COMMERCIAL IN CONFIDENCE

REPORT

Impact Assessment of Pervasive Tracking Technology

Prepared for
CSIRO

March 2019

THE CENTRE FOR INTERNATIONAL ECONOMICS
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Summary

The Cyber-physical Systems (CPS) Program within CSIRO's Data61 has delivered a suite of locational tracking technology hardware and software solutions that can drive productivity improvements across a range of Australian sectors.

'Pervasive tracking' is the ability to understand the location and movement of assets, people or animals, at any point in time, and at a diversity of spatial scales from continent- to building- level.

Australia's pervasive tracking capacity has been transformed by the CPS Program's development and adaptation of smaller sized tracking devices, innovative data collection and transfer methods, and advances in energy harvesting options, with pervasive tracking now available across difficult applications such as underground, and across large-scale geographic areas.

Technologies available to Australian industry

CPS Program outputs at a glance include:

- **Pervasive Autonomous Computing Platform** (PACP) provides a significant size reduction on traditional devices
- **Camazotz** mobile sensing platform enables long term wildlife tracking
- **LoCi platform** uses new radio technologies such as LoRaWAN and Bluetooth and a more powerful CPU to enable modelling sensing for agricultural and construction applications
- **Bluetooth Low Energy Aware Tracking (BLEAT)** provides a capability in low power sensing combined with low power Bluetooth indoor localisation
- **Sensor Scheduler software** uses multiple sensing modalities to enable adaption to changing energy availability and motion patterns, and
- **Wireless Ad-hoc System for Positioning (WASP)** is a world leading, high accuracy indoor localisation system, able to be customised to a wide range of challenging environments and demanding applications.

Meeting the needs of Australian industry

The CPS team has partnered with a range of private sector investors and developers to deliver real world applications of tracking technology in agriculture, underground mining and construction.

- Agriculture – CSIRO's tracking technology has been applied in two main applications assisting farmers in extensive agriculture. The CeresTag application provides a new form of location, behaviour and state (LBS) technology in the cattle industry, allowing greater insight into cattle herd characteristics, and the e-Shepherd application provides opportunities to advance virtual fencing applications.

- Underground mining – The licencing of CSIRO's Wireless Ad-Hoc System for Positioning (WASP) technology by Minetec, and the resulting proprietary products developed and deployed by Minetec around the world, has delivered world leading underground mining positioning technology, enhancing productivity and safety outcomes.
- Construction – CSIRO's Data61 group has partnered with the start-up company Ynomia, created with the specific purpose of commercialising the Bluetooth Low Energy Aware Tracking (BLEAT) technology. The application of precision locational tracking devices on construction sites has the potential to enhance construction sector productivity and reduce the technological lag observed between the construction sector and other economic sectors over the past decades.

Economic value of CPS Program research

Pervasive tracking capabilities address key market challenges and offer solutions to improve the productivity and sustainability of Australian industry, environment, and population health.

The purpose of this report is to assess the contribution that the CPS Program makes to these economic gains by considering:

- the challenges being faced by industries, and the costs of these challenges
- the role that locational tracking devices in general can play in resolving these challenges (the size of the prize)
- the proportion of the market that CPS based technologies represent and the resulting size of the prize being targeted, and
- attribution of CPS activities to the final technology product.

In **agriculture**, locational tracking technologies have been found to generate benefit cost ratios (BCR) of 1.1 and 1.3 in beef production — where monitoring service costs are high, and 3.8 to 5.3 —where monitoring service costs are low, assuming a gradual path to adoption over 20 years.[1,2]

Based on agricultural R&D costs to date, a BCR of 1.1 to 1.3 points to a net present value of $3.6 million to $4.3 million attributable to CPS (in present value terms, based on reported project costs and resources). The market's estimated willingness to pay for the technology based on royalty returns suggests a slightly higher BCR of 1.5 in terms of the returns to CPS.

In **mining**, improved underground tracking systems in mines have been associated with more timely diagnosis and rectification of mechanical issues, savings (8 per cent) in maintenance costs per ton of material hauled, reduced time required for evacuation and safety control tests, and large production increases (quadrupling) from various process improvements.[3]

1 A benefit cost ratio measures the size of economic benefits generated in relation to the costs incurred. Any benefit cost ratio above 1 indicates that the benefits are greater than the costs.

2 Trotter, M. (2018) Demonstrating the value of animal location and behaviour data in the red meat value chain. Prepared for Meat and Livestock Australia

3 See Dawson, T. (2018) Newtrax helps Hecla Casa Berardi Mine exceed production objectives by 4% in 2018. Available at: https://www.newtrax.com/newtrax_helps_helca-casa-berardi-

In **construction**, on-site locational technologies are estimated to generate benefits valued worth $96 million over ten years in net present value terms, with a BCR of 7.5 (excluding investment costs by CSIRO).[4] The BCR for CSIRO's contribution is estimated at 4.9, based on the markets willingness to pay for accessing the technology.

ine_exceed_production_objectives/ and Newtrax (2018) Transform your underground mining operations with solutions tailored to achieve your objectives in terms of safety, production, productivity. Available at https://www.newtrax.com/#Gold-fields-evacuation and Lee, J. et al (2014) Mining & Metals + Internet of Things: Industry opportunities and innovation. MaRS Discovery District

4 Ynomia (2017) Ynomia: Localise Anything. Presentation

1 Demand for locational tracking devices

Industry demand for locational data and information in real time, in often difficult physical domains is increasing. The specialist team at CSIRO is developing locational tracking technologies that meet this demand though development of adaptive and innovative solutions.

Providing real time information on location

Pervasive tracking refers to monitoring everything (person, animal, object), anywhere (continent-scale, city, building-scale), anytime (near-perpetual operation).

The Distributed Sensing Systems Group within the CPS Program is tasked with research on algorithms and methods that underpin large scale and long-term deployment of sensor networks to form an Internet of Things. More specifically, the group addresses the generalised problems of how to maximise information return from resource-constrained and distributed sensing devices.[5]

The work of the CPS Program covers locational tracking challenges along the spectrum of large scale, continental movement of wildlife, to close quarters, low visibility challenges in underground applications without access to satellite technology.

Growing demand for pervasive tracking technologies

Demand for real time, locational data sets is growing across many economic sectors, including health, environmental management, agriculture, smart cities and consumer applications.

The unique setting of Australia has led to demand for specialist applications of locational tracking technologies, in particular, the:

- traditional tyranny of distance challenges in monitoring, observing or accessing research targets in remote locations of northern Australia
- disproportionately high population growth in eastern cities that necessitate rapid and in-depth understanding of patterns of population movement on a daily, hourly and seasonal basis, as well as on the condition and capacity of infrastructure and utility assets to support these populations, and
- dichotomy of large-scale areas of the continent with low density of assets, animals or people to track, compared with small scale areas with high densities of potential tracking targets.

