KTN
the Knowledge Transfer Network

SILC SENSORS & INSTRUMENTATION LEADERSHIP COMMITTEE

WHITE PAPER

THE IoT TREE OF LIFE

DUNCAN BREMNER

ABSTRACT: The Internet of Things (IoT) has come to mean all things to all people. Combined with the huge amount of interest and investment into this emerging opportunity, there is a real possibility that the arising confusion will hamper adoption by the mass market. The SILC team have used their extensive Sensor Systems market and technical knowledge in an attempt to clarify the situation for individuals interested in understanding IoT, and the underpinning role of Sensor Systems.

This paper proposes a phased model of the IoT ecosystem, starting with infrastructure establishment, and culminating in exploitation through the creation of new companies and business models. It does not attempt to quantify the emerging opportunities, relying instead on the many publications dedicated to detailed market analysis. The focus is to place the opportunities in context, demonstrate the importance of sensor system technology underpinning the emerging IoT revolution, and suggests areas where the UK could establish leadership positions. Throughout the paper, examples of the likely protagonists have been used by way of illustration.

INTRODUCTION

The emerging market for the Internet of Things (IoT) is projected to be 50 billion devices by 2020[1] and many of these will be connected to the Internet via wireless. If these predictions are correct, this will mean 5 times more devices will be connected to the internet giving rise to a market opportunity of $14 Trillion[2]; we will have truly arrived at the connected society. Cisco estimates the impact of the IoT on society will be 10 times greater than the impact of the internet itself.[3]

As this opportunity emerges, the inevitable confusion and paradoxes can give rise to FUD (Fear, Uncertainty, and Doubt) in both the investment community and the end-user market. As an independent, neutral advisory committee comprising of academic and industry members, the Sensors and Instrumentation Leadership Committee (SILC) has prepared this paper to summarise WHAT is the Internet of Things, WHERE it has evolved from, and HOW it may affect our lives, communities, and businesses in the future.

The paper presented here is targeted at novices and experts alike, proposing a reference framework that will assist in understanding the IoT using common terms of reference. The focus is to place the opportunities in context, demonstrate the importance of sensor system technology underpinning the emerging IoT revolution, and suggests areas where the UK could establish a leadership position.

HISTORY

The term Internet of Things was coined by Kevin Ashton while working for4 Proctor and Gamble (P&G) in 1999 and who subsequently established the Massachusetts Institute of Technology (MIT) Auto-ID centre. The presentation described how RFID technology in P&G's supply chain could use the internet to track shipments and improve business efficiency. The original proposal was much more limited than the promise offered by IoT today, but nevertheless the original proposition still underpin the present IoT.

In 2001, Cisco created the 'Internet Business Solutions Group (IBSG)' tasked with the mission to 'accelerate customer success in the Internet economy and develop long-term customer partnerships'.5 A considerable proportion of the ISBG work stemmed from developing client's capabilities to realise business benefit through the adoption of internet technology and online business practices. Cisco's ISBG can also be credited with creating a simple quantifiable metric defining the IoT; 'the point in time where more things or objects were connected to the Internet than people'.6 In 2003, there were 6.3B people in the world and approximately 500M devices connected to the Internet; the tipping point7 for IoT according to Cisco, occurred between 2008 and 2009 and is illustrated in figure 1.

