DIGITAL FARMHAND

AGRICULTURAL ROBOTICS STUDY GUIDE

Australian Curriculum Linked
Teacher Resource Guide for Years 7-10

AGERRIS Field Robotics and Intelligent Systems

NSW GOVERNMENT

DIGITAL TECHNOLOGIES ▪ SCIENCE ▪ SUSTAINABILITY

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INTRODUCTION

This teaching resource links to the Australian Curriculum: Digital Technologies and Design and Technologies and is designed to assist educators to engage students in using the Digital Farmhand robot. The Digital Farmhand platform has been designed to assist smallholder farmers anywhere around the world to better manage yields and crop health as well as deal with weeds, pests and diseases. The guide fits well with the technologies contexts of Design and Technologies including engineering principles and systems, food and fibre production and materials and technologies specialisations. It is also relevant for Science and elective subjects in states and territories such as Agriculture.

Agerris is a robotics company that builds field robotic platforms such as the Digital Farmhand. The company's aim is to bring to all farmers the latest in air and ground-field robotic systems, intelligent tools and Artifical Intelligence (AI) solutions aimed at supporting their on-farm activities, improve farm productivity and to support environmental sustainability and animal welfare.

ABOUT THE GUIDE

The notes in this study guide offer both variety and flexibility of use for the classroom. You and your students can choose to use all or any of the five sections – although it is recommended to use them in sequence, along with all or a few of the activities within each section.

THE '5Es' MODEL

This resource employs the '5Es' instructional model designed by Biological Sciences Curriculum Study, an educational research group in the US state of Colorado. It has been found to be extremely effective in engaging students in learning science and technology. It follows a constructivist or inquiry-based approach to learning, in which students build new ideas on top of the information they have acquired through previous experience. Its components are:

ENGAGE

Students are asked to make connections between past and present learning experiences and become fully engaged in the topic to be learned.

EXPLORE

Students actively explore the concept or topic being taught. It is an informal process where the students should have fun manipulating ideas or equipment and discovering things about the topic.

EXPLAIN

This is a more formal phase where the theory behind the concept is taught. Terms are defined, and explanations are given about the models and theories.

ELABORATE

Students have the opportunity to develop a deeper understanding of sections of the topic.

EVALUATE

Both the teacher and the students evaluate what they have learned in each section.

USEFUL WEBSITES

AGERRIS
agerris.com

AGRICULTURE ROBOTICS AT THE UNIVERSITY OF SYDNEY
bit.ly/2HHvkRi

DIGITAL FARMHAND TRIALS - FIJI
bit.ly/2Lr1uV6

SALAH SUKKARIEH - BREAKING THE WALL TO SUSTAINABLE FARMING
bit.ly/2Jl8vnB

FIRST FIELD TEST OF SWAGBOT
bit.ly/2ZY4yv1

SWAGBOT AUTONOMOUS WEED SPRAYING DEMO
bit.ly/2DQJwFo

TREE CROP DEMO - FARMHAND AND SWAGBOT
bit.ly/2PR2Hn1

DIGITAL FARMHAND FIELD DEMONSTRATION
bit.ly/2JgbX2Q

CENTENARY HERO SALAH SUKKARIEH: AGRICULTURAL ROBOTICS
bit.ly/2H50zFD

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HOW TO USE THIS GUIDE

DIGITAL TECHNOLOGIES CURRICULUM

The *Agricultural Robotics Study Guide* covers 90% of the Australian Curriculum: Digital Technologies, with cross-curriculum links to Science, Asia and Sustainability. Pages 4-6 detail the links covered by all sections of the guide. Classroom activities have been individually mapped to the curriculum and appear on the relevant sections. For a full explanation of the codes refer to the Australian Curriculum website **bit.ly/ACDTlinks**

1. START HERE – INTRODUCTION & ENGAGE

Prepare your classroom for use of the Digital Farmhand.

- Read the information in the Teacher Background p8 – you can also share this with students.
- Use the 'Engage' activity p18 to start students thinking about the use of robots in agriculture (1-2 hour in-class activity).

2. GET READY TO CODE – EXPLAIN SECTION & AGERRIS TEAM VISIT

The robot will be delivered by the Agerris team. Before they come, you can do the following to help prepare:

- Read the Case Study of Junee High School's use of Digital Farmhand in the classroom on p35 and share with the school community.
- Provide students with background information on robots in agriculture using the Explain articles p31.
- Add the Agerris team visit to the school calendar.

3. USING THE DIGITAL FARMHAND – EXPLORE SECTION & DIGITAL FARMHAND CODING ACTIVITIES

Meet the Agerris team and the robot!

- The Agerris team will deliver the robot and introduce its use to the school.
- The class activities using the robot are delivered weekly by Agerris. These activities require iPads and the robot and must be carried out outdoors. The Digital Farmhand Activities are on p61 of this Guide.
- Concurrently, students can explore the Digital Technologies concepts through the Explore section on p20. These activities require minimal set up and help students learn more about how robots in agriculture work.

4. EXTEND ON STUDENT LEARNING – ELABORATE SECTION

Elaborate on student learning with additional activities not directly involving use of the robot.

- The Learning Matrix and linked classroom activities in the Elaborate section on p42 can be used flexibly to provide additional in-class activities related to the Digital Technologies Curriculum.

5. ASSESSMENT – EVALUATE SECTION

Project-based learning and self evaluation.

- The Evaluate section of the Guide on p85 provides students with an opportunity to evaluate what they have learned.
- You may want to consider a showcase demonstrating the robot and student designs and allow students to share and provide feedback on the projects and each other's work.

AUSTRALIAN CURRICULUM LINKS

DIGITAL TECHNOLOGIES	
YEARS 7-8	**YEARS 9-10**
DIGITAL TECHNOLOGIES KNOWLEDGE AND UNDERSTANDING	
Investigate how data is transmitted and secured in wired, wireless and mobile networks, and how the specifications affect performance **(ACTDIK023)** Investigate how digital systems represent text, image and audio data in binary **(ACTDIK024)**	Investigate the role of hardware and software in managing, controlling and securing the movement of and access to data in networked digital systems **(ACTDIK034)** Analyse simple compression of data and how content data is separated from presentation **(ACTDIK035)**
DIGITAL TECHNOLOGIES PROCESSES AND PRODUCTION SKILLS	
Acquire data from a range of sources and evaluate authenticity, accuracy and timeliness **(ACTDIP025)** Analyse and visualise data using a range of software to create information, and use structured data to model objects or events **(ACTDIP026)** Define and decompose real-world problems taking into account functional requirements and economic, environmental, social, technical and usability constraints **(ACTDIP027)** Design the user experience of a digital system, generating, evaluating and communicating alternative designs **(ACTDIP028)** Design algorithms represented diagrammatically and in structured English. Trace algorithms to predict output for a given input and to identify errors **(ACTDIP029)** Implement and modify programs with user interfaces involving branching, iteration and functions in a general-purpose programming language **(ACTDIP030)** Evaluate how student solutions and existing information systems meet needs, are innovative, and take account of future risks and sustainability **(ACTDIP031)** Plan and manage projects that create and communicate ideas and information collaboratively online, taking safety and social contexts into account **(ACTDIP032)**	Develop techniques for acquiring, storing and validating quantitative and qualitative data from a range of sources, considering privacy and security requirements **(ACTDIP036)** Analyse and visualise data to create information and address complex problems, and model processes, entities and their relationships using structured data **(ACTDIP037)** Define and decompose real-world problems precisely, taking into account functional and non-functional requirements and including interviewing stakeholders to identify needs **(ACTDIP038)** Design the user experience of a digital system by evaluating alternative designs against criteria including functionality, accessibility, usability, and aesthetics **(ACTDIP039)** Design algorithms represented diagrammatically and in structured English and validate algorithms and programs through tracing and test cases **(ACTDIP040)** Implement modular programs, applying selected algorithms and data structures including using an object-oriented programming language **(ACTDIP041)** Evaluate critically how student solutions and existing information systems and policies, take account of future risks and sustainability and provide opportunities for innovation and enterprise **(ACTDIP042)** Create interactive solutions for sharing ideas and information online, taking into account safety, social contexts and legal responsibilities **(ACTDIP043)** Plan and manage projects using an iterative and collaborative approach, identifying risks and considering safety and sustainability **(ACTDIP044)**

AC Digital Technologies links **bit.ly/ACDTlinks**

AUSTRALIAN CURRICULUM LINKS

DESIGN AND TECHNOLOGIES	
YEARS 7-8	**YEARS 9-10**
DESIGN AND TECHNOLOGIES KNOWLEDGE AND UNDERSTANDING	
Investigate the ways in which products, services and environments evolve locally, regionally and globally and how competing factors including social, ethical and sustainability considerations are prioritised in the development of technologies and designed solutions for preferred futures **(ACTDEK029)** Analyse how motion, force and energy are used to manipulate and control electromechanical systems when designing simple, engineered solutions **(ACTDEK031)** Analyse how food and fibre are produced when designing managed environments and how these can become more sustainable **(ACTDEK032)** Analyse ways to produce designed solutions through selecting and combining characteristics and properties of materials, systems, components, tools and equipment **(ACTDEK034)**	Critically analyse factors, including social, ethical and sustainability considerations, that impact on designed solutions for global preferred futures and the complex design and production processes involved **(ACTDEK040)** Investigate and make judgments on how the characteristics and properties of materials are combined with force, motion and energy to create engineered solutions **(ACTDEK043)** Investigate and make judgments on how the characteristics and properties of materials, systems, components, tools and equipment can be combined to create designed solutions **(ACTDEK046)** Investigate and make judgments, within a range of technologies specialisations, on how technologies can be combined to create designed solutions **(ACTDEK047)**
DESIGN AND TECHNOLOGIES PROCESSES AND PRODUCTION SKILLS	
Critique needs or opportunities for designing and investigate, analyse and select from a range of materials, components, tools, equipment and processes to develop design ideas **(ACTDEP035)** Select and justify choices of materials, components, tools, equipment and techniques to effectively and safely make designed solutions **(ACTDEP037)** Independently develop criteria for success to evaluate design ideas, processes and solutions and their sustainability **(ACTDEP038)** Use project management processes when working individually and collaboratively to coordinate production of designed solutions **(ACTDEP039)**	Critique needs or opportunities to develop design briefs and investigate and select an increasingly sophisticated range of materials, systems, components, tools and equipment to develop design ideas **(ACTDEP048)** Develop, modify and communicate design ideas by applying design thinking, creativity, innovation and enterprise skills of increasing sophistication **(ACTDEP049)** Work flexibly to effectively and safely test, select, justify and use appropriate technologies and processes to make designed solutions **(ACTDEP050)** Evaluate design ideas, processes and solutions against comprehensive criteria for success recognising the need for sustainability **(ACTDEP051)**

AC Digital Technologies links **bit.ly/ACDTlinks**

AUSTRALIAN CURRICULUM LINKS

SCIENCE	
YEAR 7-8	**YEAR 9-10**
SCIENCE AS A HUMAN ENDEAVOUR	
Scientific knowledge has changed peoples' understanding of the world and is refined as new evidence becomes available **(ACSHE119)** Science knowledge can develop through collaboration across the disciplines of science and the contributions of people from a range of cultures **(ACSHE223)** People use science understanding and skills in their occupations and these have influenced the development of practices in areas of human activity **(ACSHE121)**	Scientific understanding, including models and theories, is contestable and is refined over time through a process of review by the scientific community **(ACSHE157)** Advances in scientific understanding often rely on technological advances and are often linked to scientific discoveries **(ACSHE158)**
SCIENCE UNDERSTANDING	
PHYSICAL SCIENCE - YEAR 8 Energy appears in different forms, including movement (kinetic energy), heat and potential energy, and energy transformations and transfers cause change within systems **(ACSSU155)**	**PHYSICAL SCIENCE - YEAR 10** Energy conservation in a system can be explained by describing energy transfers and transformations **(ACSSU190)**
SCIENCE INQUIRY SKILLS	
Construct and use a range of representations, including graphs, keys and models to represent and analyse patterns or relationships in data using digital technologies as appropriate **(ACSIS129)** Reflect on scientific investigations including evaluating the quality of the data collected, and identifying improvements **(ACSIS131)**	Plan, select and use appropriate investigation types, including field work and laboratory experimentation, to collect reliable data; assess risk and address ethical issues associated with these methods **(ACSIS165)** Select and use appropriate equipment, including digital technologies, to collect and record data systematically and accurately **(ACSIS166)** Analyse patterns and trends in data, including describing relationships between variables and identifying inconsistencies **(ACSIS169)**

CROSS-CURRICULUM PRIORITIES

Sustainability:
In the Australian Curriculum: Technologies students consider economic, environmental and social sustainability. The Australian Curriculum places emphasis on sustainability as a priority for study that connects and relates relevant aspects of content across learning areas and subjects.

The premise behind the Digital Farmhand is to create a more sustainable future for farms and farmers globally. By discussion around introducing the Digital Farmhand into developing and developed countries, such as smallholder farms in Australia, students learn about sustainability.

Asia and Australia's engagement with Asia:
The Asia and Australia's engagement with Asia priority provides a regional context for learning in all areas of the curriculum. It reflects Australia's extensive engagement with Asia in social, cultural, political and economic spheres.

Discussion around the Digital Farmhand venturing into countries around the world meets the cross-curriculum priority of Asia and Australia's engagement with Asia.

AUSTRALIAN CENTRE FOR FIELD ROBOTICS, UNIVERSITY OF SYDNEY

FIELD ROBOTICS AND AGRICULTURE: TEACHER INTRODUCTION

As the world's population grows and our climate changes due to global warming, farmers face the challenge of producing enough food in a sustainable manner. Agricultural robots are being developed to assist farmers with these challenges by improving farm analytics and automating farm tasks such as weed control, harvesting, field scouting, seeding and bed preparation.

Digital Farmhand is a small, inexpensive and adaptable agricultural robot that can be used for many on-farm tasks. The robot is developed by Agerris Pty Ltd through research initially undertaken at the University of Sydney's Australian Centre for Field Robotics, and is one of a suite of agricultural robots making a difference to farms in Australia and overseas.

PART 1

BENEFITS OF FIELD ROBOTICS

The benefits of robots in agricultural contexts are varied and many. Robots undertake dull, dangerous, dirty and dear (costly) work.

• A robot can work longer hours at unusual times, such as spraying crops until three o'clock in the morning.

• Robots can perform repeated actions that cause injury to farmer's joints and muscles, such as Repetitive Strain Injury (RSI)

• Once a robot learns to do a task, that knowledge can be transferred to other robots

• Robots help farmers manage finite resources. For example by removing weeds so as to promote crop growth, or by precision spraying water on crops so that they get the right amount and a larger area can be watered.

FIELD ROBOTICS AND AGRICULTURE: TEACHER INTRODUCTION

AUSTRALIAN CENTRE FOR FIELD ROBOTICS, UNIVERSITY OF SYDNEY

AUSTRALIAN CENTRE FOR FIELD ROBOTICS, UNIVERSITY OF SYDNEY

ROBOTS CAN DO DANGEROUS WORK WITH MINIMAL RISK:

• Robots can work with chemicals that humans should not be exposed to in large quantities (although all chemicals are used with care, even when robots are using them).

• Robots can reach higher and wider places without having to use ladders or frames.

ROBOTS ENABLE GREATER PRECISION:

• Adding too much fertiliser can damage or kill crops, cause pollution and eutrophication (algal blooms).

• Adding too much water can leach out soil nutrients and further contribute to water pollution and eutrophication. Therefore the robot's precision spraying is paramount.

ROBOT READY

Before a robot like the Digital Farmhand is ready to take on a job – such as watering crops, planting seeds or weeding a crop bed – a lot of development, testing and teaching is required. Robots can be programmed to automatically learn and improve from experience. This is called machine learning, and is an example of AI. By showing the Digital Farmhand images of crops and weeds, for example, it can learn to differentiate between species, and target particular pest species with pesticides. This can reduce pesticide use, benefiting farmers and the environment.

Each farm has particular needs and every farmer does things differently. The landscape also differs from one farm to the next, so the Digital Farmhand needs to learn how to move and behave differently in each case. In developing countries, for example, crops are planted closer together due to relatively smaller land sizes and farming traditionally done by hand, so Digital Farmhand would need to be able to manoeuvre between tighter rows.

GETTING A MOVE ON

The Digital Farmhand can move autonomously by utilising sensors such as GPS, cameras and other sensors in order to navigate itself along a path. Alternatively, a farmer can control Digital Farmhand via remote control or by coding simple instructions to the robot.

The back (or 'dolly') wheels manoeuvre like the wheels of a shopping trolley. The front wheels control the steering by using different speeds on the right and left side in order to turn.

The robot is powered with batteries, which makes it more affordable, accessible and sustainable for farmers, particularly those in remote locations or developing nations.

HOW IS A ROBOT MADE?

