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| **Project title:** | GROWBOT: A Grower-Reprogrammable Robot for Ornamental Plant Production Tasks. |
| **Project number:** | HNS/PO 194 |
| **Project leader:** | Aran Sena, King's College London |
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| **Previous report:** | - |
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## AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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## GROWER SUMMARY

### Headline

Horticulture businesses face a significant labour security issue; however businesses which currently rely on manual labour struggle to achieve a high-level of automation due to the dexterity skills required. Advances in robot programming by demonstration may help provide a flexible automation solution which can be put directly into growers' hands.

### Background

Horticulture, as an industry, faces significant labour challenges. These challenges are present both in the near term, with the current uncertain political climate, and in the long term, with a general downward trend of people entering the industry[1, 2].

GROWBOT is attempting to address these labour challenges by reducing the dependency on human labour for horticultural businesses, through robotic automation. In addition to the business-focused reasons for pursuing robotic automation, many tasks in horticultural production are physically demanding and often in difficult environmental conditions. By developing automation systems which can be deployed directly by the grower, when and where it is required, this technology offers benefits to both workers and businesses.

### Summary

Labour security represents a significant risk to the long-term success of the U.K. horticultural industry, between reduced levels of people entering the industry and a heavy dependence on a migratory workforce. These long-term risks have been further highlighted by the current political uncertainty.

Robotics presents horticulture with many possible solutions to these labour issues; however horticulture presents Robotics many significant challenges. Robots are used extensively in conventional settings, such as in the automotive industry, due to their speed, accuracy and strength; however taking advantage of these traits requires the workspace of the robot being highly controlled (i.e. the positions and locations of all objects around the robot are known to

[1] https://www.theguardian.com/society/2015/jul/01/sue-biggs-rhs-horticultural-timebomb
[2] https://www.rhs.org.uk/education-learning/careers-horticulture/horticulture-matters/

high degree of accuracy). This level workspace control, or *structure,* is not possible in horticulture, as the robot must interact with organic material.

Organic material presents many uncertainties. The same varieties of a plant will all have different geometries, and plant material is flexible, making grasping the plant an uncertain process for the robot. Additionally, plant material is fragile, limiting how the robot can interact with it. These properties result in a highly challenging grasping task for the robot. This is arguably a more challenging task than that presented by the Amazon Picking Challenge[3], seen by many as a benchmark in industrial grasping, where participating teams had to use a robot to pick items from a bin and place them into a basket order with objects ranging from defined shapes, such as boxes of cereal, to flexible objects, such as sponges or gloves.

To date, agricultural robotics research addressing handling has focused on the handling of relatively well-defined fruits and vegetables, such as sweet peppers or strawberries. Autonomous harvesting of fruit and vegetable crop is supported by two features, (i) readily defined and identified features (e.g. red ripe strawberries, or bright waxy surface of peppers which are clearly visible under a bright light against a leafy background, (ii) structured growing environments. For point (i) in horticulture, the plant varieties being grown will often have obstacles in the way of grasping points, and for point (ii), unlike peppers or strawberries which can be grown in configurations easier for grasping (e.g. on a trellis structure), ornamental flowers must be grown in aesthetically natural formations. GROWBOT seeks to push robotics capabilities further toward directly handling plant material for horticulture.

Given that much of the growing which takes place in the U.K. is carried out by small and medium enterprises (SMEs), and focused on providing high-quality variety in small batches, traditional automation often cannot address their needs due to cost and flexibility issues. These challenges result in growers needing large teams of people to keep up with demand as they will often lack the volume and associated production data to justify the deployment of expensive traditional automation systems, or even the technical means to do so.

Collaborative robots (a.k.a. *cobots*) offer a possible solution to the rising need for automation; however the challenges of handling plant material, and having these systems deployable by non-experts, currently limits the extent to which cobots can help. GROWBOT aims to address these challenges by developing robotic systems which could be used directly by non-experts

[3] https://www.amazonrobotics.com/#/roboticschallenge

for horticultural tasks, so that growers can be empowered to use their horticultural knowledge more easily and reduce the amount of repetitive labour-intensive tasks that must now be done by hand.

When considering the research direction for this project, I first spent a few weeks visiting my project industry advisers around the U.K. to help get a better grasp of what horticultural tasks are currently being done, and how the people working there do them. I visited J&A Growers in Coventry, producers of young tree stalks for forestry and landscaping companies, and Kernock Park Plants, producers of a wide variety (3000+) of plants and flowers for commercial businesses.

These visits highlighted both the task diversity present in the horticulture industry, and the challenges faced by businesses in implementing further automation. A common challenge observed in both growing sites preventing wider use of automation was that the actual handling of plant material required complex dexterous handling, as seen in the grading processes shown in Fig. 1.