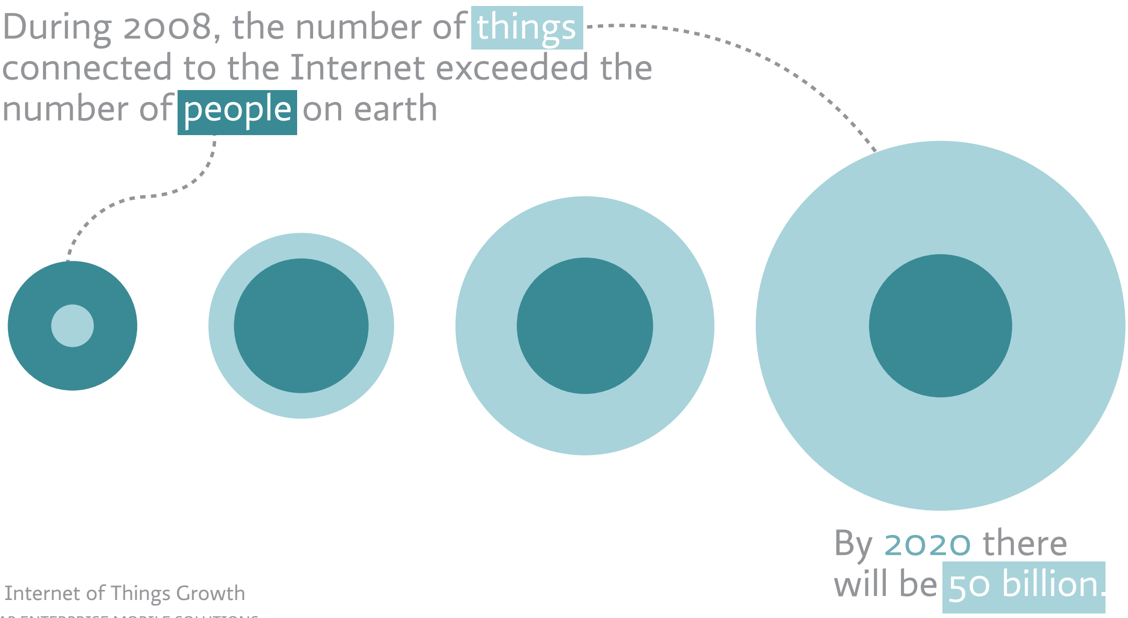

Figure 1: Internet of Things Growth
SOURCE: SAP ENTERPRISE MOBILE SOLUTIONS

These definitions provide historical context into the emergence of the 'Internet of Things' but are not helpful in understanding where the technology or business opportunities are today and how they will develop in the future.

1 https://gigaom.com/2010/04/14/ericsson-sees-the-internet-of-things-by-2020/
2 http://www.cisco.com/web/about/ac79/docs/innov/IoE_Economy.pdf
3 http://cloudtimes.org/2014/03/07/cisco-says-internet-of-things-will-have-ten-times- more-impact-on-society-than-internet/

4 http://kevinjashton.com/2009/06/22/the-internet-of-things/
5 http://www.cisco.com/web/about/ac79/csp/subsuccess.html
6 http://www.cisco.com/web/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf
7 http://gladwell.com/the-tipping-point/

THE IOT 'TREE OF LIFE'

The IoT can be divided into three distinct phases representing the present development and future opportunities within the emerging IoT market. These phases have been labelled 'Establishment, 'Enablement, and 'Exploitation' which have been related to the growth of a tree. This analogy expands on a previous concept[8] into a diagram(Figure 2) that SILC have named 'The IoT Tree of Life'.