Robot systems comprise of:

• The 'brain' is the computer which controls the robot and stores information. The internal electronics (battery, control boards, computer) bring it all together by reading information coming in, and the internal program decides what to do. That could be commands like: move forward, turn, start spraying, ask for help, go home and recharge.

• The 'body' is the structure and mechanical hardware. What it looks like depends on its purpose.

• Its 'mobility' refers to how it moves. Motors and drive controllers get the robot moving across different terrains and in different weather conditions. Actuators are used for raising and lowering implements, e.g. a hitch, seeder, spray arm, etc.

• Sensors help the robot monitor itself and 'see' its environment, e.g. cameras and GPS.

• Power activates the robot.

• Tools to do the work the robot is designed for, such as sprayers for water and chemicals, mechanical weeders for weeding, etc. Digital Farmhand can be adapted to many uses by adding different tools.

FIELD ROBOTICS AND AGRICULTURE: TEACHER INTRODUCTION

PART 2 ROBOTICS AND CODING

ROBOTS AND AGRICULTURE

There is a growing demand for using agricultural robots. Agriculture is changing to rely more on data analysis, technology and artificial intelligence. Through intelligent tools robotics can conduct non-chemical weeding, intelligent spraying and – very soon – harvesting. The AI mapping and decision system can link to the ground and air robotic platforms to detect weeds, count individual fruit, nuts, crops and animals, and provide overall crop, animal and environment assessment. This can include pest assessment, crop yield and animal tracking, all ultimately to support real-time, on-farm decision-making.

CAREERS IN CODING

Coding is an excellent skill to have as it can help solve problems and create innovative solutions. Learning to code can open many doors in your future career. People with coding skills can go on to be computer programmers, engineers, web developers, business intelligence analysts and plenty more.

LEARNING THROUGH DIGITAL TECHNOLOGIES

In the Australian Curriculum, engineering concepts are connected to the designed solutions in the Design and Technologies subject and also in Science (Physical science). Through the exploration of automation, coding and robotics, students can learn how data is transmitted and secured in digital technologies. By looking closely at the technology built into the Digital Farmhand, students gain a better understanding of how things work and how digital technologies can contribute to a more sustainable world. By designing, programming, exploring and researching, students can gain a better understanding of information systems and processes.

CODING, DATA AND THE DIGITAL FARMHAND

The Digital Farmhand is controlled using a microcontroller (MCU). A MCU is like a tiny computer. They can be very small so as to be embedded into everyday devices to control them. They typically control robots or devices so we don't need a keyboard and monitor to use them – we use a seperate computer to upload instructions (a program) to the MCU. When the MCU is powered it will run our instructions in a loop until we power down or replace the program.

There are many ways to acquire, analyse and visualise data using Digital Farmhand. The Digital Farmhand robot includes platform sensors that measure the robot's voltage, real speed and temperature. There are also external sensors like the camera, which gathers images and video that can be used to provide more information about the environment.

PART 3 ENGINEERING CONCEPTS

To design and build a robot, we need a number of different people from different fields of expertise depending on the function of the robot. A good understanding of design and technology will help build the physical systems and help the robot work correctly. A robot that functions outdoors requires a systems engineering approach that includes a combination of skills in software, mechanics, electronics and electrical engineering.

Engineering can encompass a wide range of concepts and responsibilities. In robotics, engineers are responsible for the design, build, testing and validation of the robots. There are many types of engineers that work together to make a robot such as the Digital Farmhand come to life.

Robotics relies heavily on the collective knowledge and expertise of engineers which spans multiple fields such as mechatronics, mechanical, electrical and software. Mechatronics engineers combine knowledge of mechanical, electronic and software systems to develop smart machines that are increasingly in use around us. Software engineers develop the code used to program the robot. A mechanical engineer will design, develop, build and test the robotic platform. They are also in charge of the physical make-up of the robot, i.e. its body. Electrical engineers look after the electronics, embedded systems and low-level programming.

In agricultural robotics, it's important for engineers to gain a solid understanding of the terrain and climate the robots will be working in as well as the type of plants and/ or animals the robot will need to interact with. A robot needs to be well-equipped and robust to be able to work outdoors; this means its design needs to take into account the environment, climate, weather and different types of soils and terrains it could potentially work in.

FIELD ROBOTICS AND AGRICULTURE: TEACHER INTRODUCTION

DIGITAL TECHNOLOGIES CONCEPTS

To control a robot we need to give it instructions. This is similar to giving an instruction to a friend, something like: "If it's raining, meet me at the shops". With robots we need to use computer code which gets formed into a program. Coding enables the automation a robot requires to do its job. Different languages are used in coding, like Java, Python, Perl or SmallScript.

Here are some common terms used in coding to help get you started:

Algorithm: A list of instructions in order to achieve a goal. For example, converting temperature values from Fahrenheit to Centigrade

Binary: A way of representing information using two states. Humans use decimal which means counting using 10 states, probably because we have 10 fingers so we count from zero to nine. Computers count from zero to one, similar to a light bulb being either off or on

Bug: An error in a program

Code: One or more commands or algorithms carried out by a computer

Function: A piece of code that you can repeatedly call. Functions are sometimes called 'procedures'.

If, ELIF and Else statements: These help to control the flow of a program, especially when decision-making is involved

Loops: Facilitates the execution of functions over and over

Statements: A single instruction like reading a temperature sensor

YEAR 7 – FORCES AND MACHINES

MACHINES AT WORK

Robots are machines that use forces in order to start, stop and balance. A force is a push or a pull. The forces listed on table one are all different types of pushes and pulls.

Table 1: Different types of forces

CONTACT FORCES Forces exerted when objects are in contact (touching)	**NON-CONTACT FORCES** Forces exerted by an object using an invisible force field
MECHANICAL A force where we can see objects pushing and pulling each other.	**GRAVITY** An invisible force between every object in the universe. Usually seen on Earth occurring between the massive Earth and falling objects on the Earth's surface.
FRICTION A contact force that occurs when objects rub against each other. Friction opposes the direction of motion of an object.	**ELECTROSTATICS** An invisible force between charged objects, i.e. objects with negative or positive charges.
BUOYANCY A contact force where a liquid supplies an upward force to balance the force due to gravity.	**MAGNETISM** An invisible force between magnetic objects and objects that can be influenced by magnetic objects.
SURFACE TENSION A contact force where the surface of a liquid (acting like a sheet of cling-wrap) supplies an upward force to balance the force due to gravity.	
AIR RESISTANCE A contact force that involves air particles pushing against a moving object.	

FIELD ROBOTICS AND AGRICULTURE: TEACHER INTRODUCTION

YEAR 8 – ENERGY

Energy is the ability to do work and is measured in units called joules (J). One joule of energy is used to lift a 100g mass, one metre. Energy is made useful when it can be transformed from one kind to another, such as light energy from the sun into chemical energy of a plant, or electrical energy into sound, light and heat energy in a computer.

There are two main categories of energy, potential energy (stored energy) and kinetic energy (the energy of movement). The overall energy in a closed system is neither created nor destroyed.

There are many examples of the ways in which robots use energy, from simply driving (kinetic energy) to energy storage (for example, energy stored in a robot's batteries). The battery drives a motor which produces energy in the form of mechanical energy as well as heat and sound.

Robots operate using electrical energy. Digital Farmhand can use energy from solar power or battery energy to function.

Table 2: Different types of energy

ENERGY TYPE	EXPLANATION	EXAMPLE
KINETIC	Movement	Moving car
GRAVITATIONAL POTENTIAL	Energy of an object that is high above the surface of a large body (e.g. the Earth)	A skier at the top of a ski slope
ELASTIC POTENTIAL	The energy an object has when it is stretched	A stretched rubber band
CHEMICAL POTENTIAL	The energy that is stored in chemicals	The energy in food
NUCLEAR	Energy released from atoms	The atomic reactions that occur in the Sun
SOUND	Energy caused by vibrating objects	Clapping your hands produces sound energy
HEAT	Energy caused by the vibration of particles within an object	An oven releases heat energy
LIGHT	Energy released from very hot objects or chemicals	Screens release light energy
ELECTRICAL	Energy caused by the movement of electrons	The lights in a house use electrical energy

FIELD ROBOTICS AND AGRICULTURE: TEACHER INTRODUCTION

YEAR 9 – HEAT TRANSFER

Heat transfer can occur via conduction (such as heat within a hot saucepan), convection (such as the convective heat within the Earth's mantle) and radiation (such as the heat energy from the Sun).

Conduction occurs between two objects in contact or within the substance itself due to the motion of particles within the substance. Different materials are more or less efficient at conducting heat: e.g. metal is a good conductor, while water, paper and air are poor conductors (insulators). Within a gas, conduction cannot take place as the particles are a (relatively) long way apart and do not touch each other. Radiation is heat transfer that can occur across the near vacuum of space. Electromagnetic waves from objects – such as the Sun – transfer heat energy when they encounter matter (like our skin).

When fluids are in motion, a type of heat transfer called convection takes place. When air becomes heated it becomes less dense and rises: the replacement of this warm air by cold, denser air is one example of convection and is what drives the large-scale convection currents that create wind and weather.

When heat is transferred from a hotter to a cooler object, the internal energy of each system is changed and heat may be lost according to the principles of the First Law of Thermodynamics: the change in internal energy of a system is equal to the heat added into the system plus or minus the work done in the system.

ENERGY TRANSFORMATION

Energy in its various forms is used by machines to do work. Energy may be stored (for example in a battery) or transferred from one form to another. For example, chemical energy in the battery is converted to electrical energy that powers the motors, which – through mechanical energy – drive the wheels and give Digital Farmhand its kinetic energy.

YEAR 10 – NEWTON'S LAWS OF MOTION

Newton's three Laws of Motion provide an insight into the forces and mechanics behind robotic movement and control.

NEWTON'S FIRST LAW

Every object persists in its state of rest or uniform motion in a straight line unless it is compelled to change that state by forces impressed on it. Newton's First Law of Motion, often called the law of inertia, states that an object will remain at rest unless acted upon by a force, and that once in motion, will remain so at a constant velocity unless acted upon by a force. This law is most important when considering what happens in stopping the robot or overcoming the forces of friction and gravity in order to make the robot move.

NEWTON'S SECOND LAW

$$F = ma$$

where, F = force, m = mass and a = acceleration

Newton's Second Law of Motion states that the force of an object is proportional to its change in momentum over time. Momentum is a function of mass and velocity, so the expression is often written such that the force of an object is equal to its mass multiplied by its acceleration.

NEWTON'S THIRD LAW

Newton's Third Law of Motion says that for every action there is an equal and opposite reaction. This is the reason we can drive in the first place. When we use a motor to spin the wheels of a robot, the force that the wheels exert on the surface results in an equal and opposite force by the surface pushing back on the wheels, and the robot accelerates forward.

PROFILE: PROFESSOR SALAH SUKKARIEH

PROFESSOR OF ROBOTICS AND INTELLIGENT SYSTEMS, UNIVERSITY OF SYDNEY

AUSTRALIAN CENTRE FOR FIELD ROBOTICS, UNIVERSITY OF SYDNEY

Salah Sukkarieh is the Professor of Robotics and Intelligent Systems at the University of Sydney and the CEO of Agerris, an agtech company that develops robots to improve agricultural productivity and environmental sustainability.

Professor Salah Sukkarieh has always been interested in robots, ever since he was a kid when he would take things apart and put them back together.

"I loved tinkering with electronics and mechanics when I was a kid. I pulled apart electronics at home: the car, bike, mower," he says.

After discovering a joy for exploring how things worked, he chose to take on further study in the area.

"When I got into uni I was going to do mechanical engineering and I found out they just started a new degree called Mechatronics Engineering (combining mechanical and electronics), so for me it was the right thing, and I haven't turned back."

In his last year of university, Salah worked on an exciting project where he created a robot that inspired him to carve out a career in robotics.

"It was in my final-year thesis where I built an underwater robot with my fellow engineers that it really kicked off that I wanted to be a robotics engineer," he says.

Over his illustrious career in robotics so far, Salah has celebrated many milestones and achievements.

He led the strategic research and industry engagement program in the Australian Centre for Field Robotics, the world's largest field robotics institute, as the director of research and innovation.

As an international expert in the research, development and commercialisation of field robotic systems, Salah has led a number of projects in robotics and intelligent systems in logistics, commercial aviation, aerospace, education, environment monitoring, agriculture and mining.

With a passion for robotics that is helping to create a more sustainable world, Salah works with a team of engineers that develop robots to improve farming practices and productivity. "For robotics to create a more sustainable world there needs to be some consideration to how they are used. They need to be easy to use and they need to be doing something useful that positively contributes economically, environmentally and socially," he says.

"Robots can really help with environmental sustainability because if they can work continuously, be very precise in what they do, and can do it repeatedly, then they have a lot to offer environmental monitoring and improvement, such as minimising the use of chemicals."

Salah is also working on new projects all the time to create a better world and make life a little easier for people in developing countries. – *Libby Parker*

FIELD ROBOTICS AND AGRICULTURE: TEACHER INTRODUCTION

TIMELINE OF FIELD ROBOTICS

The notion of robots can be traced right back to Ancient Greek mythology. As the field of robotics opened up in the 20th century, it was sometimes a case of life imitating fiction. The term 'robot' has its origins in the theatre, while science fiction authors such as Isaac Asimov have contributed ideas to a developing area that is now very much our reality. Today robots have countless applications in daily life, particularly in the workforce, and this will only continue to grow.

1890 The first remote-controlled vehicle is created by Nikola Tesla.

1908–1913 Ford Motor Company's production line for building cars is the first automation recorded.

1921 The word 'robot' is created by Czech author Karel Capek for his play *R.U.R.*

1936 Mathematician Alan Turing first theorises on the possibility of computers in his paper, *On Computable Numbers with an application to the Entscheidungsproblem*, calling this the 'Turing Machine'.

1942 Science Fiction author Isaac Asimov popularises the term 'robotics' and, in his story *Runaround*, devises the Three Laws of Robotics.

1948 Machina Speculatrix, thought to be the world's first electronic autonomous robots, are created by American-born, British neurophysiologist William Grey Walter.

1950 The Turing Test is devised by Alan Turing to work out whether a machine can truly think for itself.

1959 Massachusetts Institute of Technology (MIT) demonstrates the first computer-assisted manufacturing (CAM) process.

1961 General Motors in New Jersey uses an industrial robot, Unimate, in its automobile factory for the first time.

1966 The Stanford Cart, originally built to test the idea of roving the surface of the moon, reconfigured at the Stanford Artificial Intelligence Laboratory to experiment with the idea of self-driving vehicles.

1969 NASA uses robotics technology in the moon landing.

1983 The first 3D printer made by Chuck Hull.

1986 Mercedes Benz undertakes the first test-drive of a driverless car.

1992 First operation of the Lely Astronaut robotic milking machine, which becomes commercially available to dairy farmers in 1995.

1996 The Australian Centre for Field Robotics (ACFR) established.

1997 The Pathfinder Mission lands on Mars, including the robotic rover, Sojourner.

1990s Research into Simultaneous Localisation And Mapping (SLAM) algorithms allows robots to create a map of an unknown area and determine where on that map they are.

2000 ASIMO is released by Honda, a humanoid personal assistant robot that interacts with its environment.

2001 PackBots become the first robots used in a disaster response, searching the rubble from September 11, with the ability to go into areas too dangerous for humans or search dogs.

2002 The Roomba, an autonomous vacuum cleaner is released onto the market.

2002 American agricultural manufacturer Deere and Company introduce a GPS-based guidance system for its tractors.

2009 Adam, a robot scientist, is created by a joint project from Aberystwyth University and the University of Cambridge, designing and carrying out its own experiments.

2011 The Mars Science Laboratory Curiosity rover is launched by NASA.

2012 In the US, the first driverless car is registered.

2013 In Japan, a strawberry picking robot is developed by the company Shibuya Seiki.

2016 Australian Centre for Field Robotics invents Swagbot, the world's first cattle station field robot.

2016 First trials of the Digital Farmhand, a robot with row crop applications, occur in Indonesia.

2019 Wireless connections between vehicles becomes available, with the capacity to alert drivers to potential dangers and obstacles.

