Agricultural Robotics
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The Future of Agricultural Robotics

1. Introduction

Ever since the start of mankind, people have struggled to find ways to produce enough food for themselves. Farming started just as small gardens that grew cucumbers, turnips, and other food plants, but slowly evolved into the larger farming industries we see today. People added farming to their food gathering jobs, which included hunting and fishing as well, and began settling in wide expanses of land on which they could grow their own food. They refined their technique, learned about which seeds could grow where and what the specific requirements for different plants were, and before long, they made farming one of their primary food sources.

Not only could they farm and grow their own food, but they could also grow cotton, tobacco, and other crops that could trade for money and other goods. Thus, the problem about food and money was solved; farming was also rather safer than hunting, though it was far more tedious and took much more patience. After a few years, about 90% of all the overall population were farmers [1]. Now, however, with the new technology advances and various other jobs that offer a larger salary, only 3% of the population are farmers, yet they are still able to produce enough fiber and food for most of America and even some countries out past America's boundaries! [2]

But farming also has many drawbacks. It is backbreaking work to plant and harvest crops, and it takes many long and strenuous hours to finish. The only tools that the early farmers had were simple tools that were mostly hand-made; some of the times, such as during planting and harvesting, they just used their hands. Farmers usually had to hunch over for a *very* long time, which resulted in many back and hand injuries. Farmers were also very hard-pressed to produce enough food for their entire family/colony/city. They had a hard life, and are the reason we are here today.

2 Justification

In the original Star Wars movie, Luke Skywalker's uncle bartered for the sale of two robots that would help him on the family farm. These robots were R2D2 and C3PO, who would go on to help save the galaxy from the evil Empire. Although we do not expect our farm robots to be able to save the galaxy, we hope that they will be able to make farming easier and provide a more efficient source of crops. What are the advantages and disadvantages of automating our farming efforts and is the cost in time, labor and money worth it?

Here is what James Pinkerton has to say about the role of technology and automation in American agriculture [9]:

"That's the path America took on its way to becoming a great power. In agriculture, the big breakthrough came in 1831, with the invention of the McCormick Reaper. Mass-produced in Chicago, the reaper enabled two men to cut as much grain in a day as a dozen or more men using traditional reaping hooks. As a result, labor was freed up to work in factories, accelerating the Industrial Revolution - and the American Dream.

Yet, it's noteworthy that the reaper and similar productivity enhancing inventions came to the American North, not the South. In slave-holding Dixie, where labor was free - if you don't count flogging and lynching and putting down bloody uprisings as costs - there was little incentive to develop labor-saving technology. The low-tech status quo seemed quite OK to plantation owners."

In other words, Mr. Pinkerton is saying that technology and automation are nothing new, however, if a cheaper alternative is available, then farmers will take it as farming is a labor and money intensive effort. Mr. Pinkerton goes on to say that 4/5 of all farming in America is already done with machines [9], though these machines are not automated and that it is time for another revolution in agriculture: the automation revolution.

According to researcher Tony E. Grift at the University of Illinois, using robots in agriculture is nothing new and countries such as Japan and the Netherlands have been researching and building robots for use in agriculture for a number of years. However, he says these robots were designed to operate in a controlled environment. His robots are being tested in uncontrolled, outdoor environments, in other words, the real world [10].

2.1 Cost Effectiveness:

Farming is inherently a costly undertaking. Farmers must spend money on their labor force, machinery, seeds, fertilizer, pesticides, insecticides, transportation of crops, and other expenditures. Although farm bankruptcy rates were at their highest in America during the Great Depression, farm bankruptcy rates have been rising during the past 30 years and there are now 2/3 less farms in America than there was at the turn of the 20th century [11]. Tony Grift imagines a world in which huge, expensive farming machinery is replaced by smaller, more efficient and much cheaper robotic farmers. Grift claims to be using a "smaller and smarter" approach to farming. Grift asks the question "Who needs 500 horsepower to go through the field when you might as well put a few robots out there that communicate with each other like an army of ants, working the entire field and collecting data?" [12]

Grift has built robots used for agriculture for as little as $150.00 each. This beats the cost of many large, heavy machinery which sometimes costs tens or even hundreds of thousands of dollars. In addition, by employing robot workers the farmer is reducing his labor cost. He can essentially kill two birds with one stone. By utilizing cheaper agricultural robots he can reduce his machinery and labor cost in one stroke.