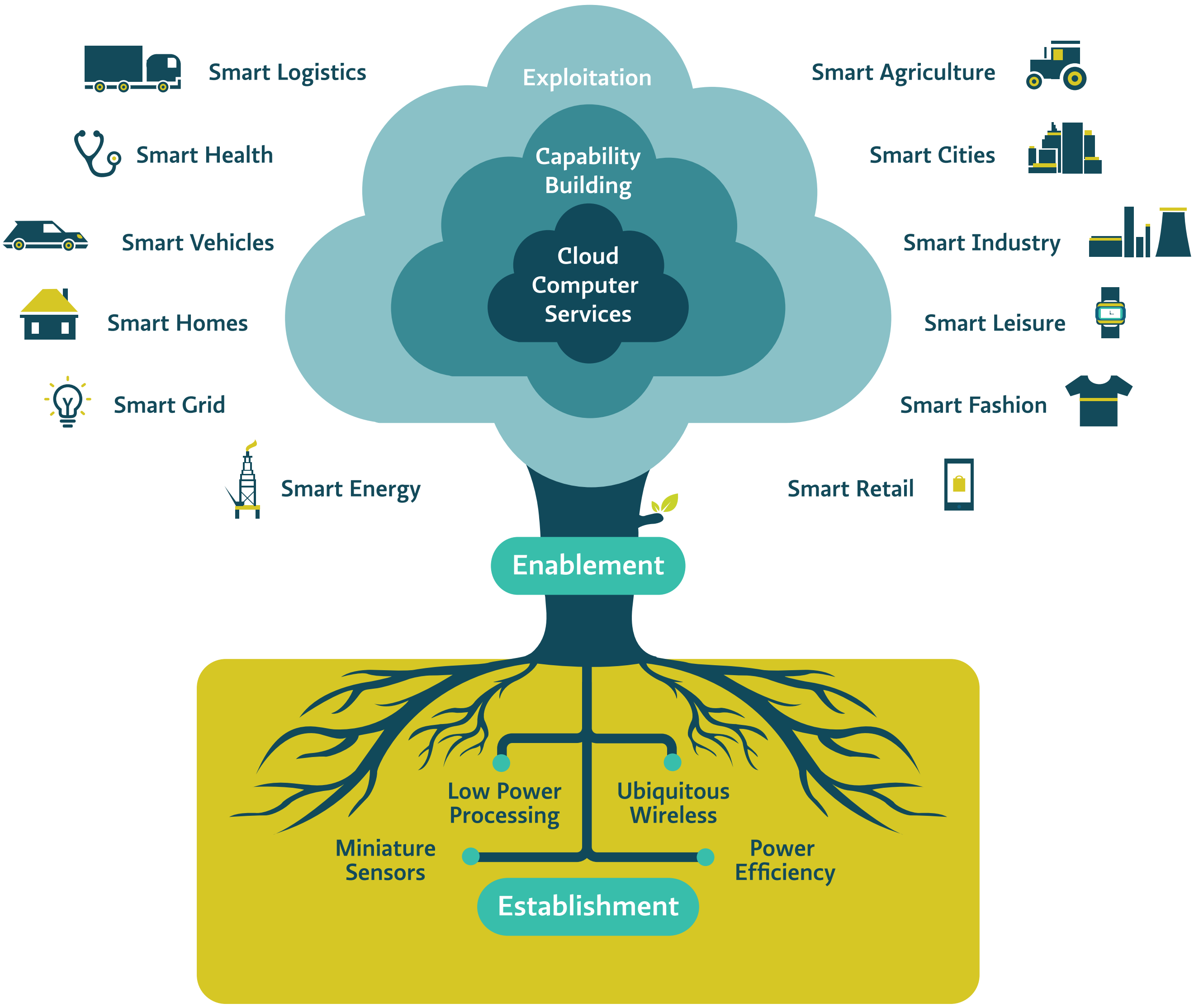

Figure 2: SILC'S IoT 'Tree of Life"

8 http://www.freescale.com/files/32bit/doc/white_paper/INTOTHNGSWP.pdf

Establishment

This first phase is well advanced and in some markets such as computing and IT is almost complete. The characteristics of this phase are the upgrading or enhancement of objects and things to make them capable of communication and being part of the IoT. Completion of the establishment phase does not in itself create the IoT, but delivers the required technologies such that devices will be able to join future IoT networks.

The establishment phase draws of 4 vital feedstock 'roots' of technology:-

- Miniaturised Sensors
- Low power processors and microcontrollers
- Ubiquitous connectivity
- Power efficiency, improved batteries and energy harvesting technology

Miniaturised Sensors. Many of the future applications and business opportunities for IoT rely on low cost, miniaturised sensors. These can easily deliver temperature, pressure, air quality, position, attitude (acceleration) or specialist measurements such as pH. Most of these sensors are available in small, surface mount packages for inclusion in mobile or battery instruments. With the emergence of sensors based on Quantum Technology,[9] the accuracy and size of these devices will continue to improve.

Low power processors and microcontrollers. Low cost /low power processing are essential to the realisation of the IoT. Many of the advances and improvements in mobile processing have been driven by the mobile communications sector but less attention has been placed on the low power requirements. As IoT applications demand Lo/No power, attention is now focused on the design of low power processing and memory solutions by leading UK companies such as ARM and SureCore.

Ubiquitous connectivity. All IoT devices depend on their ability to connect to the Internet whether wired or wirelessly. The majority of devices will depend on one or more wireless protocols (WiFi, 2G/3G/4G cellular networks, Bluetooth, 6LoWPAN etc), however devices attached to structures or plant control may elect for wired connectivity such as Power-over-Ethernet. In both instances, the costs of connectivity must be low and universally flexible allowing seamless interconnectivity across a variety of physical or virtual connections.