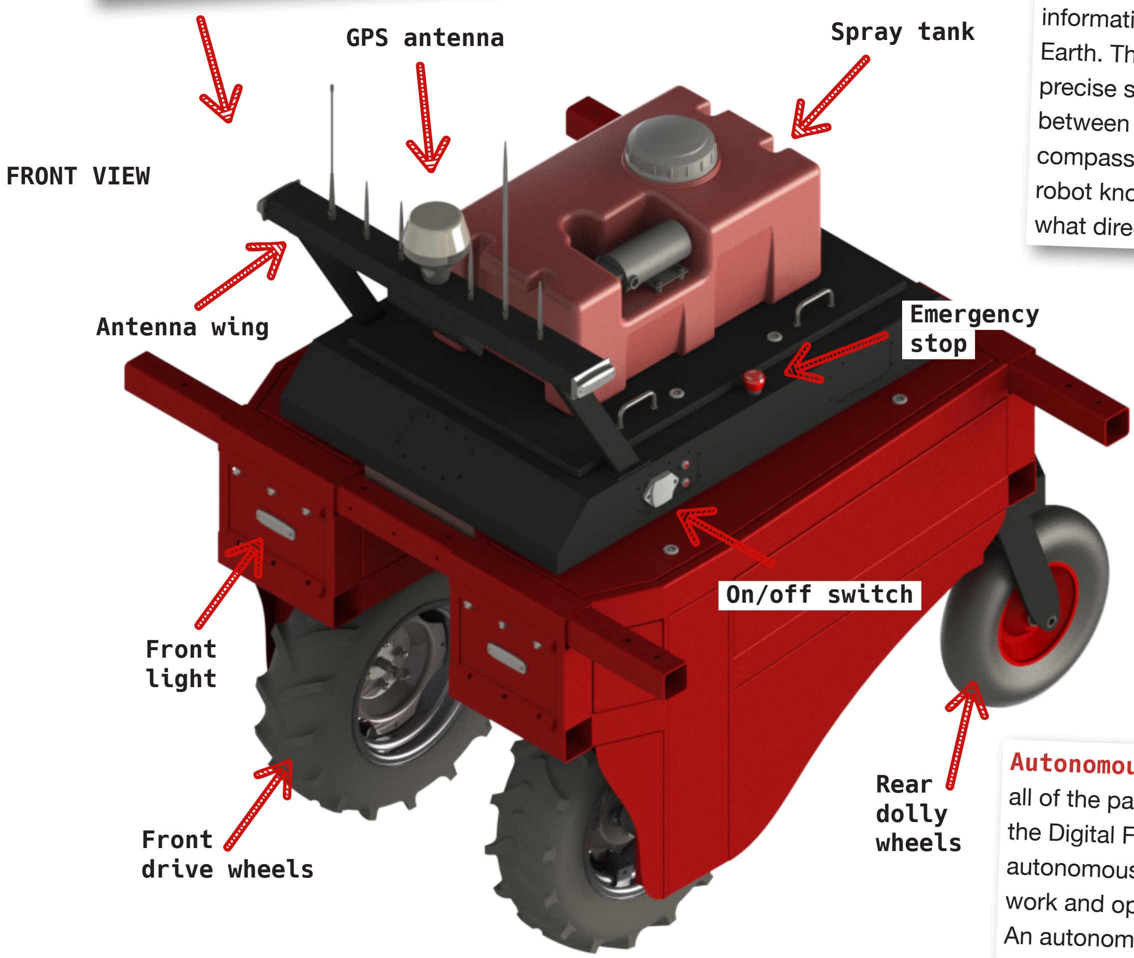
DIGITAL FARMHAND INFOGRAPHIC

INSIDE THE DIGITAL FARMHAND

Take a look at the systems and functions of the Digital Farmhand robot

Magnetometer – A digital magnetometer is used in the Digital Farmhand and works similarly to a compass. The magnetometer measures the magnetic field of the earth and can orientate the robot to a direction based on the magnetic field measurements. It is subject to a lot of interference though because of the metal on the robot affecting the magnetic field.

GPS – The Digital Farmhand can navigate using Global Positioning System (GPS) coordinates. GPS is a satellite-based navigation system that provides time and location information to receivers on Earth. The GPS needs to be precise so the robot can run between crops. The GPS and compass combined helps the robot know where it is and what direction it is taking.



Drive system – Electric drive, hydraulic drive and pneumatic drive are common drive systems used in robotics. A drive system gives the robot its capacity to move itself and its parts. The wheels in the body of the Digital Farmhand are moved by actuators powered by the drive system.

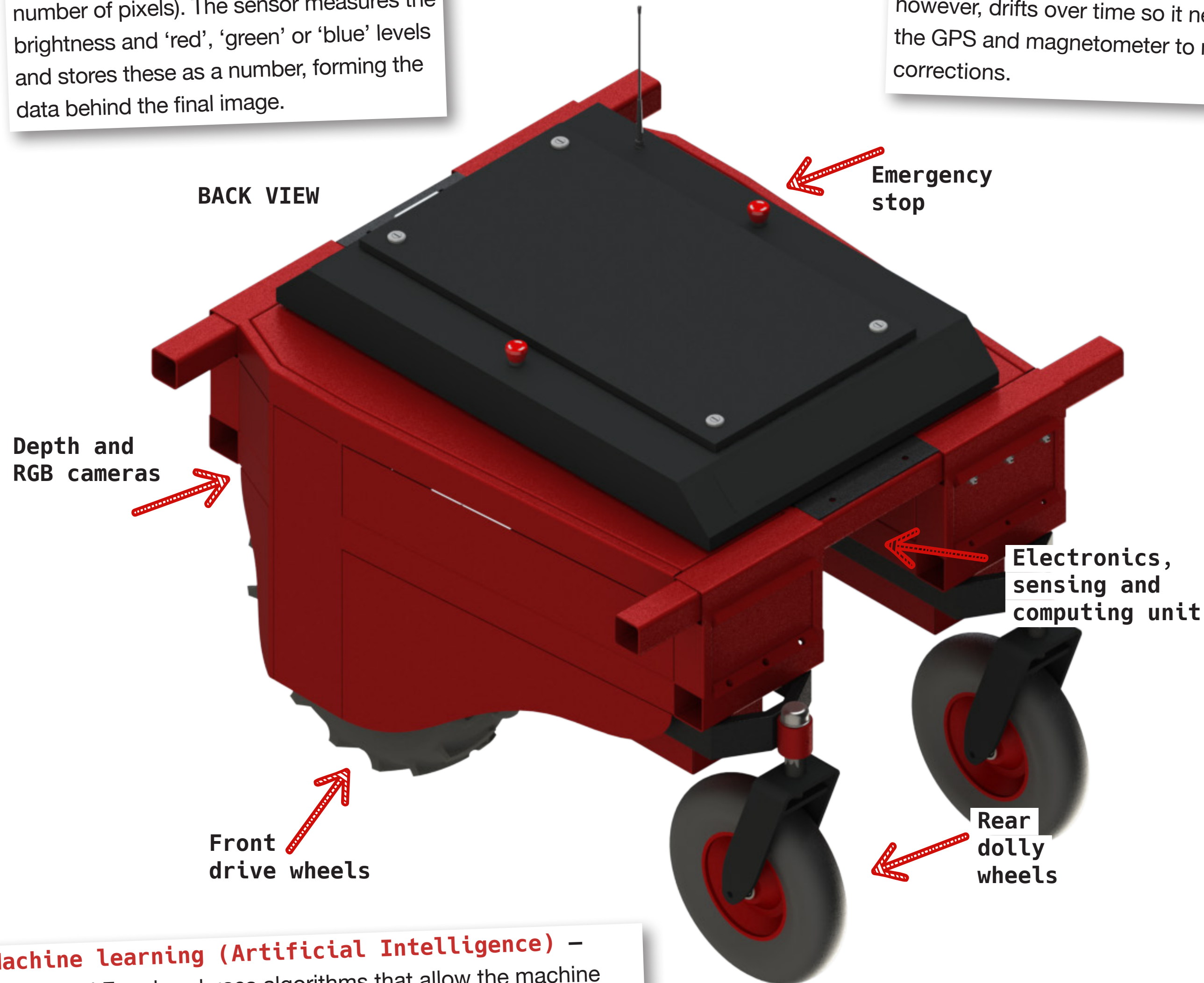
Autonomous systems – Once all of the parts are put together, the Digital Farmhand becomes an autonomous robot, where it can work and operate independently. An autonomous robot will gather information about the environment, work for an extended period of time without human intervention, move itself throughout its operating environment without human assistance and avoid situations that are harmful to itself or the environment around it.

DIGITAL FARMHAND INFOGRAPHIC

RGB camera – The Digital Farmhand uses a digital camera to gather data on its surroundings, learn from it and complete tasks. The camera captures light which is converted to electrical signals via a light detector called a charge-coupled device. Light hits the image-sensing device and is broken up into millions of pixels (it's also why some cameras have a better resolution – the image quality depends on the number of pixels). The sensor measures the brightness and 'red', 'green' or 'blue' levels and stores these as a number, forming the data behind the final image.

Depth camera – In order to detect and avoid obstacles, the Digital Farmhand needs a depth camera. This camera helps the Digital Farmhand stay on track and not bump into anything unexpected like an animal, person, branch or other obstacle.

Inertial Measurement Units (accelerometers and gyros) – An Inertial Measurement Unit (IMU) is made up of sensing devices called accelerometers and gyros (gyroscopes). Accelerometers are used to measure the Digital Farmhand's velocity, or speed, by detecting linear acceleration. Gyros are used to measure rotational rate, which can then give information about changes in the robot's heading and tilt angle. An IMU has the ability to track movement without needing outside references such as GPS and the magnetometer. Its measurement, however, drifts over time so it needs the GPS and magnetometer to make corrections.

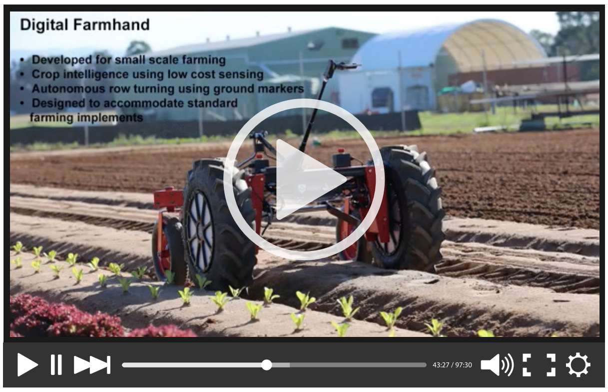


Machine learning (Artificial Intelligence) – The Digital Farmhand uses algorithms that allow the machine to effectively learn models of the world and can therefore be left to undertake tasks without the need for specific, ongoing instructions. Artificial Intelligence is gained by Digital Farmhand using Machine Learning techniques that are programmed so it can be left to complete jobs according to its code and instructions. This level of autonomy increases opportunities where technology can be applied while vastly decreasing the need for oversight, making things much more efficient for the user.

Decision-making – Planning and decision-making are critical components of an autonomous robotic system. An algorithm is set to guide the Digital Farmhand to make decisions ranging from path and motion planning to determining when to spray or weed.

ROBOTS SOLVING PROBLEMS IN THE FIELD

Watch the following clips and take a look at agricultural robots in action, then do the activity on the following page.



DIGITAL FARMHAND DEMONSTRATION
bit.ly/fieldrobodemo

WOODY WEED DETECTION
bit.ly/MLAproject

ALLIGATOR WEED DETECTION WITH UNMANNED AERIAL VEHICLES
bit.ly/AlligatorWeed

FRUIT DETECTION ON TREE CROPS
bit.ly/FruitDetection

TASK 1: MATCH SOLUTIONS TO AGRICULTURAL CHALLENGES

PROBLEM

A: Farming is tiring, physically demanding work which can sometimes be dangerous.

B: Organic farming typically requires 2.5 times more labour than conventional farming, but it yields 10 times the profit.

C: Agriculture is the largest employer in the world. In fact, 40% of the world's workers are employed in agriculture, meaning there is often a labour shortage in some areas.

D: Farmers tend to be considerably older than other workers. In 2011, the median age of Australian farmers was 53 years, compared with 40 years for people in other occupations. This is partly because new generations are less likely to join the agricutrual workforce.

E: Pesticides can be dangerous to farm workers and an estimated 2.3 billion kilograms of pesticides are applied to crops each year.

F: Farming is time-consuming and involved. In fact around 75% of farmers report spending 10 hours or more per day on the land.

SOLUTION

1. Robots can take the hard work out of farming and take risks humans should not.

2. Robots can endure longer exposure to chemicals, which can save the health and wellbeing of farm workers.

3. By programming a robot to understand the land and its qualities, the farmer can be confident more frequent checks on the land will occur and their farm is more regularly tended.

4. Robots can fill the gap left by the shortage of workers. Being autonomous, the robot can complete tasks it is programmed to do at various times of the day *or* night.

5. With robots to take the excess work required in organic farming, more profit can be made and more people can eat pesticide-free food.

6. As farmers grow older, they can rely on field robots to take on some of the heavy lifting, which frees up their time and they can retire sooner.

CHECK YOUR ANSWERS ON P68

TEACHER INFORMATION

The aim of the Explore section is for students to investigate some of the ideas around robotics. It is intended that students make their own discoveries as they work around the stations in the room. The list below outlines what is required.

STATION	EQUIPMENT
Station #1 Discovering the Digital Farmhand	Computer access to **digitalfarmhand.org**
Station #2 The Digital Farmhand in action	Computer access to videos: **bit.ly/2JgbX2Q** and **ab.co/2EFyJy9** and **bit.ly/2MaN2Rk**
Station #3 Remote devices	Remote-control car, obstacles to drive around (rows of desks and chairs)
Station #4 Navigating by GPS	Smartphone or handheld Global Positioning System (GPS) and a printed street directory (Google maps printout or street directory)
Station #5 Robot design	Selection of powered robotic toys or cars. They don't need to be expensive, just able to move independently.
Station #6 AI and data collection	Access to a computer and video: **bit.ly/2KctKs5**

STUDENT ACTIVITIES

STATION #1

TASK: DISCOVERING THE DIGITAL FARMHAND

1. Go to the website **digitalfarmhand.org**

2. Read through the information about Digital Farmhand and make dot points summarising:
   a) The way the robot works
   b) The main features and technology used in the robot
   c) The robot's benefits to the farming industry

3. In two columns, list the pros and cons of the Digital Farmhand:

Pros:

Cons:

STATION #2

TASK: THE DIGITAL FARMHAND IN ACTION

View the following videos demonstrating the Digital Farmhand: (YouTube video, one minute) **bit.ly/2JgbX2Q**, *The farming robots of tomorrow are here today* | The Future IRL (YouTube video, 10 minutes) **bit.ly/2MaN2Rk** and *Catalyst*, ABC video Series 18 *Farmer Needs A Robot* (56 minutes) **bit.ly/CatalystRobot** and answer the following questions:

1. How does an agricultural robot work?

2. What kind of data do field robots collect and how do they use it?

3. What are the problems the agricultural robots are trying to solve?

4. What are the challenges of using robots in agriculture?

5. What are the benefits of an autonomous robot on a farm?

6. Watch the section on Digital Farmhand in *Catalyst* (10:45–18:54). What challenges did Professor Salah Sukkarieh and his team face using the Digital Farmhand on the organic farm?

7. How have the farmers in the *Catalyst* episode benefited from the use of the robots?

8. What was Salah's goal in creating the robots? Did he achieve his goal?

STATION #3

TASK: REMOTE DEVICES

Field robots are controlled remotely or through programming. A robot that uses a remote control is similar to a remote-control car.

1. Set up a series of objects on your desk, in your classroom or outside similar to crops in a field. Navigate your way through the course with your vehicle.

2. Why is it important for the robot to be precise in its driving?

3. What challenges did you find?

4. How did you overcome the challenges?

STATION #4

TASK: NAVIGATING BY GPS

Global Positioning System, or GPS, is a satellite system owned by the US. Ground-based receivers (such as car SatNavs or smartphones) can exactly work out their position on Earth by receiving signals from four of the GPS satellites in orbit – like an upside-down pyramid, these four signals together precisely pinpoint the location of the receiver. GPS was once only used by the military and now anyone with a smartphone has access to the technology. The Digital Farmhand uses GPS among its tools in order to navigate its way through crops. You can read more on GPS here: **bit.ly/GPSExplained**. You can also read a brief history of GPS here: **bit.ly/GPSHistory**

1. Using a handheld GPS or smartphone with Google Maps, find your exact location:

2. Make an observation about how the GPS found your location:

3. Use the GPS to find the nearest sports oval and make notes about how to get there:

4. Use the printed street map or street directory to find the same oval:

5. Compare the process you went through to find the location through the two different tools. (Make notes about what was easy and what was challenging about each one). Was there any location where you had difficulty getting a signal? Why do you think this would happen?

STATION #5

TASK: ROBOT DESIGN

1. Examine the collection of toy robots.

2. What do you notice that is similar about the robots and what is different?

Similar:

Different:

3. How are they powered?

4. Can any of them sense their environment? How do they do this?

5. Make observations about how they move, plan and direct their course (navigate):

STATION #6

TASK: AI AND DATA COLLECTION

1. Research how AI and machine learning work in terms of data collection. Make dot points about how they work:

2. Research face-recognition technology and how it works. Make dot points of your findings:

3. List the ways face-recognition technology is used in your everyday life (Snapchat filters, border security etc.):

4. List the pros and cons of face recognition technology:

Pros:

Cons:

5. Watch the video **bit.ly/FacialRecPrivacy** and describe how face-recognition technology is being used around the world:

6. Define the following terminology used in face-recognition technology:

Surveillance:

Cross reference:

Data mining:

Image sensing:

Algorithms:

7. Do you think that you could use the facial-recognition technology to identify individual fruit on a tree, or a certain vegetable in a row of plants? Why, or why not?

