Robotics and automation for improving agriculture

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Introduction

Robotics and automation are having a significant impact on agriculture, one that is accelerating. This book reviews both key advances in their application and the research that is ongoing. It summarises developments in machine vision, navigation, actuation, communication and control technologies. In the second part of the book, ways are discussed to deploy these techniques to save labour, improve precision, speed and efficiency in agricultural operations. The state of the art is reviewed on the use of agricultural robots in applications such as crop spraying, irrigation and weed management. The book also addresses orchard management and harvesting, harvesting of soft fruit and in-field grading of harvested produce. It also reports on the application of robotics in the livestock sector.

Part 1 Technologies

The first part of the book discusses those robotic technologies that are of use in agriculture. Chapter 1 opens the volume by examining machine vision technologies for agricultural robots. After outlining basic concepts of machine vision and processing techniques, the chapter looks at the tasks to which they can be applied, from machine guidance and navigation to pest and disease identification as well as sorting fresh produce.

Moving on from machine vision, Chapter 2 looks at advances in actuation and control in agricultural robots. In recent years, agricultural robots have moved away from being pure sensor-carrying platforms for gathering data in the field into becoming action-delivering platforms providing physical interaction with the environment. The chapter discusses the actuation methods that are most commonly used on intelligent agricultural robots in order to control motion, physical interaction or manipulation. These actuation methods consist of both traditional actuators that have been transformed into precision farming tools, and novel actuators enabled by robotics and autonomous systems. The chapter introduces each actuator type before giving examples in agriculture. It concludes with a case study that looks at the way different actuators are used to automate strawberry production.

The subject of Chapter 3 is advances in communication and control systems in agricultural robots. Unmanned agricultural ground vehicles (UAGVs) have substantial potential to optimize crop yields and increase sustainability. Advances in sensing, communication, and control technologies coupled with Global Navigation Satellite Systems (GNSS) and Geographical Information Systems (GIS) are driving the transition from simple, off-road mechanical machines to machines with intelligence. Controller area networks (CAN) and
GNSS are contributing to the accelerated transition of tractors to become highly automated. These systems need to be safe and robust while operating in sub-optimal conditions compared to other autonomous systems. The variables encountered in the field, such as ground conditions, weather and the sheer size of the operations, highlight just a few of the challenges they face. The chapter shows how developments in communications technologies can help address these challenges. It introduces wireless communication before moving on to consider communication layers, network topology and communications technologies. The chapter considers person-to-machine (P2M) (cellular networks and MIMO broadband radio antenna networks) and machine-to-machine (M2M) (Wi-Fi, Bluetooth, ZigBee, 6LoWPAN and RFID) communication. Finally, the chapter discusses security issues.

Broadening the scope from purely robotic systems, Chapter 4 looks at advances in human-robot collaboration in agricultural robots. These are being developed for many on-farm tasks; though in practice current working agricultural robotics systems are still limited and fully robotized farms are not yet available. The chapter discusses the various types of interaction humans may have with robots and levels of human-robot collaboration. The chapter covers aspects of interface design and human-robot collaborative tasks such as detection, navigation, harvesting and spraying. The chapter concludes that the role of humans in agriculture will not be eliminated by introducing robotic systems and, should more autonomous systems become feasible, humans will still be needed for supervision and collaboration.

The section concludes with a brief overview in Chapter 5 of global positioning systems (GPS) for agriculture. In explaining how the system works, the technical concepts of code and carrier pseudo-ranges are mentioned, to focus on ways in which accuracy can be improved. Base stations and peer-differential systems are making an impact, while new constellations of satellites are promising to improve errors to a few centimetres even for low-cost systems.

