Autonomous Pesticide Spraying Robot for use in a Greenhouse

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Abstract

This paper presents an engineering solution to the current human health hazards involved in spraying potentially toxic chemicals in the confined space of a hot and steamy glasshouse. This is achieved by the design and construction of an autonomous mobile robot for use in pest control and disease prevention applications in commercial greenhouses. The effectiveness of this platform is shown by the platforms ability to successfully navigate itself down rows of a greenhouse, while the pesticide spraying system efficiently covers the plants evenly with spray in the set dosages.

1 Introduction

The function of a greenhouse is to create the optimal growing conditions for the full life of the plants [1]. Achievement of the desired conditions often requires the use of pesticides, fungicides, high temperatures and increased carbon dioxide and humidity levels [2]. Prolonged exposure of greenhouse workers to these conditions leads to an uncomfortable and hazardous work environment [3, 4], contravening modern Australian occupational, health and safety principles.

Often, there are substantial risks involved in greenhouse work due to the hazardous environment or dangerous operations. Specific examples of these include: repetitive strain injury, toxic chemical exposure, extreme heat exposure, extreme humidity (heatstroke) [3], and working at heights. Automating tasks within the greenhouse will enable the avoidance of unwanted or hazardous human exposure whilst potentially leading to an increase in overall efficiency and productivity.

The main application of robots in the commercial sector has been concerned with the substitution of manual human labour by robots or mechanised systems to make the work more time efficient, accurate, uniform and less costly [5]-[10]. One may argue the social implications of such developments, for example, the effects on employment through loss of blue collar jobs to the more efficient robotic counterpart; there are also ethical considerations that may be argued. Whilst there may well be some validity to the argument in some cases, this current project is unique in the number of stakeholders that are affected in a positive sense. The farmers benefits are found in more efficient maintenance of the crops and either less work for themselves or a decreased need for the employment of others (arguably, an expensive process). Increased demand on growers has begun to be met with increased specific automation in many fields, as producers believe that automation is a viable and sometimes necessary [7] method to ensure maximum profits with minimum costs [6]. Indeed Hopkins [6] argues that automation enables the expansion of a greenhouse without having to invest more financial resources on labour. Merchants may benefit from increased sales due to a lower cost product; the consumers will benefit, likewise, from a lower cost product of comparable quality. The stakeholders that benefit most, at least from an ethical or social perspective, however, are the greenhouse workers.

This paper presents the design and construction of an autonomous robot that seeks to address some of the human health concerns associated with greenhouses. This robot is designed as a base for developing systems to enable the automation of greenhouse processes such as the spraying of pesticides, picking of fruit and the caring for diseased plants. The system is designed to be as modular as possible, enabling the development and/or modification of any of the individual tasks.

The following sections of this paper are outlined as follows, Section 2 describes the current greenhouse environment and technique of pesticide application, Section 3 outlines the design of the robot, Section IV outlines the safety aspects considered in the design, Section V discusses the programs used in operation, Section VI provides a cost benefit analysis of automation within a greenhouse and Section VII provides an overview of the effectiveness and conclusions found upon implementing the robot in a real greenhouse environment.

2 Pesticide Spraying

2.1 Overview

The optimisation of carbon dioxide enrichment, temperature, humidity, root moisture, fertiliser feed, pest and fungus control allow greenhouses to produce fruits, vegetables out of season and ornamental flowers all year round. For example, carbon dioxide levels within a greenhouse are approximately five times the normal atmospheric levels [11]. The optimal temperature and humidity levels of a greenhouse during the normal working hours of the day can be quite high (up to 38°C), making it very hot and uncomfortable for someone wearing the heavy protective equipment. This can subject the worker to risks such as heat stroke and other health hazards associated with such conditions.

The inhalation of pesticides used within a greenhouse can, in some cases, be fatal or cause permanent damage to the lung tissue. Even relatively small amounts of exposure to many chemicals over long periods of time can be damaging to the worker. Due the hazards of such exposure, protective clothing and equipment must be used. However, research has showed that protective clothing does reduce the possible amount of exposure but does not stop it[3]. Many pesticides have been found to be able to penetrate clothing and even rubber gloves within half an hour and a manual spraying task can take several hours depending on the size of the greenhouse.