TEACHER INFORMATION

In this section we explain the basics of field robotics, the breakdown of how robots work and what field robots are used for, by getting students to read articles. Through literacy activities and reading comprehension, students gain a better understanding and in-depth knowledge of field robotics.

Before reading each article, brainstorm with students what you already know about agricultural robotics. Start by looking at your school or farm tractor and what it's used for. Would it be best to turn a tractor into a robot, or build a robot from scratch? Start with the mind map on the next page.

Each article contains literacy activities such as a glossary and comprehension questions.

ARTICLE ONE FIELD ROBOTICS BASICS

ARTICLE TWO CASE STUDY: JUNEE HIGH SCHOOL'S DIGITAL FARMHAND PROJECT

ARTICLE THREE CASE STUDY: SWAGBOT – ROBOT COWBOY

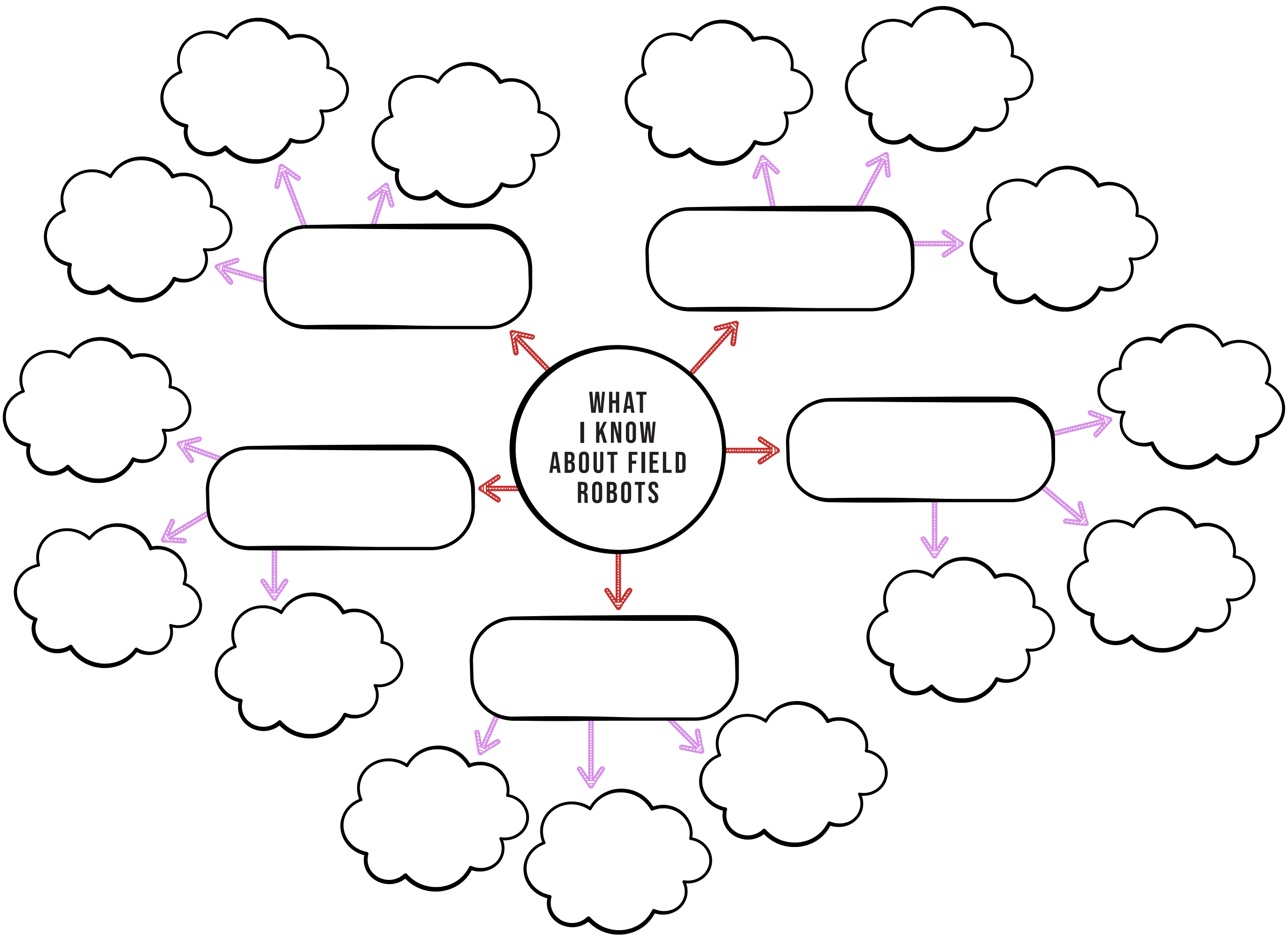
At the end, students draw together what they have learned by completing a *Questioning Toolkit*.

TASK:
BRAINSTORM WHAT YOU ALREADY KNOW ABOUT HOW FIELD ROBOTS WORK

Write dot points about what you already know about how robots work, how field robots work, what they are used for and where. What have you read about field robots? What have you seen on YouTube or television about field robotics? How are tractors used and how and why are agricultural robots different? Complete a mind map of your ideas.

What I know:

EXAMPLE CONCEPT MAP



ARTICLE ONE: FIELD ROBOTICS BASICS

AUSTRALIAN CENTRE FOR FIELD ROBOTICS, UNIVERSITY OF SYDNEY

ROBOTS ON THE FARM

Field robotics can help us improve the way we manage farms into the future

WHAT IS A FIELD ROBOT?

Field robots are automated vehicles that can operate outdoors in unstructured environments, such as farms, mine sites and in open fields. They can be small robots, like 2kg drones, or they can be as big as 400-tonne trucks.

Field robots can work independently of humans due to sensing, computing and coding, and they can collect data and learn from their environment in order to complete tasks. Robots use sophisticated guidance and navigation software to learn from their environment through the use of sensors such as GPS and navigation systems.

Agricultural field robots were developed to assist farmers, enabling some processes to be automated, such as weed control, harvesting, field scouting and imagery, seeding and bed preparation. Agricultural robots can help with major farming challenges, such as growing enough food for a large population using the same amount of land, reducing chemical use on farms and addressing labour shortages.

By creating an intelligent, autonomous robot that works all hours of the day – and be programmed to work in unstable terrains and climates – farming can be made easier and more accessible.

FIELD ROBOTICS IN AUSTRALIA

Over the past 20 years, Australia has been leading the way in field robotics. Agerris CEO and Professor of Robotics and Intelligent Systems at The University of Sydney, Salah Sukkarieh, says approaches and attitudes to robotics are changing, and ideas and innovations are rapidly evolving. “The classic

ARTICLE ONE: FIELD ROBOTICS BASICS

adage is that robots work in dull, dirty and dangerous roles; areas where humans don't want to be. Lately, the intelligence of these robots is getting better, and industries are seeing greater efficiencies to be gained by using robotics. In medicine, operations can happen with minimal injury to the patient using robotics, and robotic smart cars will minimise road accidents," he says.

"The most important advancement about 10 years ago was AI, or machine learning. The ability for robots to learn new things gave them a significant level of capability for many tasks we never thought manageable before," Salah continues. "The speed of AI means that robotic hardware, like the computers and sensors they use, is also rapidly getting better. The important developments recently are around 3D printing and the ability to build robots quickly."

FIELD ROBOTS IN AGRICULTURE

Salah and his team are building robots that will make a difference to farmers and create a more sustainable world.

"Farmers around the world are getting older and fewer people want to work on farms, because it's very hard labour. There are also many issues around climate change that mean new pests and diseases are hitting crops, and farmers are not able to keep up with dealing with these issues. Finally, there is the fact that farmers and the public want to see fewer chemicals used on farms," he says.

"For all these reasons we are trying to build tools to help farmers manage their operations. The Digital Farmhand is one such tool. It can continuously collect data about the crops and use machine learning to help the farmer identify crop growth as well as any diseases. We can add intelligent tools to the Digital Farmhand so it can do things like mechanical weeding (no chemicals) or spraying on crops but only needing to spray as much as the crop needs because our detection algorithms can determine this."

Agricultural robots can contribute effectively to farming in a number of ways:

HELPING FARMERS

- The average age of farmers is increasing. Robots can provide additional labour for ageing farmers.
- Robots can save the farmer the time, expense and trouble of labour hire, especially where labour is costly and hard to come by. Agricultural robots can be used for harvesting and picking crops, weed control, spraying water or pesticides, mowing, pruning and seeding.

IMPROVING FARMS

- Robots can limit the amount of chemicals used by mechanical weeding, or by spraying pesticides or fertilisers directly onto plants or the soil around the plants rather than over a wider area. This can save money and improve productivity.
- Data on crops and animals can provide more precise information about yields, allowing farmers to better plan for the future.
- Agricultural robots can provide real-time information about crops so that farmers can take actions quickly, for example identifying a pest or fungus and spraying these before they spread.

ADDRESSING SOCIAL CHALLENGES

- Increasing global population adds pressure to grow food for more people. Through improved analytics, field robotics can improve yields and reduce costs for farmers.
- Use of robots on farms increases the skill sets in rural areas as engineering, data science and software engineering are part of making the robots successful on farms.
- Agricultural robots can reduce the costs of producing food, therefore improving the economy.

AGRICULTURAL FIELD ROBOTS – HOW DO THEY WORK?

Field robots use technologies such as sensors, object identification algorithms, task-planning algorithms and tools for data collection and analysis. The robot includes a brain (computer), body (its outward structure), mobility (the way it moves), sensors (how it 'senses'), power (fuel or electricity) and intelligent tools to do the work.

The Digital Farmhand is an agricultural robot with two electrically powered wheel modules connected by a telescopic frame, with camera systems to collect data. The robot navigates using sensors such as GPS, ultrasound and cameras.

Digital Farmhand is particularly suited to smaller farms, where the cost of additional labour and equipment can be prohibitive. Its moving components include a motor, drive controller and actuators for raising and lowering tools. These tools can be adapted to whatever the robot is tasked with, for example water hoses, blades for cutting grass, or spraying. – *Libby Parker*

ARTICLE ONE: FIELD ROBOTICS BASICS

QUESTIONS FOR STUDENTS

GLOSSARY

TASK:

Use the table to define terms that are related to the article.

TERM	DEFINITION
ROBOTICS	
ARTIFICIAL INTELLIGENCE	
MACHINE LEARNING	
FIELD ROBOT	
GPS	
ALGORITHM	
PESTICIDE	
DROUGHT	
CLIMATE CHANGE	
ANALYTICS	

SUMMARISING

TASK:

Summarise the article features.

1. What are five issues faced by farmers today that field robots can help with?

1. __________

2. __________

3. __________

4. __________

5. __________

ARTICLE ONE: FIELD ROBOTICS BASICS

2. Explain how field robots are able to cope with the different environments from one farm to the next:

3. How is the infographic of the Digital Farmhand different from what you might expect a robot to look like?

4. Describe the different technology found in a field robot:

5. Which of the features listed above do you have experience in using? How is your usage of these different from the Digital Farmhand context?

6. Choose one feature that you are unfamiliar with and research its development and usage, making notes here:

7. The Digital Farmhand has only recently been developed. Predict whether its usage will become widespread in future years, giving reasons for your thoughts:

ARTICLE TWO CASE STUDY: JUNEE HIGH'S DIGITAL FARMHAND PROJECT

JUNEE HIGH SCHOOL'S DIGITAL FARMHAND PROJECT

A group of Junee High School students get to hang out with a robot and call it classwork

Junee High School is one of 20 regional New South Wales secondary schools involved in a statewide agricultural robotics STEM program where the programming of a Digital Farmhand robot is teaching students the specialised skill set demanded by an evolving agricultural industry.

"When the opportunity for this project came up last year we jumped at it," says the school's mathematics and information and software technologies teacher Matthew Hands, who first saw a version of the tech at Junee's Ag Vision day in 2015. He kept in contact with the developers and expressed his interest in the trial.

THE PROCESS

Digital Farmhand enables day-to-day tasks like weed control, harvesting, field-scouting and data collection to be automated. Seeders, sprayers and weeders can be added to the versatile robot, too.

"They have a number of sensors, cameras and motors that the students have learned to use," explains Matthew. "A lot of what we did was look at how these processes could be replicated in real-world scenarios." For the group, that meant engaging in day-to-day farming activities like setting the Digital Farmhand to gather data, remove weeds and spray crops.

ARTICLE TWO CASE STUDY: JUNEE HIGH'S DIGITAL FARMHAND PROJECT

AUSTRALIAN CENTRE FOR FIELD ROBOTICS, UNIVERSITY OF SYDNEY

While there was a lot of new coding to master, there was plenty of external support surrounding the project. The Museum of Applied Arts and Sciences in Sydney have provided the school with Arduino ThinkerShield Kits for coding lessons prior to working with the robot.

The school has also begun working with the Agerris engineers on class activities relating to the robot. They've now successfully run the teaching program with a group of eight interested students, who were taught the coding system for controlling the robot remotely via a series of weekly, one-hour video conferencing sessions.

Year 10 robotics student George says that although he'd been introduced to basic block coding in class, he knew nothing about this kind of programming before starting out. "I went from having absolutely no idea, to coding the Digital Farmhand in about eight weeks," he explains. "Fixing our own coding mistakes was the hardest part."

Matthew says he also needed to develop his own coding knowledge to assist his students when they got stuck in the coding process. "One spelling mistake or misplaced capital letter can ruin a whole program of code," he says, and credits the self-motivation, problem-solving and teamwork skills of his students for their success in the process.

Although George spends most of his school day with robots, he jokes that they haven't taken over his entire life just yet. He is keen to study them further though. "I'm looking to hopefully become an engineer," he says. Something that the agricultural industry will no doubt be needing a lot more of, very soon. – *Cassie Steel*

QUESTIONS FOR STUDENTS

SUMMARISING

TASK:

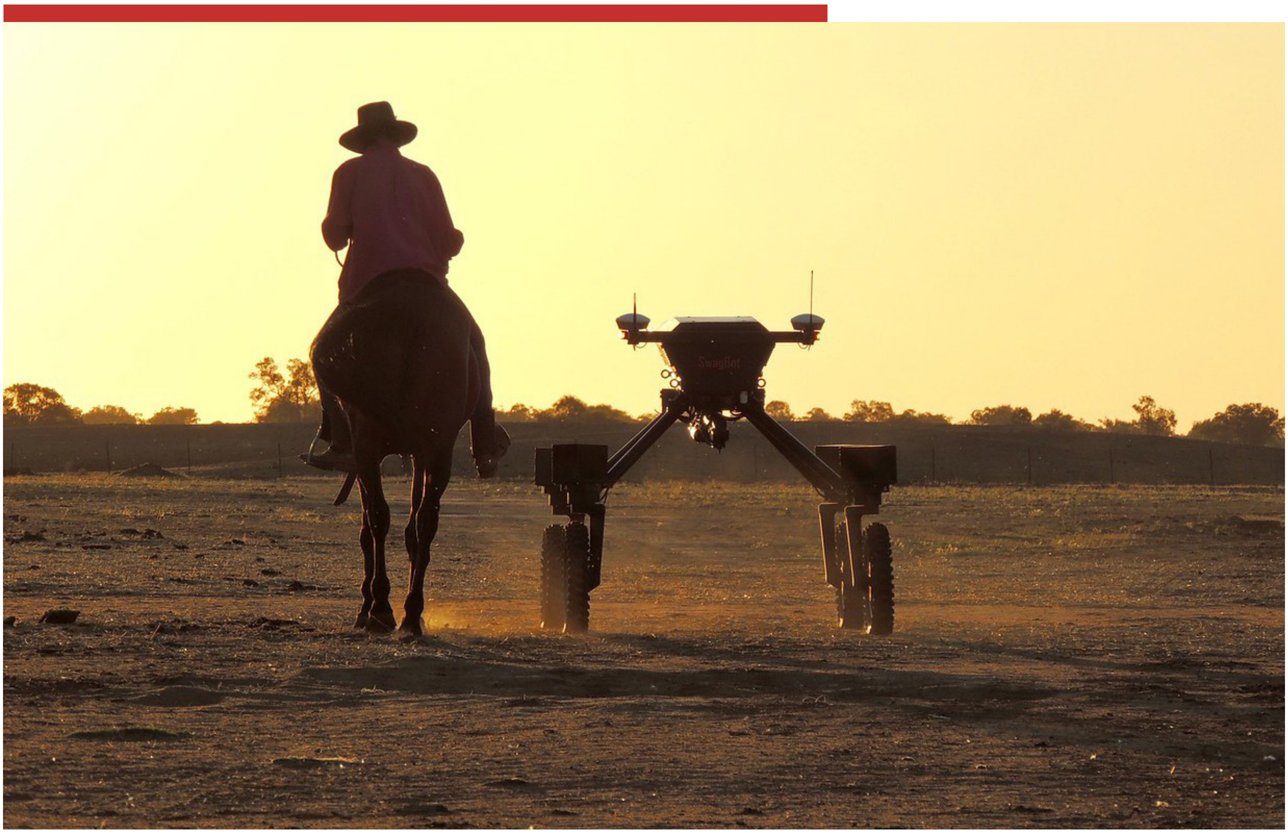
Summarise the article features.

