46. Robotics in Agriculture and Forestry

Robotics in A

John Billingsley, Arto Visala, Mark Dunn

In agriculture and forestry, robotics has made a substantial impact. Farmers are conscious of their need for automatic vehicle guidance to minimize damage to the growing zone of their soil. Automatic sensing, handling, and processing of produce are now commonplace, while there is substantial instrumentation and mechanization of livestock procedures. In forestry, legged harvesters have not yet seen great success in their application, but the automation of trimming and forwarding with simultaneous localization and mapping techniques will change the industry in the future.

Some impressive developments in walking forestry harvesters are presented, including machines targeted towards the difficult terrain of the Scandinavian forests. More-conventional cut-to-length harvesters are also highly automated, while operations such as *delimbing* must be carried out at speed. Before complete autonomous harvesting becomes possible, some of the localization and mapping techniques that are described must come to fruition.

The combination of machine vision with global positioning by satellite (GPS) allows a tractor to follow a row of crops, performing a headland turn at the end of the row. The history of a series of projects is outlined, leading to the present outcome that is in the process of being commercialized. Another project that is based on machine vision relates to the location of macadamia nuts. To select which trees should be propagated, it is necessary to attribute fallen nuts to the correct tree. Color sorting and grading of produce is not a matter of sensing alone, but involves a measure of produce handling that puts it at the fringe of robotics.

Automated milking parlours have proved their worth. However success has eluded some other projects described here, such as automated sheep-shearing and an automated abattoir. Another project is presented that literally sorts the sheep from the goats, using a swinging gate to separate different species using machine vision so that feral species are excluded from watering holes in the dry Australian outback.

Although robotics is making rapid inroads into these areas, they are still a fruitful source of application projects, some sufficiently demanding to require the development of new theoretical techniques.

46.1 Definitions

The boundaries of agriculture are not clear cut. Preparation of the soil, planting, cultivating, watering, spraying, and harvesting are evidently included, but how far into the post-harvest processes of trimming, sorting, and grading can we go before they merge with food preparation? Similarly, animal-based activities can extend beyond milking and shearing to slaughtering and butchering, at the start of a long chain of operations leading to the appearance of processed food or manufactured garments on the supermarket shelves.

Robotics made its first real appearance in the manufacturing industry with the adoption of the name *Robot* for the serial manipulator. Here manipulation and its related kinematics formed the core of the art, later developing into intelligent automation. When the essentials of robotics are applied to the much more significant industry of agriculture, however, the emphasis must be placed much more heavily on sensing than on manipulation. When a tractor is steered automatically or a gate is closed because a feral pig has been recognized, the answer to the question *Is this robotics?* is not cut and dried. Without including such applications, however, many of the advances in agricultural automation would be overlooked.

Forestry deals with the harvesting of wood. Forestry machines are today still mostly directly controlled by human drivers, with the help of distributed controller area network (CAN)-based automation systems, but these machines will become more autonomous and robot-like in the future. The machines will have a perception system, which will map the trees and localize the machine. Information about the forest stand can thus be collected so that operation of the semiautomatic crane and loader becomes possible, together with steering and driving. Most of the forests in the Northern hemisphere are natural forests that are cared for. Particularly in Nordic countries, there is efficient and sustainable silviculture, the science, art, and practice of caring for forests for human exploitation. Stands of forest trees are thinned before clear cutting and replacement trees are either seeded or planted. Autonomous machines for silviculture will be an important research area in the future.

46.1.1 Technological Developments

Perhaps the greatest impact on agriculture has been through the farmer's growing awareness of computer power. Mobile computing can log the yield during harvesting, relating it to a precision map of the property. Tasks that had been merely mechanized can now be synchronized and automated, such as the lifting of spray booms and implements when turning.

Global positioning by satellite (GPS) has been seized on for mapping and guidance operations.

Generic radio communication techniques use protocols that might be common to mobile telephone technology or networked systems such as *Zigbee* [46.1]. These systems allow remote monitoring of gates, livestock, or equipment and automatic replenishment of water troughs. They can equally contribute to fleet management and information transfer in a forestry situation. Other radio technology in the form of transponders can see each animal tagged and identified to support activities such as milking and tracking *from the paddock to the plate*.

Much farming machinery has long been hydraulically powered, but the addition of digitally controlled valves opens the way for automated steering and other *robot* operations.

