Weed Identification and Zapping via Autonomous Robot Device (WIZARD)

Will Fenno
Conner Mullen

Final Report

REVISION – 3.0
28 April 2025

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Weed Identification and Zapping via Autonomous Robot Device (WIZARD)

Will Fenno
Conner Mullen

CONCEPT OF OPERATIONS

REVISION – 3.0
28 April 2025

Concept of Operations

for

WIZARD

Team <72>

Approved by:

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Project Leader Date

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Prof. Kalafatis Date

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T/A Date

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0.0	09/15/2024	William Fenno Conner Mullen		Draft Release
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1. Executive Summary

Our project (WIZARD - Weed Identification and Zapping via Autonomous Robot Device) aims to address the challenge of weed control in organic farming through preventative measures that stray from the traditional non-organic methods using chemical herbicides or inefficient weed controlling techniques. This method involves the usage of an autonomous robot equipped with a real-time image detection and classification camera, as well as a precision targeted high voltage impulse zapper. Through this system, our robot will have the capabilities to eliminate weeds with minimal time investment, and in an organic manner. The objective of this project is to drive the integration of modern-day technology into organic farming practices that maintain high crop yields with minimal environmental footprint. However, due to the high energy required to effectively eliminate a weed, we propose that our contribution to this project will act as a proof of concept at a lower, safer voltage level.

2. Introduction

The project aims to develop an innovative solution for weed control in organic farming, where traditional chemical herbicides are not an option due to environmental and health concerns. As a result of rising demand for organic products, the amount of cropland dedicated to organic farming in the United States has increased by over 2 million acres since 2000. Because of this rapid growth, farmers face increasing challenges in managing weeds without resorting to chemicals. This project seeks to address these challenges by creating an autonomous robot that combines advanced camera recognition and high-voltage technology to identify and eliminate weeds efficiently and ecologically.

2.1. Background

Information gathered from sources listed in section 2.3		
Description	Parameters	Results
Rootwave eWeeder	High Frequency AC	Commercially Viable
Continuous Contact	100VDC for 300, 420, 540s	52%, 56%, 61% mortality
Constant Current	2mA for 12, 24, 36+ hrs	37%, 75%, 100% biomass reduction
Spark Discharge	40kV at 700μA delivering 0.16Wh (576J)	Results vary by species, but highest success by contacting leaf with electrode

Table 1: Summary of existing electrical weed control methods

In traditional, non-organic farms, the most widely used method of weed control is herbicides, typically through spraying. While this method is effective in killing weeds, the herbicides used are absorbed by the crops as well as the weeds, which renders this method of weed control “non-organic.” Since this is the easiest and most common weed control method, organic farmers face a massive challenge in replacing herbicides with something as effective and cheap.

One potential weed control method in organic farming today is electric weeding. In most electric weeding systems, a tractor is equipped with a high voltage source that electrifies a stationary copper boom positioned right above the crop canopy level to kill any tall weeds in the farm that grow above the crop. As the tractor moves along the field, weeds that are taller than crops come into contact with the copper boom and get fried. This method is proved to be more effective than mechanical weeding, but has its limitations when the weeds are small or low-growing.

Our proposed WIZARD project provides the most efficient and precise weed control method that can shape the agricultural industry. With a real-time image classification camera and a moveable high voltage impulse electrode with precise targeting, our robotic device can effectively kill weeds at any growth stage and size. This autonomous platform can provide a more sustainable alternative to current electric weeding methods, preserving crop health and bringing versatility in the weed control field.