1. According to this article, what are some of the benefits of the Digital Farmhand?

2. What was one of the major challenges for the students and teacher in this experience?

3. Discuss the benefits of experiencing this kind of robot at your school:

ARTICLE THREE CASE STUDY: SWAGBOT, THE ROBOT COWBOY



ABC

SWAGBOT, THE ROBOT COWBOY

SwagBot is the world's first agricultural robot developed for the grazing livestock industry

Wide open spaces and challenging terrain are characteristic of Australian farmland. It can take days to muster cattle on properties that stretch thousands of square kilometres across inhospitable land. Farmers face severe tests of their resources to move stock around to new pastures, monitor and prevent the spread of weeds, and get equipment to where it's most needed.

Enter SwagBot, the only robot in the world that's been developed to work with grazing livestock. SwagBot is uniquely suited to the Australian landscape. This versatile robot can lead cattle to new pastures, for example, or provide vital information on pasture and stock health. It can also identify and manage weeds – using machine learning to identify particular weed species.

With easily added attachments it can target pest species with pesticides, and, since it's able to identify particular species and control the amount of chemicals delivered, can reduce the quantity of pesticides used to manage grazing land, saving farmers time and money.

Using GPS, and working in tandem with drones, SwagBot can work out the best routes to monitor and control pest species, providing a valuable round-the-clock assistance to stock managers. It can also gather data to help farmers estimate pasture coverage and yield.

SwagBot gathers visual data and can understand texture and shape in the landscape, and using laser data can provide precise measurements of distance, for example.

ARTICLE THREE CASE STUDY: SWAGBOT, THE ROBOT COWBOY

ABC

ALL-TERRAIN VEHICLE

With a rugged chassis and all-wheel drive, SwagBot can move through water, down steep road offcuts and over obstacles like fallen trees. It can haul a trailer with feed or equipment to where it's most needed.

With the addition of temperature and motion sensors to detect changes in body temperature and walking gait, this remarkable robot could also provide information on animal health, and valuable assistance to farmers facing the challenges of managing grazing animals on large farms.

GETTING FAMILIAR

In 2017, Rod Kater and his family – wife Penny and daughter Annabel – were part of an early trial of SwagBot with their herd of 3000 beef cattle across two properties in western New South Wales.

"The most time-consuming thing is assessing the pastures and moving the cattle in a timely fashion, rather than waiting until they've eaten too much in one area," Rod told ABC program *Catalyst*, which filmed the trial.

In the trials, the cattle quickly adapted to the presence of SwagBot, especially as SwagBot towed a tray of tempting feed. With added technology, it was even able to entice the cattle to follow a recording of Rod's voice – proving that the robot could be used to independently move cattle from one pasture to another.

SwagBot is also able to work all day (and even all night) long in the hot, arid conditions of inland Australia.

"I'm not worried that it may take over the work on the stations," says Rod. "I think it will make cattle stations more efficient. Technology is definitely part of the future of primary production." – *Heather Catchpole*

SWAGBOT AUTONOMOUS WEED SPRAYING DEMONSTRATION
bit.ly/SwagbotDemo

SWAGBOT ON CATALYST (00:00-10:45)
bit.ly/CatalystRobot

SWAGBOT: THE FIRST ROBOT COWBOY (NEWSCIENTIST)
bit.ly/NSSwagBot

QUESTIONS FOR STUDENTS

GLOSSARY

TASK:

Match the terms in the article to the definitions.

TERM	DEFINITION
A. UNDULATING TERRAIN	1. Land that rises and falls
B. ANIMAL WELFARE	2. Pest plants on otherwise grazeable land
C. DRONE	3. Providing for an animal's mental and physical needs
D. LIVESTOCK	4. The base frame of a vehicle
E. PASTURE	5. Information provided by firing an intense beam of light
F. LASER DATA	6. A flying aircraft without a human on board
G. CHASSIS	7. Land covered in plants suitable for grazing animals
H. PASTURE WEEDS	8. Animals raised in a domesticated setting – such as a farm

CHECK YOUR ANSWERS ON P68

TASK:

Choose one of the following activities to summaries what you've learned about the Agerris agricultural robots.

1. Create a podcast comparing the pros and cons of SwagBot and Digital Farmhand.

2. Create an infographic to summarise the information from the three articles.

COMPLETE THE QUESTIONING TOOLKIT BELOW

Write your ideas and opinions relating to each of the different types of questions.

[Inspired by Jamie McKenzie's *Questioning Toolkit*. Further reading on questioning toolkits: McKenzie, Jamie (2000) *Beyond Technology*, FNO Press, Bellingham, Washington, USA. bit.ly/QToolkit

TYPE OF QUESTION	YOUR IDEAS AND OPINIONS
ESSENTIAL QUESTIONS These are the most important and central questions. They probe the deepest issues that confront us and can be difficult to answer. **QUESTIONS** For what purpose was the Digital Farmhand developed? Who is likely to benefit most from this technology? How can field robots help to create a more sustainable planet?	
SUBSIDIARY QUESTIONS These questions help us to manage our information by finding the most relevant details. **QUESTIONS** How are SwagBot and Digital Farmhand both similar and different robots? What important technological developments are used in these robots?	
HYPOTHETICAL QUESTIONS Questions designed to explore the possibilities, the "what ifs?" They are useful when we want to test our hunches. **QUESTIONS** Do you think the usage of Digital Farmhand will become widespread in future years? Why/why not? Can you think of a new context where a field robot like this would be useful?	
PROVOCATIVE QUESTIONS Questions to challenge convention. **QUESTIONS** What impact could field robots have on the labour market? What are the challenges posed by this new technology? What are the benefits that this technology will have in rural areas?	

LEARNING & ACTIVITY MATRIX

WHAT IS THE LEARNING MATRIX?

A learning matrix is a flexible classroom tool designed to meet the needs of a variety of different learning styles across different levels of capabilities. Students learn in many different ways. The matrix provides a series of suggestions and activities from which teachers and/or students can choose.

The matrix is designed to be time flexible as well as educationally flexible. Choose to complete one activity, or as many as you like.

You can also set up the matrix for student assessment – e.g. by assigning points to completed activities.

SCIENTIFIC PROCEDURE	Hands-on activities that follow the scientific method. Includes experiments and surveys
DESIGN YOUR OWN	Students design and carry out their own investigations
STEM PHILOSOPHY	Thinking about STEM and its role in society. Include discussion of ethical issues, debates and hypothetical situations
BEING CREATIVE	Creative thinking in STEM
STEM IN CONTEXT	Here we consider the technological developments of society by looking back in time or travelling creatively into the future

ACTIVITIES MATRIX

	YEAR 7	YEAR 8	YEAR 9	YEAR 10
SCIENTIFIC PROCEDURE	Examine the forces that make the Digital Farmhand move over crops.	Examine the method and process behind the image recognition that aids in data collection in the Digital Farmhand.	Examine the connection and interaction of the image recognition, robotics and data collection which allows the Digital Farmhand to work effectively.	Examine the workings of a robotic system that will be used in a farming area and can be controlled remotely.
DESIGN YOUR OWN	Design your own robot that can navigate around obstacles and be controlled remotely using upcycled materials. See Linked Activity 1.	Imagine you have a business that needs to keep across its inventory control. Design your own image-recognition system and use it to collect data for your business.	Imagine you are a farmer. Design your own data-collection system that will allow you to keep track of your crops to keep your farm functioning.	Design your own robot with a data-collection feature that will make a positive difference in a developing country.
STEM PHILOSOPHY	In pairs or small groups, debate the pros and cons of using robots/Artificial Intelligence (AI).	Find examples from popular culture that explore the dangers of relying too heavily on technology and suggest ways that we could avoid this in our current and future use of AI technology.	What possible problems might be caused by current data-collection practices? Suggest ways that we could safeguard ourselves from these.	Discuss the topic: access to technology is a human right.
BEING CREATIVE	Work in small groups to brainstorm and discuss where and how the Digital Farmhand technology could be used other than on small farms. Choosing one of these new contexts, identify a problem that could be solved and consider how this technology would need to be adapted to work effectively in this situation.			
STEM IN CONTEXT	What are three examples of everyday technology that you use that would be difficult to live without? Discuss what life would be like without these.		What are some of the ways that robots have changed our world? Predict new ways they could be used in the future and how this could make life easier for different segments of the population such as farmers, aged people, children and families.	

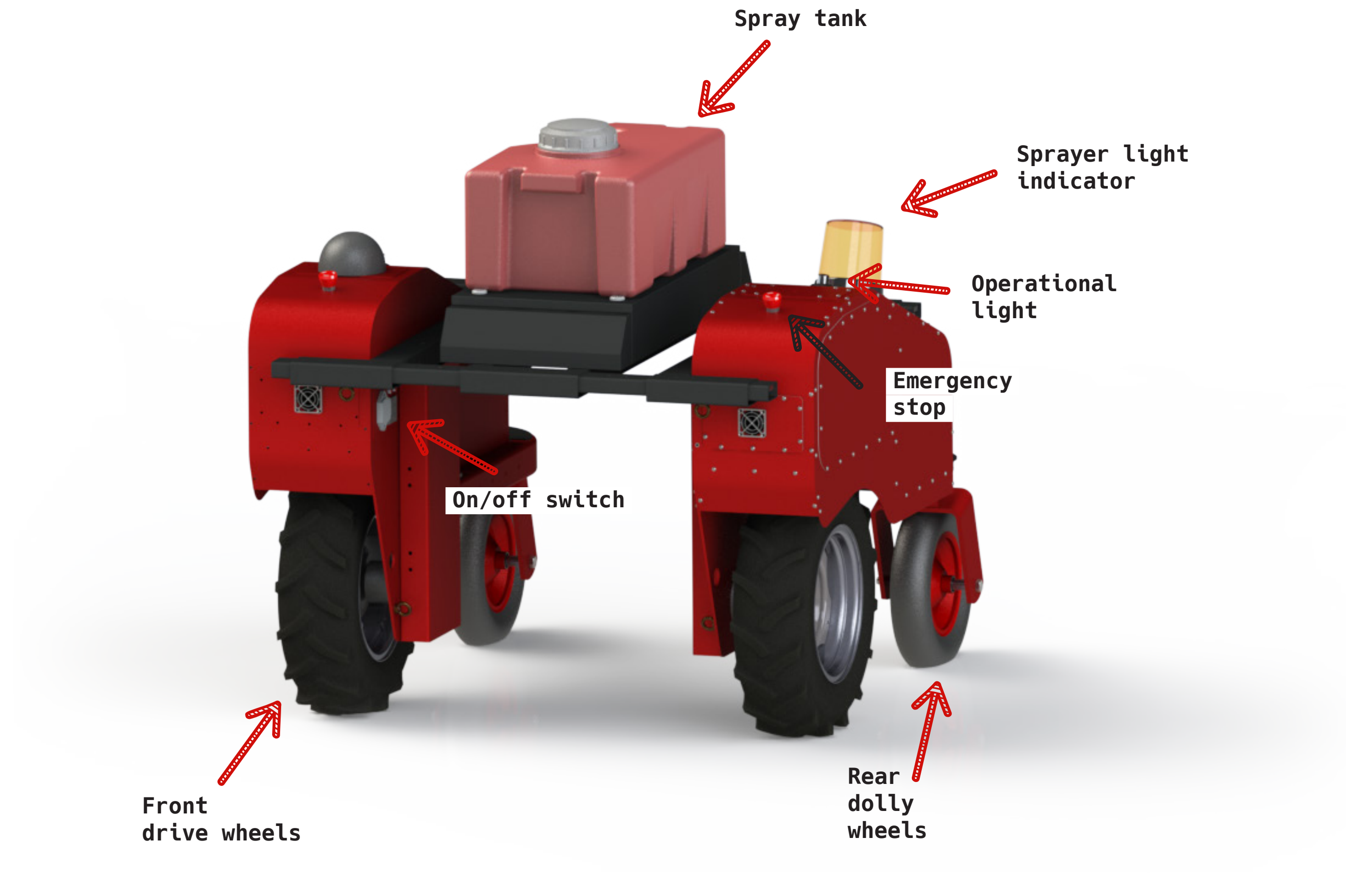
DRIVING THE DIGITAL FARMHAND

LESSON 1 - INTRODUCING THE DIGITAL FARMHAND

STUDENT OBJECTIVES

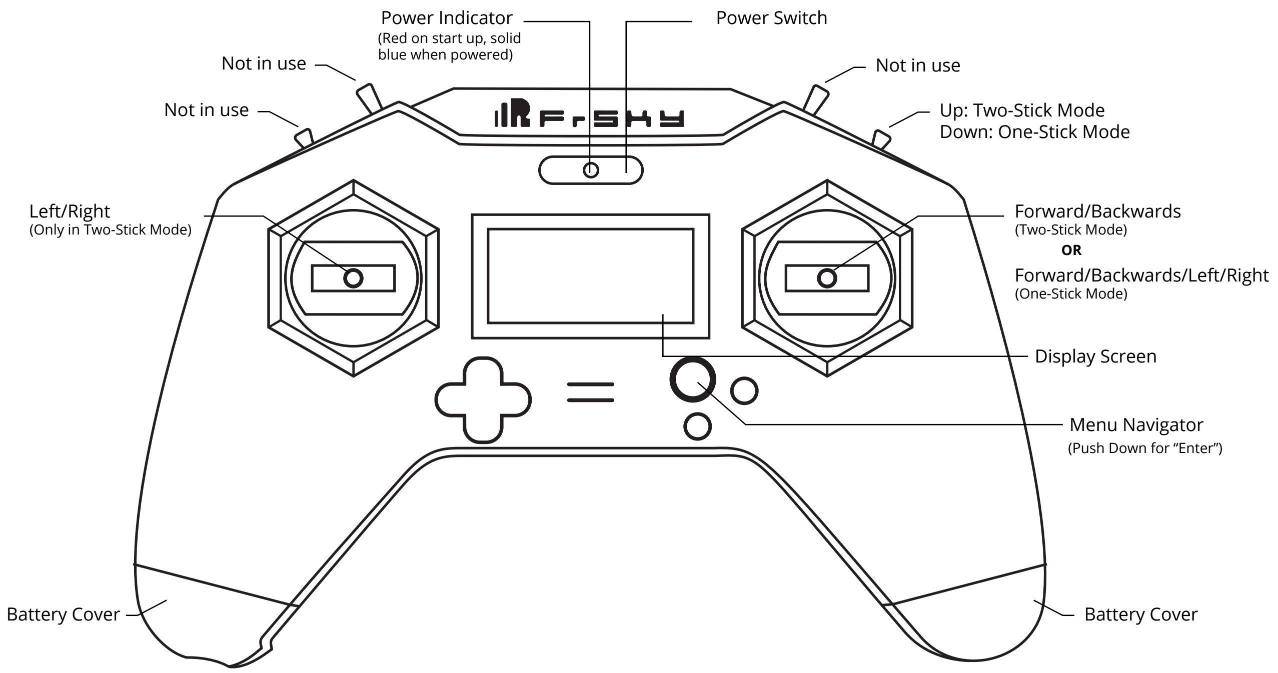
- Get to know the Digital Farmhand, its components and its features.
- Learn how to drive the Digital Farmhand

It's important to become familiar with the Digital Farmhand so that we can better understand how it would be useful on farms. Examine and familiarise yourself with the Digital Farmhand and its remote control units, by looking at the image below and identifying the main items on the actual robot.