Figure 1 shows a typical crop of greenhouse tomatoes. Contemporarily, a human worker would walk down these confined rows with a pesticide spraying gun, in an attempt to cover the foliage of the plants with an even coat of spray. An experienced worker will attempt to coat the surface of the plants with the appropriate calculated dosage. This manual application of pesticides is, as mentioned above, a time consuming, tedious and dangerous task, requiring the worker to wear protective clothing and breathing apparatus. Hence, this manual application technique is largely open for error. It is often difficult to know exactly how much pesticide it really being applied to each plant. In this harsh environment, it is possible that the worker may also apply an inappropriate amount of spray to the plants through either fatigue or haste, resulting in the inefficient application of pesticide. The alternative method to manual spraying is Fog spraying. This involves using a fogging sprayer to spray the whole greenhouse with a fine mist that covers every surface [12]. This is useful where the greenhouse is infested with small flying pests and the entire greenhouse requires spraying. this method is not always desirable and cannot cure all problems.

An autonomous pesticide spraying device would be invaluable in the avoidance of human exposure to hazardous chemicals and to ensure the optimal calculated amount of spray is applied to all plants evenly, minimising waste due to increased accuracy and precision[13]. A further advantage of using an automatic sprayer is that various concentrations of pesticides can be applied at levels where there would normally be an increased the risk of toxin exposure to the human applicator.

Figure 1: Typical crop of greenhouse tomatoes

The ideal time to spray plants within a greenhouse is in the early evening as a result of some chemicals used on plants adversely reacting to ultraviolet light and intense heat. An automatic spraying system could be set to begin operation at night avoiding out-of-hours work whilst ensuring that the plants are sprayed in conditions that cause the least amount of damage to the plants.

2.2 Cost Benefit analysis

For the future implementation of a greenhouse robot to be commercially viable, such a product would have to be at a low cost, or have the potential to carry out all, or most, of the current manual tasks within a greenhouse. Some of these potential applications include monitoring plant health, plant growth rates, removing unwanted leaves and picking the produce. In principle, a system able to satisfy these requirements seems viable, as the requirements may be met via a common basic pathway. Whilst it is recognised that there is generally more than one solution to an engineering problem, an example of a system able to achieve this would be that consisting of a mobile platform with a robot arm on an elevating platform, which would then satisfy the pruning, picking and monitoring of produce, essentially adding to the robot this paper has outlined.

As mentioned, the considerable economic and social costs related to the manual process of pesticide application within greenhouses (specifically labour costs and the human health risks respectively) is far outweighed by the economic and social benefits of an autonomous robot such as that discussed by this paper. The benefits include the decreased labour costs, reduced pesticide wastage costs and the obvious reduction in human health hazards[14][10].

Whilst this particular project has commercial expectations, the initial development model has been designed for use in the National Centre for Greenhouse Horticulture greenhouses in NSW, Australia. The commercial aspirations of this project require the total cost to be kept to a minimum. Such cost effective automation should therefore be relatively attractive to growers. In addition to the cost considerations, all parts and materials have been purchased from Australian distributors, nearly all of them Sydney based. Whilst this has been done to simplify the future manufacturing of the commercial product, the discerning Australian consumer was also considered. Finally, to enable the ease of reproduction, modification and replacement, almost all components are assembled from off the shelf parts.

3 Design

Gan-Mor et al.[10] and Michelini [15] realised the potential of steel pipes as a method of guidance for their autonomous robots. The hot water piping shown in Figure 2, is a standard installation for most modern greenhouses and can reach very hot temperatures (80-90°C). To roll along the pipes, Nylon wheels are chosen over other types as they can withstand heavy loads and high temperatures with no deviation to travel height. Figure 3 shows the CAD model of the wheel arrangement which is one of the main design aspects of this robot. The two sets of wheels; one set 100mm larger than the other (to accommodate for the 50mm pipes) is arranged in such a way that there is a seamless transition in moving onto the rails from the work area at the end of the rail set, then back again at the completion of that row. The induction sensor also visible, is connected directly to the microcontroller; allowing the robot to sense that it is indeed on the rails and on course. The arranged wheel assembly keeps the robot on the tracks allowing the robot to drive along without the need for any expensive and complicated navigation ability.

