# FNGLA Endowed Research Fund

Florida Agricultural Experiment Station

Project Enhancement Award Proposal

## Development of a Prototype Greenhouse Robotic Sprayer System:

Intersection Detection and Navigation for an Autonomous Greenhouse Sprayer using Machine Vision

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**Abstract.** *Development of a robotic greenhouse sprayer can provide more accurate spraying of pesticides and fungicides, reduce operational costs, and decrease health risks associated with human exposure to dangerous chemicals. A visual navigation system capable of tracking a path, detecting intersections, and navigating through intersections was developed for a six-wheel differential steering vehicle.*

*Path navigation was accomplished using digital images taken from a single CCD camera mounted on a robotic greenhouse sprayer. Intersection detection was accomplished by first classifying pixels of an image as path or non-path. Left and right path edges were determined from the threshold image using least squares fitting. Path pixels extending beyond a specified distance from the left and right edges indicated an approaching intersection. The distance from the vehicle to the intersection was estimated based on the set position and orientation of the camera using projective geometry. Path following was carried out by reducing path error between the vehicle center and path center using a PID controller. Intersection navigation was accomplished by 1) tracking ground features to guide the vehicle to a desired position in the intersection, 2) proceeding with a turn, and 3) concluding when the vehicle was aligned with the next path. Testing verified the vehicle's ability to follow a path, detect intersections, and navigate intersections. Results suggest that improvements in the vehicle design would improve the overall system performance.*

## Introduction

Application of nutrients, fungicides and pesticides are critical to successful greenhouse production, where spraying plays a very important role in reducing production losses. Research suggests that between 30 and 35% of production losses can be saved when harmful insects and diseases are eliminated by spraying. However, chemical runoff associated with over-application can have serious environmental consequences. Due to the toxicity of some application materials, this process can be extremely hazardous to operators. Conventional greenhouse spraying methods require an operator to manually apply chemicals with a personal sprayer. Application errors occur due to operator mistakes caused by bulky equipment and limited mobility, while working in protective equipment.

The primary motivations behind developing an autonomous sprayer for greenhouse applications are to improve the chemical efficacy, reducing chemical and labor cost, minimizing labor hazards, and reducing harmful environmental damage. The use of autonomous spraying equipment should provide uniform travel velocities and spray delivery, which should improve the efficacy of the chemicals. In addition, by removing the human operators, spray delivery systems, such as Ultra-1ow volume applications may prove beneficial for reducing chemical runoff and harmful environmental effects. This study focuses on the development of a sprayer vehicle

In 2004 an 81 x 40.64-cm autonomous greenhouse sprayer was designed and fabricated through the Agricultural and Biological Engineering Department at the University of Florida under sponsorship of the National Foliage Foundation. The vehicle was designed to navigate through 46, 51, and 61-cm aisles. Two 560-watt DC motors with 20:1 gear reducers powered two separate three-wheel drive trains. Turning was accomplished with differential steering. Vehicle control down the center of test paths was carried out independently using ultrasonic range sensors, ladar, and machine vision with a fuzzy PD controller. Although original designs were capable of steering down a straight or curved path, they were not capable of navigating through intersections. The scope of the work conducted under this research funding focused on developing a machine vision based system for navigating through greenhouse alleyways.

## Objectives

Design objectives for vehicle guidance and intersection navigation for an autonomous greenhouse sprayer were established:

- Path Following: The vehicle must be capable of driving through the center of 18 to 24-inch aisles and along single edges for the larger center aisles.
- Intersection Detection: The vehicle must be able to detect intersections between aisles with the consideration that the benches on these aisles can be as low as 2-feet tall and as high as 3-feet tall.
- Intersection Navigation: The vehicle must be able to both complete turns and drive through detected intersections.

## System Components

A Sony FCB-EX7805 CCD camera was mounted onto the robotic sprayer developed by Singh (2004), as shown in Figure 1. A single camera was chosen as opposed to a multiple camera setup or stereovision to reduce costs that come with additional equipment and reduce complexity associated with calibrating multiple cameras. An Integral Technologies Flashbus MV

Pro frame grabber was used to capture 640x480 pixel color images from the camera. Figure 2 shows the general control architecture used to guide the robotic greenhouse sprayer. A camera provided information about the scene. The PC with a 2.4 GHz processor acquired images from the camera, processed the image, and output two separate control signals ranging from 0 to 2.5 Volts to drive the left and right motor. Amplifiers scaled the control signals to 24 Volts. Finally, DC motor controllers drove the motors.