With computing power comes the ability to analyze images from cameras, which are becoming ever cheaper. Vision sensing has pervaded sorting operations, but now it extends to vision guidance and the recognition of animals to permit or deny them access to watering points.

It is unlikely that large tractors will ever be allowed to roam unmanned because of the risk of legal repercussions, but the day when cooperating teams of small autonomous *farmhand robots* will be seen in the fields is drawing ever closer [46.2].

46.2 Forestry

46.2.1 Overview

Forestry has progressed from manual to machine harvesting, such that by the end of the 1990s some 95% of the wood in Nordic countries was harvested with machines. Now the challenge of introducing robotics is being addressed. A typical harvester machine is shown in Fig. 46.1 and a forwarder, the machine that transports

Fig. 46.1 Cut-to-length (CTL) harvester made by Ponsse Oy Ltd. [46.3]

wood from the felling site to the roadside, is shown in Fig. 46.2.

Nowadays all new Nordic harvesters are controlled with a CAN-based distributed control system and information system, with GPS localization utilizing mobile communication networks to transfer data relating to harvesting. This forms a basic platform for adding more enhanced control functions. However, in a forest environment, GPS does not work well enough for the exact localization needed in machine control; simultaneous localization and mapping (SLAM) algorithms are needed.

A digital map of the forest stand and the target log assortments are downloaded to the harvester when the work begins. The diameter and volume of every log is measured when the log is *delimbed* and *bucked* (cross-cut) to the selected length. Information about the accumulated log situation is uploaded to a higher information system to manage the transportation of the wood from the side of the forest road to the mills. This logistics system incorporates trucks with digital maps and positioning systems, and is highly optimized in Nordic countries. The coordinates of every stack of different types of log are included in the information system and are delivered to the truck responsible for their collection.

Fig. 46.2 CTL forwarder by Ponsse Oy Ltd. [46.3]

46.2.2 Robot Locomotion in Forestry

Most current forestry machines use wheels as their locomotion mechanism. With active control, the machines can move in very difficult forest terrain if the slopes are not too steep. Much research and development has been performed in this area in order to stabilize and smooth locomotion with wheels over uneven terrain.

For locomotion in mountainous areas, new technological solutions such as walking are required. There are many areas in which mountainous terrain form a large

Fig. 46.3 Walking forest harvester prototype by Plustech Ltd., today part of John Deere

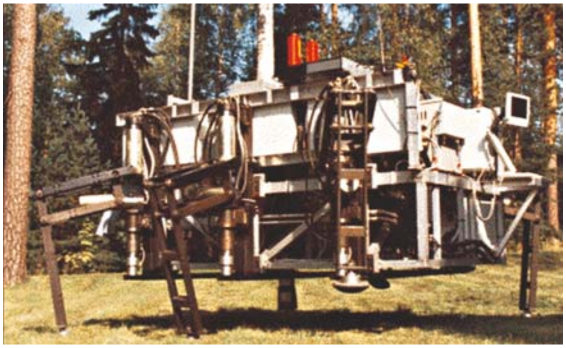

Fig. 46.4 MECANT walking machine by Halme et al. at TKK

proportion of the forest. Walking is perhaps the only safe form of locomotion on hillsides and mountainsides and has been an exciting research area in forestry robotic since the late 1980s.

In 1995, Plustech Oy published a prototype of a walking forest harvester, shown in Fig. 46.3. Plustech was owned by Timberjack Oy, which is today part of John Deere. Plustech Oy developed their walking machine independently, but most likely profited from the experience and results from a research project in which they had participated, MECANT 1989–1995. MECANT was developed at the TKK Automation Technology Laboratory led by Professor Aarne *Halme* [46.3]. MECANT, shown in Fig. 46.4, is a six-legged hydraulic remotely operated walking platform for studying locomotion in natural environments for work machines. *Halme* and *Vainio* at TKK published an article about forest robotics in 1998 [46.4], in which MECANT is also introduced. Newer research on locomotion at TKK has concentrated on combined walking with legs and wheels in each leg, rolking, developed in the Workparner platform by *Halme* et al. [46.5].

In Japan, most of the forests are in the mountains and many research projects have been conducted on walking technology for forestry, for example at Tokyo University by Toshio Nitami and co-workers.