5 https://research.csiro.au/dss/research/

Locational information delivering economic value

There are numerous examples of where and how locational tracking technology can deliver value to the economy. For instance:

- Livestock systems:
  - monitoring and understanding natural behaviour that is not readily observed
  - fine detail measurement activities such as daily livestock growth rates and reproductive performance
  - accurate estimation and modelling of livestock greenhouse gas emissions, by allowing for correlation between animal herd size and feedstock type with aggregate emissions measured by gas sensors
- Pest monitoring and research:
  - continental scale tracking of nomadic pests with technology that can collect regular fixes to identify changes in travel patterns, or locate nesting sites that would otherwise not be apparent
  - delivery of novel technology solutions to estimate herd or flock sizes
  - technology solutions that can operate over long periods of time, such as 12 months and provide flexible data download capability
- Construction supply chains:
  - allowing for increased use of just in time inventory, smart contracting and scheduling
- Underground, indoor or mining sector:
  - allowing for increased accuracy and real time location of assets and personnel
  - reduced health and safety incidents
  - improved maintenance scheduling and improved productivity
- Food supply chains with the potential to:
  - develop technologies that reduce costs associated with ascertaining food provenance and addressing supply chain inefficiencies
  - increase the use of smart contracts, data sharing, analytics using sensitive data, regulatory automation and analytics, product provenance, supply chain optimisation, trust and risk assessment to improve productivity
- Building energy efficiency:
  - drawing on real time information on occupant levels, location and movement patterns from locational technologies, adaptive heating, ventilation and cooling systems can be optimised to reduce energy usage, and
  - anticipated potential to use tracking technologies to reliably estimate thermal comfort in field deployments to optimise HVAC usage.

The role that locational services may have on economic growth and productivity has been considered in a variety of settings. The economic benefits, productivity drivers and cost savings are particular to the industry and the application deployed. However, studies consistently demonstrate that large scale economic benefits are available through a mature locational tracking technology drive.

When considering Global Navigation Satellite Systems (GNSS), a 2008 study concluded that Precision GNSS technology has the capacity to automate many manual tasks, boost agricultural crop yields, facilitate just in time supply chain management, improve deployment of resources for asset maintenance and deliver significant cost savings in materials.[6] Based on a scenario whereby a standardised network (allowing any users to log into location verified nodes) is rolled out across Australia, the technology has been estimated to increase Australia's GDP by between $6.7 billion and $12.6 billion in 2008 dollars by 2030.[7]

In the health sector, Internet of Things (IoT) startup companies are seeking to deploy Bluetooth based tracking systems to access up to hundreds of thousands of dollars in efficiency savings annually in public hospitals through improved asset management systems.[8]

6 ACIL Allen Consultation (2008) Economic benefits of high resolution positioning services. Prepared for the Victorian Department of Sustainability and Environment and the Cooperative Research Centre for Spatial Information.

7 ACIL Allen Consultation (2008) Economic benefits of high resolution positioning services. Prepared for the Victorian Department of Sustainability and Environment and the Cooperative Research Centre for Spatial Information.

8 Lew, K.P. (2018) Aus IoT startup driving efficiency in hospitals with Bluetooth asset tracking. Available at: https://itbrief.com.au/story/aus-iot-startup-driving-efficiency-hospitals-bluetooth-asset-tracking

2 Impact pathway for Pervasive Tracking

The CPS Program within CSIRO's Data61 Business Unit continues to develop leading locational tracking technologies, working closely with industry partners to deploy technologies in value generating settings across Australian industries.

Project inputs

Approximately $13.57 million of funding has been provided to the CPS Program across key projects (table 2.1). Reflecting the diversity in valuable applications of pervasive tracking, the CPS Program has received funding from multiple sources including:

- Agriculture and Food Business Unit (internal CSIRO)
- Sensors and Sensor Network TCP (internal CSIRO)
- Energy Business Unit (internal CSIRO)
- Rural Industries Research and Development Corporation
- Commonwealth Department of the Environment
- Ynomia
- Meat and Livestock Australia and CeresTag
- Data61 Challenge Program

Non-financial or in-kind contributions have also been made, including:

- access to farms for livestock experiments
- access to domain knowledge from all relevant sectors
- specialised staff from other Business Units and external partners to perform field experiments and data collection
- highly specialised facilities such as for targeted experiments with livestock (in-rumen, genetic analysis), access to building control systems for distributed control of HVAC
- access to building construction sites, and
- input from commercial partners (Blackmores, Tasmania Fresh, ProBuild) in defining industry problems.

Other parties have also invested resources in CPS projects, demonstrating commitment from industry to the research being undertaken. For instance, operations such as Minetec have invested further resources in commercialising WASP to adapt the technology and develop trademarked applications. There is also likely to be ongoing investment required by Ynomia and CPS in finalising the BLEAT technology application for the construction sector.

2.1 Pervasive Tracking Project Investment

Project Name	CSIRO Internal	External funding	Project Total
	$	$	$
Bleat (Ynomia)	400 000	700 000	1 100 000
CeresTag	1 200 000	1 800 000	3 000 000
Virtual Fencing	2 100 000	900 000	3 000 000
Batmon	2 000 000		2 000 000
WASP			
Minetec		3 000 000	3 000 000
Boeing	490 000	980 000	1 470 000
TOTAL	**6 190 000**	**7 380 000**	**13 570 000**

Source: The CIE.

Enabling research activities

The activities of the CPS centre on solving underlying challenges faced by locational tracking devices and users, such as:

- size of the tracking devices
- longevity of battery storage
- transmission of locational data, and
- long intervals between collection of location points.

Some of the key research activities have included developing devices that operate in an Energy Neutral state – making sure that energy harvested through solar, thermal or vibrations is about to replenish the energy that is being consumed and enable the devices to operate indefinitely. The research activities have included an advancement on Kinetic Energy Harvesting approaches. Such technology is able to draw on the energy produced by movement of the animal itself, and because no actual sensor (such as an accelerometer) is needed, a significant percentage of the limited harvestable energy can be saved. The work has made significant progress towards the development of self-powered wearables.

A further requirement of the tracking devices is the need to reduce costs or labour intensity of accessing data from radio tags. Many animals exhibit nomadic behaviour and can roam vast areas often moving in and out of regions with satellite or internet connectivity.

The solutions developed by the team include the design and deployment of a fixed network of wireless receiver stations, base nodes or gateways combined with local data buffering and delay-tolerant network algorithms imbedded in the tracking devices to collect meaningful data sets. While the algorithms allow for preliminary data processing and storage when required, when animals return to range, the nodes and gateways download and forward data from nearby animals to a central server.

Program outputs

The program outputs cover four categories:

- technologies delivered and being developed
- publications
- awards, and
- patents.

A summary of the technologies delivered is provided here, and lists of publications, awards and patents are provided in the Appendix.

Technologies delivered

The CPS Program has been responsible for the development of a number of highly specialised locational tracking hardware and software solutions. Collectively, these technologies allow for:

- an increase in the longevity of individual tracking devices
- a reduction in size of the devices
- an increase in tracking accuracy
- an increase in the data available for collation and reporting, and
- increases in data capture and transfer.

Descriptions of the individual research and technology developments are provided here.