2.2 Environmental and Pollution Concerns:

Growing the food required to feed the USA and the world can be environmentally devastating. The most famous case of ecosystem collapse and failure is probably the great Oklahoma dust bowl of the 1930's. Farmers, using improper and unsustainable farming techniques, depleted the land to an extent that it turned to sand, and then the famous Oklahoma wind turned the sand into giant dust storms [13].

The intensity of farming has naturally progressed as the population increases and more people need to be fed. The use of fertilizer and pesticides has increased since World War II at an alarming rate. These products are damaging to the environment, running off and polluting local streams, rivers, and lakes, and soaking into the ground water that provides drinking water for people. Fertilizers contain nitrates and phosphates which are limiting factors in the growth of algae [13]. Although pesticides have the beneficial effect of killing off unwanted pests, it can also kill off other animal species and pollute water systems. In addition pest species become resistant to the use of specific pesticides, demanding the development of even more powerful and dangerous pesticides. In Suffolk County in Long Island, at least 13 different pesticides have been measured in the groundwater and at least 12 percent of the wells in Suffolk County have exceeded the safe drinking water guidelines for some pesticides [13]. In defense, the use of fertilizers and pesticides has had the benefit of increasing the amount of food produced per acre of land which farmers are always looking for ways to do [13].

Soil erosion is a major concern to farmland. It takes about 300 years for 1 inch of topsoil to form and on average, farmland erodes 10 times faster than is replaced by natural means[13]. Topsoil contains the nutrients plants need to grow and help to retain moisture in the soil which plants utilize in photosynthesis.

Clearly, something should be done about the environmental impact of farming. Can robots help? According to Tony Grift at the University of Illinois, yes, robot farmers can help the environment. He envisions robots which can target pests "*Instead of applying all of this spray that might drift everywhere, a robot could actually 'spit' chemical at the plant with great precision, using a very small amount of chemical*" says Mr. Grift [14]. Instead of applying large amounts of herbicides, researchers envision robots which can identify weeds and communicate with other robots to come help them pull and dispose of the weeds instead of applying large amounts of chemicals to defeat the weeds [14].

3. Applications of Robots in Agriculture:

What other applications are there for Robots in Agriculture? The following briefly lists some of the lines of research and applications of robots in agriculture [15]:

- Unmanned Ariel Applicators - Unmanned robot vehicles could quickly and efficiently spray crops instead of a human controlled plane. This could easily save money as the plane would be smaller and through the use of sensors could be made to be more efficient and therefore safer and cheaper than mass spraying with a manned plane.

- Robotic Milkers - Robots could milk more cows, more efficiently and safer than human milkers.
- Robotic Sheepdogs - Robots could be used to herd sheep and other cattle.
- Driverless tractors and Sprayers - Traditional tractor and spraying systems can be made to be driverless
- Meat Processing Equipment - Robots can take the monotony out of meat processing and make it safer by not introducing possibly contaminated humans handling the meat.

4 A Brief History of Agriculture

4.1 The beginnings:

Evidence suggests that mankind first began abandoning his hunting and gathering and nomadic ways and began farming in earnest in the Mesopotamian river valley around 9,000 BC [1]. The first crops were wild grasses and cereals, planted in the fertile ground along major river valleys and now make up a large percentage of the current world agricultural production [2].

Long before the use of machinery, when mankind relied mostly on farming by hand, farmers depended upon simple hand-made tools, such as the crude wooden plow pulled by animals such as horses and mules; if they couldn't't use those, they simply did all the planting and harvesting by hand.

Even though farming at that time was essential and necessary, it took a great deal of time and strain. If the crops were not harvested in time before winter, or if the seeds were planted too late then all the work that had gone into farming the crops would have been wasted and starvation ensued. Therefore, the farmers had to perfect their farming techniques so that they could get the best results out of their crops. Several new inventions were made over time that improved the quality of the harvesting, planting, and other farm-based jobs.

In the 1790's, the cradle and the scythe were invented. The grain cradle was a scythe with four wood fingers that gathered the grain while it was being cut by an iron blade [5]. The scythe was a tool with a long metal blade used to cut and harvest crops; it resembled a hooked blade on the end of a long wooden pole [6].

