THE UNIVERSITY OF
SYDNEY

Australian
Centre for
Field Robotics

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20 November 2015

Committee Secretary
House of Representatives Standing Committee on Agriculture and Industry PO Box 6021
Canberra ACT 2600

By email: agind.reps@aph.gov.au

Inquiry into Agricultural Innovation

Thank you for your email on 21 October 2015 inviting further input from the Australian Centre for Field Robotics (ACFR) at the University of Sydney, for the Committee's new inquiry into agricultural innovation.

The information provided here is on behalf of the ACFR, elaborating further on the submission provided by the University of Sydney on 25 September 2015.

The role that automation will play in agriculture is significant, and the trend towards agriculture automation is global. The ACFR has extensive experience in the research and development of robotics and intelligent systems in agriculture, and has collaborated with a number of industry and government organisations in demonstrating these systems. The following link presents movies of the various ACFR agriculture robots and intelligent systems: www.sydney.edu.au/acfr/agriculture.

About the Australian Centre for Field Robotics

The Australian Centre for Field Robotics (ACFR) is based in the School of Aerospace, Mechanical and Mechatronic Engineering at The University of Sydney, and is dedicated to the research, development, application and dissemination of autonomous and intelligent robots and systems for operation in outdoor environments.

The ACFR is one of the largest automation research institutes in the world and has been instrumental in developing breakthrough technologies and in conducting world-leading research and development of robotic principles and systems, and in large-scale autonomous operations. Currently there are approximately 120 staff almost equally divided between PhD students, research fellows and systems engineers, undertaking R&D in a wide variety of automation programs, with approximately 90% of the ACFR's R&D funding from industry sources.

The ACFR has partnered with major national and international agencies in academia, government and industry, and has established a number of leading research centres funded by the Australian Research Council, mining, security, agriculture, aerospace and environmental industries and agencies.

The group has substantial experimental facilities including three laboratories and a field test site, a range of experimental and production vehicles, industry-quality mechanical and electrical design and fabrication facilities, and employs the latest in embedded computing, sensing and control technologies.

Examples of successful ACFR industry collaborations outside of the agriculture industry are provided at the end of this document.

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ACFR Examples of Automation in Agriculture

The ACFR has been undertaking research and development in automation for agriculture since 2007. The ACFR recognises that Australian agriculture has the potential to gain significantly from the benefits that automation can bring, including robotics for dealing with labour constraints; automation systems for precision and repeatable sensing and application of chemical and water inputs; intelligent software for automated information processing of large data; automated decision software support systems; and whole-of-value-chain optimisation. The ACFR also recognises that the agriculture industry can gain from the already substantial investment made and knowledge gained from other industries in the area of automation, and from the experience that the ACFR has developed in translating this research into operation.

Examples include:

- **Weed detection using drones:** funding from Land and Water Australia, the Australian Weeds Research Council, Meat and Livestock Australia, and NSW and Victorian DPI from 2007 to present. Recently the ACFR was awarded a two year program from the Northern Tableland Land Service under an Innovation Grant from the Department of Agriculture. The focus of these projects is on the deployment of drones and capturing multi-spectral data of large-scale areas at high precision. This data is then fed to automated information processing software running machine-learning algorithms for detecting and classifying individual weed species. The ACFR has engaged with various government agencies and growers in undertaking the research and in conducting workshops/field days for demonstrating the technology, and in educating the agencies about the potential and limitations of the technology.

The figure on the left is a robotic aircraft used to detect and spray aquatic weeds. On the right is a platform developed to detect woody weeds on cattle farms.