Operating walking harvesters on mountainsides could be risky for human operators sitting in the cabin of the machine. Such machines should be remotely controlled. Teleoperation is dealt with in more detail below.

46.2.3 Forestry Automation

Almost all cranes used in cut-to-length harvesters and grab loaders in the forwarders are today driven with hydraulics. The control system of the crane or grab loader is based on CAN controllers with electrohydraulic valves. However, in spite of these technological possibilities, human drivers still control all movements. Some combined movements exist so that linear movements can be easily controlled, but commercial harvesters or forwarders do not have any automatic or even semiautomatic work cycles in their cranes and grab loaders.

Research to realize automatic or semiautomatic crane control has been underway since the 1980s. For example laser-pointer-assisted motion control of a forestry crane was implemented and tested in 1984 by *Manninen* and *Halme* [46.6]. The principles of interactive robotics, which could be used in connection with forestry cranes, were presented by *Halme* et al. [46.7]. The crane can easily be instrumented, since it resembles an industrial robot. Other enhancements can control swinging of the load.

During recent years, research has been performed to develop better control algorithms for motion control in the harvester head. The stem should be moved as fast as possible during delimbing, but no slip is allowed. The stem should be stopped at just the right place for cross cutting because the allowed tolerance in the length of the logs is only some centimeters. *Koivo* and *Viljamaa* et al. have developed well-behaved solutions for this problem [46.8].

46.2.4 Machine Perception and SLAM in the Forest Environment

In mobile robotics, simultaneous localization and mapping (SLAM) algorithms have been extensively studied. In forestry, the main task is to detect and parameterize the valuable trees among other plants and nonvaluable trees. This is a very difficult task due to illumination changes in general, bushes and young trees, and the branches of valuable trees. The perception must also work in wintertime, when there may be more than 1 m of snow that can cover the trees, and expensive forestry machines must be driven in almost complete darkness in the early morning and late evening.

With experience in using two-dimensional (2-D) laser scanners for measuring logs, work on modeling of the trees and forest on the basis of laser scanners has been performed since the 1990s. Figure 46.5 shows forest modeling results by *Wernersson* and *Högström* [46.9]. Similar work with a three-dimensional (3-D) scanner has also been undertaken at TKK by *Halme* and *Forsman*, as shown in Fig. 46.6 [46.10]. Modeling of the forest

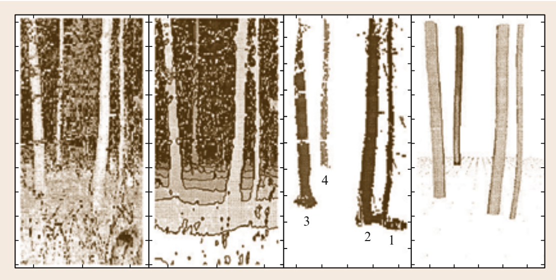

Fig. 46.5 Typical laser measurements of a typical outdoor forest scene, segmentation, and shape estimation by *Wernersson* [46.10]

on the basis of airborne 3-D laser scanners has been an important theme in remote sensing. However, because of the tops and branches of the trees, sufficient detail for forestry robotics cannot be measured from the air or space; this information must be supplemented with measurements in the forest terrain.

Autonomous SLAM capabilities are widely held to be one of the key features of outdoor mobile robots, including forestry robotics. Robot navigation has been an ongoing research topic for several years.

Navigation in outdoor environments is an open problem. The absence of simple features leads to the need for more-complex perception and modeling. 2-D laser range finders have become one of the most attractive sensors for localization and map building due to their accuracy and low cost. Most common laser scanners provide range and bearing information with sub-degree resolution and accuracies on the order of 1–10 cm for 10–50 m ranges. Valuable work has been done, particularly in the University of Sydney by *Nebot* and *Bailey* et al. [46.11–14]. Web sources concerning forestry measurements by Australian National University are also useful [46.15].

