and is heavily used.

The Academic Base

In the course of the project the Department of Electronics and Electrical Engineering at Glasgow University established a new research grouping. The Microsystems group, led by David Cumming, has a number of research activities but perhaps the largest is focused on microelectronics and its interface to non-electronic technologies. This group is now sustained by a portfolio of research projects and studentships several of which can be directly attributed to the success of IDEAS since they rely on skills and insights that were built up as a consequence of the project.

The themes that have been built up by the IDEAS project have achieved a very high profile in Glasgow University and have led to new appointments of academic staff across the Faculty of Engineering in cognate fields of research and learning. This is a trend that we confidently expect to grow in the next five years.

The ISLI has successfully won a new round of funding for the next five years. This is in part due to the success of the IDEAS project.

A number of other new activities have been successfully seeded by the IDEAS project. In the School of Engineering and Electronics at the University of Edinburgh there is new PhD research on wireless transfer of power and data into SoC devices. Edinburgh University is also host to a Doctoral Training Centre with some relevance to IDEAS.

The IP Base

A widely used term in SoC design is “intellectual property (IP) block” which in practice means a component that can be placed easily into an integrated circuit. One of the objectives of the IDEAS project was to build up a library of IP block designs that we could reuse in future projects. As the project progressed a great deal of new design work was carried out and a library was built up using the Cadence tools that are common to the universities and the ISLI thanks to the Alba project. Versions of the library are now stored on servers at the institutions responsible for the design work (Glasgow and Edinburgh Universities, and the ISLI) are now being reused in other projects.

Research Development and Innovation

The IDEAS project was set up to explore the design and exploitation of miniature communicating sensor systems containing laboratory-on-a-chip, system-on-chip and wireless technologies. Whilst the major objectives of small, smart, wireless sensor systems have been rigorously maintained throughout the project, as demonstrated by our publication record, we have piloted much of the fundamental research by studying a demonstrator system: the laboratory in a pill (LIAP).

Major innovations include:

- The demonstration of a working LIAP containing SoC, LOAC and rf wireless components
- The development of robust communication protocols
- The development of low power wireless network architectures
- The development of novel miniature sensor devices
- The development of power aware and power saving sampling algorithms and data compressors
- The integration of SoC and LOAC technologies on to a single substrate
- The development of novel low frequency communication architectures
- The development of packaging technology and incorporation of miniature power sources and switching
- The development of novel data fusion techniques
- *In situ* testing of sensor devices in animal carcasses

Increased Capacity and Expansion of the Research Base

Networks

Between Glasgow, Edinburgh and the ISLI we have created a network of researchers spanning electronics, chemistry, biology, computer science, veterinary clinical science, medical science and epidemiology that is unique.

We have also grown our range of collaboration during IDEAS and have had many useful dialogues, some of which have led new collaborations and funding. New partners include:

- Professor Peter Ghazal (genomics)
- Professor Neil McIntosh (clinical, neo-natal)
- Professor Bhal Dillon (clinical, eyes)
- Dr Robert Stewart (Gastro-intestinal)
- Professor Barry Gusterson (Pathology)
- Dr. Colin Penny (Vet)
- Professor Elaine Watson (Vet)
- Dr S. Cochran (ultrasonics)
- Dr M. Riehle (cell engineering)
- Dr Sandy Cochran (Ultrasonics)
- Dr Katherine Kirk (Ultrasonics)
- Mr David Ross (Agriculture)
- Professor Colin Green (Gastroenterology)
- The Institute of Photonics
- The MDFP Network (a national network for medical device research)

Major New Research Funding

- Feasibility Study, UK Industry, Glasgow University, £120,000.
- A Scalable Mosaic Array For Ultrasonic Imaging, EPSRC, GR/T19803/01, Awarded to Glasgow and Paisley Universities, £446,227.
- Extreme sensitivity by engineering plasmon resonance sensors, EPSRC, EP/C509927/1, Awarded to Glasgow University, £305,614.
- Drug Release, Overseas industrial sponsor, Awarded to Edinburgh University, £1,200,000.
- Image generation from a phased array system using ultrasound, Smart Award and Industrial Investor, Eleotech Ltd (Based at Edinburgh University), £100,000
- Electronics Design Centre for Heterogeneous System, EPSRC Science and Innovation Award, University of Glasgow, £3.3M.

Dissemination and Knowledge Transfer

The technical programme was successful and this is clearly indicated by the quantity and quality of the research output measured in terms of peer reviewed publications, conference presentations and invited talks given around the world. A full list of publications generated by IDEAS is presented towards the end of the report. Other activities included giving schools lectures. A good example is the annual lecture that we gave as part of the IEE's Engineering in Health Week.

One aspect of the project is that research development was considered to be of paramount importance. Our activities, especially with regard to publishing, were therefore aimed at raising the research profile as early as possible. As a consequence, the majority of the IP that was developed collaboratively was put into the public domain without first securing IPR. Considerable effort has been made to transfer the technology to industry, and we will continue to pursue this activity. Since the conclusion of the IDEAS project new IP has emerged that is being protected by patents.

In the News

The IDEAS project has captured a great many people's imagination and has attracted widespread publicity. Numerous articles have been written about the work of the IDEAS team in newspapers and the technical press including: The Times; The Financial Times; Scotland on Sunday; The Observer; The Electronics Times; The Lancet and the IEE Review. The front cover of the relevant issue of the IEE Review, shown above, is particularly striking and has attracted a lot of interest.

The Future

IDEAS has been a tremendous success, and as the initial funding period passes we are confident that we will be able to maintain the activity. It is clear that there is now an income stream of new grant money from a variety of sources, as shown above, and there is strong evidence of a significant international profile, as shown by our publication output that includes several invited talks. It is clear that opportunities will grow and that the universities are pursuing them. A pattern of committing new academic appointments to the field is emerging which is especially welcome.

Glasgow University is now planning to refurbish a 277 m^2 space to create an Electronics Design Centre for Heterogeneous Systems with EPSRC support. This new centre will enable Glasgow to build a sustainable activity in IDEAS related work over the next 10 years. The new Centre will complement the significant design strengths of the ISLI and be able to take advantage of the new James Watt Nanofabrication Centre that is currently under construction at Glasgow University in a manner that is well matched to the diverse electronic industry of Scotland and the UK as a whole. The new Centre will be supported by academic appointments in the field.

In Edinburgh, SHEFC funding will shortly create a new institute that draws directly upon the expertise developed during the IDEAS collaboration. The POEMS (Precision Optical and Electronic Miniature Systems) Institute bring Edinburgh's IMNS into long-term, funded collaboration with a complementary grouping at Heriot-Watt University, enhancing the Scottish research base's ability to work across a broad front in sensing, MEMS and actuation. The contacts developed during IDEAS, with researchers in related areas in Glasgow will allow this general area of bio-sensing, bio-electronics and medical electronics to be expanded at both ends of the M8 with minimal duplication of effort.

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Further Information

Information about the IDEAS project and related research can be found on the following web-sites.

The Microsystems Group at Glasgow University:

http://www.elec.gla.ac.uk/groups/nano/mst/

The Bioelectronics Group at Glasgow University:

http://www.elec.gla.ac.uk/groups/bio/

The Institute for Integrated Micro-and Nano-systems at Edinburgh University:

http://www.see.ed.ac.uk/research/IMNS/

The Institute for System Level Integration:

http://www.sli-institute.ac.uk

and

http://www.sli-institute.ac.uk/research/isli/ideas.htm

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