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Robotics in Plant Breeding: Robotic Technologies for High-Throughput Plant Phenotyping

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Abstract:

Plant phenotyping is an essential component of any breeding programme to develop new crop varieties. As plant breeder seek to increase crop productivity and to produce more food to fulfil the demands of increasing population, the amount of phenotype information they require will also increase. Traditional plant phenotyping relying on manual measurement is laborious, time-consuming, error-prone, and costly. Robotic plant phenotyping systems have become a high-throughput method of measuring the morphological, chemical, and physiological characteristics of many plants. Several robotic devices have been created to carry out various phenotyping tasks. Robotic phenotyping in particular has the potential to make it possible to effectively track changes in plant features over time, both in controlled conditions and field. The dynamic nature of plants and agricultural surroundings can make it difficult for these robots to operate. We optimistically anticipate that autonomous and robotic systems will make great leaps forward in the next 10 years to advance the plant phenotyping research into a new era.

Introduction:

An agricultural robot is also called as an agribot or agbot. This is an autonomous robot that is useful in agriculture. It helps the farmer to raise the crops efficiency and also reduces the need for manual labour to the farmer. We may anticipate that these agricultural robots will perform the individual tasks of tilling, sowing, harvesting, and many other farm tasks in the upcoming generations. These agricultural robots will even handle weeding and pest and disease management. These agricultural robots are equipped with arms which are specialized, end effectors and many other tools in order to work on several tasks related to agriculture. The agricultural robots can also get connected to the wireless sensor networks and by using the drones, these robots will collect a huge amount of information or data.In order to replace manual labour, the trend of using agricultural robots will dramatically increase. In the present days, robots are used for picking fruits, milking of cows and rearing of sheep and they are found to be successful in those tasks. There are many thousands of robotic milking parlours in the world right now and the mobile robots are standing as help to the farmers in the automation of tasks which include pushing of feed and the cleaning of manure.

What is Robotics?

It is the Branch of technology that deals with the design, construction, operation and application of robots to perform tasks done traditionally by human beings. Robotics is used in in various fields including agriculture ssciences.

Robotics in Agriculture:

- Robotic systems are now more frequently used in modern agriculture and are recognized as vital to digital farming or precision agriculture.
- The robots are fully autonomous and do not need experienced operators to accomplish farming tasks.
- In contrast to tractor-based systems, this is the robots' biggest incentive.
- Autonomous robots have taken over a wide range of farming operation including harvesting of different crops.

Components of Robotic Technology: it includes three parts

1) A sensing element that monitors the target plants or crops and its environment.
2) A computational module to interpret the sensed information and form adaptive or context specific decisions.
3) An actuation module to complete certain desired operations. (Example robotic probing,trait measurements and navigation)

Why Robotics?

- First off, rapid innovations in robotic technology in agriculture have seen several new applications in plant phenotyping rise.
- Second, the plant breeding and plant science communities are very interested in how these new technologies may be used into research and breeding programmes to enhance crops.

- Thirdly, robotics has advanced through cross-disciplinary collaborations between engineers and plant scientists.

Robotic technology in plant phenotyping:

1. Plant phenotyping is the quantitative and qualitative assessment of traits of a given plant or plant variety in a given environment.
2. These traits include the biochemistry, physiology, morphology, structure and performance of the plants at various organisational scales. Plant phenotypes are influenced by both genetic and environmental variables, as well as non-additive interactions between the two.
3. Phenotyping large number of plant varieties for multiple traits across multiple environments is essential task for plant breeders and hence for such large quantities robotics is used.

Phenotyping robotic system:

1. Phenotyping robotic systems have emerged to automate the phenotyping process in different aspects. The robotic manipulators and ground-based vehicles are used as platforms to attach different sensors to collect data rapidly and with higher repeatability.
2. Robotic systems are deployed to collect and measure the human define phenotypic traits.
3. Robotic systems are highly desirable in the scenario as they provide the necessary speed and accuracy for this kind of phenotyping tasks.

Robotic platforms for plant phenotyping applications can be divided into two categories:

1. Indoor or controlled environments(greenhouse or laboratory)
2. Those for outdoor environments(field)

1) Indoor or controlled environments: In controlled environment, plants are either placed in a fixed position and the robot moves around the facility to interact with the plants or Plants are transported to a fixed position where the robot functions using conveyor belts or other automated devices. The robotic arm is equipped with RGB cameras or depth sensors to acquire visible images or point cloud data without touching the plant.