2.2. Overview

The WIZARD system is a weed control system mounted on a robot that will move through rows of crops to deliver a high-precision electrical impulse to weeds. This robot will be tethered to a tractor in order to draw power from its 12 volt battery. Initially, the system will be capable of automatically identifying and targeting weeds using computer vision to distinguish between a single species of crop and a single type of weed. Of course, this system will be adaptable to more species of weed down the road as there are various sub-species of weed that all grow in the same area. A microcontroller will use information from a mounted camera to locate weeds within the target area and move electrodes into position to deliver a high voltage impulse to the targeted plant. The high voltage impulse will be generated using DC-DC conversion to step up the 12 volt input from the tractor battery to a voltage capable of eliminating the target weed.. We have determined that it takes roughly 576J to eliminate a fully developed weed, so a fully capable WIZARD module should be able to deliver a variable amount of energy up to 576J, depending on the size of the targeted weed.

2.3. Referenced Documents and Standards

- IEEE Recommended Practices for Safety in High-Voltage and High-Power Testing: IEEE 510-1983
- Rootwave: https://rootwave.com/portfolio-item/fruit/
- Exploring the potential of electric weed control: a review by Slaven, Koch, and Borger. Weed Science, Volume 71, Issue 5, September 2023, pp. 403 - 421
- Power on! Low-energy electrophysical treatment is an effective new weed control approach. Pest Management Science, Volume 77, Issue 9, September 2021, pp. 4138 - 4147

3. Operating Concept

3.1. Scope

This project is intended to distinguish between one species of crop and different species of weed using computer vision. With this information, the system will use electric current to kill a single weed at a time with minimal impact on the surrounding environment and crops.

3.2. Operational Description and Constraints

The computer vision and high voltage components of the WIZARD system will be mounted on a robot provided by an external source organized by the German team. This robot will be able to move between rows of crops, but it must be tethered to a tractor to meet the power demands of running the system for extended periods of time. The electronics will be enclosed in a waterproof container, but due to the requirement of exposed electrodes, the system should not be used in wet conditions to avoid the risk of damaging the equipment and delivering current to an unwanted plant. Due to the high voltage used for this project, the control will be autonomous for the safety of the operator, but an operator must be present to drive the tractor and monitor the WIZARD robot.

3.3. System Description

The WIZARD project is divided into two components:

- Weed Identification: Using machine learning and AI toolkits, the camera that will be installed on our robot will be able to distinguish between a weed and a crop in real time. In order to do this, an image dataset of both weeds and crops will be built to understand the distinct pattern differences between the two. After training our model on a dataset consisting of crop and weed images, the camera will be able to recognize and classify new images in various growth stages and lighting conditions.

- Weed Elimination: The robot will target the center of the weed and apply a high voltage impulse, effectively destroying the cell walls and safely killing the weed. Through our research, we found that it will take roughly 0.16 Watt-hours (576 Joules) of energy to effectively kill a plant, which would either require tens of kilovolts or several minutes of contact with the plant to accomplish. A mechanism to vary the energy delivered based on the size of the target weed will be implemented. Electrode placement and voltage regulation will be studied to ensure that arcing from weed to a crop will not occur in order to maintain the safety of the crops in the farm.

3.4. Modes of Operations

The WIZARD system will have two modes of operation: automatic and manual. Due to the large amount of power being discharged by the system and the necessity of precise delivery to a specific target, the onboard microcontroller will determine the location of the weed and move the electrodes to the correct position before either automatically delivering the high voltage impulse or delivering the impulse after confirmation from the operator. The operation of the robot is yet to be determined, as we will be mounting our components to a robot with an unknown control system.

3.5. Users

This system is intended to be used by farmers, so there will not be any technical knowledge or experience required to operate the system. All that will be required is the ability to drive the tractor and potentially operate the robot. Knowledge of electrical safety is a necessity due to the high voltage on the electrodes. This system aims to support organic farmers, who will likely meet the above requirements, and the installation will be as simple as plugging in the system to the tractor's 12 volt output, turning on the microcontroller, and setting the operation mode.

3.6. Support

Installation and setup procedure will be provided to the user, which will list all external requirements for running the system (i.e. 12 volt adapter). Additionally, operating instructions will provide detailed steps to operating the WIZARD system in both automatic and manual modes. For technical support, high-level schematics and a bill of materials will be provided in the case that a component breaks or an electrical connection becomes severed.