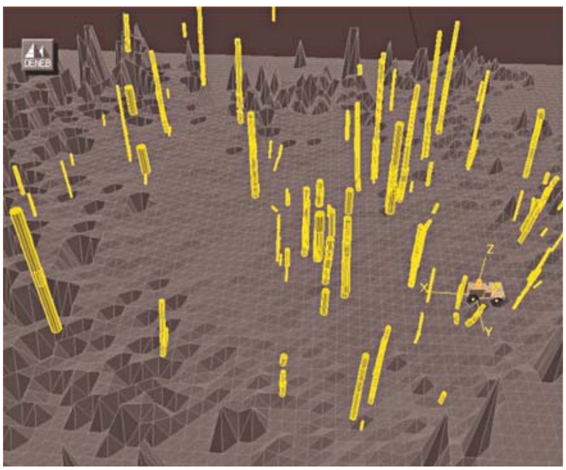

Fig. 46.6 A bird's-eye view into the combined 3-D elevation/feature model of a small forest area by *Forsman* and *Halme* [46.11]

The prospect of a fully autonomous forest harvester seems to lie far in the future. However, it is possible to advance step by step. A SLAM-based support system for the driver of the harvester seems to be reasonable and the benefits rewarding. In the ongoing Forestrix project by Visala et al. at Helsinki University of Technology TKK, forest and tree trunk measurement technologies, signal processing methods, and algorithms are studied in order to develop this kind of support system for the driver of a harvester. Semiautomatic control of forest harvesters for easy conditions is also being studied. In every forest stand, there are areas where only the human operator can control the machine. Advances in laser range finders and machine vision systems provide opportunities for new kinds of forest measurements.

46.2.5 Autonomy, Teleoperation, and Fleet Management

At Umeå University, a group led by Thomas *Helström* is developing autonomous driving of the *forwarder*. A human driver teaches the system by driving the route himself first [46.16]. This is a *real-world* study and results can be drawn from studies in the military sector.

Teleoperated loaders are already commonly used in mining. The main reasons for teleoperation are safety and efficiency, since one operator can operate several machines without being physically present in any of them. In mountainous forests, safety is a very good argument for the use of teleoperated machines. In relatively flat areas, as in Nordic countries, teleoperation can be advocated on the basis of increased efficiency. In Sweden a remote-controlled harvester operated by the driver of the forwarder has been developed by *Löfgren* et al. [46.17]. The trees are harvested directly to the cargo space of the forwarder. One remote-controlled harvester serves two forwarders.

True teleoperation over long distances requires efficient wireless communication, which can be a problem. For example live video links require quite high bandwidth, which cannot be implemented on the basis of mobile communication services existing today in the deep countryside. Teleoperated machines should therefore be intelligent enough that less efficient wireless communication is sufficient.

46.2.6 Autonomous Robots for Silviculture and Treatment

In Nordic countries, after the final clear-cutting of trees the ground of the forest stand is usually prepared for planting of seedlings or seeds. Seeding can be combined with automatic tilling. Planting has been partly mechanized over the last few years, using harvesters in which implanting units are installed in the tip of cranes. Planting could be robotized so that the planting plan is realized with a group of small robots employing real-time kinematics (RTK) GPS. However, there is much expertise and knowledge related to implanting itself, soil, and the planting site, which is difficult but not impossible to automate.

In order to automate weeding, more research is needed in this sector of forestry robotics. Pioneering research has been done in Canada by Petawawa at the National Forestry Institute [46.18].

46.2.7 Forestry Conclusions

Forestry is a demanding area for robotics. It is a harsh environment for all types of instrumentation. Reliable perception and measurement of essential objects and state parameters in real time is the bottleneck to developing more enhanced autonomous or teleoperated functions and operations in forestry machines.

46.3 Broad Acre Applications

46.3.1 An Overview of Automatic Guidance

Since the earliest horse-ploughing contests, farmers have aspired to straight lines. In Australia and other countries, this has been strengthened by the concept of *controlled traffic*. The belief is that if vehicles can be made to run in the same wheel ruts from year to year, the least damage will be done to the growing zone of the soil. These factors lend strength to the desirability of an automatic guidance system that has an accuracy of a few centimeters.

Methods that were considered included buried cables, but by the early 1990s it was clear that machine vision and the anticipated GPS offered the greatest promise. Workers at the University of Illinois had already researched means of deriving guidance information from row-crop images, but in those days computing power was limited and image capture interfaces expensive.