Figure 2: Hot water piping

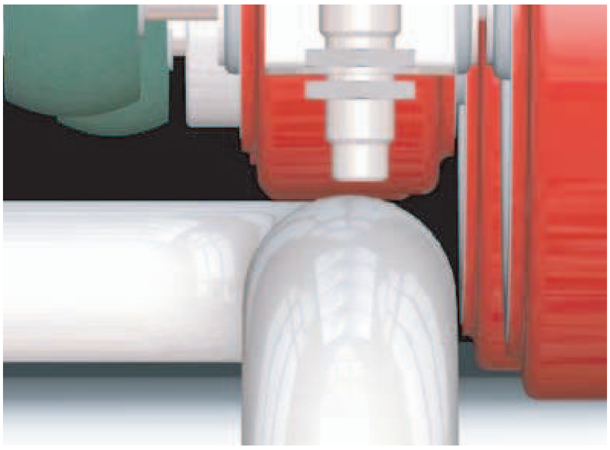

Figure 3: Precise placement and organisation of all components

For ease of design and reproduction, as few parts as possible require special machining or manufacturing in an attempt to minimise the cost of manufacturing this and repeat robots. This choice to use as many off-the-shelf products as possible carried with it significant challenges, but is mostly regarded as an important reality check in the design process enabling the optimisation of a simple and flexible design to be realised.

The robot is designed for simplicity and value for money, while still being able to effectively spray plants in the greenhouse. The robot is capable of driving to the end and back along the hot water piping rails of a row in greenhouse, requiring then to be manually moved to the next row to continue spraying. This is then repeated for each row in the greenhouse. This limitation allows the first step of the robot prototype to be realised as a functional robot.

Figure 4 shows the CAD prototype design, which is used to allow the precise placement and organisation of all components. From the micro-controller placement to aligning individual nut and bolts, each component is modelled into place to ensure the most space efficient design, minimising the physical dimensions of the robot, while keeping all simplicity and functionality.

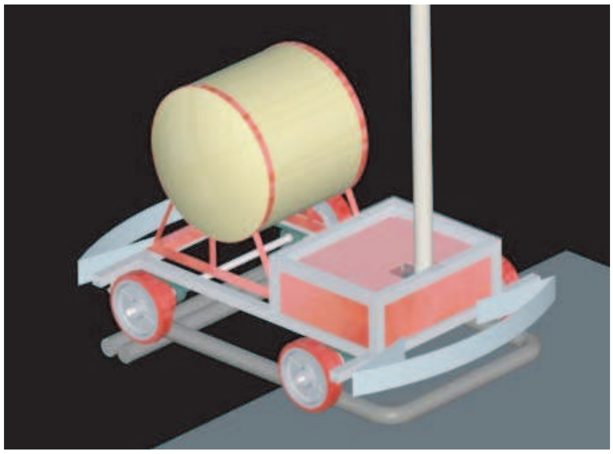

Figure 4: CAD model of the wheel alignment

4 Safety Considerations

As this system is possibly working without supervision, safety aspects must be considered to ensure the safety of the robot, the people that may be within the greenhouse and the greenhouse itself. Easily accessible Emergency Stop buttons, anti-bump start button, separate enable switches for pump and motor, Key activated power switch, fast blow fuses and bump sensors are the main safety components built into the design of this robot. If an emergency stop button is triggered by either button or microcontroller, the robot will stop and user intervention is required to restart to robot. Onboard Ethernet connectivity allows for the future realisation of remote wireless control of the robot. This allows for remote monitoring and control of robot functions.

The bump sensors are located at the front and back of the robot to stop the robot from bumping into any objects that may be in the path of travel. If triggered, the microcontroller will promptly stop the robot within its buffer zone and stop any spraying functions. Unlike the Emergency stop buttons, the robot will continue its path of travel when the obstruction that triggered the sensor is cleared and it is safe to move off.

5 Control System

Figure 5 shows the control environment currently implemented. The user interfaces have control over the running of the microprocessor and are fed back information about the status of the robot. The microprocessor reads the information and controls the movements of the robot and actions of the spraying system.

The spray system consists of a large tank for holding the pesticides, a pump and four valves to direct the allocated spray to the sections of plant either side of the robot as it moves past the desired spray area. The valves are electronically controlled by the on-board microprocessor which receives input signals from infer-red sensors on the underside of the robot. As the robot passes over reflective markers placed on the ground, the pump is turned on and off to enable selective spraying of the greenhouse plants. An additional valve is used to recycle the fluid from the valve manifold back into the tank, enabling continual mixing of pesticides within the tank.

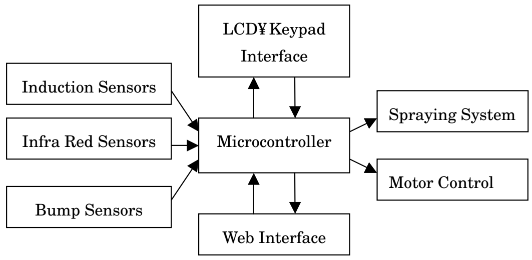

Figure 5: Control environment of the developed system

The drive system consists of a worm drive motor capable of a maximum speed of 0.26 m/s whilst driving on the heating rails. The motor is driven by a high powered PWM (Pulse Width Modulation) controller board, taking in an analogue signal from the microcontroller. The Motor controller has its own soft start and stop facilities allowing smooth stopping and starting with no processing time required for the microprocessor. The 0-5v analogue signal input also allows the microprocessor to control the speed, acceleration and declaration.