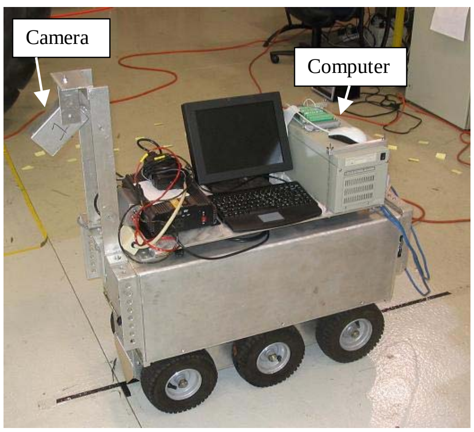


Figure 1. Camera-mounted robotic sprayer.

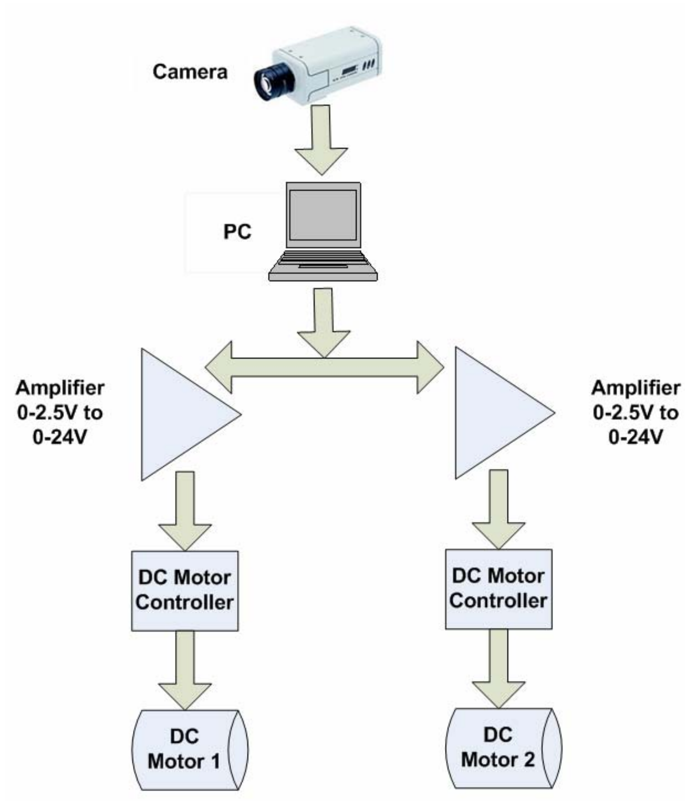


Figure 2. Control architecture.

## Experimental Setup

Experiments were designed to test the vehicle as it carried out a 90º turn, as well as drive straight through an intersection. Tests were repeated on an intersection lined with black tape and poster board, and an intersection lined with plants (see Figure 2). Both the main path and the intersecting path were 61 cm wide. Markers were attached to the front and back of the vehicle to record the path, and measurements were taken every 2.5 cm relative to the starting position of the vehicle.  Three runs were carried out for each experiment.

Figure 2. Tape path and plant path used for intersection navigation experiments.

The vehicle was instructed to follow the center of each path and drive at a speed of 20 cm/s. When turning at the intersection, the vehicle was instructed to turn at 10 deg/s.

## Results

An example of the plotted course of the vehicle making a turn and going straight through the plant intersection is shown in Figure 3. Table 1 shows the average results from the three runs. Path error was reported for the vehicle going into and out of the turn. Path error was slightly higher for the vehicle after the turn due to the offset of the vehicle from the intersecting path after turning.  A smaller number of data points acquired from the path after the turn compared to the number of points from the path before the turn also contributed to higher error after turning.

