Robotics and Intelligent Machines in Agriculture

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Abstract—**From the prehistoric times of the hunter/gatherers until the present, man has been the sole source of intelligence in his food production system. The combined factors of increased international competition in the agricultural sector, advances in computer technology, and the rapidly decreasing costs of new technology have now brought us to the time when the widespread application of intelligent machines in agriculture is imminent. Thus practical agricultural robots now seem possible. Agricultural robots and intelligent machines will increase and become commonplace in the developed countries during the next decade. The status of intelligent machines and robotics in agriculture as it stands at present is reviewed; i.e., where it is going and some of the obstacles that must be overcome.**

Where We Have Been

TRADITIONALLY, farming has been very labor intensive and filled with many menial, tiresome tasks. Agriculture has been one of the last industries to use robotics and intelligent machines. One reason other industries such as manufacturing and mining have embraced these new technologies more quickly than has agriculture is that many industries are able to use their machinery throughout the year. The seasonal nature of agriculture creates the need for equipment that is only used during certain seasons of the year, often for only a few hours per year. A planter is only needed when it is time to plant, a harvester is only useful when the crop is mature, etc. Because of the fixed annual costs of ownership, a producer often cannot afford to invest as much in a seasonal machine as in one that can be used year around.

Farming has not often been a large money-making venture, and there have been many times when there was insufficient capital to invest in mechanization. Thus the market for increased mechanization has not been consistent. Most of the early farm mechanization inventions were small and of the hand-held variety [4]. More-sophisticated agricultural mechanization has also been limited by the wide variety of conditions, many adverse, under which the machinery must operate. Many tasks are of necessity performed on rough surfaces (e.g., a plowed field) in extremes of ambient conditions, temperature, humidity, dust, mud, etc. The machine's environment is difficult to control. Agricultural products vary widely in shape, size, color, texture, and firmness or hardness.

Yet another factor that could account for some of the differences in levels of mechanization between agriculture and other industries is difficult to quantify, but nonetheless very real. There is the perception on the part of many that farming is a way of life as opposed to simply being a means of earning a living. Farmers have been willing to do considerable menial labor to maintain their way of life, and they have often accepted this as part of farming.

Manuscript received January 14, 1986; revised July 13, 1986.

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Still, the farmer has been keenly interested in ways to make his work easier. Many of the labor-saving devices and methods in agriculture have been developed by the farmers themselves. Early in our history, manpower began to be replaced with animal power. The advent of the horse-drawn reaper in 1831 to replace the scythe is one important example. Later, animal power was replaced with machine power when steam engines became common around 1890. By 1930 farm machinery began making the transition to larger, more-comprehensive machines for large-scale farming [4]. Even then, the farmer was still the one who supplied all of the intelligence to control the machines. If a robot or intelligent machine can be produced that will make his operation more profitable, the farmer will use it.

Where We Are Now

Many of the world's more technologically developed countries have been working in agricultural robotics and intelligent machines. Many experimental models have been built, and a few have been produced commercially. There are some intelligent devices being used in grading and sorting operations. According to a report by Johnson [3], the Sunkist Corporation has developed a citrus grading machine. It grades the fruit according to its size, color, blemishes and scars, and frost injury. Two presently used installations in California each have an operating capacity of approximately 480 fruit per minute. One is used in a lemon packinghouse and the other in an orange packinghouse.

Vision systems are also being used extensively in food processing. Some of the applications include a broken yolk detector in commercial egg breaking machines; a defect-removal system for potato french fry strips; a cucumber sorting and grading machine; a chocolate candy coating inspector; and a machine to detect defective pizza crusts [9].

One of the most sophisticated prototype agricultural robots can be found in Australia. The University of Western Australia has done extensive work on a robotic sheep shearer [7]. The sheep is constrained with straps on a movable platform similar to the ones used in hospitals for holding patients for brain scans. The platform can be moved in all three dimensions to any desired position. A few manual measurements such as the shoulder width and length between the front and back legs of the sheep are used by the computer to predict the surface path for the clipping shears to follow. Hydraulically positioned clippers controlled by the computer do the actual shearing of the wool. The path computations are continually updated during the shearing process. Pressure-

0882-4967/87/0200-0003$01.00

sensitive sensors within the robotic shears respond to the skin topology and prevent the shears from injuring the animal. The system will automatically remove the wool from the belly, back, sides, and neck of the sheep. The head and a small region around the tail must still be clipped manually. The robotic shearer has been tested against professional sheep shearers, and the sheep are actually nicked fewer times with the robotic shearer than when sheared by hand.

