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Feasibility and Prospects of Robotics in Agriculture: A Review

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Abstract

Achievement of a sustained and equitable development is the main goal of any production and planning system. To keep up with the increasing human population and with the available arable lands, more food production will have to be achieved over the next 50 years. Agriculture and its allied sectors depend simultaneously on both the exploitation and conservation of natural resources. Their impacts on the environment need to be reduced such that it can continue to develop sustainable production systems. However, this is rarely achieved. In most of the hilly areas of developing countries, the resources essential to these sectors are threatened by rapid population growth, extreme poverty, loss of biodiversity, pollution of air and water, soil toxicity. In western countries, the adoption of robotics technology has already initiated. In future agricultural scenario, it is envisaged that this new and latest technology holds the key to new farming systems to increase yields and generate income while improving sustainability. Swarm of robots have the characteristics of being simplistic and low cost, so that they can be manufactured and deployed in mass without being overly concerned about their survivability. It is a growing industry being put to use in creative ways. The concept has been around for decades, but groups of small robots working in teams to complete tasks have come in handy on the conservation, sustainability and agricultural front. envisage

***Keywords**:* Robotics, agriculture, sustainability, technology, farming

1. Introduction

Agriculture and its allied sectors are one of the most important industries worldwide along with the Information Technology and Business Enterprises. Agriculture not only provide food, feed and fuel necessary for human survival but also serve as an occupation for one-third of the world's population. With the global population expected to reach 9 billion by 2050 (UN, 2004), the production in agricultural, horticultural and other sectors must double to meet the increasing demand given our current food consumption habits and supply chain practices and at the same time, achieve sustainability. This increasing trend and climate change also limits the arable land in the global front and therefore productivity must increase up to 25% at least to help meet this goal. The World Development Strategy (IUCN, 1980) emphasized the idea that development and environment must be integrated to 'discharge our responsibilities as trustees of natural resources for the generations to come'. Sustainable Development (SD) is development that 'meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). According to the Global Biodiversity Strategy (WRI/IUCN/UNEP, 1992), the desired future is one where the entire landscape is being managed to conserve biodiversity, and where biological resources are used sustainably for the benefit of current and future generations.

Approximately one-third of the earth's surface area is in agricultural and horticultural use, and their shares in use of water are more than two-thirds. Selections and solutions in agriculture and horticulture have a long reaching significance with regard to the well being of people, animals and the environment. New research knowledge is of crucial importance in using natural resources in sustainable manner and in preparing to face future challenges with a trusting mind (DAS, 2011). Changes in diet in developing economies, constraints on land allocated to agriculture, high cost water and energy, plus environmental concerns and climate change are some of the key challenging factors. According to FAO (1989), build-up of crop diseases and pests also makes the agricultural and allied system unsustainable. In the highly commercial and/or monoculture farming areas such as the hilly terrains of the sub-Himalayan regions, due to reduction in crop diversity and replacement of traditional disease resistant crop varieties by a few exotic varieties and due to cultivation of the same annual crop cycle year after year, incidences of crop diseases and attack by insects/pests have increased, thereby necessitating the use of insecticides, pesticides and other hazardous chemicals in a big way. The expenditure on plant protection chemicals was worth Rs. 2689 and Rs. 422 per ha respectively in the fruit-based and vegetable-based farming systems of Himachal Pradesh, whereas, it was worth only Rs. 3 per ha in the traditional farming system (Jagdish and Wolfgang, 1997). In the absence of adequate plant protection measures, the yield and profitability of fruits and vegetable-based farming systems would become very low and uncertain. To address these issues, there is a need for an increased quality of produce and exploitation of premium and niche markets; an increased robustness of crops to deal with climate variability; the development and adoption of new technologies and policies leading to sustainable practices; and an increase in investment in R&D and education in agriculture.