The induction proximity sensors accurately detect the presence of the metal rails beneath the robot. This allows for safe, hassle free operation of the robot within the greenhouse requiring no changes to the existing greenhouse configuration. The SICK infra-red sensors accurately sense the placement of the reflective sensors as they pass beneath the robot. The reflective sensors are a simple and efficient method of marking a selected area. The sensors can be replaced with a more advanced method if detecting a selected area as the technology advances, allowing the potential for the robot to almost fully automated.

The LCD/Keypad module shows the user relevant information on the robots status and allows the user to control the robot directly with ease. The web hosting capabilities of the microprocessor allow the potential for the robot to be monitored and controlled from a remote location. Keeping the user at a safe distance for the pesticide spray whilst enabling full view and control of what is going on.

6 Control Algorithm

The on-board microprocessor controls all of the inputs and outputs of the system. The software running on the processor is Dynamic C, a variant of the common C language. Extra librarys and functions have been added to the original C language that are specific to the rabbit microprocessor. Of particular notice is the multi-tasking functions. Both The Preemptive multitasking and Cooperative multitasking is available. Pre-emptive, being the ability to time-slice the program code so that many processors can be sharing the processor time to make it seem like the processes are running at the same time. in the Co-operative multitasking inviroment, each process volentariliry passes control to the other processes. usually done while waiting for someting to happen. for example, a button press, or a delay to finish. The processor uses this usually wasted 'waiting time' to execute other processes.

Figure 6 shows the current basic program structure. The Platform Control program is used to control the mobility of the base platform. It carefully monitors the speed of the robot and monitors sensor inputs. The Sprayer Control module enables intelligent spraying of plants within the greenhouse on either side of the robot. Future developments may enable the robot to decide which areas to spray, at this stage the growers must make the decision on which plants require spraying. The following modes of spray can be used to operate the robot: Sensor spray Individual plants can be marked for spraying. Section spray Sections or groups of plants can be targeted for pesticide application. Continuous spray All plants in the greenhouse will be sprayed with the appropriate amounts of pesticides.

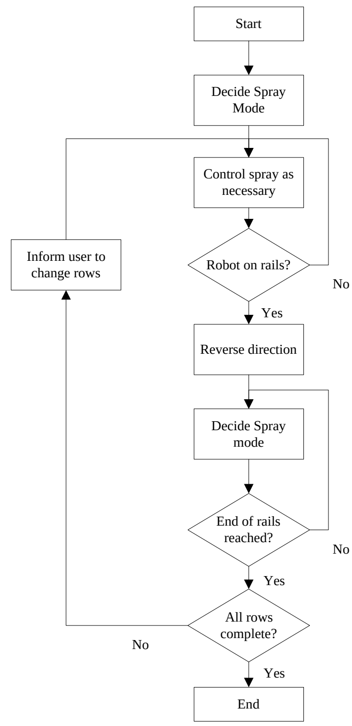

Figure 6: Control program structure

7 Testing

The robot was tested in the research greenhouse at The National Centre of Greenhouse Horticulture at Gosford, NSW where cucumber plants are grown. Figure 7 shows the on-site experiment with the developed robot where the robot is spraying on damaged plants. The tasks necessarily conducted prior to the robot spraying is the placement of reflective markers on the ground by the greenhouse scientist only. The testing consisted of single runs down to the end of a row of the greenhouse and back to the work area while spraying the plants with water. Along the run, sections of cucumber plants were marked out to be sprayed on both sides of the robot. While in operation, emergency stop buttons and bump sensors were tested for their effectiveness in a real situation.

7.1 Test 1

The platform was able to successfully and smoothly drive up and back along a row in the greenhouse and return to the work area at the end of the row. The induction sensors worked sufficiently to turn the robot around and stop the robot when it returned to the start.