Power efficiency, improved batteries and energy harvesting technology. This technology root impacts both the size / weight of IoT products, and also the environment in which they can be operated. There is a powerful drive towards very long life (>5years) or battery free (energy harvesting) solutions to enable extremely easy and flexible deployment of devices (the 'stick-on' wireless light switch is a good example).[10] Although battery technology is advancing steadily, power supply is still an area limiting many IoT solutions.

Much of this establishment activity is being driven by the existing global players who expanded during the creation of the internet. Companies such as ARM, Intel, Cisco, Microsoft, BT, Orange, Vodafone, Ericsson etc are now creating or installing the infrastructure required for the Internet of Things. In the majority of cases, the business drivers are to consolidate existing market positions in their (legacy) businesses although these companies have all expressed interest in supporting the IoT. Their objective is to drive the cost, flexibility, footprint, and interoperability of internet connections. Much of the technology in the Establishment phase already exists and is an evolution rather than revolution through the developing, installing, or upgrading of hardware platforms and infrastructure to support the Enablement phase.

Enablement

This phase builds on the hardware platforms and infrastructure created in the establishment phase and will provide the end-to-end technologies needed to realise the IoT. In 2014, much of the IoT industry is engaging with the problems and challenges of this phase, addressing challenges such as the development of software components as the push towards Machine-to-Machine (M2M) gains momentum, developing near term opportunities (but not yet IoT). Some examples of critical technology needed for the successful enablement of the devices and services are:-

- Security, Trust, Dependability, and Privacy
- Network connectivity (ubiquitous connectivity)
- Small, power efficient, Real Time Operating Systems (RTOS) for nodes
- Interoperability between devices/networks/systems
- Network / device management and control
- Low power data algorithms (to pre-process nodal data measurements)
- Deployment of IPv6 (Internet Protocol) address capability

The last of these, the deployment of IPv6 is an important step in the rollout of IoT. The existing internet operates on IPv4 which is defined by a 32bit address space limiting the total number of addresses to just less than 4.3 billion unique addresses. On 3rd Feb 2011, the pool of unique IPv4 addresses was exhausted and since then, techniques such as Network Address Translation (NAT) are being used to overcome the problem until the rollout of IPv6. This new protocol is based on a 128bit address space gives 3.4×10^{38} unique addresses, sufficient for all anticipated future needs for all our IoT devices. A short summary of the capabilities and benefits of IPv6 has been prepared by Microsoft. [11]

9 https://www.innovateuk.org/-/quantum-technology-to-receive-multimillion-pound-government-investment

10 http://www.homeeasy.eu/RemoteControlWallSwitchUnit1Gwhite/HE307/189/Product/46

11 http://www.microsoft.com/windowsembedded/en-gb/internet-of-things.aspx

As in the establishment phase, some areas and applications of the market are relatively advanced with a self-sustaining eco-system running across different platforms, technologies and vendors. The business opportunities in the enablement phase will be considerable, especially in the software area (particularly middleware) producing dedicated software components to enable seamless interoperability and security of devices. Based on the '50 billion connected devices'[12] touted by Cisco and supported by Gartner, many of these business opportunities will come to fruition during the establishment phase as new products for industrial, commercial, and private use will have a degree of 'IoT ready' capability. These software opportunities will give rise to new companies capable of developing high quality, embedded software components addressing specific challenges (such as interconnectivity or security) for IoT devices. However, this is not the Internet of Things, it is the completion of the ecosystem needed for the IoT.

Exploitation

Whereas the previous phases were delivering the ecosystem for the IoT market, the third phase is the exploitation of the IoT. By this phase virtually every device will contain a degree of intelligence and connectivity to the Internet. These connections will be seamless, automatic, and secure; enabling new business opportunities to be created across many different platforms. An important characteristic will become manifest during this stage; the disaggregation of platform ownership. Services and capabilities will utilise networked devices and nodes of varying veracity, resilience, accuracy, and data flow capacity to create as complete a data picture as possible. An example of this might be air quality, combining high quality, high cost nodes with mass deployed devices via mobile platforms (personal or vehicle mounted), where results are cross referenced against the calibrated, high quality standard to produce high resolution images. The likely first areas to be exploited will be the creation and supplying of what have been identified as capabilities on the IoT Tree of Life. Examples of these are:-