This review article looks into the adoption of new robotic technology and its future applications in agricultural and horticultural systems as a tool that could enable a transformation of practices in field and crop management leading to a significant, economical, environmental, and social impact. Robotics is transforming current practices in industries such as mining and manufacturing. Following this trend, considering the current research & development activities worldwide, it is envisaged that this technology will soon also have a significant impact on agricultural and allied sector practices. It also discusses the enabling factors and barriers for the uptake of this technology. Moreover, this paper is an attempt at exploring the concepts for the role of robotics in sustainable development. It is an exciting challenge where research and industry in both developed and developing countries can equally contribute and benefit.

2. Robotics at the future of modern farming

Agriculture is a big data problem without the big data. In conventional agricultural farming, nearly half of the inputs (fertilizers, pesticides, fungicides, herbicides, etc.) are typically wasted since they are applied in greater amount than needed or in the wrong place (between rows rather than on plants themselves). That is considered unavoidable, due to the nature of spray application or the need to avoid under-use of water and chemicals, which can be catastrophic, from disease outbreak to total crop loss. Mowing grass, spraying pesticides and monitoring crops for example, instead of regularly dousing an entire apple orchard with chemicals, towed sensors find diseases or parasites with infrared sensors and cameras, and spray only the affected trees. Commercial farms of the future may be staffed by robots that will identify, spray and pick individual pieces of produce from plants, even when their targets are grapes, peppers and apples that are as green as the leaves that surround them (Behzad, 2012). Harvesting is the most labour-intensive activity for many crops, but even advocates say that no one has built a machine that comes close to matching the sensory motor control of humans. That is poised to change as sensors and software becomes cheaper and more advanced (Anonymous, 2003). As scientists in Israel and Europe get closer to this goal, experts say the work has a number of potential benefits. For instance, autonomous agricultural robots could protect human workers from the harmful effects of handling chemicals by hand. And through a system of highly selective spraying, robots could reduce a farm's use of pesticides by up to 80 percent (Behzad, 2012). Robots could also offer a timely supply of labour in many places, where there are not enough temporary workers available at the right times in the harvesting cycle. Moreover, crop-tending robots that uses vision systems, laser sensors, satellite positioning and instruments to measure things like humidity can build up a database of information about each plant (TEN, 2009).

The use of robots in crop scouting will help to collect timely and accurate information which serves as one of the main operations within good crop management. Quantified data has tended to be expensive and sampling costs can quickly out weigh the benefits of spatially variable management. A high clearance platform is needed to carry instruments above the crop canopy and utilize GPS (Behzad, 2012). Controlled crop management and biodiversity is an opportunity that could be realized with robotic weeding where non-competitive weeds can be left to grow when they are at a distance from the crop.

Agribots

An agricultural robot or agribot is a robot deployed for agricultural purposes. The main area of application of robots in agriculture/horticulture is at the harvesting stage. Fruit picking robots, driverless tractor/sprayer, and sheep shearing robots are designed to replace human labour. The agricultural industry is behind other complementary industries in using robots because the sort of jobs involved in agriculture are not straightforward, and many repetitive tasks are not exactly the same every time. In most cases, a lot of factors have to be considered (e.g., the size and colour of the fruit to be picked) before the commencement of a task. Robots can be used for other horticultural tasks such as pruning, weeding, spraying and monitoring and can also be used in livestock applications (livestock robotics) such as milking, washing and castrating (Wikipedia, 2015). In the agriculture domain, robots could also help monitor soil conditions, the health of plants and animals and adapt actions to very local conditions, even plant by plant (Blackmore, 2009), in addition to a possible role in cultivating and harvesting crops. Robots can help increase the yield/production as in the case of a milking robot, (e.g. DeLaval Milking robot) which increases the number of litres per day that a cow produces, because the cow can access the robot at any time. An interesting point here is that it is probably the voluntary nature of the milking that is the key factor. (Guido et al., 2011).