The Agricultural Engineering department of the Louisiana Agricultural Experiment Station has developed a laboratory model robotic seedling transplanter [2]. A conventional transplanter requires one person for each row. The operator picks the transplants one at a time from a series of vertical rotating trays and drops them in the transplanting mechanism which sets them in a furrow and presses the soil around the roots. The transplanter is mounted on a drawbar and pulled by a tractor. The robotic transplanter uses a laboratory model robotic arm with five degrees-of-freedom and a gripper. The arm is mounted on a modified commercial transplanter and controlled by a microcomputer. It picks transplants from a series of horizontal trays and places them in a commercial transplanter which was modified by removing the seat, vertical trays, and several other parts. The robotic transplanter missed an average of one plant in each tray of 36 plants. The system did not use any sensors, but was pre-programmed with the coordinates of each cell in each tray of transplants. The prototype could only transplant at an average rate of six plants per minute, which is one-fifth the rate for a human operator. Development is continuing on this planter.

In Japan, Kondo and Kawamura [8] are developing a robot for harvesting tree fruit. They used a video camera mounted near the hand of a manipulator to guide it to the fruit. The system was mounted on a mobile battery-powered platform.

Another group in Japan [6] has developed a working, fully automatic grain combine. A driver on the machine makes the first pass around the edge of the field to define the limits of operation. When that is completed, the driver dismounts from the machine, and the combine continues harvesting either until its grain tank is filled and it must stop to unload, or until the field is completely harvested. Tactile sensors located near the front of the harvester sense the edge of the previously cut swath and control the steering system. The combine is powered by an internal combustion engine driving two independent tracks similar to those found on crawler tractors. Steering is provided by braking one track while allowing the other to continue moving. The combine's speed is determined by load sensors in the threshing unit. The threshing unit is responsible for removing the grain from the stalks, chaff, and other material. If the material enters the threshing unit too rapidly, its efficiency decreases and part of the grain is lost out the rear of the machine. The load sensors detect when the material flow rate is too great, and the machine's speed is decreased.

At Japan's Technology Farm [6], some researchers have been developing driverless, robotic sprayers for applying hazardous chemicals to tree crops. One model uses photosensors to control the spraying by sensing the presence of the tree trunks. Another one is automatically guided through the orchard by following a PVC pipe previously laid on the ground along the desired path.

Agricultural equipment manufacturers are marketing chemical sprayers that can monitor and automatically control the rate at which the chemicals are applied to a field. Commercial seed planters are available that can automatically plant at a selected seeding rate. Combines have an increasing number of sensors to monitor the condition of the incoming material and the behavior of the machine itself. De Baerdemaeker *et al.* [1] reported on a grain flow monitor they are developing for combines. This would be useful in detecting losses flowing through the machine.

Researchers at the University of California, Davis [5], have developed a digitally controlled tractor simulator to measure the performance of tractor operators. Ford Motor Company and DICKEY-john [10] have developed an instrumentation package for tractors using radar and other sensors to measure total land covered, rate of covering land (important for accurate chemical application), and wheel slip.

There have been significant advances in the dairy industry. A group at the University of Illinois [14] has done considerable work on developing a computerized system that feeds each milk cow on the basis of her milk production. They can also measure and record the milk production of each animal. Some systems based upon these principles are now on the market. Research is continuing on a system which can detect and warn of mastitis infections. Mastitis is a major cause of decreased milk production.

Where We Are Going

According to a study at the Honeywell Technology Strategy Center by Pejsa and Orrock [11], there are five crops identified as having high potential for robotic applications. Their analysis was based upon three criteria. The first was the nationwide annual farm yield, the second was the dollar yield per acre, and the third was the manpower requirement. The five crops are, in decreasing order of potential, as follows: tobacco, fruit from trees (citrus fruit, apples, peaches, pears, plums, prunes), strawberries, grapes, and lettuce.