4.2 The very beginnings of automation:

In the year of 1793, the invention of the cotton gin by Eli Whitney was introduced. It was a machine that quickly and easily separated the cotton fibers from the seedpods and/or sticky seeds. The cotton was pulled through a wire screen by small wire hooks, and brushes and continually removed loose cotton lint to prevent jamming. This machine was automatic but could not think on its own.

Then, in the 1800's, several more inventions came into being: Charles Newbold patented the first cast-iron plow; the reaper was patented, and the plow with steel blades was manufactured. These new inventions, made by ahead-of-their-time people, made farming and other jobs easier and less strenuous on the farmers, who, before them, had to do all the work themselves thus work for the farmers was once again reduced [7].

Butter was a staple food in meals, but to make it, farmers had to plunge the dasher up and down in the butter churn for many hours. However, the invention of the cream separator in 1877 by Carl Gustat de Laval of Sweden really changed things in our lives. By turning the crank in the separator for one single hour, you could extract all the cream from 150 pounds of milk [8]! Carl Gustat de Laval was also responsible for inventing a machine that automated the task of milking cows, thereby allowing farmers to produce more milk than before [8].

All throughout the next few years, new inventions poured in, all the way until the present times, where we now have tractors, large combines and watering systems, far different than what it was years ago. However, as advanced as these machines were, they are not true robots, they cannot think and act on their own and modern farms still require a large labor force in order to produce food for the worlds population. These machines and labor cost the farmer money. Only in recent years have great strides been made towards automating farming and agriculture.

4.3 Modern Automation:

Demeter

Demeter is a robotic harvester currently being developed to assist in large scale harvesting. Currently the robot has two modes of operation, but is not completely autonomous yet. In the future the robot will be able to harvest fields of grain on its own after being trained by its operator. The robot uses "off the shelf" parts to attain a guidance accuracy of +/- 3cm. [16]

Mushroom Picking Robot:

Another type of robot made by the researchers of Warwick in the UK in the agricultural community is the *Mushroom Picking Robot*, which has a camera that can find the best looking and healthiest mushrooms to pick. Though it can only work half as fast as a human, it can work all through the night [20].

Fruit Picking Robot

Another robot is the fruit picking robot, which must be able to reach all levels of a tree and be able to pick fruit without damaging it. The robot must have good sensory awareness—touch, sight, and image processing, and able to distinguish between certain fruits (plums: softer; oranges: harder rind) [19]. The robot uses a camera to tell the difference between

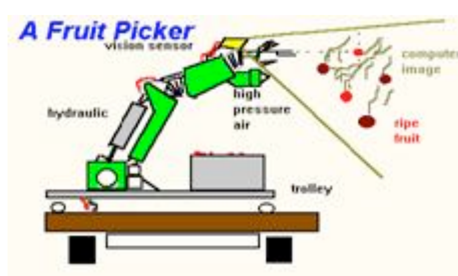


Image from
http://kernow.curtin.edu.au/www/Agrirobot1/frutrob.htm

fruit and leaves and has a air blower
to blow leaves out of the way.

Sheep Shearing Robot

The *Sheep Shearer Robot* is another robot, distributed rather frequently around sheep farms. The robot restrains the sheep firmly by the legs, while an arm that can rotate like a human limb with a shearer attached to one end lowers and shears the sheep, staying about an inch or so above the skin. (#18)

