Robotic weeding – from concept to trials

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Abstract

This paper reports on the use of robotic selective mechanical cultivation as an alternative method to herbicide control for managing weed species in zero-till cropping systems. Existing best-practice technology in weed spot spraying utilises infrared technology to detect and selectively spray weeds using herbicide at quantities significantly less than those used in normal blanket spray applications. This reduction in the herbicide de- creases operational costs and can be beneficial for the environment; however, the capital investment in the technology is substantial for farmers who wish to own and operate their equipment. While effective in reducing overall herbicide usage, the technology has done little to tackle the rapid evolution of herbicide resistant weed species. As a potential solution to this issue, our research over the past three years has been focused on the development of non-chemical methods of weed management utilising robot-enabled selective mechanical weeding. Used in conjunction with a robotic vehicle platform, a mechanical weeding array is capable of working throughout the day and night. The weeding tools have been designed to be removable and inter-changeable, allowing the use of tools especially designed for different weed species, weed densities, and soil types. The system developed consists of a one-degree-of-freedom array of weeding tines, actuated into the ground in time to remove individual weeds. Sensing of the weeds is enabled by a vision-based plant detection and classification system, while the timing for the implement actuation to hit the weed is determined as a function of the robot speed. The field trials reported in this paper demonstrate the potential of this robotic system for individualised weed treatment and multi-mode weed management methods. In particular, a trial of the mechanical weeding array in a fallow field over six weeks maintained the weed coverage in robot treated sections to be 1.5%, compared to 37% in the control areas not treated by the robot—a reduction in excess of 90% in weed coverage.

Background

Many crop production systems, in countries such as Australia, have moved to non-tillage practices in order to reduce losses of soil moisture and soil nutrients to the atmosphere. These practice relies heavily on chemical agents as a means of weed management, which has contributed to the development of weed species for which chemical agents are rapidly losing their effectiveness. In consultation with Queensland farmers regarding operational requirements for the design of the robotic platform, our team at the Queensland University of Technology has developed AgBot II - see Figure 1. This is a multi-role robotic platform designed for autonomous crop management, enabling alternative weed destruction methods and the application of fertiliser.

The weeding system consists of a state-of-the-art robotic-vision system and a weeding array. The vision system can not only detect but also classify weed species in real-time. This enables AgBot II to make an autonomous decision on what weed management method to apply—chemical or alternative, which in the case of this paper is mechanical. The weeding array can be used for multi-mode weeding operations whereby some weed species are sprayed whilst other species are mechanically removed.

AgBot II can autonomously navigate and traverse a field conducting weeding operations, return to the replenishment pod to recharge batteries and refill the chemical tank before returning to the field to continue the operation. As part of the project, AgBot II successfully managed a fallow field utilising only mechanical weeding methods for a period of six weeks. This paper documents these results.

Methods

In consultation with farmers, our team conducted contextual interviews from which they derived functional specifications (what should the robot do) and operational specifications (under which conditions can the robot operate) to develop a robotic prototype capable of managing crops (Redhead et al., 2015). This led to the development of the AgBot II platform, which included the weeding system and the energy and chemical replenishment pod. The design of AgBot II balanced a complex set of competing technical requirements (Bawden 2015). The weeding system consisted of a state-of-the-art robotic vision system capable of not only detecting the presence of weeds but also identifying the species of weed, in real-time. When traversing the field, the vision system enables AgBot II to identify the weed species and to make autonomous decisions on what weed control method to apply (chemical or alternative) to destroy the identified weed (Bawden et al. 2017). In addition, the weeding array was used to demonstrate multi-mode operations, whereby certain weed species were sprayed whilst other species were mechanically removed depending on what method was most effective for the identified weed species.

(a) AgBot II robotic system. (b) Multimode weeding array.

Figure 1. AgBot II - QUT's Agricultural Robotic Platform.

Robot Platform

Figure 2 shows the major assemblies of the robot platform as well as those of the weeding array. The robot consists of two side-units which are connected by the implement unit. The side units house the batteries and drive train as well as other electronics. The implement unit houses a herbicide tank, a small fertiliser sprayer, and the weeding array, which for the proof of concept is of one metre wide. The dimensions of the robot are matched to Australian crop layouts with a three-metre inter-wheel spacing.