The Spraying system had a small lag to fill the

Figure 7: Control program structure

pipes with water before the nozzles began to work properly. The spray was enough to penetrate the foliage and spray into the adjacent row. The identification of the reflectors was excellent until leaking water began dripping from one of the Infra-Red sensors. The water dripping from the sensor lens interfered with IR beam and the sensor begun to malfunction. After the leak was repaired the sensor began to function properly again. Observations were made on the amount of over-spray while the robot was in action. the robot was stopped and the leaves were inspected. Most of the leaves were correctly sprayed with water. However, the underside of some leaves were not sufficiently sprayed. This problem was fixed when the robot sprayed the adjacent isle. The spray then covered the patches that were missed by the initial spray.

Table 1: Results of Tests 1 and 2

	Test 1	Test 2
Run Success	90%	95%
Topside leaf coverage	95%	90%
Underside leaf coverage	95%	80%
Amount of over-spray	20%	10%

7.2 Test 2

Test 2 went much the same as Test 2, however this time the foliage was more dense. In one section the robot stopped when it became stuck on some stray foliage. The spray from the nozzles was still enough to penetrate the foliage and cause some over-spray into the next row. The healthier and larger leaves caused some parts of the foliage to become shielded from the full force of the spray, thus, not as much coverage as in Test 1. The leaking water problem was solved by moving the sprayer boom to the other end of the robot. Once again, observations were made on the coverage of spray and amount of over-spray

7.3 Results

Table 1 shows the data collected by three separate observers. Test 1 was in a greenhouse of old and sick cucumbers. The foliage was not very dense and did not protrude past the heating rails. Test 2 was in another cucumber greenhouse at the Gosford research station, However this time it was a healthy crop with a dense canopy with some leaves protruding past the heating pipes.

8 Conclusions

The results showed the robot was able to successfully fulfil the physical specifications outlined by The National Centre for Greenhouse Horticulture so as to be able to function within their greenhouses. The robot also met the economic and time constraints that it was subject to. The robot was able to drive up and back along the tracks in the greenhouse. The Induction Proximity Sensors detected the rails effectively and operated satisfactorily. The spraying device designed by another thesis student was able to selectively spray designated groups of plants in the greenhouse whilst moving along the rails. The coverage of the spray coated the plants in adequate and consistent dosage.

Even though the results do not show a 0% overspray and a 100% coverage, the results are very encouraging. When manually spraying these problems also arise. The coverage of spray way comparable to that of an experienced manual applicator and the robot was able to spray the plants an a consistent and timely manner.

At the far end of the greenhouse the induction sensors successfully detected the end of the rail, enabling the platform to change direction, moving back along the rails and returning to the start. The wheel assembly was successful in delivering a smooth transition from the rails to the concrete slab where the induction sensors identified the start of the rail and brought the platform to a stop. The bump sensors were tested for situations where people and obstacles such as branches were in the path of motion. The bumpers were successfully activated and the robot was able to be stopped within a safe distance so that no damage or injury was or could be caused.

The design and successful construction of the robot using off the shelf Australian components to undertake the task of autonomously spraying pesticides within a greenhouse shows that it is possible and can be done via a simple and cost effective manner. Being a prototype, the robot has some components (namely motor and microcontroller) that are over designed for the simple task of spraying, resulting in the robot having surplus capacity. The use of this more sophisticated micro-controller enables greater cost efficiency when reproducing a commercial product, as a dedicated microcontroller with less capability and a correctly designed motor for the final weight and performance requirements would be correspondingly cheaper.

Conversely, as a result of this over design there is a lot of further work that can be done to improve this robot without increasing the price by the additional cost of a more sophisticated micro-controller. The over-design can be justified because it can cope with multi-tasking additional attachments. A number of additional features are considered under future work. In the meantime it would be prudent to seek advice from NSW Agriculture and the horticulture sector generally to find out more about likely demands and specific requirements for a range of crops.

9 Discussion

Within commercial greenhouses there is a perceived need for automation that ranges from planting and growing disease free plants to pruning and picking the final product. Surprisingly, relatively little time and large-scale research has been employed into greenhouse robotic systems to replace human effort in this fairly hostile environment. The opportunities for increasing food production from outdoor into indoor horticultural crops are especially attractive at the high cost end of the market. In addition to boosting growth rates, glasshouses and greenhouses can be built near prime markets and do not require large tracts of fertile land to be productive.

Experience with this project places us in a good position to better understand what might be achievable in the near future in terms of viable modifications to the design. Further automation of the drive system will enable to robot autonomously navigate the entire greenhouse. Improvements to the spraying system will allow the precise application of pesticide spray at varying dosages. Improvements to the spraying hardware will enable improved coverage with reduced over-spray. Further work on the software will allow remote monitoring and operation.

10 Acknowledgment

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