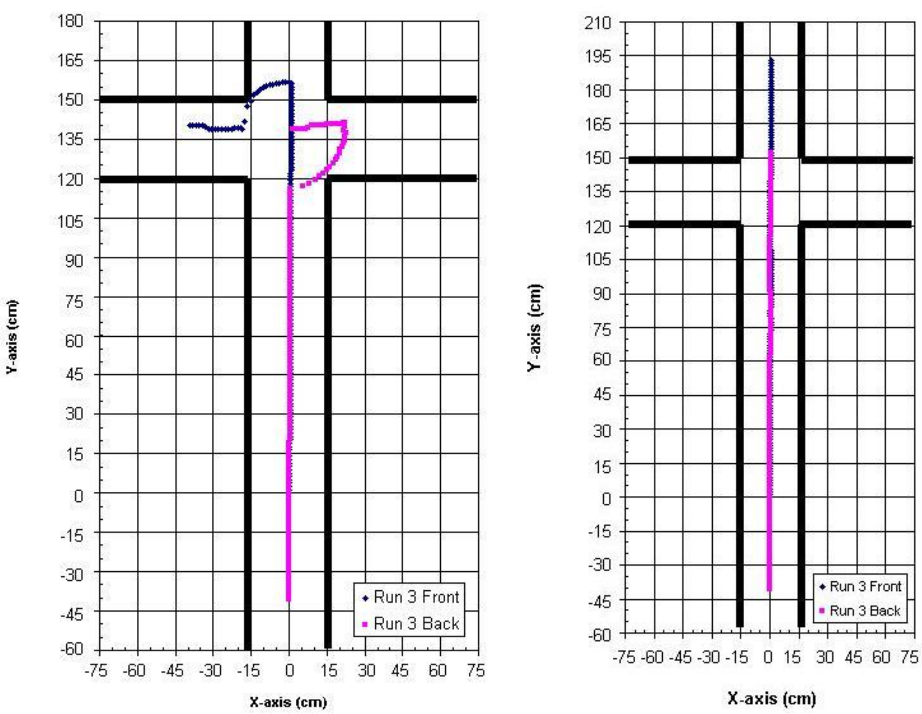


Figure 3. Plots of the vehicle making a turn and driving straight through a plant-lined intersection. The two paths represent points measured from the front and back markers.

Table 1. Performance measures for the front of vehicle during intersection navigation tests

| Navigation Task | Average Error (cm) | RMS Error (cm) | Max Error (cm) | Standard Deviation (cm) |
|---|---|---|---|---|
| Path Following Before 90º Turn (Tape Path) | 1.14 | 1.70 | 4.88 | 1.24 |
| Path Following Before 90º Turn (Plant Path) | 1.17 | 1.57 | 3.38 | 1.04 |
| Path Following After 90º Turn (Tape Path) | 3.20 | 3.76 | 8.26 | 1.83 |
| Path Following After 90º Turn (Plant Path) | 7.82 | 8.13 | 11.0 | 1.96 |
| Straight through Intersection (Tape Path) | 0.330 | 0.483 | 1.07 | 0.381 |
| Straight through Intersection (Plant Path) | 1.02 | 1.32 | 2.74 | 0.838 |

## Conclusion

Navigation algorithms were successfully developed for an autonomous greenhouse sprayer, enabling the vehicle to detect and navigate through both tape and plant-lined intersections. The navigation objectives stated earlier for successful vehicle guidance in a greenhouse environment were met:

- Path Following: The vehicle demonstrated the ability to follow the center of a 61 cm wide path. Smaller paths can also be followed with the same routine since both edges are still visible.
- Intersection Detection: Both the beginning and end of intersections were detected for flat intersections lined with tape and intersections lined with potted plants two feet tall. The intersection detection algorithm calculates the beginning and end of the intersections independent of the height of objects at the corners of the intersection.
- Intersection Navigation: The vehicle demonstrated the ability to turn at intersections, as well as drive through them.

## Recommendations

The results of these tests were very encouraging. However, several important outcomes of this research demonstrate the need to further improve the sensing, mobility and turning capabilities of the robotic vehicle. These conclusions were partially a result of a commercial feasibility discussion between UF researchers, industry representatives and a representative of DRAMM manufacturing, where it was suggested that the vehicle had a fundamental deficiency due to the differential steering jerkiness. There also seems to be some advantages to going to a multiple camera system. It is therefore recommended that a new drive-train and steering system be developed for the robot, and additional cameras be added to improve the vehicle field of view.