Other examples of Agribots:

i. Ag Ant - an inexpensive foot-long bot that works cooperatively
ii. The Oracle Robot
iii. The Shear Magic Robot
iv. Fruit Picking Robot
v. LSU's AgBot
vi. Strawberry picking robot from Robotic Harvesting and Agrobot
vii. Casmobot next generation slope mower
viii. Fieldrobot Event is a competition in mobile agricultural robotics
ix. HortiBot - A Plant Nursing Robot
x. Lettuce Bot - Organic Weed Elimination and Thinning of Lettuce
xi. Rice planting robot developed by the Japanese National Agricultural Research Centre (Wikipedia, 2015)

3. Applications of robotics

Agricultural robotics is the use of automation in bio-systems such as agriculture, forestry and fisheries. It is replacing the conventional techniques to perform the same tasks with efficiency. Applying automation to agriculture has helped create several advancements to the industry while helping farmers to save time and capital. The first crop robots to achieve commercial relevance are now entering service in the nursery and greenhouse sector of agriculture and horticulture. Contrary to popular imagination, expert prediction, and much academic research, the first successful agricultural robots are engaged in activities other than fruit and vegetable picking or row crop maintenance. This article examines the forces that drive the choice of application for commercial robots, describes an early agricultural robot, and suggests areas for further development. Also, robots can gather operational data on a broader basis than human-operated devices.

i. Farmerbots

A new robot developed by David Dorhout and colleagues from Dorhout Research & Development is designed to plant seeds in a field while coordinating with a gang of other robotic farmhands. The robot can walk in any direction while avoiding obstacles, using a sensor underneath its body to detect where seeds have already been planted. Once it finds an untouched patch, it drills a hole in the ground and releases a seed, triggering an electronic eye that guides the planting. The communication system in this swarm of robots is inspired by the way ants self-organize in nature. For instance, when an ant finds a food source, it releases a pheromone that attracts other ants. In a similar way, a robot can beam out an infrared signal to recruit help, overriding the random movement of the swarm, indicating and directing them to areas that need to be farmed. According to Dorhout, robots just follow simple rules from which complex behaviour arises and there is no long-term memory, no centralized command and control. By providing assistance, a robot swarm allows farmers to focus on the science and business side of their operation. The farmer is like the shepherd that gives the robot instructions. Robots are also able to transcend the limitations of farm equipment to maximize efficiency such as planting in a grid instead of rows. So far, the prototype is able to plant seeds only. But the system is being developed to perform other operations also *viz.* weeding, fertilizer application and harvesting etc. ultimately creating autonomous robots that can perform whatever tasks are necessary year round.

ii. Harvey robots

In mid-2012, four HV-100 robots, also known as “Harvey Robots”, from Harvest Automation achieved an elusive milestone in robotics. These robots can collect, carry and distribute container-grown plants/saplings in greenhouses and on large nursery farms thus reducing the work force, time and capital which otherwise may cost. Since their introduction, more growers have adopted Harveys, and to date, they have moved over three million plants.

iii. Drones/flying robots

The first drones which are more likely to be seen actually in use are closer to crop dusters, buzzing over farms. Rather than taking pictures and videos of people, these drones will be surveying fields, using their high-resolution sensors to improve crop yield and decrease agricultural water and chemical use. One such example of using drones in horticulture will be in the viticulture system. Since harvest times at vineyards (viticulture) can be short, the ability to have a plane/drone like this is a tool for farms to generate frequent and accurate imagery in order to obtain the highest possible yield of the crop. Soon farmers will know what is going on with every plant, spotting problems before they spread, and applying chemicals with honeybee precision (sharp and deep). They will be able to use pesticides and fungicides only when needed and in the smallest amounts necessary, lowering the chemical load in both food and environment and saving money. On a small farm, a level of precision with hand-tending can be achieved. But on a big farm, the answer is more likely to be robotics i.e. flying robots. The plane can help day-to-day operations on a farm *via* aerial imagery. For instance, the drone will capture images that the farmer can use to inspect his land. It is also able to collect images that show rapid, on-the-spot analysis, for example, ripeness of grapes in vineyards.