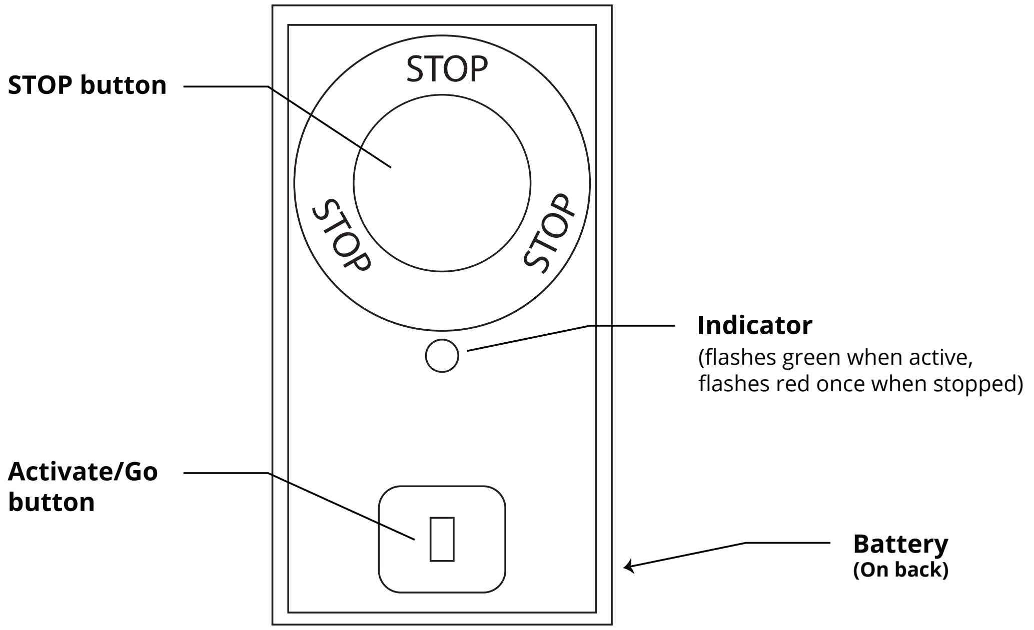
REMOTE CONTROL

You will be using this remote control unit to drive the Digital Farmhand



E-STOP

The E-Stop unit will bring the robot to a stop and disengage the remote control unit. The E-Stop unit is important for ensuring safe operations. The person who has the E-Stop unit should not be the same person who has the Remote Control Unit and should always be around the Digital Farmhand activity.

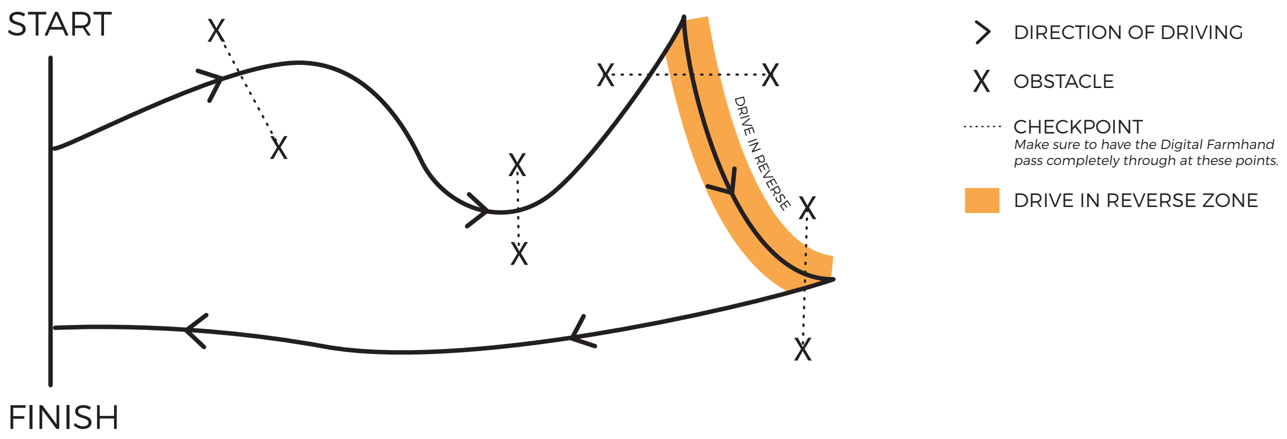


MATERIALS:

- The Digital Farmhand, remote control and E-Stop
- 3 tablets running the Digital Farmhand App
- Obstacle Course Kit

TRY IT YOURSELF

1. Before we begin the obstacle course, get familiar with the remote control unit. Drive the Digital Farmhand slowly to an area that has lots of space and flat ground. While it is driving, press the red button on the Remote E-Stop and observe what the bot does. Try driving in one-stick mode and two-stick mode. What do you find easier to control?
2. Use the various items in the Digital Farmhand kit to build an obstacle course. Make your own or use our example below.



3. Take short turns driving the robot through the obstacle course.
4. While you're waiting for your turn to drive, or if you have driven the bot already, take a look at the Digital Farmhand App on the tablets. Look through some of the different tabs on the App - these are some of the things we're going to look at over the next few lessons.

DISCUSSION

- Why is it important for us to have an E-Stop?
- Did you make it through the course without running into anything?
- Why is it important that the E-Stop locks the wheels?

LESSON 2 - ESTIMATING SPEED

STUDENT OBJECTIVES

• Determine the maximum speed of the Digital Farmhand

Sometimes we are unable to directly measure important information about the behaviour of the Digital Farmhand. Instead, we must try to measure other behaviours in order to calculate the important information we need. In this activity, we're going to estimate the maximum speed of the Digital Farmhand by measuring the distance the robot travels, and how long it takes to travel that distance.

MATERIALS:

- The Digital Farmhand, remote control and E-Stop
- 3 tablets running The Digital Farmhand App
- Measuring Tape

TRY IT YOURSELF

1. We need 3 volunteers to drive the Digital Farmhand, and 9 volunteers to run the stopwatch on the Digital Farmhand App. We'll also need 1 volunteer to hold onto the E-Stop.
2. Measure and mark out a 10m track that is free of obstacles, and is on a flat terrain.
3. Drive the Digital Farmhand over the 10m track. You want the Digital Farmhand to be driving at full speed by the time it reaches the starting line. When it reaches the starting line, start the 3 stopwatches and when it reaches the finish line, stop the stopwatches. Record these times.
4. Repeat the previous step 3 more times, changing drivers and timers each time. This should give a total of 9 stopwatch readings.
5. Once all readings have been recorded, calculate the average time taken using this formula:

$$Average\ time\ taken = \frac{\text{time 1+ time 2+ time 3+ time 4+ time 5+ time 6+ time 7+ time 8+ time 9}}{9}$$

6. Now that we have the distance and the average time taken, we can calculate the speed using the following formula:

$$Speed = \frac{Distance}{Average\ time\ taken}$$

DISCUSSION

- Search up the average speed of someone walking, riding a bike or driving a car in a school zone. How does the speed of The Digital Farmhand compare with these common activities?
- Why would we not want Digital Farmhand to go too quickly? Why not too slowly? Think of different tasks done on farm.

LESSON 3 - ESTIMATING POWER

STUDENT OBJECTIVES

- Determine the power needed to drive the Digital Farmhand at different speeds, and with varying amounts of weight on the Digital Farmhand

MATERIALS

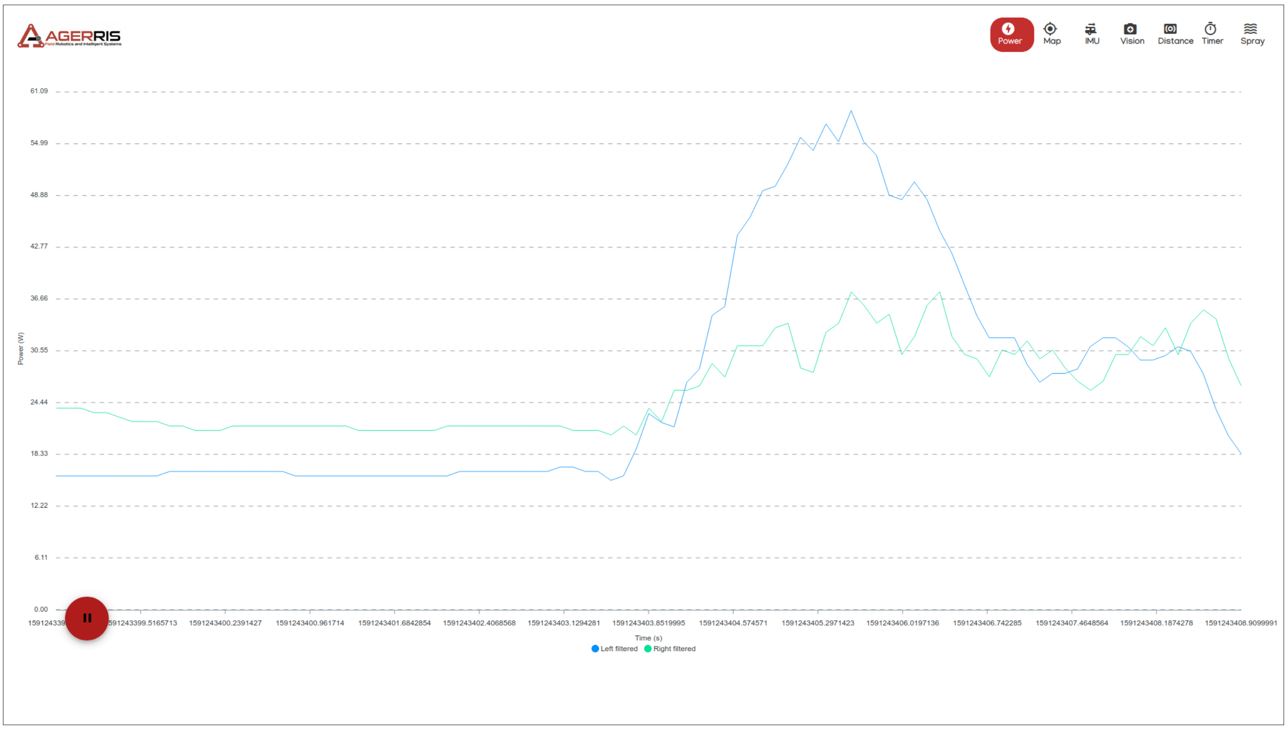
- The Digital Farmhand, remote control and E-Stop
- Source of water **OR** go to an area with a shallow slope (no more than 12 degrees).

TRY IT YOURSELF

1. We need 4 volunteers to drive the bot, and 9 volunteers to read the power values on the Digital Farmhand App. We'll also need 1 volunteer to hold onto the E-Stop.
2. Bring the robot to an area where there is plenty of space to drive around, and where there is a water source (if water restrictions are in effect in your area, find an area with a slope).
3. Now drive the robot around the space and watch the values for power change on the Power tab of the Digital Farmhand App:
    a. Drive the Digital Farmhand around the area at full speed without any water (or on flat ground) for 2 minutes. From the Power tab of the Digital Farmhand App on each tablet, record the maximum value from the chart.
    b. Change driver, and drive the Digital Farmhand around the area at a slow speed without any water (or on flat ground) for 2 minutes. From the Power tab of the Digital Farmhand App on each tablet, record the maximum value from the chart.
    c. Fill the spray tank up to halfway with water (if water restrictions are currently in effect in your area, find a shallow slope to drive the robot on.)
    d. Change driver, and drive the Digital Farmhand around the area at full speed with the spray tank half full (or up the slope) for 2 minutes. From the Power tab of the Digital Farmhand App on each tablet, record the maximum value from the chart.
    e. Change driver, and drive the Digital Farmhand around the area at a slow speed with the spray tank half full (or up the slope) for 2 minutes. From the Power tab of the Digital Farmhand App on each tablet, record the maximum value from the chart.
    f. Have a look around and see what other interesting terrain you have around;muddy or leafy ground? See how this will affect power usage.

4. We should now have 3 max power values for each of the four driving scenarios:

Scenario	Tablet 1 maximum value	Tablet 2 maximum value	Tablet 3 maximum value
Full speed without water/on flat ground			
Slow speed without water/on flat ground			
Full speed with water/up a slope			
Slow speed with water/up a slope			



DISCUSSION

- Looking at the table above, which driving scenario required the most amount of power?

Australia is a world-leading producer and exporter, and has a track record for innovation - these include drought-resistant crops, robust irrigation systems and technology that can predict yields and recommend optimal pastures and stocking density.

What we're studying in this course is robotic innovation for agriculture. Robots are great for endurance, and for repetitive tasks - so sounds like there is a good fit between robots and agriculture!

- What tasks do you think robots could be used for on farms?
- What are the benefits of using electric / battery powered vehicles over petrol / diesel?
- Have you seen or read about any farming processes that have starting using robots to automate?
- What are some benefits to using robots?
- If you have worked on a farm before, what tasks did you do? Do you think a robot could be used to do the task instead?

USING GPS TO NAVIGATE

LESSON 4 - BASIC GPS

U.S. GOVT SOURCE [PUBLIC DOMAIN]

STUDENT OBJECTIVES

• Learn the fundamentals of GPS and how it is used on the Digital Farmhand.

The Global Positioning System (GPS) provides accurate location information anywhere on earth, and is made possible by a group of satellites in Earth's orbit. These satellites transmit precise signals, allowing GPS receivers in a vehicle or carried by hand to calculate and display accurate location, speed, and time information.

- At least four satellites are needed to determine location.
- When the GPS receivers on the Digital Farmhand picks up at least four satellites, it can obtain location values, we call this getting a GPS "fix".
- We can use GPS to locate where the Digital Farmhand is on a farm, and to help the robot navigate to other places on the farm.
- We're going to see the benefits and limitations of GPS navigation and come up with some ways to improve GPS accuracy.

LATITUDE AND LONGITUDE

The GPS coordinate system allows us to describe any position on Earth. This is achieved using the values of latitude and longitude. These values are measured in degrees, and tell us how far North or South we are, and how far West or East we are.

Latitude gives our position from the equator (the middle position between the northernmost pole of the Earth, and the southernmost pole of the Earth). The range of values for latitude are between 0 and 90 degrees in the North and South direction.

Longitude tells us our position East or West from the 'prime meridian'. The range of values for longitude are between 0 (at the prime meridian) and 180 degrees in the East and West direction.

When specifying the latitude and longitude position of something, we must provide the direction: The Sydney Opera House, for example, is 33.8568° South, 151.2153° East.

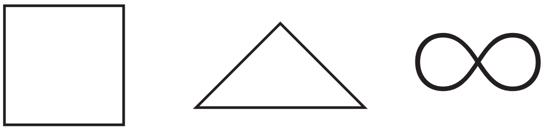
MATERIALS

- The Digital Farmhand, remote control and E-Stop
- 3 Tablets running the Digital Farmhand App

TRY IT YOURSELF

In this activity, we're going to look at how different scenarios can affect the GPS accuracy of the Digital Farmhand's position.

1. We need 3 volunteers to drive the bot, and the rest of the class to observe the GPS page of the Digital Farmhand App. We'll also need 1 volunteer to hold onto the E-Stop.
2. During this experiment, those not driving the robot should observe the GPS readings on the Digital Farmhand App. The raw readings from the GPS are plotted and shown on the map on the GPS page of the Digital Farmhand App.
3. The first driver just needs to drive the robot in an open area. Try driving in a repeated pattern, such as a square, a triangle, or a figure 8.



4. The second driver should try a similar pattern in an area near trees.
5. The third driver should try a similar pattern in an area inside / near buildings. Ensure there is ample space with no obastacles.
6. Observe and make note of the GPS readings in each of these different locations.

DISCUSSION

- Why do you think the GPS readings are different in each of the locations?
- How could this affect robotic vehicles like the Digital Farmhand? What other technologies could be introduced to avoid this?

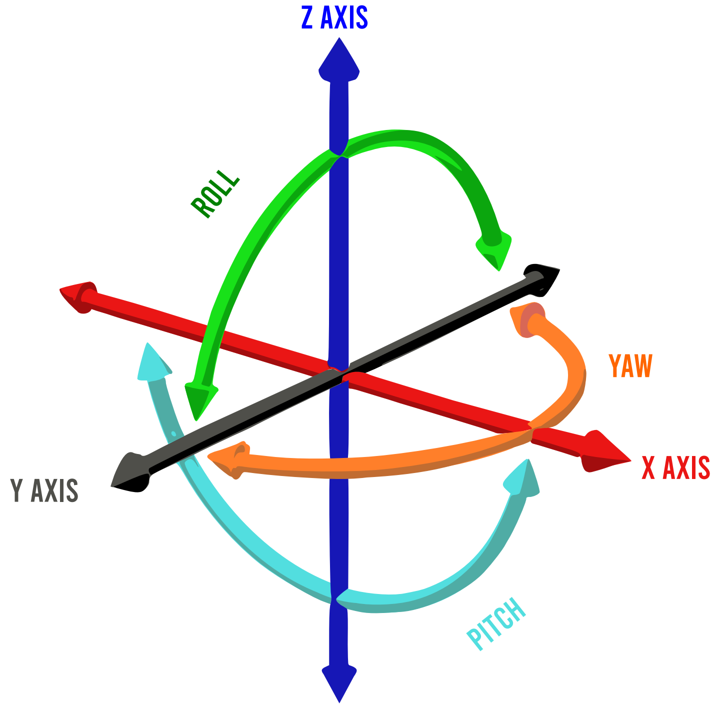
SENSORS ON THE DIGITAL FARMHAND

LESSON 5 - IMU (INERTIAL MEASUREMENT UNIT)

STUDENT OBJECTIVES

• Learn the fundamentals of IMU technologies and the adoption into the Digital Farmhand.

In a 3D world, we can describe the position of something using 6 degrees of freedom; X axis, Y axis, Z axis, yaw, pitch, and roll.



