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Review of Agriculture Robotics: Practicality and Feasibility

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***Abstract*—Concerns over food security have risen sharply in recent years. The growing human population, coupled with the shrinking agriculture resources, caused many governments and international conglomerates around the world to seek new ways to improve agriculture efficiency. This has lead to increased interest, and spending, in *Agriculture Robotics*. In Part 1 of this work, research activities on agriculture robotics were reviewed, with many showing promising results. However, agriculture robots remain experimental and far from being implemented on large operational scales. This paper investigates the possible reasons for this phenomena, by continuing the review of agriculture robots, only this time focusing on practicality and feasibility. Upon extensive review and analysis, the authors concluded that practical agriculture robots rely not only on advances in robotics, but also on the presence of a support infrastructure. This infrastructure encompasses all services and technologies needed by agriculture robots while in operation, this include a reliable wireless connection, an effective framework for Human Robot Interaction (HRI) between robots and agriculture workers, and a framework for software sharing and re-use. Without such infrastructure being in place, agriculture robots, no matter how advanced in design they could be, would remain impractical and infeasible. However, for many organizations, the technological and monitory costs of establishing such infrastructure could be very prohibitive, which renders agriculture robots uneconomical and enviable. Therefore, the paper concludes that the key to practical agriculture robotics is to find a novel, cost-effective, and a reliable approach to develop the support infrastructure needed for agriculture robots.**

***Index Terms*—Agriculture Robots, Mobile Robots, Precision Agriculture, Agriculture Automation, Outdoor Robots**

I. Introduction

Concerns over food security have risen in recent years. Human population and the demand for food is growing ever rapidly, but agriculture resources are shrinking.

Many factors contributed to this situation; the ageing population of agriculture work force, with younger generations opting for urban careers, the use of agriculture land for biofuel and alternative energy, and others. More worryingly, these factors are expected to increase in the coming years, ringing socio-economical alarms around the world [1-3]

This led to increased interest in *Agriculture Robots*, with global spending on is expected to rise from $817 million in 2013 to more than $16 billion by 2020.

Organizations from around the world are experimenting on mobile robots, manipulators, humanoids, and drones in various agriculture tasks. Robots are being tested in harvesting, picking, herding, and other agriculture activities [4-6].

This continues the effort started in 2014. When the authors published part I of this work, titled: *Review of research in the area of Agriculture Mobile Robots*, [7]. That paper reviewed an extensive list of 50 publications related to agriculture robots, highlighting their achievements.

However, despite this apparent success, as well as the recent developments in robotics in general, agriculture robots remain experimental at best, and are far from being at applied in any large scale agriculture operations.

This paper, part II of this effort, investigates this issue further, by continuing the review of agriculture robots, only this time focusing on practicality and feasibility. To identify factors preventing agriculture robots from becoming practical and feasible for large scale operations.

II. Review of Agriculture Robots: Part I: Robotics Design (Summary)

For the sake of maintaining continuity, this section summarizes part I of this work and highlights its findings.

The paper begins by discussing the importance and need for agriculture robots, then it goes on to review research activities on the subject, highlighting key achievements [7].

Agriculture robots, which operate in the outdoors and on rough terrain, pose a unique set of engineering and technological challenges that are not usually present for indoor robots. These agriculture-specific challenges were the focus these research activities.

Upon further analysis of these publications, it was found that researchers focused on the following three areas:

- Agriculture specific Navigation
- Agriculture specific Image Processing
- Agriculture specific Handling Rough Terrain

Researchers tackled issues such as navigation on a rough terrain, handling wheel slip, illumination of natural light and its effects on quality of image processing, the effects of greenery on localization, stability of tractor-trailer motion, mechanical design, and more. For specific details and references, the reader is referred to Part I of this effort [7].

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III. Review of Agriculture Robots, Part II: Practicality and Feasibility

When considered individually, the publications and achievements reviewed in Part I are promising and exciting. Researchers tackled the challenges mentioned above and reported success in tackling them.