4. Scenario(s)

4.1. Large Scale Organic Farm

The focal point of the WIZARD project is for large scale organic farms that are looking for a more ecological manner of eliminating weeds in their crop fields. Tethering this high precision robot to a tractor as it drives across vast land allows for a reduction in labor costs and adhering to organic standards. WIZARD is using modern technology and machine learning to improve large scale farming practices with efficiency.

4.2. Small Family Owned Farm

With the right specifications, small private farmers will also be able to utilize WIZARD to their needs. As the robot exclusively focuses on the protection of growing crops, farmers are able to manage their time and maintain the quality of their harvest while sustaining their cultivation with minimal labor. This will still require a 12 volt battery to run, whether it comes from a tractor or a modification to the WIZARD system made by the operator.

5. Analysis

5.1. Summary of Proposed Improvements

Describe/list the improvements that the proposed system will provide.

- WIZARD eliminates weeds in an organic manner.
- The system can run for as long as the connected tractor can run.
- The AI powered image detection uses machine learning algorithms, which is continuously improving the distinction of crops and weeds as it processes more data.
- The maneuverability of the electrodes allows for more targeted killing of weeds compared to other large-scale electrical weed control. This includes being able to target weeds that do not grow above the crop canopy and being able to actively avoid killing crops.

5.2. Disadvantages and Limitations

Describe/list any disadvantages and limitations that the proposed system will have.

- Initially, the WIZARD system is limited to the distinction of one type of crop and one type of weed until further deep learning model training is implemented.
- Only one weed can be precisely targeted and eliminated at a time, reducing the speed of the system.
- The robot must be tethered to a tractor to draw power from its 12 volt battery. This allows the robot to run as long as the tractor's engine is recharging its battery, but it reduces the range of the robot to a rough circle around the tractor.
- WIZARD can only be reliably used in fair weather conditions, as precipitation can damage the exposed electrodes and impact the path that the current moves through.
- To work properly on fully developed weeds, WIZARD will require 576J of energy to eliminate a single weed, so due to safety and cost considerations, a scaled down proof of concept will be created for this project.

5.3. Alternatives

Some alternatives to the WIZARD project are:

- Mechanical weeding: Although prevalent, this practice involves the use of hand tools and large machinery which can become very labor intensive, needing to physically remove the weeds. Some limitations from this method include crop damage risk if not done correctly, and soil erosion from excessive mechanical weeding.

- Flame Weeding: This technique uses a propane torch to apply thermal shock through high temperatures to burn the weeds and their cell walls. Flame weeding is effective for controlling isolated weeds, but is not feasible when in a crop field due to the risk of the crops getting burnt.

- Crop Rotation & Cover Cropping: These preventive measures involve rotating crops and planting cover crops to disrupt the weeds life cycle and decrease their pervasiveness. While this practice is beneficial, both plant timing and management is complex and costly.

5.4. Impact

This project has significance across multiple fields, including the following:

- Reduction in Chemical Herbicide: Using high-voltage impulse as the main method in killing weeds in organic farming negates the need for herbicides to be sprayed on the crops. This project supports more sustainable farming practices, at the same time diminishing soil contamination and chemical runoff.

- Labor Efficiency: With this project having an automatic mode of operation, it eliminates the need for manual weeding in the crop fields. Production and labor costs will decrease while improving the organic farm’s overall productivity.

- Technological Innovation in Agriculture: Integrating machine learning and AI into automated weed control drives farming techniques forward as technology advances and new methods grow in agriculture.

- Safety: A significant part of the design and functionality of the weed zapping robot is the account of crop safety. Ensuring that the high voltage impulse does not arc to an organic crop nearby is crucial. Also, the automatic operation keeps the operator out of the way of the high power components.