Figure 1: Examples of manual handling tasks during grading in hardy nursery stock (left) and protected ornamentals (right).

In both sites, the production managers were content with the current performance of their workers; however they saw the value in advancing automation for their companies in the future and for the industry in general. Top motivators for furthering automation included wanting to help their employees make better use of their time by automating the more repetitive ``simple'' tasks (that still require a great deal of dexterous skill from a robotics point of view), and more fundamental concerns over the long-term success of their company and industry due to the previously mentioned labour security issue.

Given the objective of developing robot systems which can be readily deployed for a variety of tasks in the horticulture industry, a primary direction for my research lies in human-robot skill transfer when the user of the robot system is not a robotics expert, i.e. a non-expert. Understanding and improving how non-expert users interact with and respond to adaptive learning systems is critical for GROWBOT, as the performance of an adaptive learning system is dependent on the data it is provided - if the data is provided by the non-expert user, the quality of teaching provided by the user is therefore a critical factor.

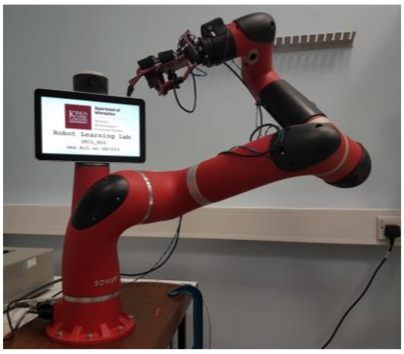


Figure 2: Rethink Robotics Sawyer Robot with AR10 Hand

The first stage of research in addressing the challenge set by GROWBOT has focused on improving the communication between robot systems and human teachers, to help non-experts better understand the learning process of a robot.

Moving forward, it is hoped that the techniques developed in this first stage of research will help the robot use the insight of a human teacher for more complicated tasks. While it may be difficult to explicitly program how to interact with plant material (even for a robotics expert), it is hoped that by combining machine learning with the adaptive problem solving of a human teacher the robot will be able to learn effective control policies for plant handling.

This next stage of research will be carried out with a current generation collaborative robot; a Rethink Robotics Sawyer robot as shown in Fig. 2, along with an Active Robotics AR10 manipulator. It is intended that by using current generation industrial equipment and manipulators, this research will take direct steps towards transferring the technology developed in GROWBOT to industry at the end of the project.

## Financial Benefits

As the project is still in early stages, it is difficult to provide exact figures. To help understand the *potential* financial benefits of robotic automation, a basic cost analysis is provided in the table below.

N.B. All numbers provided here are rough estimates based on currently available data - no guarantees are given. Actual costs and return on investment may differ. In-depth process analysis is required to determine viability of automation, and the real-world potential savings that automation can offer for your business.

**Assumptions:**

1. Salary numbers used here are assumed based on current government information[4].
2. The working week for an agricultural labourer is ~40 hours.
3. Robot cost based on estimate of £30,000 for a collaborative robot plus £10,000 for accessories (grippers, sensors, etc.)[5]. Operational life of robot based on total lifetime of 35,000 hours for Rethink Robotics Sawyer robot[6].

| | **Human** | **Robot 40 hrs/wk** | **Robot 24/7** | **Robot 60% utilisation** |
|---|---|---|---|---|
| **Hours /week** | 40 | 40 | 168 | 100 |
| **Weeks /year** | 46.4 | 52 | 52 | 52 |
| **Cost** | - | £40,000 | £40,000 | £40,000 |
| **Cost /hour** | £7.66[7] | £19.23 | £4.58 | £7.69 |
| **Cost /year** | ~£14,217[8] | - | - | - |
| **Operational Life** | - | ~16.8 years | ~4 years | ~6.7 years |

While this shows in numbers why you might want to use a robot, the main question that remains is '*what is the return on investment'*. This can be difficult to estimate, and depends on the processes being automated. Taking a naïve view, if we compare the £40,000 fixed cost of

[4] https://www.gov.uk/agricultural-workers-rights/pay-and-overtime
[5] http://blog.robotiq.com/what-is-the-price-of-collaborative-robots
[6] http://www.rethinkrobotics.com/news-item/rethink-robotics-sawyer-robot-set-for-global-deployment/
[7] Assuming Agricultural Minimum Wage (Grade 3, Hourly): £7.66
[8] This doesn't account for overtime, night work, or tied-accommodation.

the robot against the recurring £14,217 cost of the human labourer, this represents a ~2.8 year break-even period; however this is not a truly informative view on the financial benefit of robotic automation.