- **Pervasive Autonomous Computing Platform (PACP):** development of the PACP family of tiny sensing and tracking devices that provide both a generic and customisable board and embedded software for serving different applications.
- **Camazotz:** part of the PACP family, it is a light weight and feature-rich mobile sensing platform which aims at long term wildlife tracking. Camazotz uses a CC430 system on chip (SoC) with a low power GPS, inertial, acoustic, air pressure and temperature sensors, two solar panels, 300mAh Li-Ion battery, with a total weight just under 20g originally targeted at tracking smaller wildlife such as flying foxes.
- **LoCi platform:** The successor of Camaztoz platform which is being used in more recent projects such as Ceres Tag and Ynomia and includes new radio technologies such as LoRaWAN and Bluetooth and a more powerful CPU.
- **BLEAT:** Bluetooth Low Energy Aware Tracking (BLEAT) was developed as a capability in low power sensing combined with low power Bluetooth indoor localisation. This capability is applicable to our small wireless sensing devices as well as smart phones. Once the indoor localisation capability was ported to smart phones, design started on a CSIRO Site App that uses Bleat for delivering real time indoor location information to assist safety and productivity for staff contractors and visitors on CSIRO sites.
  - Consultation with potential users noted the option to share one's current location is very useful, and many would opt in to do this in order to increase safety and productivity on site.
  - Useful functions include allowing users to view the location of other active staff members, send private messages, view and report hazards, view

emergency contact information for the site and manage notification and receipt of goods from reception.
  – Mechanism for reporting hazards, which a user can submit a geotagged hazard report through the app which includes a time, description and optional photo. Users will be notified if they walk within a certain distance of the hazard and be able to view details of the hazard.
- **Sensor Scheduler software:** the development of a framework for location tracking of mobile nodes that adapts to the changing energy availability and motion patterns.
  – Task scheduler component which uses inputs from the Energy-Awareness Layer and Mobility Awareness Layer to schedule sampling of different hardware components in the Sensor Process Layer, such as the GPS receiver or inertial sensors.
  – The scheduler allows for adaptive execution of GPS sampling tasks based on the input from the energy and mobility awareness layers.
- **Wireless Ad-hoc System for Positioning (WASP):** world leading, high accuracy indoor localisation system which is highly flexible and can be tailored to a wide range of challenging environments and demanding applications. WASP features anchor nodes at known locations around the area being monitored, communicating wirelessly with small a small mobile tag attached to the object(s) being tracked. The distances between the tracking object and the anchor nodes are measured to the accuracy of nano-seconds using a novel super-resolution detection of **time-of-arrival estimation technology** which has been patented.

Adoption of pervasive tracking technology

The CPS Program (and its predecessors) has been involved with a range of partners, delivering hardware and software solutions to enhance economic, environmental and social returns across a variety of sectors. There are five primary examples of the application of the team's technologies, as follows:

- Agriculture: virtual fencing solutions (e-Shepherd) and location, behaviour and state (LBS) technology in the cattle industry (Ceres Tag).
- Underground mining: Licencing of WASP technology by Minetec, and the resulting proprietary products developed and deployed by Minetec around the world (delivered initially as part of the CSIRO Minerals Down Under Flagship).
- Construction: In developing a so-call smart work environment on construction worksites, based on the BLEAT technology.
- Environmental pest management:
  – previously utilised in the National Flying Fox Monitoring program draws on the Camazotz technology
  – currently being used in trials to monitor and predict location of feral buffalo populations in Cape York, Queensland and Arnhem Land, Northern Territory.

Current applications are summarised in boxes 2.2 to 2.6.

2.2 Virtual fencing (e-Shepherd)

e-Shepherd is a GPS enabled, solar powered smart collar system which enables producers to 'virtually' fence and monitor their cattle. GPS boundaries are loaded into the collar. Using Google maps, a personal computer or tablet, virtual boundaries can be set to a specific point on any property, and the animal is notified by the collar when it has reached a boundary.

Source: https://www.agersens.com/eshepherd/

2.3 Feral Animal Internet of Things

CSIRO and James Cook University (JCU) are collaborating with three Indigenous land management organisations – Aak Puul Ngangtam (APN) and Kalan Enterprises in Cape York Peninsula, Queensland, and Djelk Land and Sea Rangers in Arnhem Land, Northern Territory – to develop low-cost tracking devices and an environmental sensor network using the Internet of Things (IoT). To date, three IoT base stations, twenty small inexpensive environmental sensors (measuring temperature, humidity, pressure and light), three high-end weather stations and 10 GPS tracking nodes have been installed at locations in Cape York and Arnhem Land. As at October 2018, data was being collected from 22 buffaloes that had been tagged in Arnhem Land and 20 pigs on Cape York.

This will assist in monitoring large populations of feral pigs, buffalo and cattle roaming freely across vast, inaccessible areas of the Top End, destroying natural environments, undermining agricultural productivity and spreading diseases.

Source: https://www.csiro.au/en/Research/LWF/Areas/Ecosystems-biodiversity/Managing-landscapes-for-biodiversity/Feral-animals/Tracking

2.4 Agricultural animal management (Ceres Tag)

The Ceres Tag smart ear tag delivers GPS positioning, movement and health monitoring for agricultural livestock. It features geo-location for greater traceability and provenance of livestock and will provide a platform for other possible applications in the future. Data collected from the tags can be translated into knowledge to improve management of both livestock and the paddock. The ear tags will give producers greater control over grazing management, allow them to locate livestock remotely and alert them to stock theft. The aim is to reduce operating costs, increase operational efficiency and additional financing opportunities through better management of livestock through data.

Source: https://www.csiro.au/en/Research/AF/Areas/Animal-Science/Precision-livestock-management/Ceres-Tag; https://www.cerestag.com/

2.5 Wireless Ad-Hoc System for Positioning (WASP)

Known as WASP (Wireless Ad hoc System for Positioning), the technology can track people and objects to an accuracy of about half a metre in underground environments where GPS and Wi-Fi-based tracking are either inaccurate or do not work at all. The technology has been commercialised by mining communication company Minetec and incorporated into its Trax+Tags II suite. Accurate and reliable location tracking is critical to the future of underground mining, and significantly improves productivity, and reduces health and safety risks.

In surface mining, almost all safety solutions utilise a GPS centric tracking system but there can be drawbacks; blind spots, poor depth perception and faster moving vehicles are just some examples. These individual instances effectively compromise the entire system. As a result, many miners are specifically seeking a solution not reliant upon GPS. Minetec is unique in terms of the technology underpinning its solution compared to other vendors. The SafeDetect system is a peer to peer, off network solution that uses Wi-Fi ranging technology, known as WASP (wireless ad hoc system for positioning).

The uniqueness of Minetec technology to deliver underground location information was demonstrated when Anglo American put out an international market requirement for sub metre tracking for their underground mines in South Africa, six vendors around the world said they could do it but in reality, only three could demonstrate submetre tracking above ground, and Minetec was the only company that could demonstrate submetre tracking underground.

