**Vegetation Classification within a Lettuce Crop**

**Innovation Venture Investment Program**

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**Abstract**

Due to the lack of effective selective post-emergence herbicides, lettuce crops are hand weeded following cultivation to remove weeds close to the crop plants. Finding labor to perform the task has become increasingly difficult and costs are escalating. Automated/robotic weeding machines are commercially available; however, their adoption has been limited because the machines 1) provide only partial weed control and follow up hand weeding is necessary, 2) have slow travel speed which results in low work rates and high operating costs and 3) lack precision and cannot remove doubles in lettuce crops. To overcome these limitations, we propose to develop an innovative high-speed, high-precision automated weeding machine. The machine will utilize an artificial intelligence (AI) based imaging system to identify weeds and a precision sprayer to spot spray targeted weeds at the 1-cm level of resolution. The 1-cm resolution spot sprayer has already been developed and successfully tested in a laboratory setting. The primary focus of the proposed project is to develop the AI-based imaging system. An additional goal is to integrate the imaging system with the precision spot sprayer and evaluate the system in the field. With promising preliminary data, we plan to seek funding to fully develop and prototype a high-precision automated weeding machine. An additional outcome is that this research will expand the knowledge base of precision spot sprayer-based technologies for automated/robotic weeding. This effort will also educate and train the next generation of scientists and engineers interested in developing and working with advanced technologies for agriculture.

**Background**

Despite use of herbicides and mechanical cultivation, most vegetable crops require hand weeding to control in-row weeds. Labor costs are increasing, and the industry is facing labor shortages. An alternative is to use automated/robotic machines for in-row weeding. Automated weeding machines have been commercially available in Arizona and California since 2008, however adoption has been limited. One reason is that weed control is only partial and follow up hand weeding is necessary. Almost all commercialized automated weeders utilize metal blades that move in and out of the crop row to cultivate weeds between individual crop plants as the machine moves through the field. As such, soil disturbance is high which limits travel speed to ~ 1.5 mph and as a result, low work rates and high operating costs. Further, weeds close to crop plants cannot be effectively removed without injuring crop plants. Our research studies have shown that mechanical automated weeders remove about 2/3rds of in-row weeds (Lati, et al., 2016). Most of the uncontrolled weeds (~ 1/3rd) are within about 1” of the crop plant. Similarly, due to their lack of precision, current automated weeding machines cannot eliminate lettuce plants closely spaced after thinning (“doubles”) and removal by hand labor is required. High precision weeding machines that use laser beams to control weeds have recently been commercialized. These machines however are extremely expensive, costing over $1.4 million. Other drawbacks are that travel speed is typically very slow (~ 0.25 mph), and the device is only effective on very small, cotyledon sized weeds. For automated weeding machines to significantly reduce labor requirements and become more economically viable in lettuce crops, better precision is needed so that a higher percentage of weeds and doubles are removed, and higher travel speeds are required to improve work rate and lower fixed costs per acre.

**Significance**

Over the last decade, there has been tremendous investment and research towards the development of automated weeding machines. Despite these efforts, none have been widely adopted. New approaches and technologies are needed to address these shortcomings. The goal of this effort is to develop and test an automated weeding machine that identifies and spot sprays weeds at the 1-cm resolution level at speeds of 2 mph or higher. If successful, our proposed system will be a technological breakthrough and eliminate or significantly reduce hand weeding labor requirements in vegetable production.

**Approach**

In this project, we are proposing a set of software and hardware solutions that will culminate in the development of a high-speed, high precision automated weeding machine. The machine will utilize an artificial intelligence (AI) based imaging system to identify weeds and a precision sprayer to spot spray targeted weeds at the 1-cm resolution level. The 1-cm resolution spot sprayer has already been developed and successfully tested (Raja et al., 2022, Siemens et al., 2021). The spray assembly is comprised of 12 custom-built spray assemblies spaced 1 cm apart. Trial results showed that accuracy of spray delivered to 1 cm x 1 cm weed targets was ± 2 mm and that the percentage of off-target spray was less than 3%. Weed control efficacy exceeded 96% with no observable crop injury.