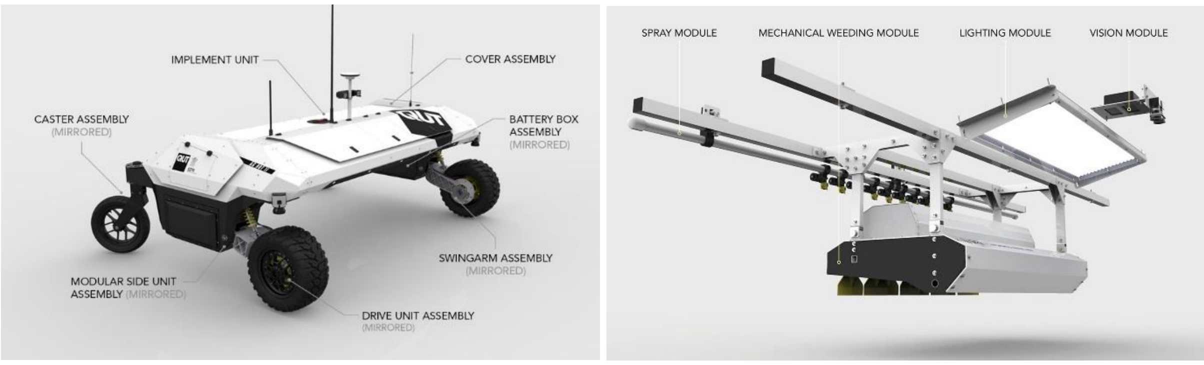
The driving configuration consists of two identical drive units that provide differential driving to the two front- driving wheels and two castor wheels at the back. This configuration reduces the number of driving units, thus reducing the cost of the unit, and also allows indented control of turning and forward motion.

The robot has a state-of-the art planning, guidance, navigation, communications, and motion control sys- tem. The boundaries of the paddock together with the crop row orientation are supplied to the planning algorithms through a user interface. The planning algorithms then produce a desired path. This path is used by the guidance system in conjunction with information from the current motion of the robot to compute commands to the motion control system. The navigation system fuses data from different sensors to infer vehicle position, velocity, heading, and heading rate. This information is used by the guidance and the motion control system. The latter translates the desired motion behaviour produced by the guidance the system and the current motion behaviour into commands to the driving motors.

Weeding array

The integrated multi-mode weed destruction system for AgBot II shown in Figure 2 incorporates both a selective mechanical weeding system and selective spray system. Individual weed species can be targeted by either the mechanical or spray system depending on the result of the vision-based weed detection and classification system.

Weeds are identified using a vision-based on-board detection and classification system comprising of a ground facing camera and an image processing computer. Weeds are first detected using colour information in the image and then an algorithm determines the species. The prototype assembly for the weed detection and classification system is capable of working continuously throughout the night and during daylight periods of uniform lighting. Once the weeds are detected and classified, the system determines the best method for weed destruction and triggers the actuation of either the mechanical or spray modules. The modules are attached to the underside of the AgBot II platform, and for the purposes of the first prototype have been designed to a width of one metre. This can be extended to the full width of the robot in future design iterations. The latency due to the processing speed of the vision-based weed detection and species classification system combined with the operational speed of the robot is used to determine to the spatial separation between the camera and the weeding actuator and the speed of actuation. Whereas the number of actuators and the expected number of actuators active determine the energy storage requirements of the robot as well the size of the accumulator of the pneumatic system that activate the mechanical weeding implements.



(a) Platform major assemblies (b) Multimode-weeding-array major assemblies

Figure 2. AgBot II and weeding array assemblies.

Further details about the robot and the weeding system design can be found in Bawden et al. 2017.

Results

A common task for an autonomous agricultural robot is to keep a fallow field free of weeds. To demonstrate the effectiveness of AgBot II in performing this task an experiment was conducted on a small fallow field. AgBot II was run over the field twice per week and the weeds were removed using the mechanical weeding implement as they appeared.

A scale map of the field used for the trial is shown in Figure 3, the field is approximately 1000 m2 (26 m by 38 m). The field was initially ploughed using a large tractor and then left alone to allow the weeds to emerge naturally. The paddock was divided into 26 three-meter wide rows related to the width of the robot, and eight rows chosen randomly were selected to be left untreated. Figure 4 shows the evolution of untreated and treated weed coverage (area covered per unit of area). The figure also shows the percentage of weed coverage in the treated and control sections of the paddock. It is clear from the figure that after the rain event (day 16), the amount of weed coverage in the control area grows rapidly, however, the coverage in the treated area grows slowly then starts to recede.