Public announcements provide insight into the range of successes Minetec has achieved through their commercialisation and adaptation of the WASP technology:

- $1 million contract with PYBAR Mining Services Pty Ltd for the delivery of high precision tracking, visualization and task management for the South Australian Carrapateena copper-gold exploration project
- $1.8 million contract with RUC Cementation Mining Contractors Pty Ltd for the delivery of high precision tracking, visualization, task management and proximity detection solutions in a Western Australian mine
- Unspecified value contract with Boliden, Sweden, for non-GPS reliant surface mining Proximity Detection System
  - Minetec is unique in terms of the technology underpinning its solution compared to other vendors. The SafeDetect system is a peer to peer, off network solution that uses Wi-Fi ranging technology, known as WASP
- Integration of Minetec proprietary technology into the Caterpillar technology solution MineStar®

Sources: Chester, S. (2013) WASPs enable underground tracking, available at: https://www.spatialsource.com.au/latest-news/wasps-aid-in-underground-tracking; Minetec (2018) Minetec secures contract with Boliden, located in Sweden, for non-GPS reliant, surface mining Proximity Detection System, available at http://minetec.com.au/news/minetec-grows-from-strength-to-strength-secures-a-contract-with-boliden-located-in-sweden-for-non-gps-reliant-surface-mining-proximity-detection-system/; and Hosie, E. (2018) Significant Statistics, available at https://www.australianmining.com.au/features/significant-statistics/

2.6 Smart work environment

A collaboration between Data61, Probuild and Ynomia (an IoT construction start up) collaboration will deploy BLEAT (Bluetooth low energy active) sensors, across Probuild construction sites to provide workflows, asset tracking and improved HSE insights. Bluetooth low-energy localisation algorithms are used to track materials on site, on both a horizontal and vertical plane. Using very little power, and without requiring any additional network connection, it is designed to be scalable and easy to deploy.

Objectives are set for smart program scheduling, via Ynomia's IoT platform, with AI predictive outputs for construction management.

Ynomia states that the localisation product developed is a complete package, offering advances on competitors in the market.

2.7 Comparison of Ynomia and competitor localisation technologies

Companies	3D real-time localisation	Ease of deployment	Localise anything, even where no 3G/4G	Active data capture	Scalable self localisation
Ynomia	✓	✓	✓	✓	✓
Redpoint	✓			✓	✓
Triax	✓			✓	✓
Doxel				✓	
Veerum				✓	

Source: Ynomia

Source: https://research.csiro.au/dss/delivering-the-connected-job-site-with-bleat/; http://www.probuild.com.au/news/news/probuild-announces-tripartite-collaboration-with-csiros-data61-ynomia-and-probuild

3 Valuing the benefits

There is a recognised role for high resolution locational tracking technologies to deliver economic benefits in agriculture, underground mining and construction.

Some of these benefits are attributable to the CPS Program for the role that their research and development activities (in hardware and software) have had in advancing the state of locational tracking systems, particularly in terms of energy harvesting, delay tolerance systems and underground applications.

In agriculture, locational tracking technologies have been found to generate benefit cost ratios of 1.1 and 1.3 in beef production — where monitoring service costs are high, and 3.8 to 5.3 —where monitoring service costs are low, assuming a gradual path to adoption over 20 years. Based on agricultural R&D costs to date, a BCR of 1.1 to 1.3 points to a net present value of $3.6 million to $4.3 million attributable to the CPS Program.

In mining, improved underground tracking systems in mines have been associated with more timely diagnosis and rectification of mechanical issues, savings (8 per cent) in maintenance costs per ton of material hauled, reduced time required for evacuation and safety control tests, and large production increases (quadrupling) from various process improvements.

In construction, on-site locational technologies are estimated to generate benefits valued worth $96 million over ten years in net present value terms, with a BCR of 7.5 (excluding investment costs by CSIRO). The BCR for CSIRO's contribution is estimated at 4.9, based on the markets willingness to pay for accessing the technology.

Technology–specific potential for productivity improvements

There are a range of potential economic impacts that are relevant to the Pervasive Tracking program, related specifically to:

- reducing costs associated with current activities:
  - reduced labour costs with increased use of remote tracking
  - reduced inefficiencies (time saved, health and safety incidents avoided)
- improved decision-making processes due to:
  - higher quality data, and
  - greater volume of data.

Table 3.1 provides a high-level indication of the range of economic impacts that could be attributable to the technologies developed and deployed by the CPS Program, and the value attributable to the CPS Program, noting that for most instances, CSIRO–funded technology seeds further industry investment and application development.

Each of these technologies are at different stages of development and deployment.

By way of example, various studies have assessed the value of locational technologies in agriculture, construction, and mining.

3.1 Summary of impacts likely from Pervasive Tracking outputs

Product	Industry	Posited productivity impacts	Current status	Notes on adoption profile	CSIRO attribution
CSIRO Site App	CSIRO	▪ Time savings for package delivery ▪ Health and safety impacts from reported site hazards	Currently in use	Unknown wider use than CSIRO	Full
e-Shepherd, virtual fencing	Agriculture	▪ Reduced fencing costs ▪ Reduced labour costs ▪ Improved animal welfare	Trials	Likely conservative initial uptake, likely to be used of for tracking purposes initially rather than fencing purposes	Partial
CeresTag	Agriculture	▪ Reduced costs in location of stock ▪ Observation of grazing patterns ▪ Reduction of operating costs ▪ Increased productivity through better stock management	In development	Likely conservative initial uptake, most likely for use in large scale properties, but unlikely to completely replace helicopters and visual inspections	Majority – long term licencing deal
Ynomia	Construction	▪ Reduced labour costs ▪ Reduced time costs ▪ Reduced asset losses	Currently being trialled on ProBuild worksites	Ynomia outlines the target market of domestic construction sector, with an aim at 10 per cent penetration	Majority – long term licencing deal and royalties
MineTec	Underground mining	▪ Reduced number and severity of health and safety incidents ▪ Reduced labour costs of locating personnel and assets ▪ Shorter shift changes and tool downtime ▪ Increased site productivity and movement of vehicles	Currently in use - as part of trademarked products developed by MineTec Trax+Tags II suite	Highly specialised use - CSIRO technology needs attribution to overall application benefit calculation	Partial
Flying Fox monitoring program	Pest control	▪ Reduced crop and wildlife damage due to improved pest management techniques deployed	Program ran until 2015. No information on scale or impact of new data to improve decision making and reduce damage	N/A	N/A

Product	Industry	Posited productivity impacts	Current status	Notes on adoption profile	CSIRO attribution
Feral Animal IoT		▪ Improved productivity of feral animal management strategies (same costs)	Trial phase in Cape York and Arnhem Land	Too early to identify	N/A

Source: The CIE

Economic returns to agriculture

The development of location, behaviour, state (LBS) technologies is still in the early stages in Australia and internationally, with a range of technologies spanning the continuum from currently available, to trials and prototypes, to academic discussions.[9]

A recent study commissioned by Meat and Livestock Australia attempted to quantify the range of benefits, costs and possible applications of LBS technology in the Australian red meat sector.