With a simple frame-grabber that captured a sparse binary image, researchers in Southern Queensland achieved automatic steering to centimeter accuracy. In a mere five years, low-cost video capture systems became available which enabled a colou-based system to be developed, tested, and brought to market [46.19]. The central algorithm was based on a regression fit of lines to plants seen in *keyholes* that moved to track the rows. Discrimination of *plant/not plant* employed a variable level that tracked a farmer-entered estimate of percentage ground cover. Steering was implemented by a submodule with an embedded microprocessor that switched valves in the hydraulic steering system, the loop being closed by a Hall-effect steering sensor. Figure 46.7 shows the row-fitting algorithm in action.

Despite great field success, the marketing effort through a major US tractor-maker saw few units sold. It is thought that the price was set too low, so that dealers were reluctant to take responsibility for high-technology equipment in sites that were mainly remote. Another handicap was the growing publicity for GPS guidance.

In those days, to achieve an accuracy that was claimed to be better than 10 cm GPS systems needed to be based on two-band receivers with a ground

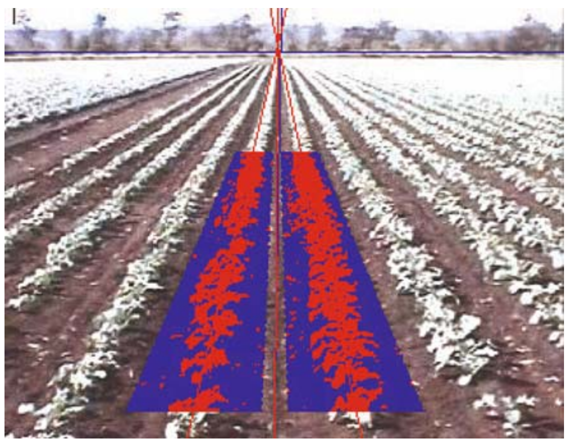

Fig. 46.7 Camera view with rows identified

base-station and RTK. Nobody could accuse the market-leading systems of being underpriced, with price tags of as much as 80 000 Australian dollars. However the initial products did not provide automatic guidance but merely displayed a guide bar for a human driver. The steering submodule that had been developed for vision guidance was sold in quantity to adapt the GPS systems for automatic operation. These *steering ready kits* sold for double the end-user price of the entire vision guidance system of which they had been a minor part.

With the convergence of computing and entertainment, cameras can now be directly interfaced through universal serial bus (USB) ports. Processing power and software are abundant. Differential carrier-based techniques allow low-cost GPS receivers to offer centimeter displacement tracking and the new generation of systems combine vision, GPS, and inertial sensors.

Whether tractors will ever be fully autonomous lies more in the hands of the litigation lawyers than in those of the engineers.

46.3.2 Sowing, Weeding, Spraying, and Broad-Acre Harvesting

When the individual operations are considered, the technologies vary in their importance. For spraying, 0.5 m accuracy is usually sufficient. Here, however, demands of speed are at their most important, so there is a trade-off between a GPS with a once-per-second update with inertial assistance and the 5 Hz GPS that is becoming more common. For yield monitoring, where the harvested yield might be apportioned into 5 m squares, GPS with 0.5 m precision is also sufficient.

When *listing up*, there is little or no visual reference in the field. Precision GPS and inertial sensors have a clear lead. However, when a good furrow has been formed, planting can employ a simple mechanical *furrow follower*, a ball or wheel trailed from an arm projecting in front of the tractor.

When seedlings have emerged, machine vision offers great advantages over GPS guidance. While cultivating, any dynamic positional errors at the planting stage will be added to steering positional errors; the blades must be set further from the row if the risk of destroying plants is to be contained. Vision can track the wander in the planted rows so that only one level of errors will be involved.

When a cotton crop is ready for harvesting, simple methods can again be used. Mechanical *stem feelers* are ideal for guiding the harvester precisely along the rows and these have been successfully field-tested by the National Center for Engineering in Agriculture (NCEA). For wheat, however, vision could still be supreme. The Illinois researchers have investigated visual ways of detecting the boundary of the previous cut.

A simpler robot already in widespread use is the center-pivot irrigation device [46.20]. These systems are self-propelled, irrigating an area of up to 600 acres per pass. Add-ons such as GPS, moisture monitors, and even imaging devices add sensory input for decision making. In this way, water and fertilizer may be applied to specific areas of the field at specific rates dependent on conditions [46.21, 22].