However, and despite this success, as well as the recent advances in robotics, agriculture robotics remain experimental. There is no reported application of agriculture robots on *industrial* level, or in large scale agriculture operations, [5].

For that to happen, agriculture robots need to become practical and feasible, and the following researchers recognized this fact, and attempted to enhance their robots with support systems, this section reviews these works, highlighting strengths and weakness in each.

A. Durmus et al. (2015)

This team developed *Agrobot*; a multi-purpose agriculture robot. From the start, they divided their work into two main parts; designing the robot, and developing a cloud-based service to link that robot to farmers via their mobile devices.

They built their robot in-house under a 2000$ budget, using available tooling and equipment, and were able to control it using a wireless controller, [8].

The interesting thing about their work, is that they identified what makes a successful agriculture robot; not just a complete mobile robot, but also a robot that is connected to the farmers wirelessly, through a cloud service, and through the farmers' mobile devices, [8].

Unfortunately however, their implementation of this idea was not yet complete. Their robot's software focuses only hardware abstraction, and it is not autonomous. Secondly, although they outlined their plans for the their cloud service, they are yet to publish or report about it.

Aside from the vague *RF Link* needed to connect the robot to the cloud, there was no mention of how this link-up would take place, and how the service would be compatible with the farmer's mobile devices.

B. Kashiwazaki et al. (2010)

This team proposed the *Greenhouse Partner Robot System*, which is an agricultural support system designed to facilitate cooperation between humans and robots. Focusing on two agriculture activities; harvesting and pest control, [9].

They introduced a four-wheeled mobile carts, that run autonomously on a guidance line in the greenhouse using its tracker sensors. For controlling the harvesting and pest control activities, the carts also contain a control area that includes a joystick, control panel, and an RFID tag reader, [9].

The robot travel within the space of the greenhouse autonomously, while the human *Partner* uses its control panel to perform the required agriculture tasks, [9].

This team, as did the first team, recognized the importance of establishing an interaction between robots and the agriculture robots, hence the emphasise that was placed on the support system and not just the actual robot.

Another interesting thing about this work, is how they separated the design and programming of the robot into two parts; the design and programming of the autonomous robot, and that of the agriculture task. In essence, compartmentalizing the task of programming the agriculture robot, which allowed for more focus and complexity to be achieved.

However, and although the robot in this set-up did automate the target agriculture tasks (harvesting and pest control), it is still limited to the controlled environment of the greenhouse. The robot is not suitable for the open field as there is not protocol for a long distance interaction.

C. Amer et al. (2015)

This team developed a prototype for a multi-purpose agriculture robot, named *Agribot*, to perform multiple agriculture tasks. Through its hexpad body design and walking mechanism, the robot could travel in any direction with ease, [10].

Their robot is linked to the world via WiFi, its on-board laptop connects to a WiFi signal. Through this connection, the robot is linked to its operator. Also, the WiFi connection allows the robot to connect to other robots and coordinate tasks, [10].

While this robot demonstrated great agriculture versatility, through its ability to perform various agricultural tasks, such as harvesting, and weeding. The obvious limitation of this robot is its dependence on WiFi.

As reported by the team themselves, the robot is limited to a small area where the WiFi signal is present, and although the use of WiFi signal booster was discussed in the report, it was not actually tested, [10].

This is an example of how lack of infrastructure and support would render an agriculture robot impractical, no matter how good its design and performance are. In this work, it would be impractical to establish WiFi connections in the open fields, as WiFi routers and cables would be exposed to the elements, power and maintenance costs would be too high.

D. Tardaguila et al. (2014)

This group developed the *VineRobot*, an autonomous agriculture mobile robot designed to help in the production and agriculture of wine by the Seventh Framework Program, which is sponsored by the European Union (EU), figure 1, [11]

Figure 1. The VineRobot, an agriculture mobile robot, [12]

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The VineRobot is designed to roam the field autonomously, collecting data on the state of the vineyard, such as the vegetative development, water status, grape composition, and other important data.