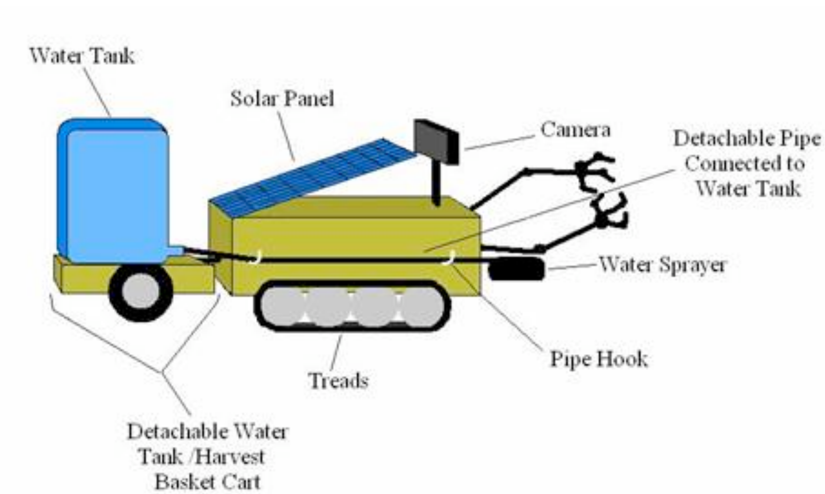
Ag Ant

University of Illinois at Urbana-Champaign developed a robot ("Ag Ants") that walks on its spider-like legs through the rows of crops; when one detects weeds or other plants that should not be growing in that area, its calls in other robots to "attack" them as a team. The UIUC has also developed many other robots, such as one that can measure the distance between corn stalks.

The long-term goal is to be able to make these smaller, more inexpensive robots do the jobs of the larger farming equipment.
Quote from one of the Illinois agricultural engineer: "We're thinking about building 10 or more of these robots and making an ecosystem out of them," Grift said. "If you look at bees, they will go out and find nectar somewhere. Then a bee will go back and share this with the group and the whole group will collect the food. Similarly, one robot might find weed plants. Then it would communicate this location to the other robots and they would attack the plants together as a group–an ecosystem, if you will." Grift wants to live long enough to be able to see an entire farm run entirely by robots, though right now they are still focusing on navigation skills [17].

5.0 PROBLEM & SOLUTION

5.1 Presenting: Plantinator

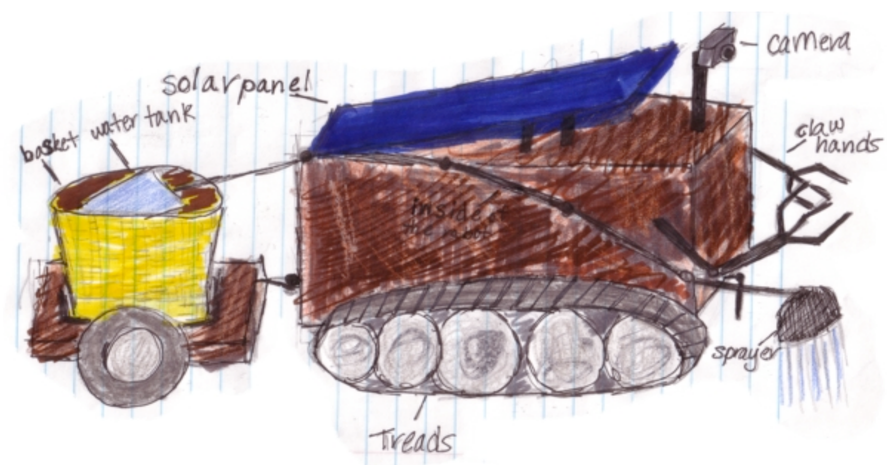


5.2 Problem:

How can we design a robot that can care for and harvest crops in the easiest way possible for the farmer, while still yielding the best results. If this robot is successful in its work, it will be able to:

- Produce healthier crops in a more efficient manner by caring for and monitoring the health of the crops.
- Reduce the workload of the farmer.
- Reduce the costs to the farmer.
- Reduce the amount of pollution produced by the farm.

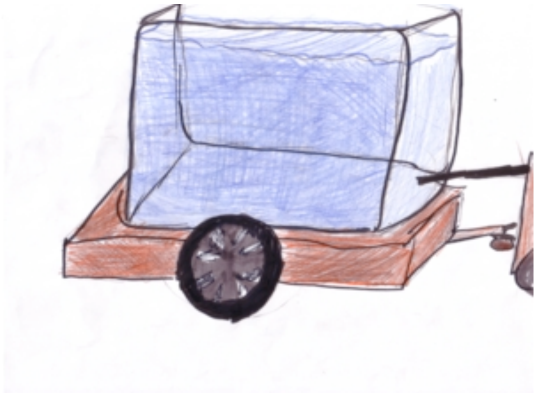
5.3 Solutions:



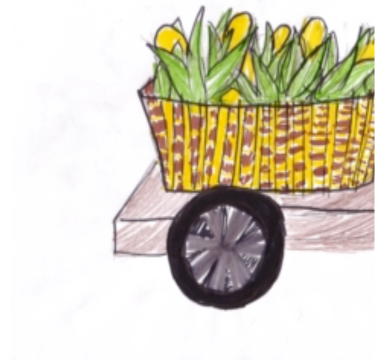
Our first rough draft appears above.