46.4 Horticulture

46.4.1 Picking of Fruit and Vegetables

Once we leave broad-acre crops, harvesting can require selection and sensing. Brute force *tree shakers* might be used for picking some citrus fruit, but hand-picking is still common. Intelligent picking has presented a challenge to many robotics researchers [46.23–27].

Picking can sometimes take the form of a location or localization task, deriving a target position for the picking actuator. At other times there is an additional requirement to determine which of the fruit are ready for picking and which must be left to ripen. At present, the *automation* consists of no more than conveyor belts extending each side of a tractor while hand-pickers walk the field, choosing which to cut, be they broccoli, rock melons, or cauliflowers.

The gathering of macadamia nuts is performed by a manually steered vehicle with a *bristle roller* which gathers up the nuts from the ground. What brings it to the attention of robotics is a localization task associated with selecting for varietal strains. It is necessary to attribute each kernel to the correct tree, meaning that the absolute position must be measured.

Cameras inspect the rollers just before the nuts are stripped, as shown in Fig. 46.8, so that the pick-up location is known precisely with respect to the vehicle, but that leaves the task of locating the vehicle. GPS is unreliable under the tree canopy, so the system

Fig. 46.8 Macadamia harvester with cameras

combines odometry with tree-trunk location using both sideways-looking visual streaming and radio frequency identification (RFID) tagging [46.28].

46.4.2 Color Sorting and Produce Grading

Some tomato growers resort to mass-harvesting tomatoes that are still green and rock hard, relying on ripening them in a controlled atmosphere. The selection task is then transformed from a field operation to a color-sorting line.

The actuation aspect of a sorting line might be a simple tipping mechanism that ejects a fruit from a carrier to fall into an appropriate bin. Alternatively it can take the form of an air-jet that deflects a falling nut kernel, causing it to miss a catching scoop. An essential difference is the substantial delay until a conveyor system reaches the required station compared with the few milliseconds required to actuate a valve to deflect a falling nut.

In all cases there is the task of singulation, separating each item for individual inspection. Apples and tomatoes will roll into cup-shaped depressions, but nut kernels need to be shaken onto a pair of contra-rotating rollers that form a chute down which the nuts can slide. As the nut falls through the viewing window a decision must be made within milliseconds to either let it fall or to deflect it with the jet.

Some applications hardly warrant the term *machine vision*. In an early nut sorter, light was separated by dichroic mirrors into two chosen wavelengths, to be measured by simple photocells. The transient was interpreted for color and for the presence of shell. A conventional camera would be ineffective, since the delay associated with the frame rate would be long compared with the time of flight. In a tomato sorter, on the other hand, the three conventional red–green–blue (RGB) color bands of a television camera suffice to determine both ripeness and size.

When an early investigation was made of the sorting of broccoli heads, image capture was a substantial hurdle to overcome [46.29]. The reward was the quality of information gathered, enabling grade boundaries to be adjusted when separating the produce for varying destinations. However the project was handicapped by the automation task of separating the heads from bins of produce, to load them into the inspection carriers.

One of the factors used to determine citrus quality is the texture of the skin, which is a combination of wrinkles, dimples and lumps, or flat spots. Previously, measurements were made using a stylus on the revolving fruit [46.30]. In the machine-vision solution, the rotating fruit is illuminated from the side, so that it appears as a *half-moon* to the camera mounted in front of it [46.31]. The *terminator*, dividing lit and portions in shadow, appears as a ragged vertical line, with a statistical distribution of horizontal *roughness* that is readily related to the texture.

Today the vision grading system could well be carried on the harvesting vehicle. There is a growing appreciation of the benefits of single-handling, with grading and packing being performed in the field as part of the picking operation.

46.5 Livestock

46.5.1 Robot Milking

Although matters have come a long way from hand-milking, the milking parlour still requires many operations. The cow must be identified, moved to the milking station, and restrained, then he udder must be inspected and prepared, and the teat cups attached. The milk must be assessed to ensure that it can safely be added to the storage, the teat cups removed, and the udder treated post-milking.

According to a review paper [46.32] there were over 400 milking robots in operation by 1999, each capable of tending 40–70 cows by performing these operations. It is now the cow's responsibility to determine the time of milking. The visit to the milking station is rewarded with grain feeding, but training is required to establish a routine.