The acquired images and data generated by the robot is then transferred wirelessly to the grape growers and technicians monitoring the robot in real time.

This data is then processed in real time and used to focus efforts and resources, such as manpower and equipment, where they are needed in the field, hence fulfilling the meaning of the term *Precision Agriculture*, [11], [12].

In this setup, this robot is an example of a *non-intrusive* agriculture robot; the task of this robot, roaming the field and collecting data, does not interrupt the activities of the farmers or growers, nor does it require direct interaction with them.

Instead, the robot can perform its task independently from the farmers, who would be busy picking grapes, working the lands, and others tasks, perhaps oblivious the very existence of the robot and its activites.

Being non-intrusive may be possible for this task, but is not the case for other agriculture tasks. Also, an effective human robot interaction is still needed for monitoring and diagnostics purposes. Also, and as discussed earlier, an effective wireless communication is needed between the robot and its operators.

E. Eaton et al. (2008)

This team identified the need to establish a dedicated infrastructure for agriculture robotics. They proposed the *Precision Farming System* to manage the various automated agriculture activities, as shown in figure 2, [13].

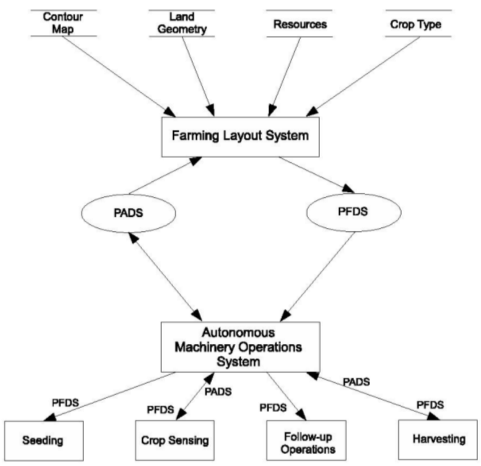

Figure 2. The farming system architecture, proposed by [13]

The proposed system is built on two primary subsystems; the *Precision Farming Data Set* (PFDS), and the *Precision Agriculture Data Set* (PADS). Together, these two system would enable the functionality of agriculture robots.

However, and as reported by the authors themselves, the proposed system is a complex system of systems, each with its own subsystems as well. Also, these systems require redefining and pre-planning of the layouts of the fields prior to operations, which is obviously very disruptive.

Although their idea may have been too complex to achieve, the concept itself is commendable. Agriculture robots do need a support system that outlines field information, establishes wireless contact with human operators, and helps robots gather information about the field.

F. Emmi et al. (2014)

This group of researchers argued that incorporating many electronic systems in agriculture robots would boost their functions, but it would also increase its size, weight, costs, and reliability. Therefore, they proposed that for an agriculture robot to be successful, it must strike a balance between complexity and functionality.

They developed their own system architecture, named the RHEA project. The RHEA caters for robot design and control, WiFi communication, software interface for human users. Basically, all the important points discussed so far about agriculture robots, [14]

They reported a successful implementation of their project, their prototype comprises of three ground mobile units based on a commercial tractor chassis, fitted with various equipment, as shown in figure 3, [14].

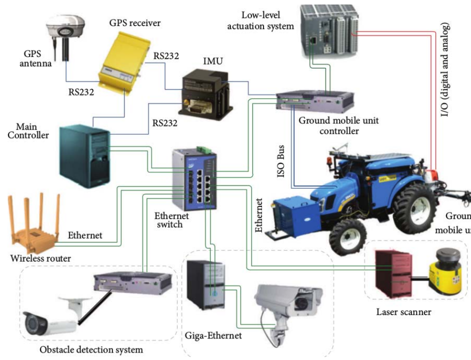

Figure 3. General hardware architecture for the RHEA project, [14]

Although they identified the need to reduce size, complexity, and costs of agriculture robots. Their design, as shown in the figure, is far from small, simple, or cheap. Furthermore, and as reported by the authors themselves, this work is limited by the WiFi signal, which is just around 150 meters at best, [14]

This is yet another example of a great concept, but not a practical implementation. Although this team demonstrated their ideas and showed a proof of concept, they cannot implement this in a high volume operations due to the limited networking capabilities of the WiFi network.