Weed Identification and Zapping via Autonomous Robot Device (WIZARD)

Will Fenno
Conner Mullen

FUNCTIONAL SYSTEM REQUIREMENTS

REVISION – 3.0
28 April 2025

Functional System Requirements

for

WIZARD

Team <72>

Approved by:

Project Leader Date

Prof. Kalafatis Date

T/A Date

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0.0	09/15/2024	William Fenno Conner Mullen		Draft Release
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1. Introduction

1.1. Purpose and Scope

Organic farming practices today face struggles with effective weed control without the use of chemical herbicides. WIZARD aims to address these challenges by creating an automated solution that combines advanced camera recognition and high-voltage technology on a robotic device to identify and eliminate weeds efficiently and ecologically. Our system will limit the need for laborious weed control, and drive organic farming practices forward with the integration of AI.

This specification defines the technical requirements for the development items and support subsystems delivered to the client for the project. Figure 1 shows a representative integration of the project in the proposed ConOps. The verification requirements for the project are contained in a separate Verification and Validation Plan.

1.2. Responsibility and Change Authority

Changes to performance requirements can be made by WIZARD's sponsor Professor Markus Zink, or by the joint approval of all team members. The team leader, Will Fenno, will be responsible for verifying all project requirements are met. These requirements can only be changed with the approval of the team leader, Professor Markus Zink, and Professor Stavros Kalafatis. Subsystem owners are responsible for ensuring the requirements for their subsystems are met. Each subsystem responsibility is assigned and labeled as follows:

Will Fenno: Computer Vision (Machine Learning)
Conner Mullen: High Voltage Impulse Zapper

2. Applicable and Reference Documents

2.1. Applicable Documents

The following documents, of the exact issue and revision shown, form a part of this specification to the extent specified herein:

Document Number	Revision/Release Date	Document Title
ISO 25119	Revision 2018	Agricultural and forestry machinery – Safety of electrical and electronic control systems
IEC 60204-1	Revision 2016	Safety of Machinery – Electrical Equipment of Machines
IEC 61010-1	Revision 2017	Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use
ISO 15003	Revision 2017	Agricultural Engineering – Tractors and Machinery for Agriculture – Electromagnetic Compatibility
MIL-HDBK-338	Revision B – 10/1/1998	Electronic Reliability Design
MIL-STD-882	Revision E – 5/11/2012	Standard Practice for System Safety
MIL-STD-464	Revision D – 12/24/2020	Electromagnetic Environmental Effects Requirements for Systems
ISO/IEC 25012	Revision 2008	Data Quality Model
ISO/IEC 23894	Revision 2023	AI Systems – Robustness and Risk Management

Table 1: Applicable Documents

2.2. Reference Documents

The following documents are reference documents utilized in the development of this specification. These documents do not form a part of this specification and are not controlled by their reference herein.

Document Number	Revision/Release Date	Document Title
Python 3.9 Documentation	2020	Official Python 3.9 Language Reference
TensorFlow v2.10.1	2022	API Documentation
IEEE 829-2008	2008	IEEE Standard for Software and System Test Documentation

Table 2: Reference Documents

2.3. Order of Precedence

In the event of a conflict between the text of this specification and an applicable document cited herein, the text of this specification takes precedence without any exceptions.

All specifications, standards, exhibits, drawings or other documents that are invoked as “applicable” in this specification are incorporated as cited. All documents that are referred to within an applicable report are considered to be for guidance and information only, except ICDs that have their relevant documents considered to be incorporated as cited.

3. Requirements

3.1. System Definition

The WIZARD project is divided into two main subsystems: the computer vision (Machine Learning), and the high voltage impulse zapper. The computer vision subsystem is responsible for building a machine learning model that will be trained on an extensive dataset consisting of soybean crop and redroot pigweed images. This AI model will have two functions: classifying an image in real time, and communicating the center coordinates of a weed to the impulse zapper. The high voltage subsystem is responsible for delivering a series of high voltage impulses across two electrodes that will be in contact with the target plant. These impulses will come from repeatedly charging and discharging a capacitor at the direction of the computer vision subsystem.