New developments in two areas are critical if robotics and intelligent machines are to play a significant role in agricultural production: improved sensors and a better understanding of the biological behavior of plants and animals. We may also need to genetically alter some of our food plants to make them more adaptable to care and harvesting by new machines.

Work is under way at many universities, private institutions, and companies to make crops which are more easily harvested mechanically. This includes crops that will all mature over a short period of time; i.e., fruit with lower abscission forces for easier removal, plants (tree, vine, etc.) that are trained to grow in a desired pattern, and fruits and vegetables that can withstand the rigors of mechanical handling while still maintaining their desirability for consumers.

Grain Drying: Extensive research has already been conducted in the area of grain drying. The ideal dryer would use the minimum amount of energy to dry the grain, without damaging it, to a moisture content where it could be safely stored. In order to perform this function, the dryer must continuously monitor the conditions of the following: 1) the grain, 2) the ambient air, and 3) the heated air. The dryer must be able to control the amount of air recirculated through the grain and the amount of heat added to the drying air. It may under some conditions also need to dehumidify the drying air. Additionally, the dryer must also have an accurate understanding of the behavior of the grain. It would contain a detailed model of the grain's behavior under various drying conditions. It must know under what conditions the grain will stress or crack, how long it can remain at different moisture contents without spoiling, and how quickly moisture can be removed from the grain under different drying regimes. The dryer must be able to determine whether it is more economical to dry the grain with ambient air or if supplemental heat is required. Since much research has already been done modeling corn, soybeans, rice, and other grains, we may be close to developing this ideal dryer, at least for some grains.

Irrigation Scheduling: Applying an adequate amount of water without any excess to a crop becomes more important as water resources dwindle and pumping costs increase. An irrigation system should apply the proper amount of water to the plant when it will best use it, and in a manner which will minimize losses through evaporation, runoff, or percolation through the soil. This requires a system that understands the soil type and condition and the plant's response to water in various weather conditions and stages of growth. There are sensors available that can measure soil moisture conditions in some specific situations over limited soil moisture ranges. However, none exist which can be used in all soil types and moisture ranges, and these two factors can both vary widely even within a single field. There also remains work to be done on crop models to accurately predict when the plant most needs additional moisture. An alternative method to using crop models would be to use plant stress sensors to actually measure the water stress of the plant in the field. Letting the plant itself indicate when water was needed could be the most direct solution to the problem. Work is continuing in this area. The irrigation scheduler would also have to know the costs of irrigation so it could select the maximum profit point located somewhere between the point of lowest cost (no irrigation) and maximum yield (all the water the plant can use.)

Pest Control: Weeds, insects, and diseases must be controlled to achieve peak crop production. Computer models are needed which can accurately describe the growth and behavior of the various plant pests both individually and in interaction with one another. Pest growth models have been developed in many universities with varying levels of success. The usefulness of the computer models are dependent upon accurate mathematical descriptions of the various pest physiologies and upon the accuracy of the inputs (initial levels of infestation and weather). Most of the National Weather Service weather stations are located in metropolitan areas and quite often at airports. Obviously, better pest control could be achieved by using locally measured weather conditions to drive the pest computer models and predict the optimal time to apply the pesticides. Several states, including Louisiana and Nebraska, have established networks of rural weather stations that continuously measure and record air and soil temperatures, solar radiation, pan evaporation, wind speed and direction, and rainfall. The information is stored on microcomputer data-logging systems. These systems are queried each day by a central computer via a modem and telephone line and automatically upload their data to the central computer for use by researchers using the pest and plant growth models.

Smarter Machines: Room still exists for improving grain harvesters and planters. If reliable and accurate sensors existed for measuring the moisture content of the grain entering the harvester and the amount of grain lost out the rear of the machine, the machine could be automatically adjusted to meet varying harvesting conditions. An instantaneous soil moisture sensor could be mounted on a planter to place the seeds at the optimum depth for the amount of moisture present. Any machine which would reduce the harvesting or planting costs should have a ready market.

Meat Processing: Some robotics possibilities exist in the meat processing plants. Some of the tasks, particularly those requiring saws or knives, can be very hazardous. A robot with a vision system could perform many of the cutting, slicing, and other meat handling operations. A study by the University of Florida Agricultural Engineering Department [13] predicted a present worth value of more than ten million dollars by using a robotic/automation system in the poultry processing plant chosen for their case study.