Part 2  Applications

The second part of the volume looks at applications of robotic technology in agriculture. Chapter 6 examines the use of agricultural robots in crop spraying. A robotic sprayer can help reduce pesticide application while removing the human operator from the hazardous pesticide environment. The chapter provides an introduction to robotic sprayers and key challenges such as guidance and mapping, target detection and control. It includes a detailed case study of the development of a smart robotic sprayer for use in spraying vineyards, including the development of key components such as an automatic adjustable spraying device. The chapter also describes the development of an operational framework supporting human-robot collaboration.
The subject of Chapter 7 is the use of intelligent/autonomous systems in crop irrigation. Climate change, combined with the need to feed an increasing population with decreasing arable land, requires a radical re-think of the way water is delivered to crops to increase efficiency and minimize wasted water. The chapter examines how robotic and artificial intelligence can be used to improve precision irrigation in vineyards. The chapter pays particular attention to RAPID (Robot Assisted Precision Irrigation Delivery), a novel system currently being developed and tested at the University of California. The chapter presents some of the preliminary results from RAPID testing.

Chapter 8 considers the use of agricultural robots in weed monitoring and control. Weed control is essential for the production of high yielding and high-quality crops, and advances in weed control technology have had a huge impact on agricultural productivity. Any effective weed control technology needs to be both robust and adaptable. Robust weed control technology will successfully control weeds in spite of variability in the field conditions. Adaptable weed control technology has the capacity to change its strategy in the context of evolving weed populations, genetics and climatic conditions. The chapter focuses on key work in the development of robotic weeders, including weed perception systems and weed control mechanisms. The chapter addresses the challenges of robotic weed control, focussing on both perception systems, which can detect and classify weed plants from crop plants, and weed control mechanisms, covering both chemical and mechanical weed control. The chapter provides a case study of an automated weeding system.

Shifting from the field to the orchard, Chapter 9 looks at the use of agricultural robots in orchard management. The use of robotic or automated machines in orchard operations is primarily a response to growing labor shortages and costs. The introduction of robotic technologies is critical for improving yield of high-quality fruit with minimal dependence on seasonal human labor. The chapter provides an overview of robotic technologies for major tree fruit production tasks, including robotic pruning, thinning, spraying, harvesting and fruit transportation.

Chapter 10 turns to advances in automated in-field grading of harvested crops. Mechanical harvesting machines such as canopy and trunk shakers are widely used for the collection of some crops; however, most fruits and vegetables produced for the fresh market have to be collected manually. The chapter reviews the current state of mechanized collection technology, such as the development of harvest-assist platforms, as well as the possibilities of these machines to incorporate artificial vision systems to perform a pre-grading of the product in the field. The main advantages of each system are discussed and the problems encountered in the field are described. The chapter presents a case study on the use of harvest-assist platforms in citrus orchards, describing prototypes that are capable of both inspecting collected fruits and separating them into categories using computer vision.
Turning from fields and orchards to forests, Chapter 11 deals with advances in using robots in forestry operations. Advances in automation will enable forestry operations to be conducted in a more sustainable way. The chapter examines the challenges associated with using robots in forestry operations, focusing on the importance of knowing the state of the machine, where the machine is located, the location of surrounding objects, and how to plan work tasks. The chapter looks at the challenges of moving around in the forest, reaching and handling the trees, converting trees into products, and extracting logs or trees to roadside landings. The chapter also considers remote-controlled operations.

Chapter 12 moves to dairy production, considering advances in robotic milking. In recent years, growth in the number of robotic milking installations on farms has been driven by the need for better labour management and also for improved quality of life for dairy producers. The chapter reviews published research on such robotic milking systems (RMS), considering barn design, feeding management, and udder health in automated systems. The authors’ field observations on RMS herds in Minnesota and Wisconsin, USA, are also included. The chapter covers feeding cows in RMS, milk quality and milk production using RMS and the economic considerations of implementing RMS on the farm. The chapter concludes that the trend towards robotic milking is set to continue into the future and the percent of dairy farms around the world using automation for milking their cows will further increase.