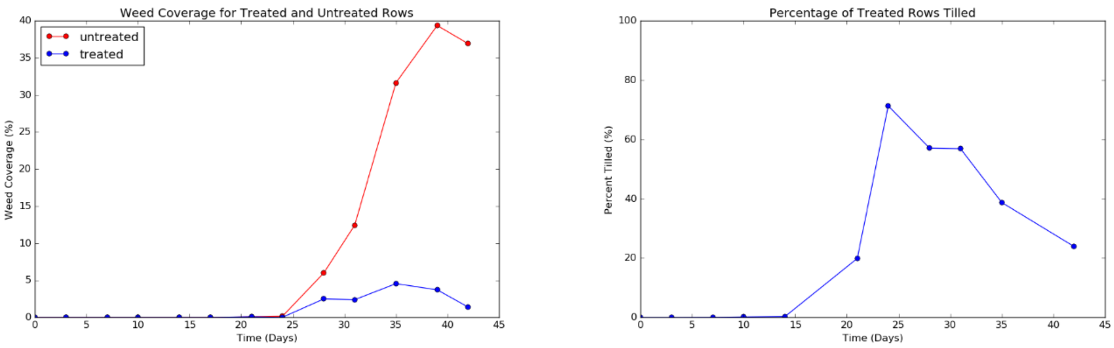
The weed coverage in the treated area peaks at 4.5% while the weed coverage in the control area reaches 37%. At the conclusion of the trial, the weed coverage in the treated area is reduced to 1.5% demonstrating the efficacy of the AgBot II and the autonomous weeding array at weed management in a fallow paddock. The weed coverage is non-zero because new weeds are continuously germinating in the field due to the large seed bank and the summer weather.

Figure 3. Scale map of the paddock used for the trial. The yellow (clear) rows indicate the sections that were treated by AgBot II, while the green (dark) rows were left untreated.

Another way to measure weed coverage is to count the number of weeds per unit of area. In the initial stages of the trial, this was possible, however, as the weed density increased and the weeds grew larger it was no longer possible to compute this measure for the control areas. Thus, the percentage area of weed coverage is used instead. In the treated sections of the field, however, the weed density peaked at about 11 weeds per m2 on day 21.

Figure 7 shows the growth of the weeds in the field at the beginning, middle and end of the trial. The maps of the field were created using the images collected from the weeding camera on the AgBot II whilst conducting the weed management operation. The images are stitched together to form an ultra-high resolution mosaic of the field with one pixel representing an area of 1mm by 1mm. This resolution is high enough that individual weed species can be distinguished.

The breakout images on the right of Figure 7 show increasingly zoomed images of the same section of the test paddock. In particular, in the right most breakout in Figure 6, individual recently germinated weeds can be seen clearly.



(a) The percentage of the field covered in weeds

(b) The percentage of the field mechanically treated

Figure 4. Weed growth and subsequent weed treatment over time during the trial.

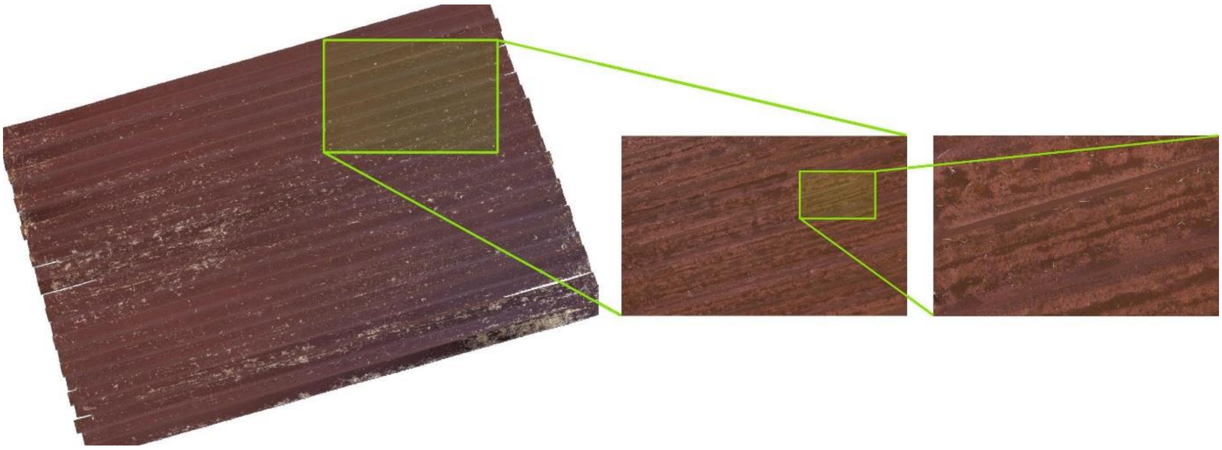


Figure 5. The fallow paddock at the beginning of the trial.

Discussion

The trials documented in this paper show the feasibility of treating paddocks with robotic weeding using alternative methods—in this case mechanical weeding. Regular passes of AgBot II over the paddock allows weed management techniques to be applied to the weed very shortly after it germinates when it is much easier to manage and before they seed. Different mechanical implements can be more effective for different weed species and soil types. The hoe tested in the trials, for example, is very effective for broad-leaf weeds; however, a stirrup hoe can be more effective for grasses.