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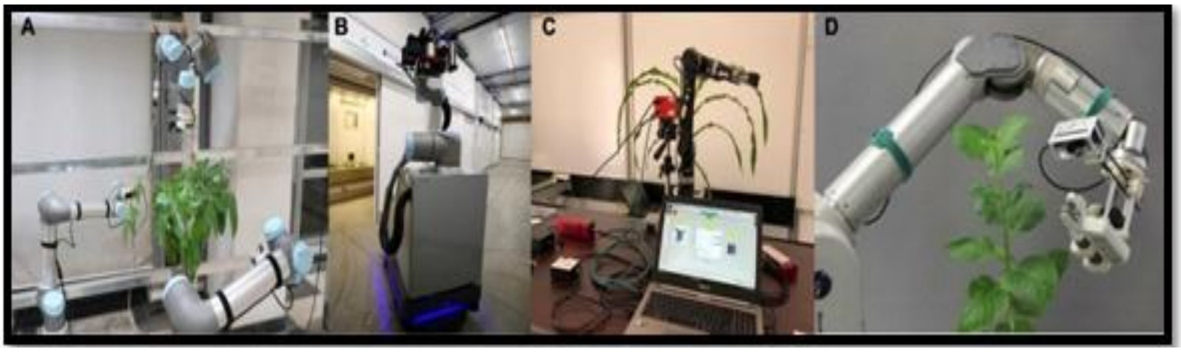


Plant phenotyping robotic system for indoor environment

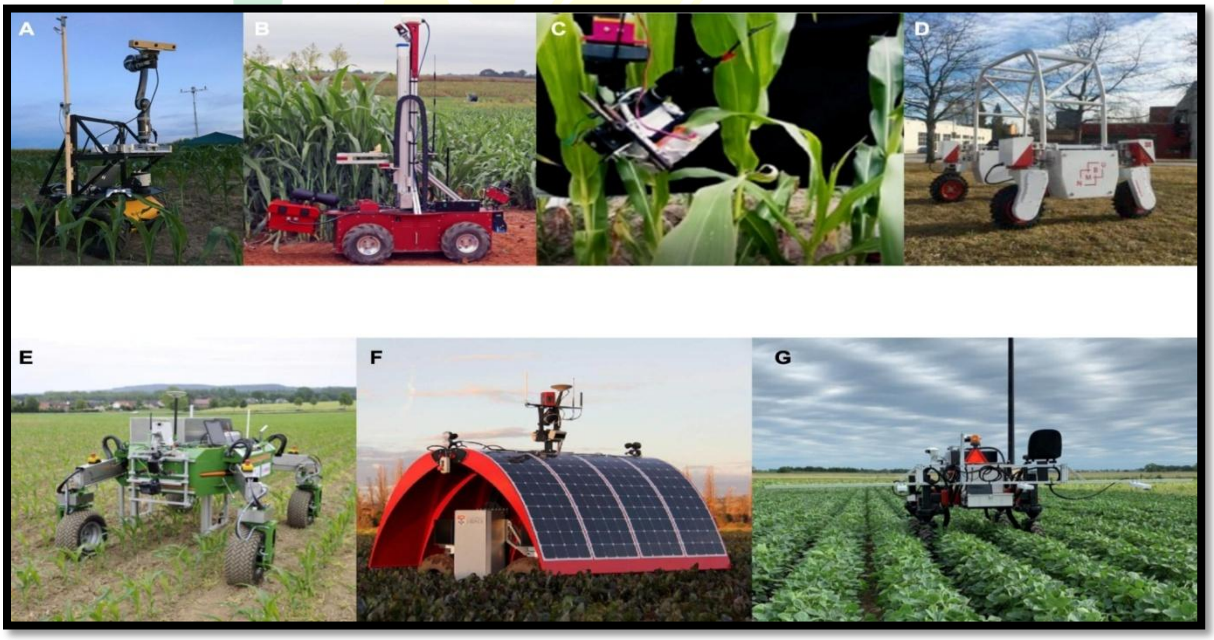
Fig(A) A multi-robot system equipped with deep learning technique to determine optimal viewpoints for 3d model reconstruction.

Fig(B) Sensor-equipped robot to measure the reflectance spectra, temperature, and fluorescence of leaf.

Fig(C) Robotic system to measure leaf reflectance and leaf temperature.

Fig(D) Robotic system for direct measurement of leaf chlorophyll concentrations.