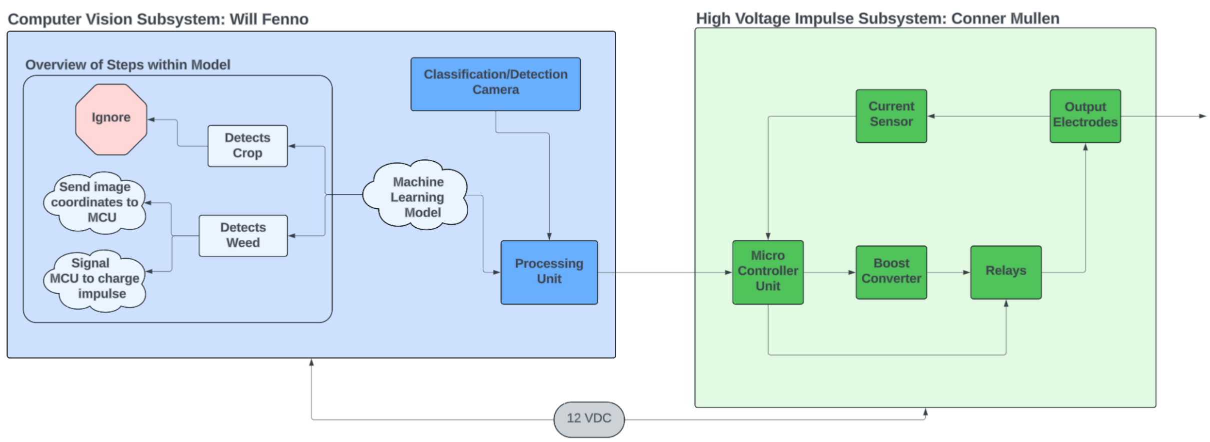

Figure 1: Block Diagram of Interconnected Subsystems

As stated previously, our system is divided into two distinct sections. The processor for WIZARD contains a machine learning model that has been trained on an extensive dataset with image classification and object detection capabilities. When the camera detects a weed, it signals the microcontroller, which then activates the impulse charging circuit through a boost converter and relays. Simultaneously, the processor calculates the coordinates of the weed bounding box center and communicates with the electrode to position accordingly. Depending on the size of the detected weed, the required level of charge is built and the impulse is discharged through the electrode and zaps the weed. Currently, the entire system is assumed to be energized by a +12VDC rated power supply from a tractor battery, but may be subject to change according to the information available from our sponsor.

3.2. Characteristics

3.2.1. Functional / Performance Requirements

3.2.1.1. Capacitor Charge and Discharge Time

Each impulse of energy shall be generated and discharged into the stem of the weed in a short amount of time, to be determined by research performed by the German students.

> *Rationale: The system targets a single weed at a time and may require multiple impulses for each weed, so each impulse must be short to improve the speed of operation.*

3.2.1.2. Electrode Discharge Mode

The voltage impulse shall only be discharged when the electrodes are in contact with the targeted weed.

> *Rationale: Only allowing the energy to be discharged when the electrodes are in contact with the plant to avoid unexpected arcing and to ensure the energy is only delivered to the desired target.*

3.2.1.3. False Positive Rate (FPR)

The machine learning model's image classification shall have a false positive rate of less than 5% to prevent unintended crop damage.

> *Rationale: A high false positive rate tolerance results in the machine incorrectly classifying crops as weeds. Maintaining a FP rate under 5% minimizes unintended zapping of crops.*

3.2.1.4. False Negative Rate (FNR)

The machine learning model's image classification shall have a false negative rate of less than 5% to prevent missed weeds.

> *Rationale: A high false negative rate tolerance results in the machine incorrectly classifying weeds as crops. Maintaining a FN rate under 5% minimizes unintended neglect of weeds.*

3.2.1.5. Camera Field of View (FOV)

The system's camera will detect objects within the range of 62.2 degrees horizontally and 48.8 degrees vertically.

