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Indian agriculture-Potential aspects of robotics: Context and future

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Abstract
Agriculture can surely benefit from the adoption of robots. Small robots can easily match the constantly reducing small size of farms in India and can compensate for the diversion of agriculture labour to other economic sectors. These autonomous machines, once adopted, can definitely reduce farming costs and increase the income of the farmer. Besides saving costs, these robots can also save precious agricultural resources like seeds, fertilizers, irrigation water, etc., by their precise application in the field. Human errors in repetitive tasks and toiling work can be eliminated by these precise machines. Soil compaction, which is a major problem associated with heavy farm machines, can be alleviated. Robots can make advantageous use of solar energy abundantly available in Indian farms. Various agricultural robots are being developed for a variety of farm operations in different parts of the world. This review paper covers different recently developed robots in India and abroad and their context in Indian agriculture. These robots are categorized according to different agricultural operations, starting from ploughing and ending with the harvesting of crops.

Keywords: precision agriculture, autonomous machines, precision farming, robotics

Introduction

Robotics can play a very important role in the automation of repetitive tasks in agriculture. Less power requiring repetitive tasks like weeding, sowing of seeds can be accurately carried out by these autonomous machines. Human errors and drudgery related to these agricultural operations can be reduced or alleviated completely. Once these robots get cheaper due to their large production in India, these machines can transform farming completely. These machines also have the ability to tackle the problem of shortage of labour in the country as well as low income of the farmer. Due to the induction of rural employment schemes like Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) by the government, a large chunk of agricultural labour has been diverted from agricultural farms. As per an estimate, the agricultural labour is expected to get reduced to 120 million (Mehta *et al.,* 2014) [26]. This diversion of labour can be easily compensated by the induction of robots in agriculture. A lot of progress has been made in the mechanization of harvesting and other main farm operations, but this progress can be further be enhanced by automating these operations. Automated machines require little or no human intervention while performing field operations. In India, where farm size is reducing day by day, these robots can be vital for future farming needs. Instead of buying commonly available big farm machines, which can also be left to the prevalent custom hiring centers in India, the small farmer can purchase small robots specific to their crop requirements.

Nowadays, precious agricultural inputs like seeds, fertilizers, pesticides are used in farms in more quantity than required. Robots can be easily trained to perform these jobs efficiently while saving these resources. This will not only increase farmer's net profit but also help the national economy in a positive way. Most prominently used farm machines like tractors can also be equipped with features GIS based automatic steering, automatic speed selection by sensing field conditions, etc. Post-harvest farm operations of perishable crops like fruits and vegetables also show good scope of implementation of robotics. Fruits and vegetables can be graded based on their sensory properties like colour, firmness, texture, etc. This will fetch higher income to the food grower pocket with the same amount of crop output. Fruits and vegetables which are likely to perish within a short time period can be processed at farms, while firm ones can be exported to the mandis. This will benefit the farmer in two ways- first in a reduction in post-harvest losses and second in getting higher prices for higher quality graded crops. Although in initial phases, the affordability of robots by the poor farmers can be a prominent issue, it can be tackled easily by subsidy and other direct modes of financial help to them. Entrepreneurs or agriculture engineering students can also make a big difference in the adoption price of robotic farm machines by indigenization of the technology and development of large-scale local production facilities. This paper largely addresses robots developed for agricultural use, which can be used in different agricultural operations in India.

Robots for Agricultural use

Agricultural operations include various operations like seed processing, sowing/ planting, irrigation, weeding, spraying or plant protection, harvesting and post-harvest processing of the crops. Nearly every farming operation shows scope for the introduction of robotics in it. Various efforts have been carried out in different parts of India and abroad for the development of agricultural robots. Some of the prominent ones are discussed in the following sections.

Ploughing and Seeding robots

Ploughing is a less precision requiring task, so very less no. of robots were developed for this task. Sneha *et al.* (2015)

[38] developed a robot for field ploughing and seeding purposes. It consisted of an AVR ATmega based microcontroller which supervised all its functions with input from an ultrasonic sensor. It simultaneously tilled the field and sowed the crop seeds. It also has the facility to communicate with farmer mobile phones through a Bluetooth pairing enabled application. Attaching it with water sprinklers, it can automatically switch on irrigation water based on the humidity level of the environment.