- Machine-to-machine interaction/automation
- Air quality / environmental monitor and control
- Building automation (beyond the basic capabilities today)
- Vehicle safety (excluding driverless but including driver assisted)
- Appliance / Equipment remote monitoring / maintenance
- Supply chain automation

Initially, these will exist in 'walled gardens'[13] however as trust and security improves and networks become resilient, these independent 'gardens' will merge to become the IoT. This amalgamation of capability networks and services will also be the producers of large, open datasets of information that will feed into the emerging parallel sector known as 'Big Data'. The Big Data sector is significantly different from the IoT but sits alongside and is dependent upon it. Whereas IoT is occupied with the collection of information and passing it to the cloud, Big Data seeks to determine information by the combination of several datasets to infer results. IoT businesses and associated devices and services will be the physical interfaces through which society will communicate with Big Data solutions. *IoT is the interface with the real world.*

Core to the exploitation of IoT is Cloud Computing services. Cloud storage already exists and will be developed to deliver computing services for Big Data and IoT exploiters. The significance of cloud services, despite concerns about data security and privacy, is the 'always on / always accessible' capability. IoT will rely on cloud storage and computing to flourish. Furthermore, high value added services will rely on fully supported cloud services in order to enable access across a variety of platforms.

New start-ups exploiting the IoT market are likely to operate in an entirely virtual world; their entire business model being supported on 3rd party hardware and firmware platforms while the companies focus on delivering customer experience and value. The concept of a vertically integrated company exploiting the IoT will cease to exist. Instead, diversification of the supply chain (compute, storage, or delivery platforms) will ensure business continuity. Business and society in the IoT age will interact and operate in an entirely different way.

12 http://telsoc.org/event/vic/2013-02-27/enterprise_mobile_solutions

13 http://www.linuxfoundation.org/news-media/blogs/browse/2013/12/open-source-tears-down-walled-gardens-connect-internet-everything

However, according to Cisco,[14] the drivers which will characterise the adoption of IoT and the associated 'value at stake' of $14 Trillion will be:-

- *Asset Utilisation ($2.5 Trillion)* – IoE[15] reduces selling, general , and administration costs (S,G & A) expenses and costs of goods sold (CoGS) by improving business processing execution and capital efficiency.
- *Employee productivity ($2.5 Trillion)* – IoE creates labour efficiencies that result in fewer or more productive man-hours.
- *Supply Chain and Logistics ($2.7 Trillion)* – IoE eliminates waste and improves process efficiencies
- *Customer Experience ($3.7 Trillion)* – IoE increases customer lifetime value and grows market share by adding more customers
- *Innovation, including reducing time-to-market ($3.0 Trillion)* – IoE increases the return of R&D investments, reduces time to market, and creates additional revenue streams from new business models and opportunities.

SOURCE: CISCO: EMBRACING THE INTERNET OF EVERYTHING TO CAPTURE YOUR SHARE OF $14.4 TRILLION

This list reflects the enablement of capabilities suggested earlier, indicating the most likely business areas to deliver immediate financial returns to established company and governmental operations. The development and deployment of these capabilities and data services will deliver both the technical resources and the market awareness enabling new companies to be created to serve the true market for IoT.

THE PLAYERS

The calculation of the overall business opportunities for IoT is difficult given the emerging nature of the market and the immaturity of the technology. The approach adopted here takes a qualitative approach in identifying the likely participants in each phase of the market development.

In the establishment phase, the majority of participants will be incumbents seeking to consolidate their position as product or equipment suppliers. The logic and justification for this statement is twofold: firstly, the incumbent providers have business interests already serving the sector and have a supply chain optimised to deliver the required market evolution. Examples of these are Cisco or Ericsson (network equipment), BT or Vodaphone (Network Operators), Intel or Arm (processing / wireless technology), or Broadcom / Microchip /TI (System–on-chip silicon solutions). The second justification is the present value of the market during the establishment phase is low due to limited volume and revenue generation. The only organisations capable of supporting such long term strategic bets are those with a highly developed business model generating profitability from their core business. In SILC's opinion, there is limited if any opportunity for new entrants to generate income during the establishment phase, the most likely scenario will be delivering point product components or sub-systems to existing infra-structure providers.