The volume’s final chapter, Chapter 13, looks at advances in the use of robots in meat processing operations. Meat processing presents a particular challenge to robotics, as it deals with deformable biological products that lack uniformity, which makes automation extremely challenging. The chapter surveys advances in robotic automation of the processing of fish, beef, pork and lamb, as well as poultry, providing a detailed case study of the latter based on the author’s own research.
Chapter 1

An overview of machine vision technologies for agricultural robots and automation

John Billingsley, University of Southern Queensland, Australia

1 Introduction

A mere two-and-a-half decades ago, when our own research concerned machine vision for tractor guidance, the equipment involved a tower-case computer, a black-and-white CRT monitor and a ‘Video Blaster’ card to grab video stream from a camcorder mounted on the roof of the tractor. Today everything that is needed can be found within a supermarket smartphone that might cost well under a hundred dollars. As an OEM component the price of the camera used in such a phone is measured in cents. When attached to drones, cameras such as this can enable video to be captured, storing hours of image data on a microSD card that is smaller than a little fingernail.

Vision is becoming an essential solution to a vast array of control and measurement tasks, not least on the farm. Any attempt to nail applications down to the equipment and the software of the day runs the danger of becoming obsolete within a very few years. The names of research topics come in and out of fashion. The fundamental principles endure, but are christened with new titles that herald a parade of papers.

Control theory has seen fashions of ‘modern’, adaptive, predictive, variable structure, neural and fuzzy, to name but a few. The essence of the latter pair is the synthesis of nonlinear functions of multiple variables with back-propagation
being used for adaptation. Convolution and correlation underlie the techniques of systems analysis and now ‘deep learning’ is taking to the stage.

‘Deep learning’ has already entered the vocabulary of vision research and no doubt there are many more terms to come. But one thing is certain. The greatest impact will continue to be made by advances that are powered by their application in the mass market.

Today every smartphone can not only locate a face in the image, but even assess the quality of the smile of the subject. Surveillance cameras are adept at identifying faces. Here is a technology that can be borrowed and adapted for agricultural use, whether to grade vegetable by shape or identify cattle as individuals.

Some of the more elementary principles of machine vision will be detailed here, but in general this chapter will attempt a broad analysis of the tasks that can be helped by vision and the possibilities for its application.

2 Basic concepts

In general, the main functions of vision are location and recognition. Location allows a vehicle to be guided and fields to be mapped. Recognition allows the thing that you are locating to be identified, such as a tree to be avoided, a ripe fruit to be harvested or a weed to be killed.

In many ways, computer vision has the potential to be greatly superior to the human eye for both functions, though the eye colludes with the brain to achieve some remarkable results of its own. In the human eye, a colour is perceived as the ratios of just three measurements, seen primarily as red, green and blue. Video systems exploit this by measuring and showing just three sets of red, green and blue dots on the screen. But visible light consists of a continuous spectrum of wavelengths which can carry very much more colour information than the human eye can differentiate.

When red light is added to green light, the result is seen as yellow. The light from a sodium street light is also seen as yellow. But in the mixture of red and green light, an object with red and green stripes will show them clearly as colours, while in sodium light they will merely appear as shades of grey.

Common camera sensors peer through a multicoloured film of dots to give an image in three planes of red, green and blue. Though the sensor can detect light a substantial way into the infrared and ultraviolet, these are blocked by a filter in the lens. Monochrome intruder cameras are the exception to this. By adding a specialised colour filter, such a camera can be made sensitive to any combination of wavelengths we choose. By comparing views through two different filters, colour differences can be perceived that the human eye cannot discern. The name given to this is ‘multispectral vision’ or ‘microspectral vision’.
2.1 Discrimination by colour

Discrimination by colour can be implemented in many ways. Of course, in many cases the differences can be seen in the conventional views. If this is not the case, two or more cameras could be used, but it can be more expedient to spin filters of special colours in front of a single camera, as was done in the very early television systems. Simpler still is to split the view of a single camera between stripes of filters and use the progress of the vehicle to move the image of the plant from one colour filter to the next. With autonomous machines that can work at night while the farmer is asleep, lights of special wavelengths can be used instead of filters.