Based on a small-scale survey of producers, asked about their potential uses, likely adoption patterns and estimates of value, the results point to benefits if the technology is adopted more widely in the Australian red meat sector.

Table 3.2 summarises the gross benefit estimates of producers that responded to quantitative survey questions. In general, producers made assessments based on herd deployment, where the entire herd is monitored individually, compared to sentinel deployment where only 5 per cent of the herd is selectively monitored.

Overall, cost savings were reported in the cattle sector of between 0.6 per cent (sentinel) and 3.8 per cent (herd), and revenue effects in the order of 2.7 (sentinel) and 6.8 per cent (herd). Prevented revenue losses were minor in comparison to other benefit types.

3.2 Animal location, behaviour and state data returns to the red meat industry

	Whole herd deployment			Sentinel deployment		
	Cost reduction %	Increased revenue %	Prevented losses from catastrophic/ unusual event %	Cost reduction %	Increased revenue %	Prevented losses from catastrophic/ unusual event %
Beef: pastoral	3.8	6.8	0.2	0.6	2.7	0.0
Beef: High-rainfall/ sheep-wheat beef	4.7	6.0	1.6	0.6	2.6	0.0
Sheep: high rainfall/ sheep wheat zone	2.6	5.0	0.9	0.3	2.0	0.9

Note: Revenue impacts for sheep producers excludes value from genetic matching of ewes and lambs, which was an outlier result with high estimated benefits.

Source: Trotter, M. (2018) Demonstrating the value of animal location and behaviour data in the red meat value chain. Prepared for Meat and Livestock Australia

9 Trotter, M. (2018) Demonstrating the value of animal location and behaviour data in the red meat value chain. Prepared for Meat and Livestock Australia, Appendix 2.

The financial impact of LBS technologies depends on industry adoption, particularly as many of the benefits, such as monitoring and managing landscape utilisation, require an increased level of skill (and investment) to implement.

Trotter (2018) estimated adoption rates by year 20 of:

- 80 per cent for basic applications that are simple to adopt, and the path to value easily achieved (e.g. mustering efficiency, water related behaviours, basic animal location)
- 50 per cent for more advanced applications associated with animal state, calving activities, and health, which require more technical development, skill, and may be difficult to implement (e.g. oestrus detection, pregnancy detection, disease detection), and
- 10 per cent for advanced applications relating to feed–base that require more skill and infrastructure to realist benefits (e.g. refining fertilizer application, timing grazing rotations).[10]

Adoption rates were not deemed to be sensitive to the monitoring service charge, which only effected the cost of implementation and gross margin.

Based on these adoption rates for all potential applications (easy, moderate, and challenging), LBS adoption was found to be economically viable **for beef producers** using both herd and sentinel deployment, however, substantive gains required monitoring service costs to be low ($10 per head for herd deployment and $50 per head for sentinel deployment).

For sheep producers, MBS adoption was only economically viable if monitoring service costs were low ($10 per head for herd deployment and $50 per head for sentinel deployment). At higher monitoring unit costs, the net present value of returns was negative. While not shown in table 3.4, the net present value was also positive for sentinel deployment (only) if the maximum (rather than average) expected gains were achieved.

3.3 NPV and BCRs for LBS adoption over 20 years for beef producers

	Herd deployment		Sentinel deployment	
Sensor cost per unit	Low, $10	High, $50	Low, $50	High, $150
Net present value $m	2 004	149	321	89
Benefit cost ratio	5.3	1.1	3.8	1.3

Note: Applies a real discount rate of 7 per cent. Results shown reflect the average of expected impacts, which were reported in Trotter (2018) as Minimum results.

Source: Trotter, M. (2018) Demonstrating the value of animal location and behaviour data in the red meat value chain. Prepared for Meat and Livestock Australia

10 Ibid, p. 112.

3.4 NPV and BCRs for LBS adoption over 20 years for sheep producers

	Herd deployment		Sentinel deployment	
Sensor cost per unit	Low, $10	High, $50	Low, $50	High, $150
Net present value $m	507	-4 664	52	-594
Benefit cost ratio	1.4	0.3	1.2	0.4

Note: Applies a real discount rate of 7 per cent. Results shown reflect the average of expected impacts, which were reported in Trotter (2018) as Minimum results.

Source: Trotter, M. (2018) Demonstrating the value of animal location and behaviour data in the red meat value chain. Prepared for Meat and Livestock Australia

Given the status of the CeresTag and e-Shepherd applications, it is not feasible to draw out whether there are any fundamental differences in these applications from the generic applications considered in Trotter (2018).

At this stage is it reasonable to expect that the CeresTag and e-Shepherd applications could drive economic returns and benefit cost ratios to the same scale – between 1.1 and 5.3 depending on deployment profile, and more critically, on the cost per unit for monitoring.

The CPS team is of the understanding that the applications being developed by CeresTag and e-Shepherd are anticipated to be mid-range on the cost spectrum. While this bodes well for economic viability, the scale of benefits would depend on the ease of implementation, and the extent to which applications target high yielding changes (increasing revenue from the herd, followed by cost saving measures, and then preventing losses associated with catastrophic or unusual events).

Modelling on the applications and costs of CeresTag and e-Shepherd specifically would require a completed field trial and survey of their applications. However, if anticipated costs are 'mid-range,' and the benefits are in line with those assessed by Trotter (2018), then benefit cost ratios of 1.1 to 1.3 should be achievable and conservative.

Attribution to the CPS Program

Total project resources for agriculture reported at $6 million, $3.3 million of which is CSIRO investment (24 per cent). If cost shares are a reasonable indicator of relative benefit shares, then CSIRO's investment in CeresTag and e-Shepherd could be valued at around **$3.6-$4.3 million** if a BCR of 1.1 to 1.3 is achieved (current dollars).

Royalty arrangements for CSIRO also serve to illustrate the value of CSIRO's contribution as it represents the willingness to pay of a party to acquire the technology. Based on annual royalty estimates provided by the CPS Program, royalties payable for CeresTag over 10 years are approximately **$4.8 million** in present value terms. This suggests that CSIRO achieved good value in its royalty arrangement and/or the expected BCR is closer to 1.5.

Interestingly, the report on LBS technologies found that while there was unlikely to be a need for publicly funded hardware development for tracking devices in general, there was an exception of the development of research grade hardware which might be shared across the livestock community to provide recommendations to commercial developers around sensor duty cycling and algorithm development.

These are two key fundamental research areas of the CPS Program, which supports the alignment of the group's research activities with public research benefits.

Economic value to underground mining

There is significant opportunity for productivity improvements – labour and capital – for the underground mining sector globally.

Underground mining is known to have much lower utilisation levels than surface mining, in the order of 35 per cent to 70 per cent.[11] These differences can represent significant differences in productivity and returns.