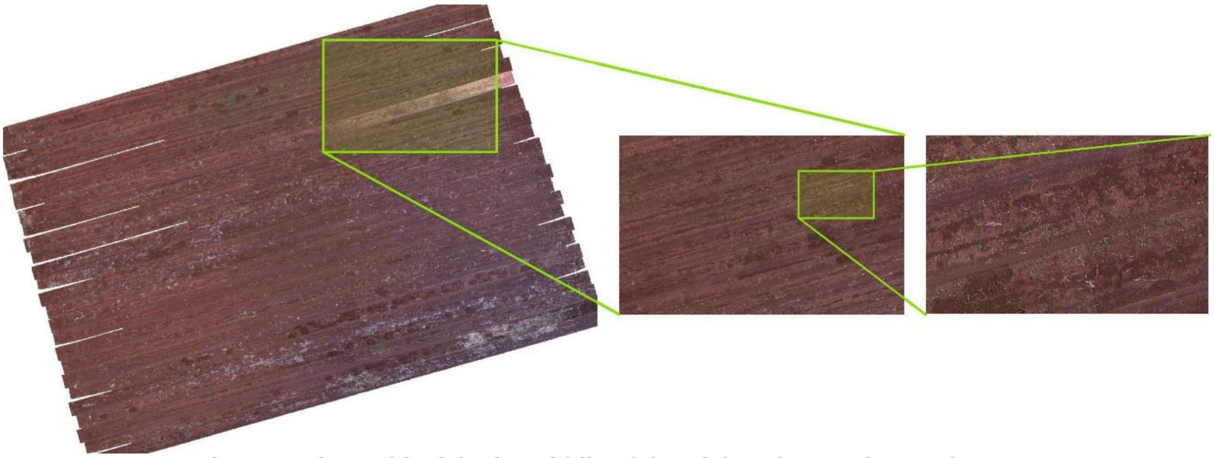


Figure 6. The paddock in the middle of the trial as the weeds germinate.

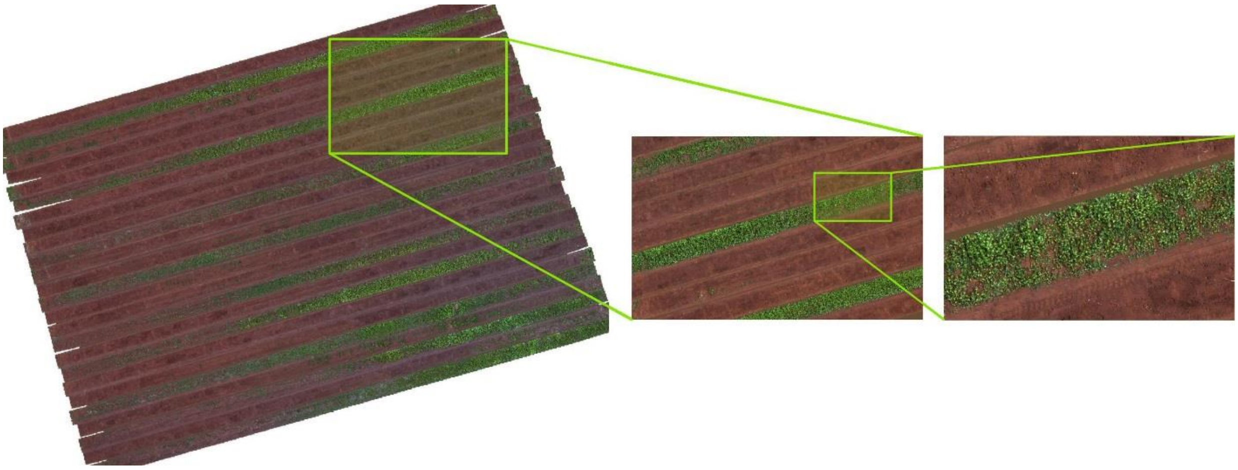


Figure 7. The paddock at the end of the trial clearly showing the treated and untreated sections.

As part of the trial, we have also shown the capability of AgBot II to collect high definition imagery. This can have different purposes. For example, these images can be used to continue evolving the performance of the machine learning algorithms used in the vision system, and also for the development of weed maps that can be aggregated and use to monitor the regional evolution of different weed species as the introduction of new ones.

During the trial, it was experienced that after a rain event a very large number of weeds germinate at the same time. It was found that AgBot II was able to manage higher than anticipated weed densities. In these cases, robotic weeding presents another advantage relative to heavy standard weed control machinery. Since the robots are of a relative lower weight.

Conclusion

This paper documents the results of a mechanical-robotic-weeding trial of six weeks. The results of about 90% in weed density are very encouraging. The trial also demonstrates the potential use of the robot-vision system to capture key data related to weed species that could be used in applications of bio-security.

Australia spends approximately AUD$1.5 billion per annum in weeding operations and it is estimated that a further AUD$2.5 billion per annum in losses of agricultural production results from weeds. AgBot II has the potential to reduce weeding costs in excess of 90 percent and to also reduce the impact of weeds on agricultural production.

References

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