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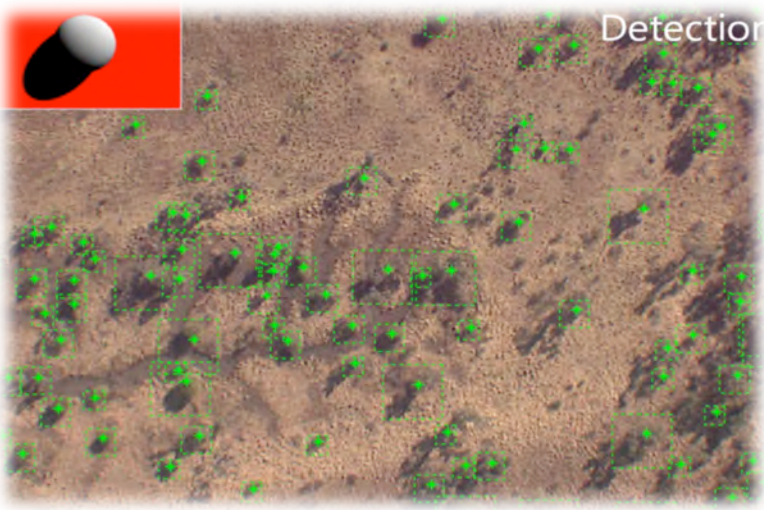
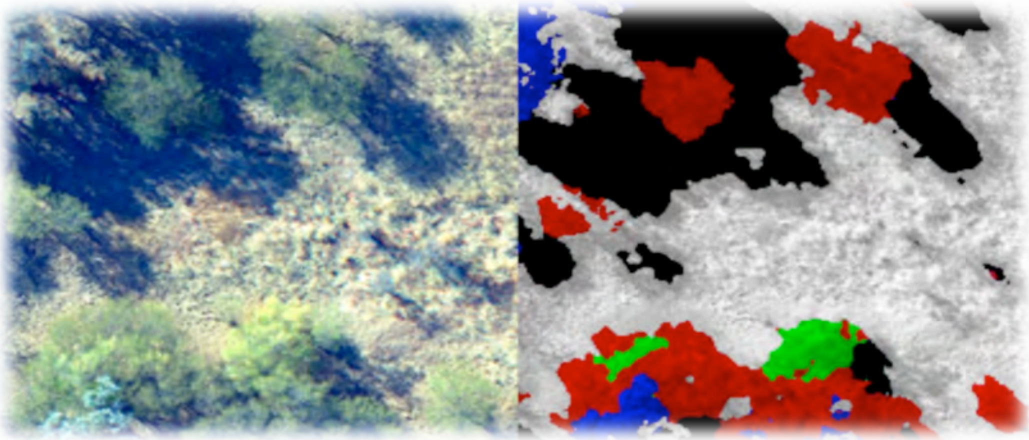


This figure shows the output of a software algorithm that can automatically detect individual trees and determine their volume. The software also uses the shadow footprint to infer the height of the tree.



Results from a machine learning classifier after the software has detected the trees. The different colours on the right present the classification results of the different types of trees. In this case the separation of native vegetation from woody weeds.

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- **Animal Detection and Tracking:** funding from Australian Research Council for using drones in detecting locusts and swift parrots. The technology focusses on developing flight control systems that dictate to the drone how to intelligently and autonomously track the animal based on signals received from radio tags on the animal. Research was also funded for 4 years by QLD Biosecurity to develop machine-learning techniques for detecting Red Imported Fire Ants from aerial surveys. Recent work has also looked at developing novel tracking algorithms on ground robots for detecting the location of dairy cattle in the paddock. The aim of this research is on gaining a better understanding of how animals behave in the field in order to determine measures for invasive species prevention, or for better management of animal health and environment sustainability.

This figure shows a robotic aircraft used for animal tracking. The antennae are used to detect signals from radio tags placed on the animals. The signal is digitised by the flight control system and used to autonomously change the flight trajectory of the robot.

The figure on the left shows an ACFR ground robot used in trials on a dairy farm. The robot can automatically detect and track individual cows as shown in the image on the right.