During the enablement phase there is likely to be some opportunities for new entrants, but those successful companies engaged in this phase will utilise conventional business processes to generate revenue from new products. The most likely source of opportunities will be the demand for low power solutions, system integration to reduce the size or weight, or dedicated products to address specific needs (such as security) in the emerging IoT market. The early opportunities will develop from Machine-to-Machine (M2M) applications where much of the hardware infrastructure already exists and the business case for such applications has been proven. Given the dedicated and specific nature of M2M applications, it is likely that there may be demand for software and hardware entrants to supply specialist needs. Many of these opportunities will rely upon close partnerships with the incumbent suppliers to 'gap fill' or enhance their existing solutions.

14 http://www.cisco.com/web/about/ac79/docs/innov/IoE_Economy.pdf
15 Cisco have adopted the term 'Internet of Everything (IoE)' instead of IoT. For this discussion they should be considered synonymous.

The most ill-defined but lucrative phase is the exploitation phase. Although some of the existing incumbents, particularly in the software and operating system space have expressed interest in entering this market,[16] the exploitation will be driven by new entrants. These will adopt new business models, and deliver new services to end users and service aggregators. Through its investment in initiatives such as the digital catapult coupled with the UK's expertise in Sensor systems, there is excellent opportunity for the UK to dominate the exploitation phase. However, in order to fully capitalise on the opportunity, the capital and venture funding markets in the UK must become familiar with alternative business models where companies 'piggy-back' on hardware and infrastructure components supplied, operated, and owned by others. The concept of vertically integrated business models and supply chains will only exist in low value, conservative industries. The high growth, high value opportunities are likely to emerge in a much more virtual model.

CONCLUSION

It is appreciated that any attempt to define the future with any degree of accuracy is futile, however this paper attempts to establish a framework around which the IoT market development can be compared. Drawing upon simple macro-economics, engineering economics, and market characteristics, SILC has tried to project ***the most likely scenario*** for the development of IoT. It is entirely possible that the exemplar players discussed here may change but are likely to be replaced by organisations with similar characteristics. It is clear that the IoT has significant support from the incumbent industries, primarily to further develop and consolidate their already dominant market positions. However, the emergence of the IoT is not just 'marketing hype', the societal and economic benefit is clear and this will drive adoption. Today, various stakeholders are vying for power and influence; it is imperative that UK plc engage throughout the early stages of growth in order to capitalise on the lucrative exploitation phase.

SILC believe the UK is well positioned to substantially benefit from IoT through the country's expertise and skills in the underpinning sensors systems technology, leadership in low power processing and memory, and the commitment to initiatives such as the Catapults. The SILC committee implore BIS, Innovate UK, EPSRC, and ultimately the UK government to have the foresight and commitment today to support the UK capabilities in its Universities and Industry to reap the benefits of IoT tomorrow.

16 http://www.microsoft.com/windowsembedded/en-gb/internet-of-things.aspx

Duncan Bremner works for the University of Glasgow within the School of Engineering, and is a member of the SILC committee. With over 25 years in the semiconductor industry, he has an in-depth understanding of new technology adoption.

For more information regarding the contents of this paper, please contact:

EMAIL: **duncan.bremner@glasgow.ac.uk**

TEL: **+44 (0)7801 729 454**

Graeme Philp chairs the SILC committee, a UK advisory group comprising a multi-disciplinary team with common interests in sensors and instrumentation technology. These two areas are particularly relevant for the emerging Internet of Things and also for the realisation of Industry 4.0.

For further details on the activities of SILC or Industry 4.0, please contact:-

EMAIL: **graeme.philp@gambica.org.uk**

Mark Littlewood is Head of Sensor Systems within the KTN. Established to foster better collaboration between science, creativity and business, KTN has specialist teams covering all sectors of the economy – from defence and aerospace to the creative industries, the built environment to biotechnology and robotics.

For further information on the KTN, please contact:

EMAIL: **mark.littlewood@ktn-uk.org**

TEL: **+44 (0)7734 957471**