Based on industry wide benchmarking, McKinsey Global have estimated global average overall equipment effectiveness (OEE) performance to be 27 percent for underground mining, 39 percent for open-pit mining, and 69 percent for crushing and grinding activities — compared with 88 percent for upstream oil and gas, 90 percent for steel, and 92 percent for oil refining.[12]

The IoT, defined simply as 'the connection of objects such as computing machines, imbedded devices, equipment, appliances and sensor to the internet' has a growing number of case studies demonstrating the ways that it can add value to the mining sector. These productivity improvements work towards greater asset utilisation on a daily or shift basis, reduced lags related to maintenance activities, and enhanced health and safety outcomes. Some examples include:

- Anecdotal reports noting the potential scale of efficiency dividends from improved underground tracking systems in mines delivering:
  - savings of an average 1 hour per day of operations activities due to more timely diagnosis and rectification of mechanical issues, driven predominantly by a reduction of 10 per cent of over speeds, improved targeted training and reduced alarms and alerts
  - a 7.8 per cent saving in maintenance costs per ton of material hauled, annually
  - 20 minutes saved per event in evacuation and safety control test, and
  - generalized increase in equipment availability, costs, maintenance and operations[13]
- A quadrupling of production from 0.5 million to 2 million tons of gold was reported by Dundee Precious Metals in Bulgaria following the tracking of the location of miners and vehicles, automating building controls and utilising

11 Lee, J. et al (2014) Mining & Metals + Internet of Things: Industry opportunities and innovation. MaRS Discovery District.

12 https://www.mckinsey.com/industries/metals-and-mining/our-insights/how-digital-innovation-can-improve-mining-productivity

13 See Dawson, T. (2018) Newtrax helps Hecla Casa Berardi Mine exceed production objectives by 4% in 2018. Available at: https://www.newtrax.com/newtrax_helps_helca-casa-berardi-ine_exceed_production_objectives/ and Newtrax (2018) Transform your underground mining operations with solutions tailored to achieve your objectives in terms of safety, production, productivity. Available at https://www.newtrax.com/#Gold-fields-evacuation.

software that could map, model, estimate, design, schedule, simulate and manage production based on real-time data.[14]

- The 2008 European Commission EU Raw Material Initiative focused on increasing the sustainability of the raw material supply through a range of factors including automated boundary layer and material detection systems, an automatic guidance system for positioning and cutting, and an integrated modular system for process optimisation resulted in a 17 per cent improvement in efficiency and a 20 per cent reduction in costs for deep deposit mining production.[15]

While industry adoption of technology in mining has traditionally been mixed, the mining downturn is expected to spur greater focus on maximising efficiency and operation optimisation, with greater uptake of technology and use of analytics in coming years.

Analysis by the McKinsey Global Institute shows that the economic value of digitisation in mining can be considerable (chart 3.5). These values consider the efficiency lag that is currently being felt in the sector through generally low levels of adoption of digital technologies.

Estimates span the global mining sector, including both underground and open cut operations, and assume a high level of adoption of digital technologies towards a fully automated mining supply chain: 80 per cent in operations management and 100 per cent in equipment maintenance.

While it is not possible to isolate impacts in an Australian, or underground mining context, it is true that pervasive tracking technology such as that deployed by Minetec, utilising WASP, is able to influence the majority of these digitisation applications.

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14 Lee, J. et al (2014) Mining & Metals + Internet of Things: Industry opportunities and innovation. MaRS Discovery District.

15 Lee, J. et al (2014) Mining & Metals + Internet of Things: Industry opportunities and innovation. MaRS Discovery District.

3.5 Estimated value of digitisation to mining

Applications	Description	Potential economic impact of sized[a] applications in 2025
		$ billion, annually
Operations management	Deeper understanding of the resource base Optimisation of material and equipment flow Increase in mechanisation through automation Monitoring of real-time performance vs plan	250
Equipment maintenance	Improved anticipation of failures Reduced unscheduled breakdowns Longer equipment life	100
Health and safety	Minimised exposure to dangerous conditions	10
Equipment supply	Improved purchasing analytics Internet of Things-enabled R & D into cost-efficient equipment design	5
Human productivity	Augmented reality (built on better human-machine interaction) Tasked-based activity monitoring	5
Total		370

Source: McKinsey Global Institute – estimates based on high-adoption-rates case (80% in operations management and 100% in equipment maintenance).

[a] Sized applications are those applications for which the economic value has been analysed.

Economic value to the construction sector

Recent analyses of the construction sector note a strong lag in sectoral productivity compared to the global economy in general, and manufacturing sector in particular. McKinsey Global Institute (MGI) in 2017 noted that the global construction sector had observed an average annual productivity growth rate of 1 per cent, compared to total economy measures of 2.8 per cent annual average growth and manufacturing of 3.6 per cent annual average growth.[16]

MGI identified seven initiatives to improve construction sector productivity — widespread adoption of which could raise productivity by up to 60 per cent.

1 Reshape regulation and raise transparency

2 Rewire the contractual framework

16 McKinsey (2017) Reinventing Construction: A route to higher productivity.

3 Rethink design and engineering processes
4 Improve procurement and supply-chain management
5 Improve on-site execution
6 Infuse digital technology, new materials and advanced automation
7 Reskill the workforce. [17]

At least three of these (4, 5, and 6) are addressed through the Ynomia onsite application of BLEAT technology, which covers:

- asset management
  - decreased waste and safety risks
  - reduced overtime (waste management)
  - reduced budget pressures
- plant & equipment safety management
  - onsite visibility, location and auditing status
  - man > Machine 2 party verification
- real-time material flows
  - measured material workflows (site and workforce)
  - project timeline aligned with labour, material and machine productivity
- dynamic programming
  - historical data for better planning
  - better tendering data and project timing forecasts, and
  - establishment of risks and aiding go-no go decisions.[18]

Ynomia's market analysis estimates that the use of on-site locational technologies can reduce menial/overtime budgets by 50 per cent per major construction project (conservatively estimated at 2 per cent of average project value).[19]

The market analysis provides further details to the analytical scenario as follows:

- approximately 450 large scale construction projects, based on 1.5 cranes per project and a total Australian crane count of 684
- assumed market penetration of 10 per cent – or 45 large scale projects
- average project value of $1.5 million over 2 years (or $750 000 annually)
- Ynomia cost of $200 000 (assumed to include capital and development costs), and
- average net cost savings of approximately $1.3 million per two-year deployment.

While there are a number of areas of uncertainty in these figures, a first-round estimate of the average annual net benefits of the construction sector deployment is approximately $29.25 million at peak penetration of 10 per cent (with 45 projects achieving returns of $750 000 annually).

This level of market penetration could be achieved over time. Assuming adoption over ten years in line with a normal cumulative distribution (maximum annual growth in uptake in the middle years, and slower uptake to complete market

17 McKinsey (2017) Reinventing Construction: A route to higher productivity.

18 Ynomia (2017) Ynomia: Localise Anything. Presentation.

19 Ynomia (2017) Ynomia: Localise Anything. Presentation.

penetration in later years), the net present value of economic benefits to the construction sector could be worth $96 million over ten years.

These figures assume over the ten-year period:

- total number of projects deploying Ynomia is 243, and
- total cost of Ynomia product development is $15 million over 10 years in present value terms.