> *Rationale: The system's camera offers a balance between wide coverage area and detection accuracy at acceptable ranges.*

3.2.2. Physical Characteristics

3.2.2.1. Electrode Placement

The output electrodes shall be placed no more than 6 inches (15 cm) from each other.

> *Rationale: The longer the current must travel through the plant, the higher the resistance it sees, and reducing the resistance of the plant will improve the discharge speed.*

3.2.2.2. Mounting

The camera and electrode mounting information for the WIZARD system shall be captured in the WIZARD project ICD.

> *Rationale: As the camera and the electrodes both mount to the autonomous robotic device, mounting requirements have detailed ranges and placements.*

3.2.3. Software Characteristics

3.2.3.1. TensorFlow Use

The processing unit for this system shall use TensorFlow 2.10.1 for image recognition and machine learning modeling.

> *Rationale: TensorFlow is an open source software that is well supported, highly documented, and integrates seamlessly with various versions of Python3.*

3.2.3.2. Python Version and Environment

The machine learning model and training shall be written using Python version 3.9 within a virtual environment containing the corresponding packages and installations.

> *Rationale: Python 3.9 is a reliable version and is compatible with various resources and libraries including support for TensorFlow 2.10.1.*

3.2.4. Electrical Characteristics

3.2.4.1. Power Source

The WIZARD system shall operate from a power supply of +12VDC coming from a tractor battery. For components that require a different voltage, the conversion shall be handled within the system.

> *Rationale: This system will be used on farmland, and a tractor with a 12V battery is a standard piece of equipment on farms.*

3.2.4.2. Inputs

The operator shall have a way to turn on and off the system as well as switch between automatic and manual operating modes. For manual operating, there shall be an input that allows the operator to trigger the discharge.

Rationale: The system should be capable of being powered off (EMO) for the safety of the operator and for maintenance purposes, and the manual operating mode is only possible with an input from the operator.

3.2.4.3. Outputs

The electrodes will discharge high voltage impulse(s) into the targeted plant after confirming contact with the plant. LEDs will be used to indicate whether contact has been detected and whether there is high voltage present.

Rationale: The discharge into the plant is the main directive of the project, and the LEDs will give the operator an idea of what is currently happening in the circuit.

3.2.4.4. Interface Between Processor and Electronics

Information on the interface between components of WIZARD are outlined in the ICD.

3.2.5. Environmental Requirements

3.2.5.1. Temperature

The system shall be able to function properly in an environment with a temperature range of 10°C (50°F) to 45°C (113°F).

Rationale: This system will be used in an agricultural environment, so WIZARD shall operate properly in any temperature that soybean crops can grow.

3.2.5.2. External Contamination

The WIZARD electrodes shall function properly despite exposure to common farmland contaminants such as pollen, dirt, and organic matter. The remaining electrical components will be shielded from contamination by a casing.

Rationale: This system will be used on farmland, so it needs to be able to function properly in such an environment.

3.2.5.3. Rain

The system will not be designed to work properly in rainy weather conditions.

Rationale: WIZARD utilizes electrodes that will be exposed to rain, and those electrodes will not contact the plant or detect contact properly in the rain.

3.2.5.4. Humidity

The automated system shall be designed to withstand and operate in a relative humidity range of 5% to 95%.

3.2.6. Failure Propagation

3.2.6.1. Built-In Test (BIT)

The WIZARD system shall execute an internal command to signal a built-in camera test before operations, indicating a failure in the camera start with a red LED activation.

> *Rationale: This requirement ensures that the camera is functioning properly before running, allowing for quick identification of issues and preventing system errors.*

3.2.6.2. Isolation and Recovery

The WIZARD system shall provide fault isolation and recovery by enabling subsystem resets based upon the result of the BIT.