iv. Swarmbots

Small, simple machines that do simple tasks, very well, may be used to solve many problems in the real world. Developing useful swarmbots poses formidable challenges at several levels. From a practical perspective, the construction of potentially thousands of physical robots needs to be economically feasible. Each robot needs to be complex enough to be able to carry out its part of the task, but simple enough that it is cheap and simple to build and re-program (Sze-Tek, 2006). Robots need to be able to interact and communicate with each other either directly or indirectly. The rules each robot is following need to be designed carefully to ensure the successful completion of the task. Evolutionary theory might offer the solution to this problem by artificially evolving behavioural and communication rules for the swarms (Dorigo and Stutzle, 2004). Whether their job is to harvest or simply to map or video the large farms (e.g. in vineyards), swarms can cover a far greater area and work when one member's batteries run out. Moreover, in a swarm system, there is no single point of failure – if a unit fails, the whole system still keeps on going, which makes it very fault-tolerant and robust (Dorigo and Stutzle, 2004). Wherever there is a heavy load that a human cannot perform or manipulate by himself, using a swarm of robots to do the job, would be very sensible. According to Prof. Simon Blackmore, Head of Engineering at Harper Adams University, swarms are able to identify weeds and administer chemicals using less herbicide to do so. In countries where smaller fields are operated by big tractors, smaller robots might have a bigger impact around the world than big machines. In the whole of Asia, the average field size is about one acre. There is a significant middle area round the world of smaller farming systems where if robots were made cheap enough and reliable enough, it would actually be applicable.

v. Robobees

One famous example of swarm robotics in the agricultural and horticultural field is a project out of Harvard University involving "Robobees." Harvard Microrobotics Laboratory has been working on the development of bio-inspired robots that are about the same size as a bee, can fly, assumed and expected to work autonomously as a robotic colony. In the near future, the "robobees" will be used and are expected to find an artificial solution to pollination to address the current decline in the global bee population because of the Colony Collapse Disorder (CCD) (HU, 2015) which has become a main issue in the last decades. Apart from crop pollination, traffic monitoring, military surveillance and search and rescue may also be possible with the Robobees. The team will also aim to develop a high-power energy source compact enough to fit on the robot but efficient enough to power it and to even develop a kind of “hive mentality” (HU, 2015)

4. Enabling factors and barriers in uptake of robotic technology

Like any other technologies having some disadvantages in their operations, swarm robotics or drones, no doubt, have its own. Those can be categorized under the following sub-headings:

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i. Every crop is different: There are hundreds of different kinds of farms, ranging from trees to roots. Each crop needs to be measured differently to generate actionable data. There is no universal crop survey solution, and it will probably be specialists in each particular crop type who ultimately deliver solutions to farmers. Hence, a particular robot for a crop may either be functional or non-functional.

ii. One-click auto missions, not "flying". Since most of the farmers are not equipped with the new technologies, operating a drone for surveying the field may be questionable. Therefore, agricultural UAVs (unmanned air vehicles) or agricultural drones should be fully-autonomous, from takeoff to landing. The experience should be as simple as pressing a "Start" button on a phone and the drone flies the entire mission on its own.

iii. Fly the camera, not the aircraft: What the farmer is interested in from the field survey is a clear picture, not the acquisition of the picture. Therefore, sophisticated planning tools need to be figured out within the robotic system on how to gather the right images precisely.

iv. Time is money. Drones can get answers fast and cheaply, taking advantage of their "anywhere, anytime access to the sky" abilities. That means "timely data on time", such as daily surveys to find exactly the right time to harvest. The aim of crop surveying is to show the farmers something they cannot see with their own eyes, and the time dimension is a great example of that. By doing regular crop surveys (every day or week) and using software to highlight differences over time, it is possible to zero in on growing differences between areas of a field, which may be directly correlated to productivity.