46.5.2 Sheep Shearing

Without doubt, one of the most spectacular aspects of robotics research for agriculture was the University of Western Australia system for robot shearing, *Shear Magic* [46.33]. A hydraulic robot arm was developed to enable shears to be manipulated in an emulation of the *blows* that are actions of a human shearer. Innovative capacitance sensors enabled the shears to *float* accurately close to and parallel with the skin of the animal, so that nicks and cuts could be reduced below the level a human shearer might impose.

After spending many of millions of dollars, however, the project was discontinued. In an industry where contests are held for speed, the failure of the robot system to achieve similar speeds and cost efficiency left it without support.

A similar fate befell the two-armed system announced in 1985 [46.34]. This was developed for automatically shearing part of the sheep by the Merino Wool Harvesting Pty., which ran out of funding in 1993.

Nevertheless there have been valuable spin-off lessons. An aspect that makes shearing arduous is the need to manhandle the sheep. The robot demanded that the sheep be presented in a structured manner, and the sheep loading animal manipulation platform (SLAMP) sheep-handling part of the university research surely lent concepts to systems such as *ShearExpress* [46.35, 36]. This is a system whereby the legs of the sheep are cuffed, presenting the sheep at various attitudes for the convenience of manual shearers who can now perform their task standing up rather than crouching, each specializing in a different part of the fleece.

ShearExpress also addresses the problem of bringing sheep and technology into the same physical location, taking the form of a complete mobile shearing shed. Even so, its future is also in question.

There has also been considerable *strategic* payoff from such research. Shearers have moderated their pay demands and industrial relations behavior since the technology was demonstrated. The progress of projects such as these has been hampered by the inability of the industry to gather sufficient investment capital against which to leverage external investment funds.

Fig. 46.9 *Shear Magic*

46.5.3 Slaughtering

Delegates to a Brisbane robotics conference in 1993 were taken on a visit to see a robotic slaughtering system installed at Kilcoy. They were able to compare the manual system, in which each beast is stunned and then hoisted by a hind leg to have its throat cut, against the Fututech system in which the stunning and exsanguination process were automated.

The emotional impact was striking, much more so than the economic factors. The dead animal was toppled onto a moving cradle, where it could be dismantled by human butchers. There were islands of technology, such as the skinning station and the saw that accurately split the carcase in two under sensory control. However the automation was made somewhat cumbersome by the centralized control, requiring extensive cabling to the control and computing booth. The actual saving in manpower was slight, with 30 or so butchers still required for jointing.

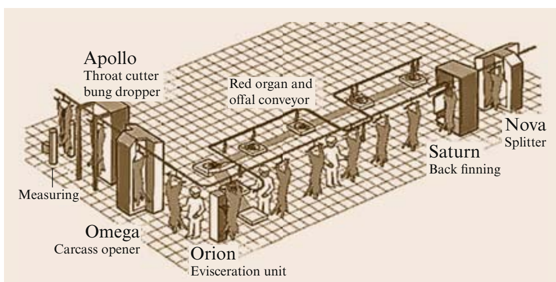

Fig. 46.10 Danish pig line

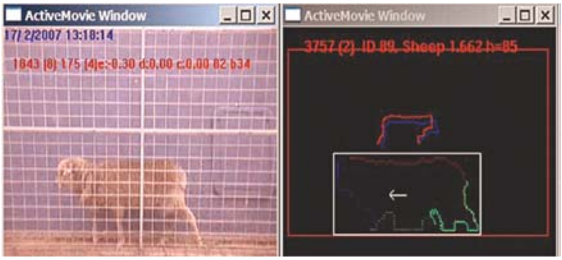

Fig. 46.11 Sheep with identifying outline

Soon afterwards, the project was wound up. In Hansard on 7 May 1996 [46.37] it was reported that Senator O'Chee said, *What became apparent as the trials went on was that the process was not working. The idea that these animals would be automatically killed just was not happening*. He went on, *That has seen the cost blow out from AU$2.2 million, which was the estimated cost of the Kilcoy portion of the Fututech program, to $20 million for that portion of the program. That is half of the $40 million which was expended in relation to Fututech*.