Seeding and planting require a high amount of precision. The robot must have a straight line movement, efficient seed metering mechanism and a good seed placement system. Many robots have been developed for these sowing operations. Yedave *et al.* (2019) [44] developed agrobot for seed sowing of crops soybean, groundnuts and jowar at desirable spacing. It was an Arduino Uno-based robot. It consisted of a DC motor, a battery and a cell seed metering mechanism. It also had an IR-based sensor for obstacle detection. Sunitha *et al.* (2017) [39] studied a Raspberry pi based seeding robot. It used a camera for image acquisition, an image processing system for seed to seed distance measurement and a fluted roller-like seeder mechanism. It was used for ploughing wetland with the help of two tentacles and sowing two rows. A similar robot was designed by Jayakrishna *et al.* (2018) [17], which used input from a keypad for seed to seed distancing and Arduino mega board for decision making. The seeding mechanism used for dropping the seed was a wheel with a protruding hole that collected seed from a seedbox and dropped it in the field through a slider. A solenoid valve can also be used in a robot for dropping the onion seeds in the field (Abdulrahman *et al.*, 2017) [4].

Haibo *et al.* (2015) [18] experimented with a precision seeding mobile robot for sowing wheat crops (Figure-1). It had a servo-motor-based four-wheel drive and stepped motor-based steering system. It was powered by lead-acid batteries. It used a vacuum fan-based seed metering mechanism. It depicted more than 93% desirable rates of wheat seeding at different sowing speeds.

Fig 1: Wheat crop sowing robot, Haibo *et al.*, (2015) [18]

Nilawar *et al.* (2018) [29] developed a wireless hand gesture-controlled based robot for seed sowing. A hand gesture signaled the robot to start moving and dispersing seeds. Detection of an empty seedbox and clogging of seed in the puddle was carried out using a sensor. Saravanan *et al.* (2018) [35] developed a seeding robot that was PIC microcontroller based. It reported many difficulties like zigzag line sowing, uneven distribution of seeds, non-uniform depth of seed placement, varying speed while sowing, etc. Binu *et al.* (2019) [10] used a MATLAB based seed defect detection in a seed sowing robot. The robot only moved when the seed was either normal or good. Agetano *et al.* (2018) [2] developed a mobile application-operated robot for maize seed sowing, which was able to plough land up to a depth of 1.5 inches and sowing 3-5 seeds at equal spacing. An Arduino-based gantry robot for seed sowing in a nursery was also developed by Bhargav *et al.* (2020) [9], which was able to move in X, Y, Z directions. Harmanda *et al.* (2019) [19] designed an agriculture robot that was able to dig a hole, plant the seed and then closed the hole again.

From an agriculture point of view, most of these small robots lacked optimized tool-soil interaction, effective seed metering mechanism and controlling slippage of tyres. Except few one, none seemed to replace commonly used tractor mounted seed drills.

Weeding and spraying robots

Weeding is the removal of unwanted plants from the field. The robot for weeding, obviously must have a system for detection of crop plants and differentiation from weed plants along with a proper row-guidance system. Weeding can be carried out either with ploughing or spraying chemicals on weeds. Such robots have been made by many researchers in the world.

Bakker *et al.* (2010) [7] designed a robotic weeding platform with a 31.3 kW diesel engine and 360 degrees four-wheel steering system for sugar beet. It had a GPS and sensor-based navigation system. It correctly confined itself to a specified area. A ground clearance of 50 cm was provided to avoid damage to the crop.

Fig 2: BoniRob Robot, Wu *et al.*, (2020) [41]

Xue *et al.* (2017) [43] developed a multipurpose robot for a greenhouse to perform multiple tasks like weeding and spraying. It used a vision-based navigation system. It was accurate up to a maximum lateral error of 47 mm. It sprayed 16-20 plants per minute. A similar machine vision-based weeding robot was developed by ChunLong *et al.* (2011) [15]. It had a maximum traveling speed of 1.5 meters per second. It identified the weeds by machine vision and removed them with a three-finger manipulator. It had a weeding efficiency of 90 percent. Ovchinnikov *et al.* (2019) [32] studied a weeding robot and determined its kinematics. It had five degrees of freedom for its weeding arm. Nan *et al.* (2015) [28] tested an intra-row weeding robot based on machine vision. It accurately identified maize, cauliflower and lettuce with 95% efficacy. It faced difficulty in identifying weeds that were too close to the crop plants.

