A Precision Pesticide Sprayer for the Thorvald Robot Platform

Josh Davy, University of Lincoln
25375628@students.lincoln.ac.uk

***Abstract*—The desire to reduce pesticide usage for managing crops has lead to the development of robotic prescion crop spraying systems. These allow a large reduction in pesticide usage by allowing targeted spraying of weeds. In this work, a 2 DOF robot arm is developed in simulation for precise weed spraying. This arm is designed for the Thorvald robotic platform. The performance of the sprayer is then evaluated on a simulated farm enviroment.**

***Index Terms*—robotic weeding, agriculture 4.0, weeding, crop management.**

I. Introduction

PESTICIDES are a vital part of modern food production, giving higher crop yields by reducing losses due to disease and pests. However, pesticides can be harmful to the environment in large quantities by contaminating soils and waterways and harming animals [1]. Further, pesticides come at an expense, therefore reducing pesticide use offers both a environmental and economical appeal. Robotic precision sprayers allow the reduction of pesticide usage by only spraying pesticides where and when they are required, this reduces usage compared to the traditional method of spraying entire fields at a time. These systems can be fully autonomous and operate without human intervention further reducing costs and the required labour to manage crops. These systems require the integration of vision based weed detection algorithms with precise control of the robot in a challenging environment.

The Thorvald platform, developed by SAGA robotics [2], is an agricultural robotic platform developed for a variety of tasks. The platform has been designed in such a way to allow expansion and modularity. In this work, the objective is to implement a realistic robot sprayer for Thorvald in simulation, develop control algorithms that allow high level control of the arm, and evaluate the system on a simulated farm environment in Gazebo.

The existing robot sprayer for the Thorvald simulation is non actuated and relies on spraying a wide area to cover the crop row. A precision crop sprayer would add more realism to the simulated enviroment. This will allow the development of planning and vision systems which are more realistic and therefore more deployable in the real world.

Precision robotic spraying systems fall into one of two categories. Those with multiple fixed nozzles and those with singular actuated nozzles. Having multiple fixed nozzles offers the advantage of simplicity of mechanical design and control. This allows simple planning as the nozzle solenoids open when a weed is underneath them. This means that the sprayer can be moved over the crops and operate independently of the movement of the robot. These systems are suitable for large flat crop fields and are often incorporated into tractor booms. The alternative is a actuated nozzle. An actuated nozzle can move precisely over the weed and further reduce the pesticide required. This better suits smaller robots such as IBEX [3] where the planning of arm control and the robot can be incorporated. These smaller robots are more appropriate for sparse environments and those with more challenging terrain as the arm can be actuated and controlled around possible obstacles and other plants. Actuated arms can also better suit non chemical weeding techniques such as electrical [4] or laser based systems [5] due to the need to move in close proximity of the weeds.. Mechanical solutions for actuated robot sprayers vary. Ecorobotix [6] use a a dual delta configuration on their autonomous robot weeder. This allows the arm to move fast over the crop rows, allowing the base to keep a constant velocity of 0.4 m/s across the field. The delta configuration allows movement in three degrees of freedom allowing the nozzle to move backwards to compensate for the robot's forward velocity and hold constant over the weed. A robot platform developed by the China Agricultural University used a 4 DOF ZUTO460 series manipulator with a mounted sprayer [7]. This platform was designed to work inside greenhouses and in their work they consider the motion planning of the arm as the robot moves across the crop rows at constant velocity. This arm allow the movement of the sprayer in a tight space and also reach down to crop level. The system is designed to suit crops stored on multiple shelves. This use of a small 4 DOF arm suits this situation as the arm can reach multiple heights.