Barriers to Agricultural Robotics

The following list some prevailing barriers to agricultural robotics. *Sense of Direction:* The future of agricultural robotics in this country is not altogether clear. One of the problems is the present uncertainty in the direction of American agriculture. There is not a consistent long-term national policy or direction for agriculture. Many of the international markets for United States' agricultural products have disappeared or diminished over the past few years. Former customers are now our competitors. The good news is that this may result in our producers becoming more efficient. The competitive pressures of other countries may well result in a growing utilization of robotics and intelligent machines in order to meet the challenges. We will always need a significant capability for producing affordable food and fiber.

Low Value Product: Many agricultural commodities have a low per-unit value. Robots tend to handle objects one at a time, and they must need to be manipulating objects with relatively high value in order to be justified.

Variable Product: Nature is not known for its uniformity, but robotic devices function best with well-defined, uniform products. If, for example, all oranges were the same size, shape, and color, and if they always grew at a set of known positions on a tree, a robotic orange picker would be a relatively straightforward machine to develop. The randomness of nature makes the agricultural robot more difficult to develop.

Variable Work Space: The plant positions and orientation in the row may change from one plant to the next. The fields may have irregular shapes and topography with obstacles such as drainage ditches, irrigation hoses, fences, and trees. Different crops will have different row spacings. A field robot must be able to work on uneven terrain, in soil conditions ranging from sand to clay to blowing silt, in snow, heat, rain, and in varying humidity levels.

Emphasis of the Developers: If the developers of agricultural robots concentrate primarily on devices that will replace an operator, practical robots are likely to be a long time in coming. However, if the concentration is on devices that will assist the operator, robotic devices and intelligent machines in agriculture will gain much wider acceptance. For example, to harvest citrus fruit from trees, one could develop a completely autonomous robot that would use a vision system and computer to detect, locate, grasp, and pick each fruit. On the other hand, one could develop a machine that would depend upon the operator to identify the fruit and let the machine harvest it. The operator might even wear a helmet with a "heads-up" display similar to that used by fighter pilots in choosing their targets. The operator could simply look at each fruit to harvest, and the harvester's computer would move its picking arm to the fruit. This would let the human brain operate in an area where it is strong—locating and identifying a nonuniform object in an ill-defined and unstructured environment—and let the robot perform the task at which it is faster and better adapted; i.e., the actual picking operation.

Support System: Someone is going to have to be able to repair these new machines. A sophisticated broken machine is not as useful as a less sophisticated one which is working. As the machines become more complex, the skill level of maintenance personnel will have to increase commensurately. This kind of support will be particularly difficult for agricultural robots, because the service area will be more spread out than in a factory environment, and very few, if any, producers will have the expertise or equipment to perform their own repair or maintenance. Turnaround time for repair will often be critical. When the crop is ready for harvesting, delays can be disastrous.

Driving Function: Are the directions we are heading now in agricultural robotics and intelligent machines a result of developers/researchers meeting specific producer needs or are they developing devices which they believe the producer *should* need? Just because something can be done does not mean there is a need for it to be done, or that it will be accepted. On the other hand, some developments have created previously unperceived needs and opportunities. The electronic calculator is a good example of that. We may see that happen with agricultural robots.

Conclusion

The basics of agricultural production have remained unchanged for centuries. It is still man's task to raise crops and animals for human and animal consumption. Crop production requires preparing the land, planting the seed, nurturing the plant, harvesting, and processing the crop. Animal husbandry involves caring for the animal from conception through processing of the meat.

If the following statement by Len Richardson [12], editor of *Agrichemical Age,* is correct as this author believes him to be, American agriculture is going to need all of the help it can get in order to once again become a strong and healthy industry.

> So the bottom line is that while we all talk a great production ag story, we are no different than the steel and auto industry—we have lost the competitive edge. ...American agriculture is competing in a world market, and we do not have the advantage.

An expertise concerning the capabilities of intelligent machines and robotics combined with an understanding of the needs of agricultural producers will be required to effectively meet our present and future needs. The development and proliferation of intelligent machines and robotics in agriculture will continue and progress insofar as they are able to help us produce, process, and transport food and fiber at a competitive price in a world market.

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