Wu *et al.* (2020) [41] tested a robotic weed control system mounted on a proprietary robot 'BoniRob' (Figure-2) in sugar beet fields for spraying and mechanical weed removal. It showed a reliable in-row weed removal system. Patel *et al.* (2018) [33] designed a solar-powered weeding system for the cotton crop. It used a Raspberry Pi-based board, a camera module, ultrasonic sensor and DC motors. For weeding, it used a mini rotavator. The software compared the captured images and compared it with commonly found weed images in cotton, which were already stored in its memory. Based on comparison output, it removed the weeds. Reiser *et al.* (2019) [34] developed an intra-row rotary weeding system for vineyards and orchards. It used two sensors- an electromechanical sensor and a sonar sensor for the detection of trunks. The sonar sensor performed better than the electromechanical sensor. For weeding, it used a rotary tiller weeder. A laser-based weeding mechanical arm was developed by Zhenyang *et al.* (2013) [46], which used image processing for identifying weed plants and laser beams to destroy them. A special kind of robot which mimicked the duck movement in the paddy field was developed by Nakamura *et al.* (2016) [27] (Figure-3).

Fig 3: Duck mimicking Robot, Nakamura *et al.,* (2016) [27]

In weeding robots, the accurate positioning of weed remover is very important. Due to uneven field surface, the weeding arm can fluctuate in its vertical position. Chen *et al.* (2016) [13] developed an automatic leveling system for a weeding robot. It was able to efficiently reduce the effect of the rough field. Many of the discussed weeding robots depicted promising results and can be advantageously used on the commercial scale in India. Mechanical weeding-based robots can also be very helpful in organic farming and poly-house farming.

Crop monitoring robots

Crop monitoring is a time-consuming task. Also, human monitoring is not very accurate owing to a different person to personal interpretation of the same field conditions. Both these can be overcome by autonomous machines. These machines can be augmented with high-resolution imagery, which is impossible for a person's eye to capture and analyze. This complex process is chipped by different researchers. Oliveira *et al.* (2019) [30] modeled and developed a mobile robot for monitoring cotton crops. It had autonomous navigation based on image processing. It was able to drive through real cotton rows by identifying the midpoint of two rows. Bayati and Fotouhi (2018) [8] developed a farm vehicle-based robotic platform with a long boom mounted with different sensors, cameras and other equipment. It measured canopy height, temperature and NDVI as well as RGB images. The images obtained through different cameras were processed for data visualization. It was GPS enabled for geo-tagging in the field. Young *et al.* (2019) [45] designed a ground robot for measuring different plant traits like biomass yield in a single row operation. The cameras were mounted on different heights for different crops. It measured plant height with 15% error and stemmed width with 13% error. Various diseases and nutritional deficiencies can also be identified with robots equipped with cameras. High-quality images in different spectral bands can be analyzed for the early detection of diseases. Rey et al. (2019) used a field robot for the detection of a bacterial disease- Xylella fastidiosa on the olive trees. It was mounted with multiple cameras like colour, hyperspectral, thermal, multispectral, and modified DSLR to capture BNDVI (Blue Normalized Difference Vegetation Index) images. It used multivariate models including spatial, structural and spectral data to predict the level of pest infestation. BNDVI and NDVI alone were not able to identify the disease. Vakilian & Massah (2012) detected nitrogen deficiency in cucumber crops grown in a hydroponic greenhouse. It was capable of identifying the deficiency problem two days earlier than diagnosed by a human eye. Aravind & Raja (2016) also simulated a greenhouse robot in MATLAB software for disease identification.