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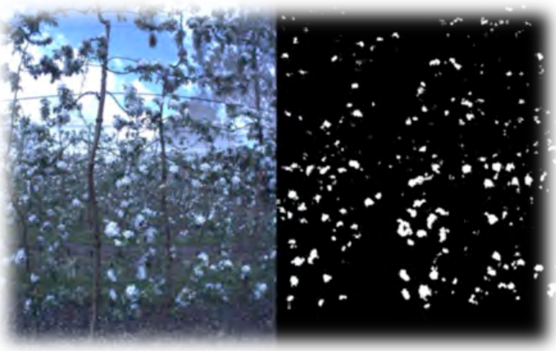
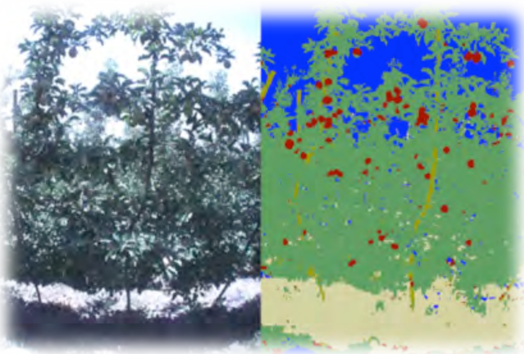
- **Tree Crops:** Since 2012 the ACFR has received funding from Horticulture Innovation Australia (HIA) to undertake research in autonomous precision agriculture with the aim of moving away from paddock management to individual tree and crop management. The ACFR has used ground robots with precision sensing capability to undertake research in novel software algorithms that can automatically process the large amounts of data collected. Capabilities demonstrated include individual flower and fruit detection in real-time providing unprecedented accuracy of the current status of the crop on-demand. The crops included apple, almonds, bananas and mango. The ACFR is currently part of a three-year project with HIA funded under the Department of Agriculture's Rural R&D program to extend this work into multi-scale and multi-seasonal scenarios.

This figure shows two ground robots and an aerial robot used in a series of projects to demonstrate the capability of autonomous individual tree crop management. The robots can collect detailed multi-spectral information down to the flower and fruit level.





The figures above show the output a software system using machine learning and classification algorithms that can automatically detect and geo-reference individual flowers and fruit. This information can be used to help the grower determine optimal pollination and harvesting times as well as precision spray routines.

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- **Vegetable Crops:** Since 2014 the ACFR has received funding from HIA and Ausveg to develop novel ground robots and intelligent software systems for the vegetable row crop industry. Two examples include the Ladybird Robot and RIPPA. The robots are battery operated and capable of operating for 10-12 hours. They are fitted with solar panels for automatic recharging and extending operational hours. Novel software using data analytics and machine learning provide automated systems for mapping the crops to millimetre accuracy and to detect the difference between crops and weeds, and to detect the different stages of crop growth. The robots also contain a precision fluid dispenser that can precisely spray fertiliser/pesticide onto the crop and weed.

The figure on the left shows the Ladybird Robot. It is a battery operated, solar powered platform, with adjustable wheelbase and wings so that it can accommodate different crops. The platform was designed as a research tool to demonstrate capabilities in novel locomotion, novel energy systems, and automated information processing. The image on the right shows the robotic arm inside the Ladybird Robot that can precisely detect individual crops and target them specifically with chemicals such as pesticide or fertiliser. The project also demonstrated the use of physical tools to mechanically remove weeds.

This figure shows RIPPA (Robot for Intelligent Perception and Precision Application). The project funding from HIA and Ausveg was to develop the next generation robot as a pre-production model that could operate autonomous 24/7 gathering detailed multi-spectral data of the vegetable crops, and precisely detect and target individual crops and weeds.

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Addressing the Terms of Reference

Emerging technologies relevant to the agricultural sector

Robotics, automation and intelligent systems (sensors, computing and software) will provide the capability of acquiring information and acting upon that information at unprecedented levels, as well as improving land and labour productivity. Farms of the future will be highly automated, with growers taking on an overall business role and supervision of the automated events in the field.