HORIA IONESCU [PUBLIC DOMAIN]

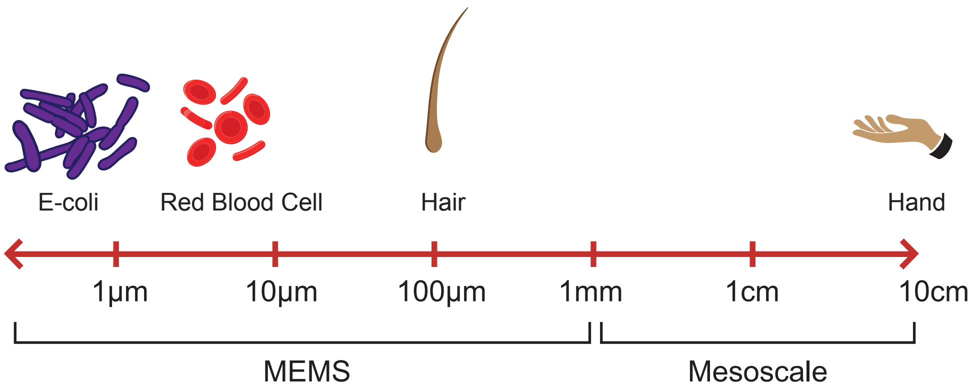
These values are relative to an origin: the position in which all values for location and rotation are zero.

From the perspective of the Digital Farmhand, it needs the position and rotation values so that it can understand where it exists in the real world. Then when it is instructed to do something, it can figure out in what direction and how far it needs to move in order to complete the task.

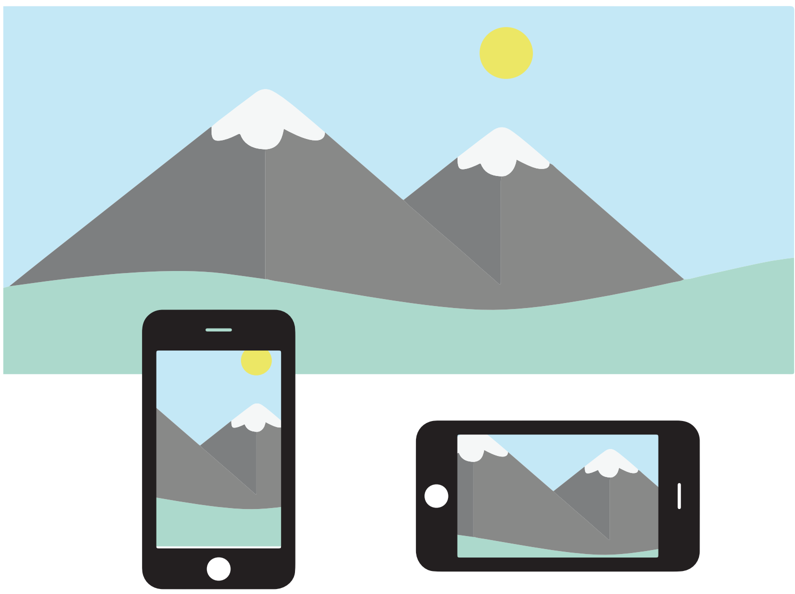
We learned in the previous lesson that the GPS position gives us some idea about the robot's location; specifically, it tells us the latitude and longitude of the GPS receiver on the robot. Some additional sensors are required in order to determine which way it is facing, and the directions that it might be tilting.

The Inertial Measurement Unit (IMU) is a sensor that consists of a number of smaller sensors: 3 accelerometers (that measure acceleration), 3 gyroscopes (that measure rotation) and a compass (that measures heading).

In the Digital Farmhand all of these sensors are classified as 'Micro-Electro-Mechanical Systems' (MEMS). These are devices and structures that are sized anywhere from a few millimetres down to less than one micron (μm)! Some IMUs are so small, they can fit on a fingertip. This scale below can show just how miniscule these sensors can be:



It's almost certain that you have used the IMU sensor in a mobile device, it's what detects whether a phone is vertical or horizontal.



The accelerometer of the IMU measures acceleration from which we can get straight line movement along the X-Y-Z axis. The gyroscope of the IMU measures rotational movement about the X-Y-Z axis. The gyroscope and the accelerometer combined give us 6 dimensions of information.

MATERIALS

- The Digital Farmhand, remote control and E-Stop
- 3 Tablets running the Digital Farmhand App

TRY IT YOURSELF

1. We need 3 volunteers to drive the bot, 1 volunteer to hold onto the E-Stop, and 1 volunteer to shake the bot. Everyone else in the class needs to observe the output on the IMU tab in the App running on the tablet.

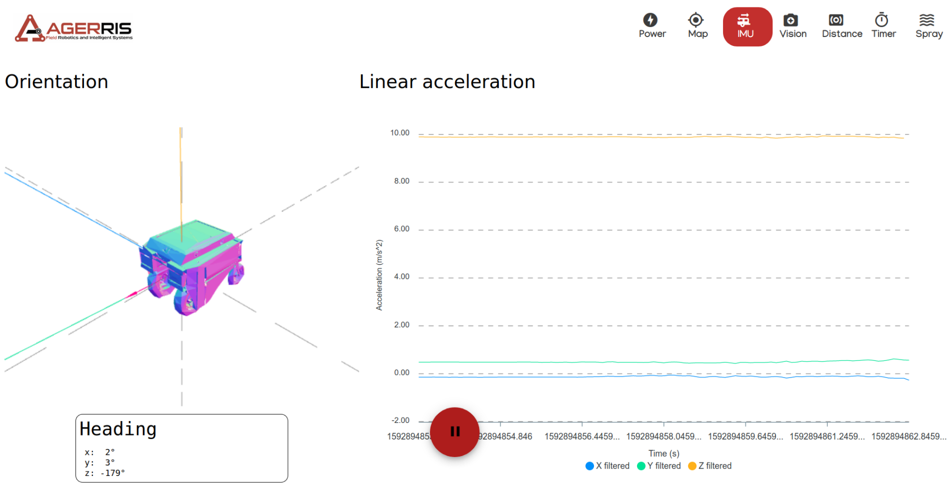
2. The first driver just needs to turn on the spot until the Digital Farmhand has turned 180 degrees. Compare the robot's orientation in the 3D render to the orientation in the real world. How accurately does the IMU represent the actual position of the robot? Continue rotating the Digital Farmhand. Does the 3D render keep up with the robots position after multiple turns?

3. Now swap drivers. The second driver needs to drive the robot onto an incline. Don't drive on any slope that's too steep (less than 12 degrees), since there's a risk the Digital Farmhand can fall over. Stop on the incline, and compare the robot's tilt in the 3D render to the tilt in the real world.

4. Now swap drivers. The third driver needs to drive forward on flat ground and stop suddenly. You should see the lines on the chart on the Digital Farmhand App change as you drive, and jitter when you suddenly stop.

5. Now park the Digital Farmhand on flat ground and press the E-Stop. We need someone to stand to the side of the robot and shake it - observe how the line charts on the Digital Farmhand App change.

6. Now move to the front of the robot (keep the E-Stop pressed) and shake it - observe how the line charts on the Digital Farmhand App change.



DISCUSSION

- The z-axis is consistently sitting around 9.8 m/s2 on the line chart - this indicates a force continually pushing down on the bot. What could this be?

- Do you notice any offset in the x or y axes? What could be the cause of that?

- What happened to the line chart when you shook the bot in different directions?

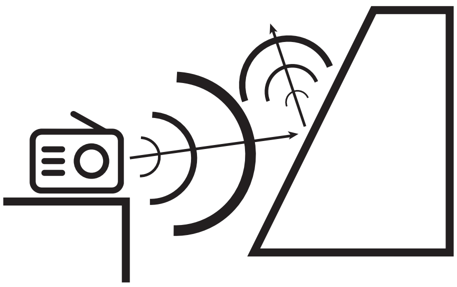
- How accurately did the IMU predict the position/location of the robot after turning or driving up an incline?

LESSON 6 - ULTRASONIC SENSORS

STUDENT OBJECTIVES

- Learn about ultrasonic distance sensors.
- Learn about the potential uses for an ultrasonic distance sensor in agricultural robotics.
- Learn about the inaccuracies of ultrasonic distance sensors.

The Ultrasonic Sensor is a distance measuring sensor that uses sound to calculate how far away an object is. Sounds are made up of waves of energy vibrating through the air. These waves can bounce off objects and continue travelling in new directions. This is why you can hear sounds around corners. Sometimes these sound waves can bounce straight back to us, which is how echo works.



Sound travels at around 340m/s through air. That means every 3 seconds the sound travels about 1km! Did you know you can use this fact to estimate how far away lightning is? This works because light is a lot faster than sound, at nearly 1 million times faster.

Next time there's a lightning strike, count out how many seconds there are between the flash and the sound. Every 3 seconds counted is another 1km away.

We can calculate how far something has moved by measuring its speed and the time it took for it to travel that speed.

$$Distance\ travelled(m) = \frac{Speed\ (m/s)}{Time\ (s)}$$

To measure an object's distance, the sensor will send out sound waves. These will travel through the air, hit the object and bounce back. As we discussed before, we know that sound will always travel at the same speed through air, at about 340m/s. The sensor can time how long it takes between sending the pulses and receiving them. From this we can use the equation above to calculate the distance the sound traveled.

We must remember that the sound waves had to travel to the object and back again. That means that we timed the sound wave travel twice as far as the object is from us. To get the distance of the object from the sensor, we must halve the distance travelled:

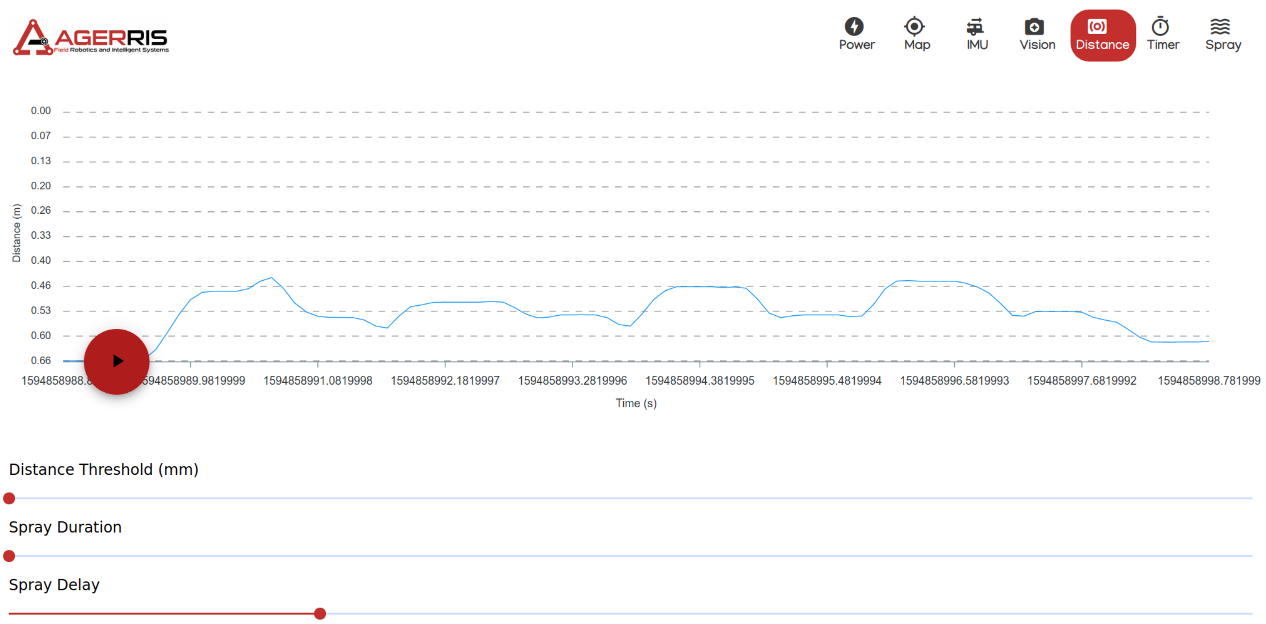
$$Distance\ away(m) = \frac{Distance\ travelled(m)}{2}$$

MATERIALS

- The Digital Farmhand, remote controller and E-Stop
- 3 Tablets running the Digital Farmhand App
- Set of items to target
- Measuring Tape

TRY IT YOURSELF

1. We will need 1 volunteer to drive the Digital Farmhand, 1 Volunteer to hold the E-Stop, 1 volunteer to measure distances, and 3 volunteers to observe the output on the Digital Farmhand app.
2. Make sure the E-Stop has been pressed on the Digital Farmhand. Measure the distance of the front bar of the robot to the ground. Is the measurement similar to what's reported by the ultrasonic when no objects are underneath the robot?
3. Drive the Digital Farmhand into an open area with no obstacles in front of it. Place an object on the ground, in the robot's path (targets are provided for this activity in the AGERRIS STEM kit).
4. Now while volunteers are observing the chart on the Ultrasonic tab of the Digital Farmhand App, drive the Digital Farmhand over the object, so that the object passes between the wheels of the Digital Farmhand. The sound waves produced by the ultrasonic will reflect off the object, and you will be able to see an estimate of the object's height on the Ultrasonic tab of the Digital Farmhand App. Press the pause button on the chart, and record the change in distance recorded on the chart. Does it match the height of the object if you measure it with a measuring tape?
5. Repeat step 3 for other objects, by placing the objects in a line and driving the robot over the objects, so that the objects pass between the wheels of the Digital Farmhand. Try some taller objects as well - is the ultrasonic able to detect objects closer to the camera?
6. Drive the bot over the targets and use the threshold and sprayer control sliders to trigger the sprayer. The threshold slider is used to set a distance at which the sprayer will be activated; any object that is tall enough will be detected by the sensor and sprayed. Since the sprayer is sitting behind the bot however, you need to use the delay and duration sliders to time when the sprayer will be triggered.



DISCUSSION

Now that we have an understanding of how an ultrasonic sensor works, briefly describe the role of the sensor for the following applications:

- Parking Sensors
- Automatic Doors

- Was the reading consistent with the ruler measurements?

- What would happen if you had multiple sensors pointing at each other?

- What happens if the sensor tries to read the distance of an object that does not reflect sound straight back?

- Do you think weather conditions could affect the ultrasonic sensor? If it were to rain before the Digital Farmhand went out, and there were water droplets on the produce, would it have any effect on readings? Why or why not?

If sound doesn't reflect back to the sensor, we'd assume no object is within range - this is how a stealth fighter is able to hide from radar.

U.S. GOVT SOURCE [PUBLIC DOMAIN]

CAMERAS

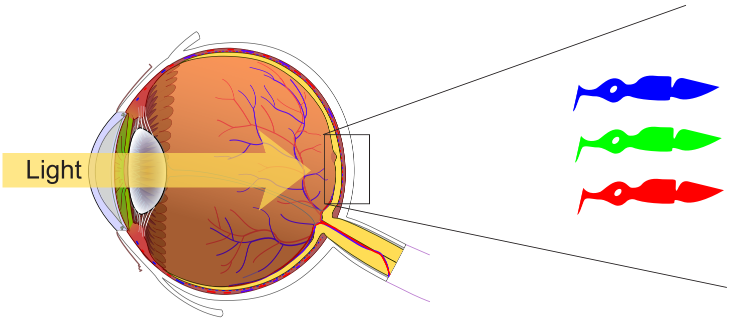
LESSON 7 - CAMERAS

STUDENT OBJECTIVES

- Understand the properties that the depth camera can capture (shape and texture), as well as the ways different plants can be detected based on these properties.

Humans see colours using two different types of cells that detect and respond to light; these photoreceptors are called 'rods' and 'cones'. On average, each eye has about 6 million cones, and 110 million rods.

Cones are stimulated by brighter environments and they contain colour-detecting molecules. Humans typically have three types of these molecules that are sensitive to different wavelengths of visible light - these different wavelengths correspond to the primary colours (red, green and blue).



(reference on bottom of page)

HOW HUMANS SEE COLOUR

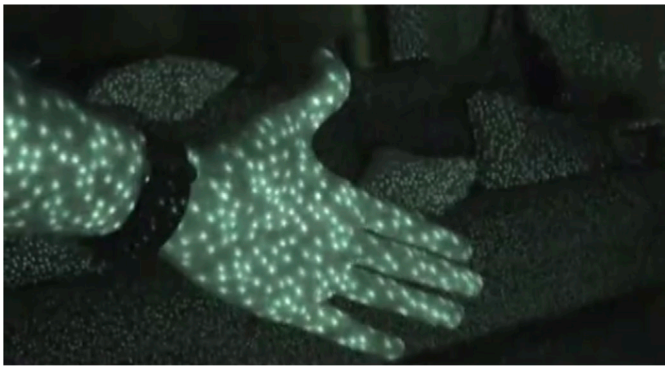
In a well-lit environment, a lemon will reflect light that activates red and green cones. The cones then send a signal to the visual cortex of the brain. The brain processes the number of cones that were activated and the strength of their signal. After the signals are processed, you see a colour— in this case, yellow.

Rods are cells that are activated when you are in low / dim lighting environments, but don't detect colour, only light intensity. Colour cameras essentially work the same way as the rods and cones in your eyes.