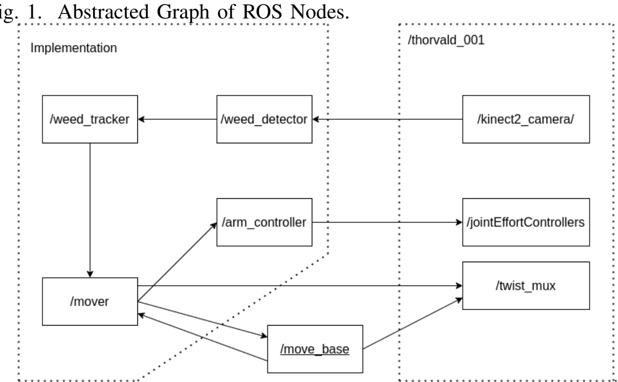
II. Approach

For the Thorvald robot, a 2 joint arm mounted to the rear of the robot was designed. This had several advantages. One is that the arm can move precisely over each weed allowing accurate spraying by getting down to ground level, secondly this design would be feasible in real life and could make use of commercially available actuators. Further, because of this simple design, the robot kinematics can be solved analytically, negating the need for any numerical kinematic solvers. This will simplify the control code and the computational power to calculate joint angles. For evaluating the performance of the system, a simple colour filter vision based node is also developed along with a movement controller that synchronises control between the arm and robot platform.

A. Implementation in ROS

ROS (Robot Operating System) [8] is used for the software implementation. The *mover* node operates as the master controller for the system and coordinates the robot and arm movement based on detected weeds. *weed_detector* locates weeds seen by the Kinect2 camera. *weed_tracker* tracks the movement of these weeds as the robot moves in the environment from the robot odometry. The kinematics and control parameters are calculated by *arm_controller.*

Fig. 1. Abstracted Graph of ROS Nodes.



B. Arm Implementation and control node.

The initial arm design was made in Solidworks CAD software. This was chosen due to the SolidWorks to URDF Exporter plugin [9]. This allows the automatic generation of the relevant URDF structure of the arm, adding the relevant joints and mass/inertia calculations. The arm is made of four fixed link sections *base_link, link_1, link_2 and nozzle.* The *base_link* is meant to represent the base actuator of the robot and house any electronics that would be necessary. The arm is designed so that self collision of the arm is not possible. The arm lengths and range of motion are also constrained to limit the arm reach to within the frame of Thorvald whilst also allowing the arm to reach crop level ($l_1 = l_2 = 0.320m$). Link mass were decided on to reflect real robot actuators such as 0.6kg MIT actuator [10] as well as accounting for the mass of the links themselves. A max joint torque of $15nm$ was used also reflecting that of the MIT actuator.

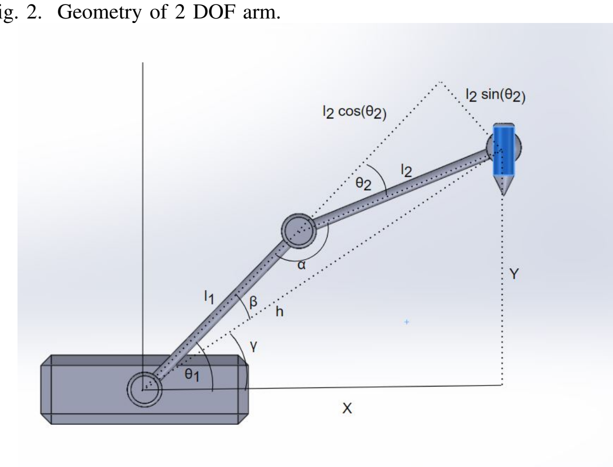
An effort controller, commands the joint forces for the arm in order to reach a desired angle. PID values were tuned by hand to find suitable values allowing the arm to move quickly and without vibration. Arm properties are summarised below:

Arm Link	**Mass** (kg)
base_link	1.35
link_1	0.65
link_2	0.65
nozzle	0.30

PID Values for Joints	**P**	**I**	**D**
joint_1	80	0.2	6
joint_2	40	0.2	6
joint 3	10	0.1	1

To command the end effector position, an inverse kinematic solution is needed. This can be used to calculate the relevant joint angles for a desired end effector position in the workspace. Due to the simple arm design, this solution can be solved analytically using the arm geometry and trigonometric identities.

Fig. 2. Geometry of 2 DOF arm.