This implies a benefit cost ratio of 7.5, although does not include any research costs by CSIRO or other parties prior to Ynomia's product development costs. Table 3.6 provides a summary of the assumptions and calculations used.

3.6 Estimation of Ynomia economic returns

Element	Value
Discount rate %	7%
Peak market penetration at year 10 (projects per year)	45
Peak annual net cost savings per year $m	$29.25
Present value of cost savings over ten years $m (a)	$111.41
Cost of Ynomia per project $m (annualised)	$0.10
Net present value over ten years $m	$96.56
Net present value of Ynomia purchase costs $m (b)	$14.86
Benefit cost ratio (a)/(b)	7.5

Source: The CIE based on Ynomia market penetration and project level data

Attribution to the CPS team

In the absence of information on CSIRO investment costs, royalty returns are used as a proxy for the value of the input of the CPS Program to achieving economic returns to the construction sector.

It is understood that Ynomia paid almost $2 million over 10 years for the technology in present value terms, depending on the value of an equity swap, with CSIRO receiving 15 per cent of revenue.

This implies a benefit cost ratio for CSIRO's investment of 4.9, lower, but still favourable returns compared to the estimated returns to Ynomia.

PART A

Appendix

A Program outputs continued

Publications

K. Geissdoerfer, R. Jurdak, B. Kusy, M. Zimmerling, “Getting More Out of Solar-harvesting Systems: Energy Management under Time-varying Utility with PREACT,” International Conference on Information Processing in Sensor Networks (IPSN 2019), Montreal, Canada, April, 2019.

P. Sommer, K. Geissdoerfer, R. Jurdak, B. Kusy, J. Liu, K. Zhao, A. Mckeown, D. Westcott, Energy- and Mobility-Aware Scheduling for Perpetual Trajectory Tracking, IEEE Transactions on Mobile Computing, Published online, ISSN, 1536-1233, DOI: 10.1109/TMC.2019.2895336, February, 2019.

K, Li, C. Yuen, B. Kusy, R. Jurdak, A. Ignjatovic, S. Kanhere, S. Jha, Fair Scheduling for Data Collection in Mobile Sensor Networks with Energy Harvesting, IEEE Transactions on Mobile Computing, July, 2018.

A. Ahmed, R. Arablouei, F. De Hoog, B. Kusy, R. Jurdak, N. Bergmann, “Estimating Angle of Arrival and Time of Flight for Multipath Components Using WiFi Channel State Information,” Sensors, May, 2018.

P. Sommer, B. Kusy, P. Valencia, R. Dungavell, R. Jurdak, “Delay-Tolerant Networking for Long-Term Animal Tracking,” IEEE Internet Computing, 22(1):62-72, 2018.

K. Geissdoerfer, R. Jurdak, B. Kusy, “PREACT: Long-term energy-neutral operation under time-varying utility,” In proceedings of Information Processing in Sensor Networks, Porto Portugal, April, 2018. Winner of 2nd Place – Best Poster Award

V. Kumar, R. Arablouei, R. Jurdak, B. Kusy, N. Bergmann, “Multi-mode Tracking of a Group of Mobile Sensors,” In proceedings of the 20th IEEE Symposium on Wireless Personal Multimedia Communications (WPMC), Yogyakarta, Indonesia, December 2017.

V. Kumar, R. Arablouei, R. Jurdak, B. Kusy, N. Bergmann, “RSSI-Based Self-Localization with Perturbed Anchor Position, “In proceedings of the IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), Montreal, Canada, October, 2017.

K. Zhao and R. Jurdak, “Understanding the spatiotemporal pattern of grazing cattle movement,” Nature Scientific Reports, 6:31967 EP, August 2016.

M. Kaviani, B. Kusy, R. Jurdak, N. Bergmann, and V. Liu, “Energy–aware Forwarding Strategies for Delay Tolerant Network Routing Protocols,” Journal of Sensor and Actuator Networks, November, 5(18), 2016.

L. Salt, R. Jurdak, B. Kusy, “Hybrid Ensemble Learning for Triggering of GPS in Long-Term Tracking Applications,” International Journal of Hybrid Intelligent Systems, 13 (2016) 183–194.

V. Kumar, N. Bergmann, R. Jurdak, B. Kusy, “Cluster-based Position Tracking of Mobile Sensors,” In proceedings of The IEEE Conference on Wireless Sensors (ICWiSe), Langkawi, Malaysia, October, 2016. Winner of Best Paper Award

P. Sommer, J. Liu, K. Zhao, B. Kusy, R. Jurdak, "Information Bang for the Energy Buck: Energy- and Mobility-Aware Tracking," In proceedings of The International Conference on Embedded Wireless Systems and Networks (EWSN), Graz, Austria, February, 2016.Winner of Best Paper Award

L. Salt, B. Kusy, R. Jurdak, "Adaptive Threshold Triggering of GPS for Long-term Tracking in WSN," In proceedings of the 7th IEEE International Conference on Soft Computing and Pattern Recognition (SoCPaR), Fukuoka, Japan, November, 2015.

M. Kaviani, B. Kusy, R. Jurdak, N. Bergmann, K. Zhao, V. Liu, "Delay Tolerant Routing Protocols for Energy-Neutral Animal Tracking," In proceedings of The 3rd International Workshop on Energy Harvesting and Energy-Neutral Sensing Systems (ENSsys), co-located with ACM Sensys, Seoul, South Korea, November, 2015.

A. El Shoughry, B. Kusy, R. Jurdak, N. Bergmann, "Augur: A Delay Aware Forwarding Protocol for Delay-tolerant Networks," In proceedings of the IEEE International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), Abu Dhabi, UAE, October, 2015.

P. Sommer, B. Kusy, R. Jurdak, N. Kottege, J. Liu, K. Zhao, A. McKeown, D. Westcott, "From the Lab into the Wild: Design and Deployment Methods for Multi-Modal Tracking Platforms," Published online at Pervasive and Mobile Computing , September, 2015.

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R. Jurdak, "Long-term tracking in Batmon: Lessons and Open Challenges," Keynote Speech Abstract, in proceedings of the second Machine Learning for Sensory Data Analysis (MLSDA) Workshop, Gold Coast, Australia, December 2014.

G. Murtaza, S. Kanhere, A. Ignjatovic, R. Jurdak, and S. Jha, "Trajectory Approximation for Resource Constrained Mobile Sensor Networks," In proceedings of the 9th IEEE Conference on Distributed Computing in Sensor Systems (DCOSS), Marina Del Rey, CA, USA, May, 2014.

K. Li, B. Kusy, R. Jurdak, A. Ignjatovic, S. Kanhere, S. Jha, "κ-FSOM: Fair Link Scheduling Optimization for Energy-Aware Data Collection in Mobile Sensor Networks," In Proceedings of the 11th European Conference on Wireless Sensor Networks (EWSN), Oxford, UK, February 2014.