5. Case study

The Maharashtra Government, for the first time, will use two drones in the drought-hit Osmanabad district to survey the loss of crops due to water scarcity. The data would be used to determine the compensation to be paid to the farmers. According to Shankar Totawar, Osmanabad superintendent Agriculture Officer, these drones fly at a height of about 150 metres, can survey area in the radius of 7 km in a single flight, generating around 1,000 photos for every five meters of area. The district does not have adequate drinking water for humans and animals and the crop losses due to shortage of water further trouble the farmers. To get proper details of the loss, drones have been utilized for surveying. As many as 51 villages in Osmanabad will be surveyed by the two drones and later, would be used in the drought-hit Yavatmal and Aurangabad regions. A contract of Rs. 2 crores has been given by the Govt. to Noida-based Skymet for survey. Once the entire area is surveyed, the company will submit a report on the loss of crops. They are being used under the Rashtriya Krishi Bima Yojana for better verification of crop losses. Drones will now be used during the harvest season of both Kharif and Rabi crops and thus bringing an end to the existing method of manual survey and approximate assessment permanently.

6. Conclusion and Future thrust

The large and growing population, extensive nature of agriculture, adoption of monoculture commercial crops, excess use of chemicals and fertilizers, soil erosion and land destruction, overgrazing of pastures and increased stress on forest resources are creating loss of biological diversity. On the basis of the factors identified to be affecting biodiversity, expansion of agriculture and its allied sectors are one of the main reasons for deforestation and loss of biodiversity since they exploit and conserve the resources simultaneously. Increase in yields in agriculture will reduce the need for areas expansion which can be achieved only through new technologies. Hence, there is need for research to generate appropriate technologies where robotics application in future farming and sustainability stands out as the latest one. Robotics for sustainability could develop from a combination of classical and sustainable technology and new application models. Continuing development in agricultural robotics suggests that farmers and those involved in allied occupation will soon live in a world of largely autonomous, self-maintaining and self-healing devices and farming will become easier in the coming years. More broadly, a sophisticated control of swarm and robotic technologies offers unprecedented potential for rapid, time-saving, low-cost chemical application, low input food production, construction and maintenance of every form of crop management. Today, new practices and technology can easily spread globally once their benefits are known to mankind. The future holds many challenges for robotics research in agriculture and the strategic objectives should be to make agricultural robotics more adaptable, efficient and robust and to make their usage more affordable.

Many applications of robotics are currently in development. This area is still in its infancy as a research field, but several exciting developments point to possible future technologies with potential to transform many aspects of human life. While there are dangers in excessive speculation, history suggests that it is equally risky to try to ignore the possible impacts of such transformative technologies (Goodland et al., 1987).

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A Brief Author Biography

Dr. Devina Seram graduated from Assam Agricultural University, Jorhat in B.Sc. (Agriculture) with specialization in Agricultural Entomology. She completed her post-graduation (M.Sc. in Agricultural Entomology) from College of Post Graduate Studies (Umiam), Central Agricultural University, Imphal, Manipur, India (through 15th ICAR-AIEEA-PG exam-2010). She was a recipient of CAU Merit Scholarship and a gold medalist in her master's program. She qualified 18th ICAR-SRF(PGS) Exam in the year 2013. She completed her Ph.D. in Agricultural Entomology from the prestigious Tamil Nadu Agricultural University, Coimbatore with DST-INSPIRE fellowship (INSPIRE Fellow No. IF139032) of Department of Science and Technology (DST), New Delhi, India. She has also qualified ICAR-NET in 2013 conducted by ASRB (Agricultural Scientists Recruitment Board).

Her research specialization and interests include host plant resistance, insect resistance bioassay, environment and insect relationships, insect ecology, eco-friendly insect management, storage entomology, molecular biology (DNA extraction, polymerase chain reaction, molecular markers).

1. Harvey Robot

2. Flying Robot/Drone

3. Harvester Robot

4. Scouting Robot

5. Field Robot

6. Robot Weeder

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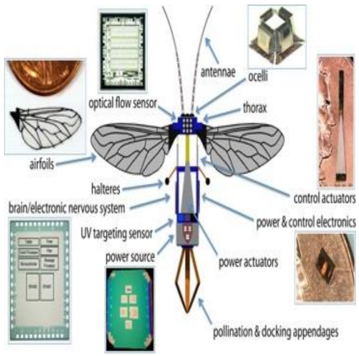
7. Agribot



8. Robobees

9. Robotic Colony

(Assumption/Expectation)

Figure: Examples of AgriBots used in agricultural and aorticultural systems