Fig 4: Agrob V14 assembled, Santos *et al.,* 2016

In hilly areas, crop monitoring is a difficult task owing to harsh terrains. This task can be eased by robotics. Santos *et al.* (2016) [35] developed a robotic platform (Figure-4) for vineyards that was able to overcome ditches, rocks, and high slopes (up to 30%). With a simultaneous localization and mapping (SLAM) system, the robot performed various crop monitoring tasks and measured crop yield, soil temperature and humidity, and crop water stress index. Botterill *et al.* (2016) [11] developed a robot for the pruning of grapevines. It pruned vines with a six degree of freedom robotic arm while 3D imaging the vine by a set of trinocular stereo cameras. All these robotics developments, although many of them are for green-houses, show a great amount of hope for identifying crop threats and precise application of control measures.

Irrigation robots

Accurate moisture measurement is a critical factor in sustainable agricultural practices. It not only saves irrigation water but also saves a lot of fertilizer costs also. Moisture can be measured with two methods- estimation by image analysis and direct measurement by instruments. Aerial images can be acquired by unmanned aerial vehicles (UAV) and analyzed for water stress indices. But ground solutions like sensors can be more accurate and static. Hernández *et al.,* (2013) [22] used a lightweight robot for moisture measurement in crop fields. The robot had a magnetometer to roll down along a straight line in the crop field and collect geo-referenced moisture data. Irrigation robots can be beneficial in the Indian context. Sensing the moisture requirement of a plant and applying a desirable amount of water can reduce the burden on moisture in the soil and applying the required water to it automatically. Similar robots were developed by Adeodu *et al.* (2019) [5] for watering crops. Kurt (2020) [24] developed a human-scaled six-legged water-powered autonomous irrigation device. It was found to be suitable for small-scale farms. A different kind of snake bone-armed bionic arm robot was developed by Huang and Chang (2019) [23] for watering and spraying on the crop. Chen *et al.* (2020) [14] designed an adaptive irrigation robot (Figure-5) with a foldable sprinkler device and a 20-liter water tank. An Arduino Uno-based robot was also developed by Bodunde *et al.* (2019) [12]. These irrigation robots can efficiently save water while irrigating the plant as required. Proper moisture maps can also be developed for irrigation purposes in large fields.

Fig 5: Foldable sprinkler Robot, Chen *et al.*, (2020) [14]

Harvesting robots

Harvesting a horticulture crop without damage or loss is a challenging task in agriculture. This task can be performed by robots efficiently. Various harvesting robots have been developed for grape, apple, cucumber, etc. Onishi *et al*, (2019) [31] developed an apple harvesting robot. It had a robotic arm and a stereo camera. It accurately located 90% or more fruits on the plant. The speed to harvest one apple was 16 s. De-An *et al.* developed an apple harvesting consisting of a manipulator, end-effector and image-based vision system. It had a harvest success rate of 77% in the field and spent 15 s per apple. Scarfe (2009) [37] developed an autonomous picking robot for kiwifruit. Eight webcams were used to identify kiwifruit in the plant canopy. Hayashi *et al.* (2010) [20] developed a strawberry-harvesting robot for the greenhouse. Its success rate ranged from 34.9%-41.3% and spent 11.5 s per fruit harvesting. A strawberry harvesting robot was developed by Xiong *et al.* (2019) [42], which had 53.6% success rate without causing damage to the strawberries. Automatic vegetables harvester were developed for many crops. Henten *et al.* (2009) [29] designed an autonomous cucumber harvesting machine in greenhouses. It used a four-link PPRR type manipulator. Arad *et al.* (2020) [3] developed a robot for sweet peppers grown in a greenhouse. It took 18-25 s to pick one pepper. A robotic harvester developed by Bac *et al.* (2017) [6] showed 26-33% success rate while harvesting sweet pepper. Lili *et al.*, (2017) [25] harvested tomato by a harvesting robot which had a successful recognition rate of ripe tomatoes of 99.3%.
Harvesting robots developed so far are limited to high-value horticulture crops and green-house crops only. Their identification of fruits and vegetables is also very low. Robots for field crops need to be developed. There should be better solutions for the human labour and drudgery involved in crop harvesting.

Conclusions

Different robots are being developed in different parts of the world as well as in India. These precision autonomous machines underline their bright future. These machines can overcome many problems faced by an Indian farmer. These robots need to be further explored for different crops in field conditions. Local production of the successfully tested robots will definitely reduce their adoption cost low and ensure a better adoption rate by the farmer.

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