- **Robotic platforms –** various unmanned air, ground and marine based robotic platforms will be more readily developed, demonstrated and commercialised for use in agriculture that will be spurred by the rapid acceptance of 3D printing and optimisation software. This will provide novel developments that will not constrain growers to current systems offered in the market, but instead allow growers to tune their own platforms for their specific needs. For example automated manipulation systems that can handle specific types of crops and targeting of weeds without herbicide; robotic aircraft that can detect and handle/spray specific types of pests, or monitor animals; flexible robotic systems for better manoeuvrability around crops and animals; biodegradable micro and nano robotics for very small scale interaction with plants and animals; and robotic systems that can consume agriculture waste and use the stored energy for autonomous activity.
- **Sensors –** there are a number of novel sensors being trialled that can measure important information about the environment (soil, pasture, animal, weather) at various spectral frequencies. These will provide the agriculture community with information that has not been available before. Laser, radar, hyperspectral and biosensors are currently being researched for agriculture as well as automated spectroscopy techniques for the identification of invasive species and crop/animal health, and soil quality. The development of these sensors is occurring at a rapid pace with dramatic reductions in cost and size. This will lead to the ease of installing sensor networks on the farm that can measure a wide variety of information at high spatial and temporal frequencies. These sensor networks will have their own communication and processing systems and hence will not be impacted by the lack of fixed communication infrastructure.
- **Data Analytics and Decision Support Systems –** the sensors described above will acquire and fuse information on different scales (from millimetres through to kilometres) seamlessly providing a multi-faceted, multi-spectral view of farm production and a common operational picture for both the growers and the automated systems. Novel techniques in data mining and machine learning will help discover bio-physical patterns that were previously unknown. Agriculture is relatively data poor but model rich. As more data becomes available then our current agriculture models will be tested and modified if not completely discarded. This rich information will be processed via decision support software that will act locally by informing robotic systems to undertake specific actions (spray, selectively harvest, muster, remove, sense etc), on the individual animal and crop level, as well as on the global farm management level (potential revenue, timing of harvesting, logistics requirements, packhouse requirements etc). These global farm management decisions will be based on probabilistic bio-physical models – thus the output of these decision support systems will inform the farm manager of the potential outcomes given various decisions, to allow the manager to choose appropriate actions that meet his or her own business risk profile. Eventually, approaches in machine learning will advance to the point where these systems will learn the grower decisions and improve upon them.
- **Infrastructure –** the computing and communication infrastructure for agriculture will exist on the farm without a reliance on significant external infrastructure needs. Sensors and robotic systems will house enough communication and computational power to undertake the data analytics and decision support automation required and hence will be conducted in the field. The storage and transfer of the data is important when passing it onto the rest of the supply/value chain although this is minimal when compared to what happens in the field. Cloud-computing will be housed on the farm via the intelligent hardware that is operating in the field.

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Improvements in the efficiency of agricultural practices due to new technology, and the scope for further improvements

Current robotics and automation practices are already demonstrating improvements in land and labour productivity. Robotics provides a means to precisely and repeatedly undertake actions and thus reduce chemical inputs, minimise soil compaction, reduce operation costs such as fuel and maintenance, improve animal well-being, improve crop quality, reduce crop variability, and improve system performance because of better predictability.

The rate at which robotics and automation will expand and be adopted will be exponential because of the combinatorial explosion of the various technologies that make up these intelligent systems. Agriculture in Australia will be significantly aided by the technology adoption of robotics in other industries such as stevedoring, mining and aviation, and further improvements in the transfer of this technology across industries will support this adoption.

Furthermore, the opportunity exists to capitalise on the IP that can be generated from the incorporation of robotics and intelligent systems into agriculture. For example the IP developed and generated in the ACFR programs within other industries has been transferred globally, and a similar story could be played out in the agriculture sector.