The primary focus of this effort will be to develop the AI-based imaging software for detecting and targeting weeds. This imaging system will then be integrated with the precision spot sprayer and tested in the field. To develop the AI weed detection algorithm, images of lettuce crop plants and weeds will be captured in-situ with a specialized, high-resolution Machine Vision digital RGB camera mounted on a frame attached to a ground following linkage assembly. As the assembly is pulled through the field, a high-performance microcontroller will coordinate the camera operation with the tractor movement by orchestrating the image acquisition at regular time/distance intervals. Images at ‘mm’ level resolution and accuracy will be georeferenced and will drive the spray nozzle array. The AI algorithm will operate in real-time to: 1) identify crop plants, 2) establish a user-defined crop safety zone/buffer distance (~ 1 cm) around each crop plant, 3) identify the weeds using a training approach that relies on features like weed location relative to the crop row, shape, size, color, plant height, and 4) create a weed targeting map at 1-cm scale resolution. We note here that team member Evan McGinnis, Ph.D. candidate, has already prototyped the preliminary AI algorithm using a limited set of images captured from a cell phone. The results of separating green plant material from background non-plant material (soil) and identifying weeds for targeting weeds have been very promising, approaching 99% detection with no false commission or weed omission. An example of the image processing routine is provided in Fig. 1.

Once the AI system has been vetted, we will integrate it with controller hardware and the existing 1-cm scale resolution spot sprayer. The integrated system will be tested in field trials at the Yuma Ag Center. System improvements will be made as necessary. Performance assessments will include the percentage of weeds and crop plants correctly identified, the percentage of weeds sprayed, weed mortality, and crop injury. It should be noted that the main goal of the field testing will be to debug the system and get it to work correctly with a focus on perfecting the weed identification and treatment maps.

**Expected Results and Next Steps**

By year one, we expect to have developed, debugged, and vetted the AI system. Our goal is to achieve identifying and targeting weeds in real time at the 1-cm scale level of resolution at travel speeds of 2 mph. Criteria for success will be > 95% accuracy and < 1% false positives (crop classified as weed). We also expect to have a functioning, but very early prototype automated weeding machine that can spot spray weeds at the 1-cm resolution level. Promising proof of concept data collected from this project will be used to seek funding from other granting agencies to build and test a fully functional, two-row prototype machine.

Results of this project will be disseminated to vegetable producers and industry through field day demonstrations and extension meetings. Examples include the 2023 and 2024 Southwest Ag Summit, 2023 and 2024 Pre-Season Vegetable Workshop. Informational videos will also be made and posted on extension websites as well as on other media outlets such as YouTube. We will also seek to identify and work with companies interested in further developing and commercializing the technology.

**References**

Lati, R.N, Siemens, M.C., Rachuy, J.S. & Fennimore, S.A. (2016). Intrarow Weed Removal in Broccoli and Transplanted Lettuce with an Intelligent Cultivator. Weed Technology, 30(3), 655-663.

Raja, R., Slaughter, D.C., Fennimore, S.A. & Siemens, M.C. 2022. Real-time control of high-resolution micro-jet sprayer integrated with machine vision for precision weed control. Biosystems Eng. (submitted)

Siemens, M.C., Godinez, Jr., V. & Gayler, R.R. 2021. Centimeter Scale Resolution Spot Sprayer for Precision In-Row Weed Control. In Proc. *73rd Annual California Weed Science Society* 73:44. Salinas, Calif.: California Weed Science Society.

Graphical user interface, website

Description automatically generated

**Fig. 1. Lettuce plant and weed identification and weed targeting with an artificial intelligence computer algorithm. Raw image (a) is processed to remove all non-plant pixels (green) and lettuce plants and weeds are identified (b). Based on spray nozzle and weed location, a weed targeting map is produced (c).**

**Budget and Budget Justification**

| **Budget Summary** | |
| --- | --- |
| **Expense Category** | **Funds Requested** |
| **Personnel** | $2,500 |
| **Supplies** | $6,450 |
| **Travel** | $1,050 |
| **Direct Costs Subtotal** | $10,000 |

Personnel

Funds are requested to help support Evan McGinnis, a Ph.D. graduate student, who will conduct this research as part of his dissertation thesis. Mr. McGinnis will lead and conduct all aspects of the research. The work will be conducted under the guidance and direction of advisors Dr. Kamel Didan and Dr. Mark Siemens.

Supplies

Funding is requested to offset the cost of developing and testing the prototype automated precision weeding machine. Various electronic components including high-performance onboard microcontrollers, specialized GPU, cameras, gimbal, optical encoders, cables, and other miscellaneous parts are needed ($3,700). Funding is requested to raise crops needed to develop and evaluate the automated precision in-row weeding machine (0.5 acres @ $3,500/acre = $1,750). Various supplies are needed to operate and maintain the tractor, machine shop and precision sprayer assembly used for this project ($1,000)

Travel

Funds are requested to offset costs for the Ph.D. student to travel from Tucson, AZ to Yuma, AZ to conduct the planned research. We are requesting funding for two trips ($1,050). Costs per trip include mileage ($225) and per diem ($300). Estimated number of miles is 500 and per diem includes meals (3 days) and lodging (2 nights) for one person.