As the robot represents a fixed asset investment, key factors for estimating the benefit of automation are what *rate, r,* it can perform a task compared to a human, and the *utilisation*, *u*, per day/week compared to the human (i.e. for a human labourer we assume 40 hours per week in the above table). Looking purely at the financial benefits, ideally:

$$r_{human} * u_{human} \leq r_{robot} * u_{robot}$$

In this case, a robot might work at a slower rate compared to the human worker, but it can perform for longer duration, consistently.

In addition to potential financial benefits, additional benefits to robotic automation include: consistent performance (addressing quality issues relating to worker fatigue), eliminating lengthy training cycles (addressing issues in getting a new human labourer 'up to speed'), availability (i.e. replacing a robot at the end of its life, or in the event of a breakdown, or if you must purchase additional robots to expand capacity), and allowing growers to redeploy human labourers to more value-adding work.

Ultimately, it does not make sense to try consider return on investment unless the automation is actually *capable* of performing the required tasks. Current industrial systems generally lack the capabilities required for horticultural automation involving direct plant handling, where there is low volume and high variety. GROWBOT is therefore primarily focused on addressing this capability issue, to (hopefully soon) make the decision of whether to automate or not easier for growers.

## Action Points

Given the early stage of this research, there are no explicit action points.

From observations made during industry site visits, it can be seen that there are often processes which are possible to automate using current technology; however a lack of awareness can result in missed automation opportunities. It is worthwhile to review currently available automation options, such as collaborative robots, and to consider what processes are currently labour intensive that could be adapted to better suit automation.

## SCIENCE SECTION

### Note

Research from recent months has just been submitted for review to the 2018 IEEE International Conference on Robotics and Automation, on the 15th of September 2017; as such a full discussion of experimental work and results cannot be published in this report.

If this research is accepted for publication, it will be available in the conference proceedings online at IEEE Xplore Digital Library[9] from 21st May 2018 under the title “Teaching Human Teachers to Teach Robot Learners”. Details of the research will also be provided in the next annual report.

Presented below is a brief outline of the research conducted in recent months.

### Outline

A key objective for GROWBOT is to not just develop a robot system *capable* of automated ornamental plant production, but also to develop a system which can be *reprogrammed* by growers. A field of robotics which I am exploring for this purpose is *Programming by Demonstration* (PbD).

There have been recent advances in PbD methods which have allowed non-experts (i.e., those without technical expertise in robotics) to ‘teach’ a robot how to perform a task which can be *generalised*. Teaching is achieved by demonstrating to the robot how to perform the task, either by the robot observing your actions through sensors, you controlling the robot via a joystick, or directly handling the robot to show it what should be done e.g. if you wanted to program a robot how to pick up a cup, you could take hold of its arm and guide it through the motions. Generalised task learning allows the robot to then extend user provided demonstrations to unseen situations, i.e. with a generalised learning method you could show a robot how to pick up a cup from one position, and it could then pick up the same cup in a different position (or better yet a different object altogether).

The amount of generalisation a robot is capable of is then a function of both the machine learning method employed, and the quality of teaching provided by the human user. While

[9] http://ieeexplore.ieee.org

there are many useful machine learning methods for generalised task learning, current research is lacking in how exactly to ensure good teaching from the human user. The robot learner's performance is entirely dependent on the data provided by the teacher. As noted in Argall et al. (2009), two key data set issues that can arise as a result of poor teaching in PbD are undemonstrated states, and ambiguous demonstrations which might confuse the robot learner. Undemonstrated states result in the robot failing to perform a task from certain configurations due to insufficient data, and ambiguous demonstrations result in the robot's knowledge of the task either not improving or degrading.

While there are some very useful machine learning methods for this which can be deployed to a robot system to achieve generalisation, current research is lacking in how exactly to ensure good teaching from the human user. With a goal of minimising the training required to use collaborative robots, it becomes difficult to ensure users will understand the learning process of the robot, so that they provide demonstrations which are unambiguous and complete.

My research which has been submitted for review, has focused on closing this gap in understanding between robots and non-experts, by improving the communication process between them.

By closing this gap and allowing growers to better understand the robot's machine learning process, it is hoped that robots may be more practically and rapidly deployed in horticulture. Additionally, by improving the communication link between the human user and the robot, it is hoped that robot systems will be able to better incorporate the human user to further extend its own capabilities, by leveraging the adaptability of the user.

## References

B. D. Argall, S. Chernova, M. Veloso, and B. Browning, "A survey of robot learning from demonstration," Robotics and Autonomous Systems, vol. 57, no. 5, pp. 469–483, 2009.