Barriers to the adoption of emerging technology

- **Standards –** there is a lack of coordinated data and safety standards for agriculture robotic systems that is preventing their incorporation onto the farm. By developing these standards growers will be provided with the capability of easily implementing robotic and intelligent systems in a safe manner, it will open the market to new entrants, and prevent the siloing of technology to specific OEMs. Thus growers will have the freedom to plug-and-play hardware and software technologies from different providers that will meet their needs. This includes the incorporation of open-source software that will become more prevalent in the agriculture automation space.
- **Aging workforce and technology education (and re-education) –** the ageing farmer population is not only a concern in the decline of farming, but also in the adoption of emerging technologies such as robotics and intelligent software systems. There is a need to educate the new generation of growers as farm system managers using this technology. The education should also begin early with better incorporation of technology related subjects in rural primary and high schools including robotics as well as programs to educate current growers on the technology pathways and the rapid growth of the various sub-technologies (3D printing, computing, robotics, sensing etc). The ACFR experience has been extremely positive when undertaking STEM based robotics courses, with a growing awareness by the younger generation that agriculture can be rewarding sector when coupled with the digital experience. This has also been demonstrated repeatedly in other sectors (mining and stevedoring for example) that has opened up the opportunity for a wider range of people to be involved through robotics and digitisation

Examples of ACFR Industry R&D Achievements that would benefit Automation in Agriculture

- **Stevedoring:** In 1997 the ACFR and Patrick Stevedores formed a partnership to undertake research into the automation of straddle carriers, Autostrads, (machines that move containers around container terminals), concluding in 2005. This included the development of novel navigation and guidance systems, and in the automated optimisation of the stevedoring operation. The technology was adopted by Patrick Stevedores and implemented in the Port of Brisbane operations, and recently in Port Botany.
- **Mining:** The ACFR has had a long history of collaboration with various mining programs. Initially this research collaboration was part of the CRC in Mining. Work focused predominately on safety systems for driver and truck monitoring, and a company, Acumine, was formed to commercialise the technology. In 2007 Rio Tinto and the ACFR formed a long-term

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strategic partnership to support Rio Tinto's vision of "The Mine of the Future™". The focus of the collaboration is to develop theories, methods and tools for the automation of mine equipment and of complete mining operations. The ACFR plays a key role in the development of this technology and in the translation of the research into operation.

- **Security:** In 1999 the ACFR and BAE Systems formed a partnership to undertake research in the development of robotics and automation that concluded in 2011. The partnership focused on a broad range of activities including the research and development of unmanned air vehicles (UAVs or drones), unmanned ground vehicles (UGVs), and their interaction in autonomous operations. The projects were highly successful drawing in funding from various agencies.
- **Intelligent Transportation:** Since 2010 the ACFR has been collaborating with a number of industry partners in developing novel sensing, data fusion and optimisation algorithms for efficient transportation. Work has focused on intelligent ground transportation such as autonomous driving, vehicle to vehicle communication, and pedestrian tracking. Current research work with Qantas Airways has focused on developing novel flight planning and fuel prediction algorithms along with operational software that has demonstrated improvement in fuel burn and hence fuel savings.
- **Marine:** The ACFR has a significant R&D undertaking in sub-sea robotics with support from the Australian Research Council and IMOS (Integrated Marine Observing System through NCRIS) since 2006. The activity has supported extensive autonomous underwater surveying of marine habitats around Australia and internationally, in collaboration with marine biologists and archeologists. The marine robotics activity has worldwide recognition. Examples include the mapping of a first century BC ship wreck off the coast of the Greek island Antikythera, the surveying of ancient wrecks and hydrothermal vent sites in the Caribbean, and in the deployment of systems at Okinawa, Japan, for the study of hydrothermal vents.

I would like to invite the Committee to visit the ACFR at a mutually convenient time in order for members to gain a hands-on appreciation of the technologies that have been described in this submission. I would also welcome the opportunity to answer any further enquires.

Sincerely,

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Director of Research and Innovation at the Australian Centre for Field Robotics

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