Because illumination is not uniform, it is necessary to consider ratios, rather than absolute brightness. To give an example, a blue object will look brighter than a red one in blue light, but darker than that red one in red light, however bright the lights are. So when seeking to see a colour difference in two sorts of leaf, a spectrophotometer can be used in research to find at least two wavelengths where in one A is more reflective than B, while in the other the reverse is true. Once those wavelengths have been determined, coloured plastic filters can be sufficient to perform the comparison.

2.2 Recognition by shape

The human brain tends to see images in terms of outlines rather than patches of shades. One of the tricks of the eye is to ‘invent’ lines between areas of slightly differing brightness, as can be seen in Fig. 9. This strongly suggests that outlines are a better basis for object recognition than correlation of the pixels of an image. In graphic computer art there are several ways to represent an image. The original form is the ‘bitmap’, an array of coloured pixels, as in a .gif, .jpg or .png file. But gaining more prominence is the SVG, scalable vector graphic, that represents a set of outlines of areas each filled with a colour.

By tracing the outline of an object, its shape can be encoded in many fewer bytes. Even fewer bytes are needed to define an ‘s-psi’ plot. This represents the angle of a tangent as we move around the entire circumference. By encoding the angle as an 8-bit byte, giving increments of just under one-and-a-half degrees, a meaningful outline can be defined in just 256 bytes. This s-psi plot will be the same for all objects of the same shape, whatever their size. If the object is tilted, the plot values have a constant added to them. So the s-psi plot represents the shape in a form that is much simpler to use for identification by matching against templates.

3 The tools

Many of the figures in this chapter have been captured from JavaScript applications that can be found at www.essdyn.com/vision. Some of these show a window of code that can be changed in a browser to experiment with new values.
3.1 The camera

Evolving from the ‘flying spot scanner’ of the early days of television, today’s cameras still use the concept of a ‘raster’. The view is scanned by a line that runs left to right, moving down the picture from top to bottom to present a frame of data. In digital terms, each spot of the image is a ‘pixel’, so in a full HD scan of 1080 lines of 1920 pixels they number a couple of million, arriving at some fifty million per second. From this barrage of data our purpose might be to resolve a simple binary question such as ‘is it a weed?’ or just to obtain a couple of numbers defining the location of a landmark.

The software driver of the camera will grab each frame to the computer memory as a string of bytes, 3 or 4 to a pixel. Though one might think of these bytes as an array laid out as an image, they are in fact just a linear sequence. The pixel at location (50, 100) is held by the bytes starting from location (100 * width + 50) times the number of bytes per pixel. So until the fundamental camera design changes, any software has to start with this data set in order to extract the information that will perform the actual control or identification.

3.2 Image processing

Many software libraries exist with routines for processing image or video information, of which one of the best known is ‘Open CV’ (2018). Many of the functions in these libraries have the purpose of making the image more appealing to look at, such as ‘filters’ that identify edges, or sharpen or blur images by adding weighted sums of neighbouring pixel values.

The filter consists of a matrix of weights and can be thought of as a ‘patch’. The patch is moved to be centred over each pixel of the image in turn then the sum is taken of each weight times the pixel value beneath it. The result is a new array of pixel values to be displayed.

3.3 Binary images

For shape analysis, images are often subjected to a threshold to simplify their analysis. Consider a very simple binary image, where each pixel is represented as either black or white, denoted by a value of either 0 or 1. It might appear as Fig. 1.

It can be ‘smoothed’ by adding up the pixel values in a 3 by 3 patch. The totals are shown in Fig. 2.

The new value of the central pixel is then set to 1 if the total exceeds 4, or to 0 otherwise, as shown in Fig. 3.

This has removed the straggling pixels and holes. It can be regarded as the application of the filter patch.
Figure 1 Rough binary image.

Figure 2 Numbers are shown for calculating smoothing.

Figure 3 Result of smoothing.
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