Like the rods, the sensors in red, green, blue (RGB) or colour cameras are used to detect total light intensity, and like the cones, filters are used to split the light beam entering the camera into red, blue and green channels. In this section, we'll look at how cameras can use different filtering techniques in order to split the total light intensity into each of the primary colours - allowing us to recreate the colours of the image in software.

Depth cameras also take inspiration from the way humans perceive depth, and perform depth calculations in a similar manner. The depth information comes from using two cameras that are positioned a small distance apart. This idea of using two cameras to estimate depth is similar to how humans get depth information from matching the images from their two eyes. For humans we call this binocular vision, in computer science it's called *stereo vision*. When using stereo vision each camera emits infra-red light beams which allows the camera to calculate the depth by measuring the angles created by the beams of light.

* Adapted from https://commons.wikimedia.org/wiki/File:Diagram_of_human_eye_without_labels.svg [Creative Commons](https://creativecommons.org/licenses/by-sa/3.0/deed.en)"



The infra-red light, emitted by the camera, is out of the range of what our eyes can detect, which is why we can't see it. By using a special camera, we can see what the depth cameras see.

← This is what the depth camera sees.

MATERIALS

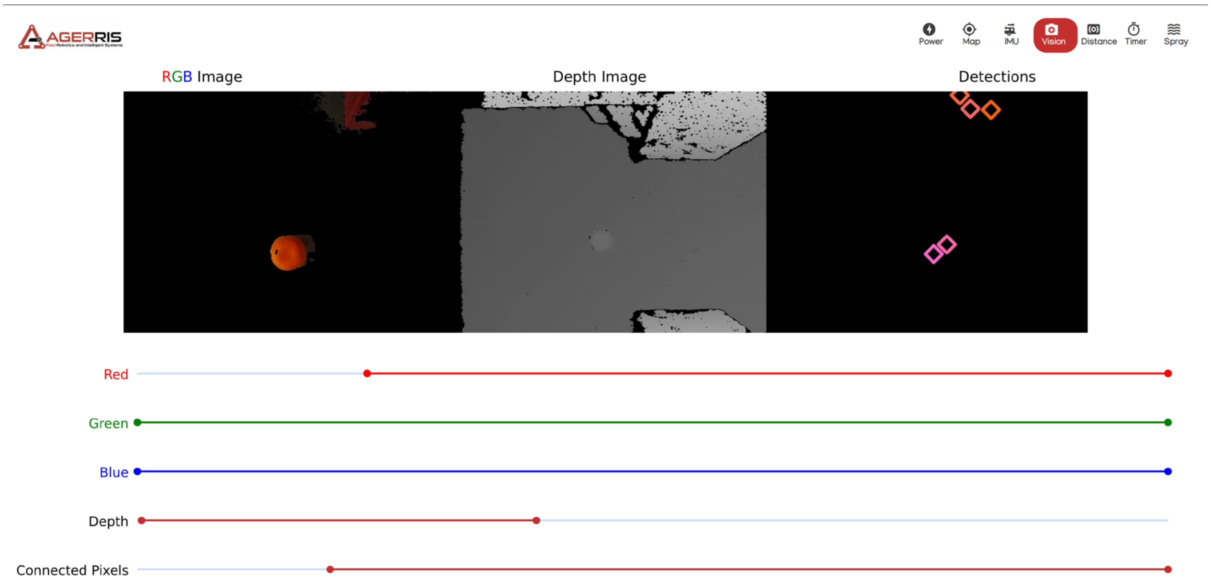
- The Digital Farmhand, remote control and E-Stop
- 3 Tablets running the Digital Farmhand App
- A number of coloured targets (some items are provided in the STEM kits)

TRY IT YOURSELF

In this activity, we're going to apply filters to images in order to change the way the Digital Farmhand sees the world around it.

1. We need 1 volunteer to drive the bot, and 8 volunteers to try filtering images on the Digital Farmhand App. We'll also need 1 volunteer to hold onto the E-Stop.
2. Drive the Digital Farmhand to a well-lit area, and open up the Digital Farmhand App on the tablets. Have a look on the vision tab at the images coming through the camera. If the images look colour-accurate and not too dim, press the E-Stop on the robot. We won't need to drive for the rest of the activity (unless the lighting conditions change).
3. For the following sections, have one volunteer change the camera values on the vision tab, while others just observe on their own tablets. The 8 volunteers that will be filtering images, need to form pairs so everyone gets a look at the tablet.
4. Pick one item to target and slide it under the Digital Farmhand so that it is in the camera's field of view.

   Important: During the next steps, only one tablet at a time is allowed to move the sliders! Other users can just observe the output on the Vision tab.



5. One member of the pair needs to change the upper and lower thresholds of the depth slider. Others can look on, using other tablets, but no one else may make any changes otherwise you'll send new values to the Digital Farmhand. The aim is to filter out everything except the target.

6. Once happy with the filtering, the other member of the pair needs to change the RGB values. Again, the aim is to filter out everything except the target.

7. Repeat steps 4 to 6 with different pairs and a different target. It may be more difficult when you have different coloured targets in the same image.

DISCUSSION

There are many uses for computer vision in robotics. Images are rich in information - while sequences of images tell us even more about the environment around us. As shown with the depth camera, robots also have the ability to see in a wider range than humans, so there are even more uses for computer vision in robotics.

- How can depth cameras assist the Digital Farmhand on farms?

- What new applications can you think of for depth cameras?

- How are colour and depth cameras useful for drones?

AUTOMATED SPRAYING ON FARM

LESSON 8 - PRECISION SPRAYING

STUDENT OBJECTIVES

- Explore the advantages of precision spraying of agricultural inputs such as water, fertiliser, herbicides or pesticides using the Digital Farmhand.

Precision agriculture is about making food production more efficient. The Digital Farmhand robot is one new technology that farmers can use to increase food production while reducing the cost and wastage. Let's look at some examples:

- By more precisely and intelligently targeting weeds, the Digital Farmhand can reduce the amount of chemicals (herbicide / pesticide) needed to perform weeding.
- Through the early identification of crop diseases and pests, farmers can minimise losses, by spraying the right chemical only on the plant.
- By reducing wastage and maximising the crop yield (the amount of food produced), by spraying fertiliser only where needed, we may be able to use the Digital Farmhand to one day feed the world.

MATERIALS

- The Digital Farmhand, remote control and E-Stop
- 3 tablets running the Digital Farmhand App
- A number of coloured targets (some items are provided in the AGERRIS STEM kits)

TRY IT YOURSELF

1. For this activity we'll need 6 volunteers to set filters on the Digital Farmhand App, and one volunteer to hold the E-Stop.
2. Turn on the Digital Farmhand and fill up the water tank before you drive to somewhere you can spray water.
3. Turn on the sprayer pump on the Digital Farmhand, located on the spray tank attached to the robot. There is a light connected to the same solenoid (switch) that activates the sprayer, so if there are water restrictions, run the activity without turning on the pump.
4. Take turns activating the sprayer, by navigating to the Spray tab of the Digital Farmhand App and pressing the spray button. You can hold down the spray button to spray for longer.
5. Drive the Digital Farmhand to an area with good lighting, and press down on the E-Stop, so that the robot cannot move.
6. Place the coloured targets underneath the robot's camera, so that each target is visible on the Digital Farmhand App's Vision tab.

   Important: During the next steps, only one tablet at a time is allowed to move the sliders! Other users can just observe the output on the Vision tab.

7. The first 2 volunteers will pick one of the targets to focus on. Try and isolate the selected target using the RGB, depth and blob sliders of the Digital Farmhand App's Vision tab.

   - Use the RGB sliders to isolate the object based on its colour
   - Use the Depth sliders to isolate the object based on its distance away from the camera
   - Use the Connected Pixels slider to isolate the object based on its size.

8. If an object is isolated successfully, the Vision tab will show 'Object detected'. Both the RGB and depth windows will show only the target, and the blob window will show very few symbols.

9. Test out the values you've put into the app! First, spread out the targets in a line. Then release the E-Stop and drive to the start of the line. Turn on the spray pump and drive the Digital Farmhand over the targets. If the filtering worked and the lighting conditions were good, the Digital Farmhand should only spray the selected target.

10. Repeat steps 5-9 for each of the targets, swapping volunteers each time.

DISCUSS

- Why is precision spraying important to the farmer?

- Why is precision spraying important to the environment?

- What are the advantages of the following Digital Farmhand features:

   - running on rechargable batteries?
   - by being small and lightweight?
   - collecting data for analysis by farmers?

- What are the advantages and disadvantages of operating a piece of machinery like Digital Farmhand when it is spraying from a mobile device? What would this solve?

EXTRA LESSONS

MAKE YOUR OWN BOT

In this activity students are going to work as a team to develop an ag robot from their existing knowledge of agriculture and the Digital Farmhand activity. The objective is to think about the needs of farmers and growers rather than creating something completely new. They will then present a quick pitch to the class about their idea.

MATERIALS

- Students grouped into 3-4
- Multiple sheets of paper/butchers paper for each group

TRY IT YOURSELF

1. Read 'Robots On The Farm' article and complete questions (pages 31-34 in guide).
2. Divide class into groups of 3-4 and have them think up their own ag robot. Answer some of the drawbacks of the Digital Farmhand - get creative! While you have some creative license, try not to create a bot which is completely unrealistic to be made in the next 5-10 years.

Consider the following points and try to answer them in the presentation:

- What are some of the disadvantages that the Digital Farmhand has that this bot will fix?
- What are the advantages of this bot?
- What new disadvantages does this bot present?
- What tasks could your bot(s) be used for on farms?
- How is the robot powered? and why? (electric / petrol / diesel)
- How many wheels does it have?
- Does your robot use wheels or tracks or legs and why? Does it fly, partially fiy and why?
- Is it targeting vegetable crops or tree crops?
- What sensors do you think it would need? (gps / cameras / others)
- What attachments could it carry / pull to make it more useful to farmers? How do they attach?

DISCUSSION

- Discuss what skills are needed in a team to build an agriculture robot. Think of all the different types of skills required to design, build and then test.
- What were some challenges in the design phase and how did you overcome them?
- How do you think the digital farmhand differs from your ag bots?
- Discuss the steps you would take to test it properly across different farms. What feedback would you want from the farmer?

LESSON TEACHER'S NOTES

LESSON 1 - INTRODUCING THE DIGITAL FARMHAND

ACTIVITY TIPS

- Ensure all students understand the controls before operating the robot
- Keep students 1.5m away from robot when armed (E-Stop off)
- The Digital Farmhand's controller includes a single stick option for easier mobility for single handed use. Please ensure there is extra time for the students requiring this option so everyone is comfortable and confident in using the bot.
- Create a "competition" by timing students driving through the obstacle course and keeping a leaderboard
- Encourage students to familiarise themselves with the app

EXAMPLE DISCUSSION ANSWERS

- E-Stop important
  - for quick stop in emergency
  - In case bot is unable to receive the controller input
  - To prevent accidental controller input moving the robot
- Running into anything
  - Yes or No
  - Why? Was it too fast? Not familiar with controls? In reverse? Couldn't see the object?
- E-Stop locks wheels
  - Bot doesn't roll away if pushed or on a hill
  - If bot was moving, bot comes to immediate stop

LESSON 2 - ESTIMATING SPEED

ACTIVITY TIPS

- Make sure bot has space to drive
- Make sure students understand that bot is driven at full speed
- Record times on small whiteboard for ease of calculations

EXAMPLE DISCUSSION ANSWERS

- (Question may be excluded) Average speed of person walking is 1.4m/s
- Too quickly can be dangerous
- Too slowly will be inefficient, won't get enough done in the day
- For plant health, we need it to be able to run correctly and not make mistakes and damage the plants

LESSON 3 - ESTIMATING POWER

ACTIVITY TIPS

- Going to a shallow slope is only needed if there are water restrictions in place in your location. Alternatively if there is time at the end of the lesson, you can also do the slope option.

EXAMPLE DISCUSSION ANSWERS

- Robot tasks on farm; weeding, picking fruit, harvesting vegetables, herding animals.

- Benefits of using electric/battery powered vehicles; better for the environment, cheaper to run

LESSON 4 - BASIC GPS

ACTIVITY TIPS

- Have students drive the robot in a large shape so it is easy for them to see on the GPS

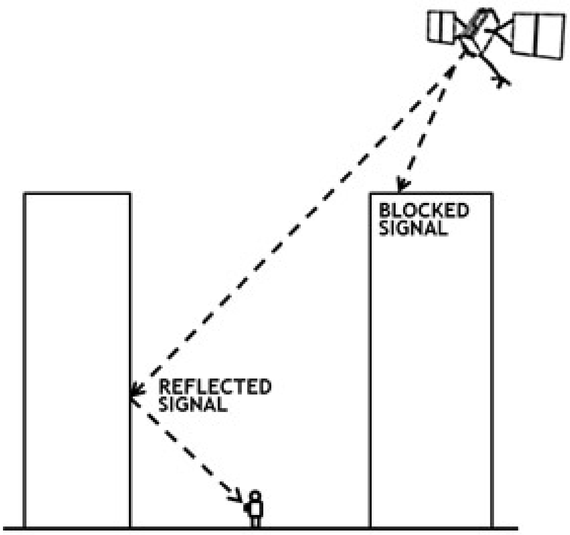
- “Open Area” ideally is large 30-50m to ensure clear fix from satellites

EXAMPLE DISCUSSION ANSWERS

- Signal becomes jumpy and inaccurate when signal is affected by signals bouncing off objects

- Signal is not strong enough to travel through walls, so gps doesn’t work inside

- This could affect tech as they can’t use gps to drive autonomous near trees or inside (docking in shed)



LESSON 5 - IMU

ACTIVITY TIPS

- Have the bot rotate slowly so the students can see it rotate on the tablet

EXAMPLE DISCUSSION ANSWERS

- Z-axis represents gravity

  • May deviate from 9.8 m/s^2 (9-10.5m/s^2) due to tilt or sensor inaccuracies. Need to make sure on level ground.

- X and Y offset caused by tilt in sensor (means x & y are affected by gravity) and sensor inaccuracies

- Front/back of The Digital Farmhand is X-axis, side of bot is Y axiz

- Should be fairly accurate

LESSON 6 - ULTRASONIC SENSORS

- Ultrasonic sensor sends out pulses of sound that reflect off most objects

ACTIVITY TIPS

- Graph plot of ultrasonic reading will represent reality closer if bot drives slower

EXAMPLE DISCUSSION ANSWERS

- Parking sensor - beeps to let you know if you're going to hit something
- Automatic Doors - senses if someone is walking near the door
- Reading should be close to ruler measurement
    - Slight deviations due to sensor accuracy and approximate readings from graph
- Multiple sensors could cause interference, get wrong readings
- If the surface is non-reflective distance won't be read
    - Examples include loose cloth
    - Surface on angle
- The Digital Farmhand's ultrasonic camera will not be affected by weather changes.

LESSON 7 - CAMERAS

ACTIVITY TIPS

- Start with the first slider, bring the bottom of the slider up as high as you can without removing all the colour of the object of interest.
- Then slide top of slider down as far as possible without removing all colour of the object of interest
- Repeat for 2nd and third slider
- Adjust top and bottom of height slider until only top surface of object can be seen
- Adjust top and bottom of blob slider until detections only occur on object

EXAMPLE DISCUSSION ANSWERS

- Depth cameras can be used to sense how far away objects are, to give more information on the environment around them
    - Detect objects in the way (animals, farmer, obstacles)
    - Detect how far away plants are
- New applications - room for creativity here
    - Examples include Medical applications, tracking animals on the farm, navigating through small spaces, gaming (VR)
- Cameras are useful for drones, like robots, to help them see the world
    - Examples include detecting crops, condition of the land, counting animals, calculating distances

LESSON 8 - PRECISION SPRAYING

ACTIVITY TIPS

- Aim to get camera working reliably like previous lesson
- First determine spray delay for the Digital Farmhand
    - How long the Digital Farmhand needs to wait before it starts spraying so it doesn't waste water
    - This is easier if the Digital Farmhand is driving at a consistent speed
- Then determine how long the Digital Farmhand needs to spray to cover the whole object and not over spray
- It's the final lesson, the hope is the students have fun with this one and enjoy the lesson as a round off of the course

EXAMPLE DISCUSSION ANSWERS

- Precision spraying saves money by being more efficient with pesticides/water so they have to buy less
- Uses less pesticides which is better for the environment
- Advantage of the Digital Farmhand from mobile device
    - It is easy to control
    - It can be done anywhere with a signal
    - Don't need to be out on the farm in the sun all the time
    - Can be doing other tasks while it works so it is more efficient
- Disadvantages include
    - Can't see the Digital Farmhand if something goes wrong
    - Can't control the Digital Farmhand if the signal drops out
    - Need to be on your phone and have enough battery

ANSWER TO ENGAGE TASK P19: A1; B5; C4; D6; E2; F3
ANSWER TO EXPLAIN TASK P40: A1; B3; C6; D8; E7; F5; G4; H2