G. Ishibashi et al. (2013)

Recognizing the limitation of WiFi, this team developed a cost effective, web-based monitoring system for their agriculture robot [15].

The robot's on-board computer would gather robot's data, then this data is sent via bluetooth to a mobile device placed

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on the robot. The phone is pre-programmed to send this data through the telecommunication network to an HTTP server, where it would be picked up by web-application, running on a personal computer or another smart phone.

However, this is a one-way communication, as the the operator can only observe the robot, but cannot control it, or stop it, diagnose it, or influence it in any other way. Secondly, the amount and type of data is limited to simple text. higher level data such as images, or any other type of decoded data can be transmitted using this approach.

Although the implementation is limited, this is an excellent example of using existing technologies to develop a cost effective infrastructure. Apart from the cost of the mobile device and the Telecom subscription, there was no further costs needed to achieve this connectivity, [15].

IV. Implementing Practical Agriculture Robots

From the reviews conducted in Parts I and II of this work, the following understanding can be developed.

For agriculture robots to become practical and feasible, the following set of unique technological challenges must be overcome, namely:

1) Hardware Incorporation of Agriculture Machinery: The first step of automation of agriculture machinery is *Hardware Abstraction*; which is developing the software models that describe the machinery/robots to the automoation system.

Before a computer program is able to tell a robot to perform an agriculture task, the program needs to know the robot's physical attributes and its control system, this includes the robot's dimensions, size, sensors, actuators, and controllers.

Whether agriculture robots are built in-house, purchased from a supplier, or customized from existing agriculture machinery, its hardware needs to be successfully incorporated before any automation software is developed.

2) Establishing Wireless Connectivity between robots and humans: For agriculture robots and humans to interact, there needs to be a dedicated wireless network to establish communication. This network must cover the size of the open field, and it must cater for two modes of interactions needed in agriculture; *close proximity*, and *long-range* connections.

In close proximity connection, the robots and humans are in direct visual contact and share the work same space, usually collaborating on an agriculture task, such as picking, harvesting, and transportation.

In long-range interaction, robots are far out of visual contact, operators monitor the robot from a computer on a remote location, often via tracking devices and visualization tools.

3) Developing Software for agriculture robots: As discussed earlier, programming agriculture robots present developers with a unique set of challenges that are not present for indoor robots. These agriculture specific challenges must be tackled and managed when programming for Navigation of agriculture robots.

This include software for sensor data processing, while tackling illumination issues, obstacle avoidance, both dymanic and static, localization withing a field of greenery, and handling the effects of slip and stability on rough terrains.

Furthermore, software that allows the robot perform generic agriculture task is also needed, such as: harvesting, picking, watering, transportation, and others.

4) Implementing Human Robot Interaction tools: The role of human workers in agriculture would not be completely eliminated by the introduction of robots. Humans are still needed for supervision and collaborative tasks. In many cases, humans would still be needed to load/unload robots, help guide/restablize robots, and generally work with robots.

Also, operators monitoring the robots, be it from near or far, are surely needed to observe the robot while in action, perform online diagnostics and analysis, and so insure proper peerformance.

For all of this to happen, an effective *Human Robot Interaction (HRI)* is needed. This include hardware and software tools, such as portable command consoles, installed with proper robot software, to control, monitor, and work with the robots.

5) Software re-usability and reliability: Generally speaking, agriculture tasks are similar or generic. For example, the agriculture task of *picking* in one field, say field A, is more or less the same *picking* task in another field, field B. This is specially true if the crop being picked is the same.

As such, if an organization operating fields A and B would like to automate their operations, they do not need to create new software from scratch for field B, but rather re-use software already utilized in field A.