Basic Design

The actual robot will be 3 feet long by 1.5 foot wide by 1.5 feet high. It will be a box shaped robot with two arms for grabbing attached to the side. The robot will have a solar panel on the top for power and a camera that can turn 360 degrees for vision. There will be a sprayer on the robot that can spray water and other things the plants may need. The robot will have a water tank behind it to supply the sprayer. The water tank can be disconnected so other attachments can be put on the robot in the future such as a reaping and sowing attachment.



These two pictures show the attachments currently available for our robot: the watering and nutrients attachment and the reaping and sowing attachment.



Power system

To allow the robot to work at night as well as day, a solar panel will be situated on the top of the robot to absorb enough energy to power it through the night. During the day it will run off solar power and batteries, excess energy will go back into the batteries so that at night the robot can work on batteries alone.

Locomotion and Navigation

We will use treads for the wheels on the robot so it will be able to get more friction, and won't topple over. We have discovered through our own robot building experience in Botball that treads allow robots to move over obstacles better and robots with treads are more stable. Our robot will be mounted in a way that allows the robot to rise up to reach higher plants.

There will be 3 homing beacons around the perimeter so that the robot will know where it is. The beacons will be radio beacons and the robot will be able to tune in these beacons and triangulate its position in the farm using them.

Features

Toward the front of the robot there will be camera that can rotate 360 degrees, and is able to look upward and downward. The camera will be used to help navigate the robot around obstacles and avoid hitting plants.

There will be a base attached to the back of the robot where you can strap down a basket for harvesting crops,or a water tank for watering the plants. The base of the attachment along with the base of the robot will have two plates with wheels attached, and grooves in the plates so that the base can be changed in size if the rows of plants are bigger than what the base comes as. If a water tank is attached to the base, a hose will pump the water to a sprayer which will water the plants.

The Plantinator will have a soil probe in the front that will be able to check the nutrients, soil pH, and humidity of the soil. The computer inside will be able to determine if the plant needs water or nutrients and water the plant or give it nutrients. If the robot cant help the plant it will send a message to the farmer.

Additional Functions

The Plantinator will be able to plant seeds at equal intervals throughout the entire field using its camera measure the length of each interval. The water tank can be replaced with a seed bucket and the robotic hands can be used to plant seeds at equal intervals very quickly. This would help prevent waste and make planting more efficient.

The Plantinator will be able to use its camera to monitor the health and growth rates of plants. If it determines that something is wrong it can try to fix it, if it cant it can alert the farmer.

Cost Analysis

We envision that our robot will be equal to one HP of a combine. We used a website's calculations, found at [21], to calculate the cost analysis for certain combines compared to our robot's power level.

Horse Power	Cost	Corn/Acre	Grain/Acre	Average/Acre
340 HP Combine	$232000	$24.05	$20.87	$22.47
340 Plantinators	$102000	$10.24	$7.46	$8.86
305 HP Combine	$217000	$26.30	$20.97	$23.64
305 Plantinators	$93025	$10.65	$8.76	$9.72
265 HP Combine	$186000	$29.10	$24.36	$26.74
265 Plantinators	$70225	$10.16	$8.70	$9.43

You can easily see that our small robot is 2-3 times cheaper than a large combine and our robot does not even need human operators!

Conclusion

Our original problem was to cut down on farming pollution and reduce costs, and we have done this by creating a robot that will shoot the water directly at each plant, not using pesticides, and reducing the use of fertilizers on the plants. In addition, our robot can be built with off-the-shelf parts that can be bought at a very cheap price, and we estimate the cost of the robot at about $300. Even if the farmer bought a hundred of these robots, the cost would be a mere $30,000, which would be much less than a fully equipped and non-automatic combine. In addition, the workload on the farmer is reduced because no one has to control the robots or hire people to take care of the crops. The farmer can sit back and relax and reap the benefits.

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