2) Those for outdoor environments (field):



Plant phenotyping system for outdoor environment. fig2(A) Vinobot – robotic system including six robotic manipulator & a 3D imaging sensor mounting on a mobile plateform to measure plant height. Fig2(B) Robotanist-UGV based robotic system equipped with a three DOF robotic manipulator and a force guage for stalk strength measurement. Fig2(c) A robotic system to slide leafspec across entire leaf to collect its hyperspectral images. Fig2(D) Thorvald: VIS/NIR multispectral camera mounted on a mobile robot to measure NDVI. Fig2(E) BoniRob: autonomous robot platform using spectral imaging and 3D TOF cameras to measure plant height, stem thickness, biomass and spectral reflection. Fig2(F) Ladybird-ground based system consisted of a hyperspectral camera, a stereo, a thermal camera, and LIDAR to measure crop height crop closure and NDVI. Fig2(G) Flex-ro:high: throughput plant phenotying system equipped with a passive fibre optic.

Phenotyping Robots faces several challenges:

There are several outstanding challenges in the development of robotic system for plant phenotyping.

1. **Complex and deformable nature of plants represents a major issue for robots'vision and sensing system:** The UGV or robotic manipulator equipped with contact/non-contact-based sensing systems offer a great potential to measure plant phenotypic data compare to non-autonomous robotic sensing system.
2. **Robotic control system needs to deal with dynamic and unstructured environment:** The size & orientation of the plant organs are constantly changing across the growth stages. Therefore, the lack of needed DOF or enough workspace of the robotic manipulator are the limitation for the robots to grasp the plant organs and sense the properties successfully.
3. **Issues with robot software for phenotyping robotic system development:** Two main drawbacks present in many robot software are: (1) The lack of support for certain functional packages (of open source software)(2) real-time constraints (that causes system malfunction due to latency)
4. **Other challenges are:** Managing big data, Reliable power source, Durability under harsh environments and High cost.

Potential Improvements of Phenotyping Robots:

1. **Sensors and Controllers fusion technique can improve the performance of robots:** Sensing-reasoning, and task planning excecution are two essential functions for autonomous phenotyping robots. They sense the environment, apply an appropriate control algorithm, make decision and act in real time to perform the phenotyping tasks.

2. **Internet of robotic things (IoRT): Technology to manage big data for phenotyping robots-** Internet of things technologies are helpful to send lots of data collected by different sensors over internet in a real time manner. The IoRT is the confluence of autonomous robotic system with IoT which is an emerging paradigm that can be employed for phenotyping robots.
3. **Solar panels and Hydrogen fuel cell: Renewable power sources for phenotyping robots-**Solar panels and Hydrogen fuel cell are two technologies that produce clean, renewable, and sustainable energy. A solar panel consist of many small units called photovoltaic cells which convert sunlight into electricity.

Perspective Applications of Robotics Phenotyping:

1. **Phenoyping robots has great potential to measure other plant properties-** "Many indoor &outdoor robots were developed to measure a wide range of plant traits" introduced the robotic systems for indoor and outdoor applications to measure several different plant traits. However, other leaf/stem characterstics are also reliable indicator to detect the symptoms of biotic/abiotic stresses and monitor the plant health during a growing season. Stomatal conductance, gas exchange, &chlorophyll fluorescence of leaves are indicative of their water status, photosynthesis, and chlorophyll content.
2. **Robots in Greenhouses complement the Image-based phenotyping:**Automatic greenhouses such as lemnaTec monitor plants using image-based technique. While it has great potential to measure &predict the plant traits, many hurdles cannot be handled by this technology.
3. **Swarm robot is a new frontier to efficiently accomplish complex phenotyping tasks:** Swarm robotics is a new frontier technology which has potential application for proximal sensing of plants and data/sample collection in a large field. A swarm robotics system composed of large no. of autonomous robots that are coordinated local sensing and communication and a decentralized control system.

Fig. (A) Mobile agriculture robot swarms for seeding purpose.

Fig. (B)UAV-UGV cooperative system to measure environmental variables in greenhouses.

Conclusion:

Autonomous robotic technologies have the potential to substantially increase the speed, capacity, repeatability, and accuracy of data collection in plant phenotyping tasks. Many robotic systems are successfully developed & deployed in both greenhouses and field environments, tested on a variety of plant species (row crops, specialty crops, and vineyards) and capable of measuring a wide range of morphology, structure, development, and physiology-related traits. Sensing, localization, path planning, object detection, and obstacle avoidance still have many technical difficulties.

Reference:

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