Perhaps some of the problems lay in overoptimistic overall budget expectations and in the choice of animal to butcher. In Denmark, an automatic slaughter line for pigs claims a throughput rate of 78 000 pigs per week [46.38]. *Islands of automation* handle evisceration and back splitting with methods bearing a similarity to those of Fututech. This part of the US$270 million DanishCrown Horsens plant was engineered by SFK Meat Systems at a cost of some 20 million dollars [46.39]. Production started in late 2004.

46.5.4 Livestock Inspection

As with produce, grading and classification of livestock carcasses is becoming more commonplace. Poultry [46.40] is one application where the advances in image sensors and filters for particular spectra combine to provide automatic detection of disease and contaminants in a poultry processing line.

An application involving individual recognition of production animals is in full commercial use by *Big Dutchman* [46.41]. In this circumstance, pigs are tagged with unique radiofrequency identification (RFID) ear tags. As each animal enters a feeding bay, the tag is read and an appropriate ration of food is delivered. This allows individualized diets and medication delivery to improve the bottom-line cost/benefit for pork producers.

Another novel method of identifying and controlling animals is being developed in Southern Queensland [46.42]. Using machine vision, each animal proceeding along a laneway towards water is classified at the species level. An automated gate then either allows or denies access to the watering point. The same technology can be used to remotely draft production animals based on a condition score into several different categories.

Fig. 46.12 Robocow with horse and rider

46.5.5 Robotic *Animals*

The Robotic Sheepdog [46.43] was initially developed to herd ducks, with the expectation that it could be applied equally to herding sheep. The robot was controlled by a remote personal computer (PC) using a fixed television (TV) camera to locate both the flock of ducks and the physical robot. The duck behavior was modeled and fed back to the robot position control to herd the animals from one end of an arena to the other.

At the fringes of agriculture can be found country sports such as *cutting contests* and *camp drafting*. Both are contests of horsemanship, requiring a small beast to be manoeuvred by moving the horse relative to the beast. In fact the horse must take many of the decisions. It must be trained to react appropriately to the beast's actions, requiring hours of interaction with a steer or heifer.

The beast is prone to lose patience rather quickly and simply wander away from the horse, so Robocow was developed as a training aid [46.44]. As seen in Fig. 46.12, the steer-shaped body is mounted on a steered tricycle that can spin on the spot or accelerate rapidly on rough ground. Originally programmed to *dance* a chosen pattern, there is a new project to add *bovine intelligence* by enabling it to react directly to the movement of the horse.

46.6 Unmanned Vehicles

There is a rise in the use of unmanned arial vehicles (UAVs) to address tasks in agriculture. The most advanced applications are already at a commercial stage. Helicopters from Yamaha [46.45] can be programmed to take aerial photographs over a specific flight path. Manual override control allows user interruption, with the capability of resuming the flight path from where it left off. This type of vehicle offers unprecedented availability of a stable platform for image sensors and hyperspectral sensor devices.

UAV collaborative, which has a cooperative research agreement with the National Aeronautical and Space Administration (NASA), uses long duration flight time UAVs such as the Pathfinder [46.46] to perform unmanned flight operations. The applications range from testing coffee ripeness in Hawaii, to real-time acquisition and distribution of thermal images over a controlled fire in California.

While full-sized tractors may never be fully autonomous, there is scope for smaller, cooperative vehicles to perform set tasks. Many researchers are currently investigating various platforms, including several approaches from researchers in Illinois [46.47]. The idea behind smaller units will be that they can work cooperatively and constantly, thus providing the same amount of horsepower with much reduced risk.

46.7 Conclusions and Future Directions

Robotics is percolating into all aspects of agriculture. The applications are many and various, but there is still great scope for further innovation. A constant grumble is the shortage of manpower for farming, both skilled and for seasonal harvesting operations. Intelligent robotics will be welcome in this most essential industry.

The main challenge facing robotics in forestry is the harsh environment. This is due to a combination of both weather conditions and rapidly changing illumination. Improvements to forest machines are ongoing and some recent results in this direction have been reported by the research project Forestix [46.48, 49].

In agriculture generally, there are a number of issues that must be confronted.

- The ongoing loss of expertise in the industry;
- New robust reliable sensors and actuators will be required to withstand the environmental extremes that are the basic working conditions in many agricultural areas;
- A unit-cost barrier exists due to the small profit margin of many agricultural areas. This will require either a generalized methodology for robotic system, or some other measure to lower unit costs.

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