For this to happen, there needs to be a mechanism for sharing and re-using software, along with collaboration of knowledge and expertise. This can also be expanded to all types of software discussed so far, such as software used in hardware abstraction, connectivity, and HRI tools.

V. Discussion: Challenges of implementing Agriculture Robots

To summarize the points discussed above, implementing practical agriculture robots requires establishing and performing the following:

1) Incorporating agriculture machinery
2) Establishing wireless connectivity (short and long range)
3) Developing robot software for agriculture robots
4) Implementing effective HRI tools
5) Enabling software re-usability and reliability.

As it cen be seen, aside from robot design and technology, practical agriculture robots requires the setup of other factors, such as an established *Connectivity*, an effective HRI, and the re-usability of software. Collectively, let us term these issues as the *Support Infrastructure* for agriculture robots.

This explains why agriculture robots today remain experimental and far from being opertational. Researchers, such as those reviewed in Part I of this work, focused entirely on robotics design and technology, but not on the Support Infrastructure related issues, such as connectivity, HRI, and software sharing and re-usability.

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VI. Discussion: Establishing the Support Infrastructure for Agriculture Robots

Establishing the Support Infrastructure for agriculture robots is not an easy undertaking. Setting up wireless connectivity, networking, and routing is not simple. HRI tools, software and hardware, require time and effort to design and build. Finally, mechanism for software sharing and re-usability needs to be designed and deployed as well.

As such, the technological and monitory costs of implementing the Support Infrastructure is just too high and might be prohibitive for many. This may offset the very benefit of implementing agriculture robots in the first place.

For many organizations and conglomerates, this renders agriculture robots impractical and infeasible. A visual representation of this situation is shown in figure 4.

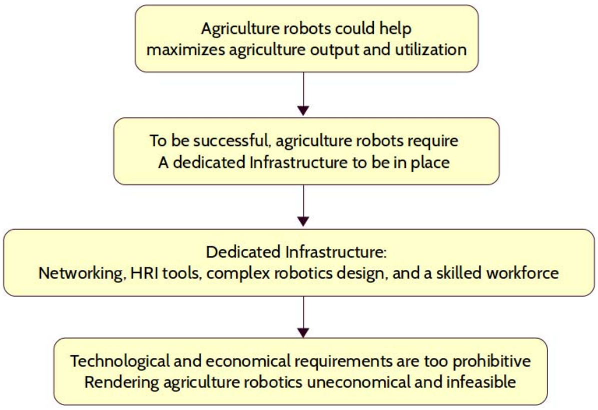

Figure 4. The Challenge of Implementing Agriculture Robots

As such, the key to implementing practical agriculture robots, is solving the technological challenges associated with establishing the support infrastructure needed by agriculture robots. Specifically, challenges to establishing connectivity, HRI tools, and software sharing and re-usability.

To achieve this, a novel approach (or a collection of approaches) is needed to solve these technological challenges, help setup the required support infrastructure, and so facilitate the implementation of practical agriculture robots.

VII. Conclusions

Interest in agriculture robotics have soared in recent years. Global spending and research activities on the subject is experiencing a near exponential growth.

Part I of this work reviewed over 50 of these activities, highlighting their achievements. These include agriculture-specific navigation, image processing, and other robotics challenges agriculture robots face. However, despite these successes, agriculture robots remain far from being operational. This indicates that something else is needed.

This paper, Part II of this work, showed that agriculture robots need a support infrastructure. This would provide a reliable wireless connectivity for the robots in the field, an effective HRI tools between robots and humans, and a framework for robot software sharing and re-usability.

At the moment, implementing such infrastructure is very challenging, the technological and monitory costs of implementing such infrastructure could be prohibitive.

This in turn, renders agriculture robots impractical and infeasible. Therefore, The key to implementing agriculture robots is to to find a novel, practical, and a reliable approach to implementing the support infrastructure it needs.

VIII. Ackhnowledgements

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