H. Parry, D. Westcott, A. McKeown, K. Zhao, Philipp Sommer, R. Jurdak, and B. Kusy, "Empirical agent-based simulation of movement: the integration of high frequency Flying-fox tracking data with a simulation model of population dynamics in time and space," In MODSIM2013, 20th International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2013, pp. 2506–2512. ISBN: 978-0-9872143-3-1.

P. Sommer, B. Kusy, and R. Jurdak, “The Big Night Out: Experiences from Tracking Flying Foxes with Delay Tolerant Wireless Networking,” To appear in proceedings of the Fifth Workshop on Real-World Wireless Sensor Networks (RealWSN), Como Lake, Italy, September 2013.

R. Jurdak, P. Corke, A. Cotillon, D. Dharman, C. Crossman, and G. Salagnac, “Energy-efficient Localisation: GPS Duty Cycling with Radio Ranging,” ACM Transactions on Sensor Networks, Vol. 9, Iss. 2, May 2013.

R. Jurdak, B. Kusy, P. Sommer, N. Kottege, C. Crossman, A. McKeown, D. Westcott, “Camazotz: Multimodal Activity-based GPS Sampling,” In proceedings of the 12th International Conference on Information Processing in Sensor Networks (IPSN), Philadelphia, USA, April, 2013.

R. Jurdak, B. Kusy, and A. Cotillon, “Group-based Motion Detection for Energy-efficient Localization,” Journal of Sensor and Actuator Networks. 1(3):183-216, October 2012. (Invited paper)

W. Xu, G. Lan, Q. Lin, S. Khalifa, N. Bergmann, M. Hassan, W. Hu. “KEH-Gait: Using Kinetic Energy Harvesting for Gait-based User Authentication System”, Accepted for publication in a future issue of the IEEE Transactions on Mobile Computing, 2018.

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S. Seneviratne, Y. Hu, T. Tham Nguyen, G. Lan, S. Khalifa, K. Thilakarathna, M. Hassan, A.Seneviratne, ”A survey of wearable devices and challenges”, IEEE Communications Surveys & Tutorials, vol. 19, no. 4, 2017.

G. Lan, W. Xu, S. Khalifa, M. Hassan, and W. Hu, “VEH-COM: Demodulating Vibration Energy Harvesting for Short Range Communication”, in proceedings of IEEE Percom 2017.

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Marzieh Jalal Abadi, Sara Khalifa, Salil S Kanhere, and Mahbub Hassan, ” Energy Harvesting Wearables Can Tell Which Train Route You Have Taken”, in the 10th IEEE LCN Workshop On User MObility and VEhicular Networks, Dubai UAE, November 7-10, 2016.

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S. Khalifa, M. Hassan, and A. Seneviratne, "Step detection from power generation pattern in energy-lharvesting wearable devices", in proceedings of IEEE iThings 2015, Sydney, Australia, 11-13 December, 2015.

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S. Khalifa, M. Hassan, and A. Seneviratne, "Pervasive Self-powered Human Activity Recognition without the Accelerometer", in proceedings of the (Percom 2015), St Louis, Missouri, USA, March 23-27, 2015 (Acceptance rate 14.7%)

Awards received

Our paper titled "Information Bang for the Energy Buck: Towards Energy- and Mobility- Aware Tracking" has won the Best Paper Award at the International Conference on Embedded Wireless Systems and Networks (EWSN) in Graz, Austria.

Camazotz wins the QLD State Merit iAward 2014

Distributed Sensing Systems student Sean Purdon won the IEEE Region 10 Best Final Year Thesis Award in All Fields of Electrical Engineering and Information Technology. Sean's thesis is titled "Collaborative Control of Mobile Nodes Using Wireless Sensor Networks", and was jointly supervised by Brano Kusy and Navinda Kottege.

Merit Recipient of the 2017 Asia Pacific ICT Alliance (APICTA) Award, commonly known as the "Oscar" of ICT industry in Asia Pacific, in the category of Research and Development for "KEH-Sense: game-changing technology for self-powering wearables", December 2017.

Merit Recipient of the 2017 National iAwards Research and Development Innovation of the year for "KEH-Sense: game-changing technology for self-powering wearables", August 2017.

Winner of the 2017 NSW iAwards Mobility Innovation of the year for "KEH-Sense: game-changing technology for self-powering wearables", June 2017.

Winner of the 2017 NSW iAwards Research and Development Innovation of the year for "KEH-Sense: game-changing technology for self-powering wearables", June 2017.

Winner of the 2017 John Makepeace Bennett award for the Australasian Distinguished Doctoral Dissertation, February 2017. Dissertation title "Energy-efficient Human Activity Recognition for Self-powered Wearable Devices". This Award is presented by CORE (Computing Research and Education Association of Australasia) for the best PhD thesis of the year within Australia and New Zealand in the field of Computer Science.

Winner of the 2016 "NASSCOM Highly Commended" award of the IT Technical Innovation category, April 2016. Innovation title "Efficient use of kinetic energy harvesting for self-powered wearables". The NASSCOM Student Innovation Awards promote innovation in the field of Information Technology and the competition was open for entire Australia.

Winner of the best poster award in the Work In Progress session in IEEE International Conference of Pervasive Computing and Communication (Percom2016, Rank A* conference). Poste title "Transportation Mode Detection Using Kinetic Energy Harvesting Wearables", March 2016.

Winner of the 2015 Canon Information Systems Research Australia (CISRA) Best Research Paper Prize at UNSW, November 2015. Paper title: "Pervasive Self-powered Human Activity Recognition without the Accelerometer". The prize is valued $2000 and a certificate form Deputy vice chancellor and the dean.

Winner of the best presentation prize over school of Computer Science and Engineering in the 2015 UNSW Engineering Postgraduate Research Symposium, November 2015. Presentation title" Energy-efficient Human Activity Recognition for Wearable Devices". The competition included 100 PhD students from all schools of the faculty of Engineering in UNSW, including 11 students from School of Computer Science and Engineering. The prize is valued $500 and a certificate from the Dean.

Winner of the best poster Award in IEEE Technologies of the Future (iToF 2015); Category of "Signal processing, imaging, and embedded systems", October 2015. Poster title "Enabling Battery-less Wearables: Tracking Activities from Body's Kinetic Energy". The competition was open for entire NSW universities and the prize comprising of a certificate and $500 cash.

Patents

J. Liu, P. Sommer, K. Zhao, B. Kusy, and R.Jurdak. "Position Tracking Method and Apparatus", WO/2015/149132 2015.

S. Khalifa, M. Hassan, and A. Seneviratne, "Energy Harvesting for Sensor Systems". (Provisional Patent Application No. 2016900941), filed on 14 March 2016.

S. Khalifa, M. Hassan, A. Seneviratne, and Wen Hu, "Energy Harvesting for Sensor Systems PART 2" (Provisional Patent Application No. 2016900940), filed on 14 March 2016.

S. Khalifa, M. Hassan, and A. Seneviratne, "Energy Harvesting for Sensor Systems PART 3, Activity Pulse" (Provisional Patent Application No. 2016900938), filed on 14 March 2016.