Using the cosine rule and the geometry we can find the relationship between θ_2 and the end effector position. From Figure X we can see

$$h^2 = x^2 + y^2,$$

$$h^2 = l_1^2 + l_2^2 - 2l_1 l_2 cos(c),$$

$$\theta_2 = \pi - c,$$

therefore,

$$\theta_2 = -acos(\frac{x^2 + y^2 - l_1^2 - l_2^2}{2l_1 l_2}).$$

To calculate θ_1

$$\gamma = atan(\frac{y}{x}),$$

$$\beta = atan(\frac{l2sin(\theta_2)}{l_1 + l_2cos(\theta_2)}),$$

therefore,

$$\theta_1 = atan(\frac{y}{x}) + atan(\frac{l2sin(\theta_2)}{l_1 + l_2cos(\theta_2)}).$$

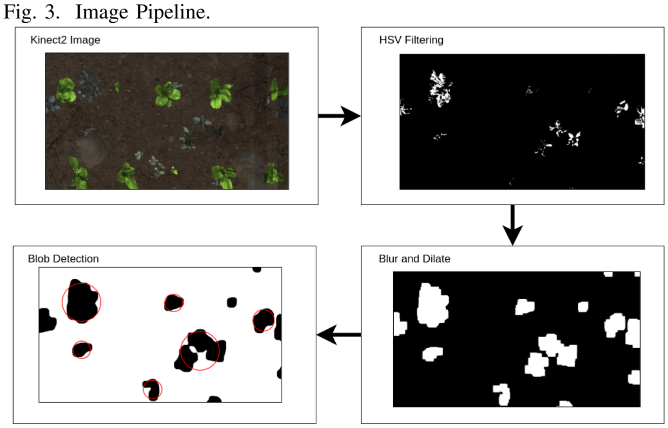
Therefore to reach a desired position, the required joint angles can be therefore calculated. Then, the required forces are calculated by the PID controllers. A third joint is present which controls the angle of the nozzle. This, however is not considered in the kinematics and is set to always point vertically down as such

$$\theta_3 = -\theta_1 - \theta_2.$$

C. Weed Detection and Tracking

The weed tracked is based on simple colour filters. This would not be viable for realistic crop rows, but for the purpose of evaluating the arm it is viable. The main computer vision pipeline is implemented with OpenCV [11]. The image is first put through a HSV filter this can separate the pixels containing weeds from the crops and ground. The image is then blurred with a 31x31 median blur filter. This helps remove any artifacts. Dilation is then used to enlarge areas containing relevant pixels. A blob detector algorithm then locate the centre points of the weeds in the image. Weed locations are then tracked relative to the robots odometry, this allows the location of weeds to be tracked as the robot moves, so the arm can make appropriate motion plans when a weed is within its range.

Fig. 3. Image Pipeline.



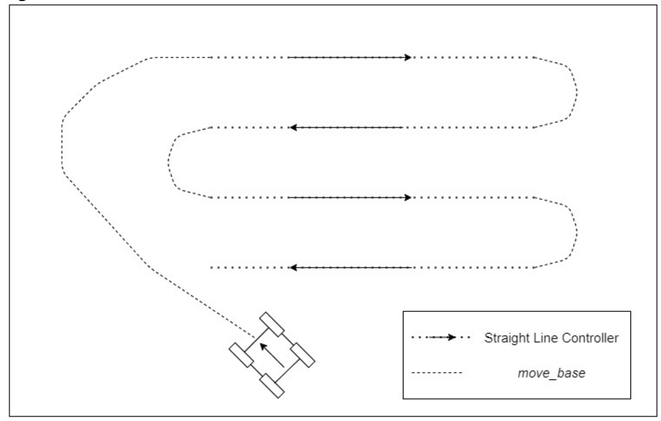
D. Base Controller

Control must be synchronised between the robot base and the arm. The inbuilt ROS navigation stack is used with the *move_base* node to navigate the farm and move to the start of crop rows. *move_base* is reliant on the existing map of the enviroment and the odometry of the robot and allows basic obstacle avoidance. In this work, the odometry is obtained directly from the simulated environment so there is no error is present and therefore no localisation is used. Crop row starts and ends are also given by a configuration file. At the start of the crop rows a straight line movement controller takes over. This moves the robot directly towards the goal. When a tracked weed is within the arms reach, the robot stops moving and the arm moves over the crop. Once the arm has reached the desired position, the spray service is called creating a red box directly below the nozzle, representing the pesticide. The straight line controller is based on a proportional controller. This controller aims to reduce the angle between the the current angle and the angle between the current position and the goal (the end of the crop row). When navigating between crop rows the arm moves to a neutral position to avoid collisions.

III. Evaluation

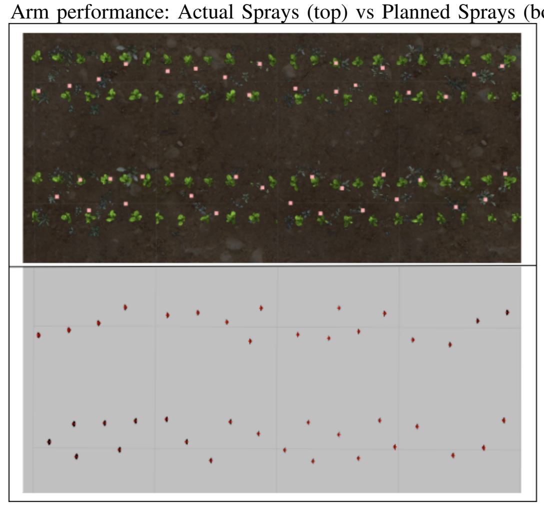
Overall the arm performs well on the simulated farm enviroment. The controller manages to coordinate the movement of

Fig. 4. Overview of Movement Control.



arm and base allowing the robot to successfully spray weeds in its path. The arm range is limited to operate within the internal frame of the Thorvald robot. This means the robot sometimes cannot fully reach weeds that lie out of this range. Apart from these out of range weeds, the robot successfully manages to spray all weeds it tracks as seen in Fig 5.

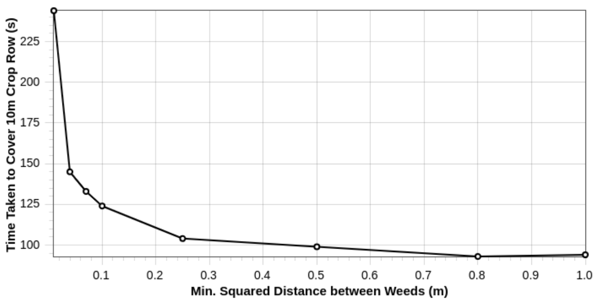
Fig. 5. Arm performance: Actual Sprays (top) vs Planned Sprays (bottom).



The current robot motion planning involves stopping, then moving the arm, spraying the weed then continuing moving. This limits the speed the robot can work at especially when working with a high weed density. Fig 6 shows the relationship between the weed density and the time taken to complete one 10m row of the simulated enviroment. This shows that the singular actuated nozzle may not be the ideal solution for higher weed density environments.

The arm design developed in this work proposes a realistic solution for an actuated sprayer. The arm is a mechanically viable solution and is shown to be feasible based on the modelling of realistic actuators. The controller and vision detection system provided a valuable way to evaluate the arm's performance on a simulated farm enviroment. The system has been designed to easily expanded and integrated with more realistic vision systems and complex controllers.

Fig. 6. Time Taken to Complete a Row of the Simulated Farm against Weed Density.



IV. Future Work

The control of the actuated sprayer could be improved with motion planning and collision detection. This would allow the robot to get closer to the crops and navigate around crop plants or more complex terrain. At the moment no motion planning is used so the arm occasionally can get stuck as it attempts to move between one position and another. Due to the use of inbuilt ROS motor controllers the integration of the arm into the ROS MoveIt library[12] would allow this existing infrastructure to be used. MoveIt could also control the movement of the robot base in its enviroment, this could allow the tighter integration of robot and arm control. This control could be expanded further to have continuous movement of the platform. By tracking the upcoming weeds and their density the velocity of Thorvald could be adjusted to allow the arm to plan its motion and be ready to spray the weeds as they come past. With higher weed density the robot could slow down or stop to make sure all weeds are sprayed.

With more complex arm planning, the arm could be used to move round obstacles. This could be integrated with 3D plant structures where the arm could attempt to move underneath crops in order to reach occluded weeds. In the current simulation the terrain is completely flat, with more complex terrain and integration with depth readings from the camera, the arm could get as close to the ground as possible spraying the weeds more precisely.

For real world deployment, the integration with localisation systems would of course be necessary due to the inaccuracies of real world odometry. This would mean for systems such as the weed tracker, uncertainty in weed locations would need to be accounted for. The straight line controller, although suitable for this work, would be unrealistic in a real farm. Crop rows are rarely straight and a more advanced controller would be needed. Crop row detection could be used to predict and follow these paths. This again would make the arm path planning more complex as the controller would have to account for these changes in direction.

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