> *Rationale: This requirement allows the system to identify faulty subsystems and restore normal operation through resets, minimizing downtime in the possibility of a failure.*

4. Support Requirements

This part of the WIZARD subsystem will provide one NVIDIA Jetson processor with the computer vision model on it, one enclosed circuit board that generates and delivers the high voltage impulse, and the electrodes that will contact the weed. The user must provide a 12VDC power source, ideally from a tractor to ensure a long running time. The electrodes will require periodic cleaning to ensure that proper contact with the weed is made, and the frequency of these cleanings will vary based on the time of year and frequency of use.

Appendix A: Acronyms and Abbreviations

AI	Artificial Intelligence
BIT	Built-in Test
EMO	Emergency Machine Off
FNR	False Negative Rate
FOV	Field of View
FPR	False Positive Rate
ICD	Interface Control Document
IEEE	Institute of Electrical and Electronics Engineers
LED	Light Emitting Diode
MCU	Microcontroller Unit
V	Volts
VDC	Volts Direct Current
WIZARD	Weed Identification and Zapping via Autonomous Robot Device

Appendix B: Definition of Terms

Appendix C: Interface Control Documents

Interface Control Document is attached as a separate document.

Weed Identification and Zapping via Autonomous Robot Device (WIZARD)

Will Fenno
Conner Mullen

INTERFACE CONTROL DOCUMENT

REVISION – 3.0
28 April 2025

Interface Control Document

FOR

WIZARD

Team <72>

Approved by:

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Project Leader Date

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Prof. Kalafatis Date

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T/A Date

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1. Overview

This Interface Control Document will list and explain all interfaces to and from the WIZARD system. Any inputs and outputs to the system will be recorded in this document along with their purpose and how WIZARD will interact with them. Additionally, this document will outline the interfaces between subsystems, especially the communication between the processor and electronics.

2. References and Definitions

2.1. References

Refer to section 2.2 of the Functional System Requirements Document

2.2. Definitions

A	Amperes
GPIO	General Purpose Input/Output
I^2C	Inter-Integrated Circuit
LED	Light Emitting Diode
MCU	Microcontroller Unit
POC	Proof of Concept
PWM	Pulse Width Modulation
V	Volts
VDC	Volts Direct Current
WIZARD	Weed Identification and Zapping via Autonomous Robot Device

3. Physical Interface

3.1. Weight

Component	Weight	Quantity	Total Weight
NVIDIA Jetson Nano	8.8 ounces	1	8.8 ounces
Raspberry Pi Camera Module V2	1.41 ounces	1	1.41 ounces
High Voltage Subsystem PCB	TBD	1	TBD
Electrodes	TBD	1	TBD
Electronics Housing	TBD	1	TBD

Table 1: Weight of All WIZARD Components

3.2. Dimensions

Dimensions are in inches.

3.2.1. Dimensions of Computer Vision Subsystem

Component	Dimensions
NVIDIA Jetson Nano	3.9 x 3.1 x 1.1
Raspberry Pi Camera Module V2	0.98 x 0.94 x 0.35

Table 2: Dimensions of Computer Vision Subsystem Components

3.2.2. Dimensions of High Voltage Subsystem

Component	Dimensions
High Voltage Subsystem PCB	TBD
Electrodes	TBD
Electronics Housing	TBD

Table 3: Dimensions of High Voltage Subsystem Components

3.3. Mounting

The computer vision and high voltage subsystems of the WIZARD system will be mounted to a robot that will be provided by the German team. The electrodes must be mounted on some form of actuator so they can move to the target plant, and the camera must be mounted with a top-down view of the ground. The specific mounting locations are undetermined, as the German team has yet to start their fall semester.

4. Thermal Interface

The NVIDIA Jetson will come with a heatsink placed on top of the processing unit as standard to provide cooling and prevent thermal throttling. The casing for the electronics will allow for constant airflow to keep the operating temperature of the PCB in an acceptable range. This will be accomplished by using a mesh screen to allow airflow while protecting the electronics inside of the casing from external contaminants in the crop fields.

5. Electrical Interface

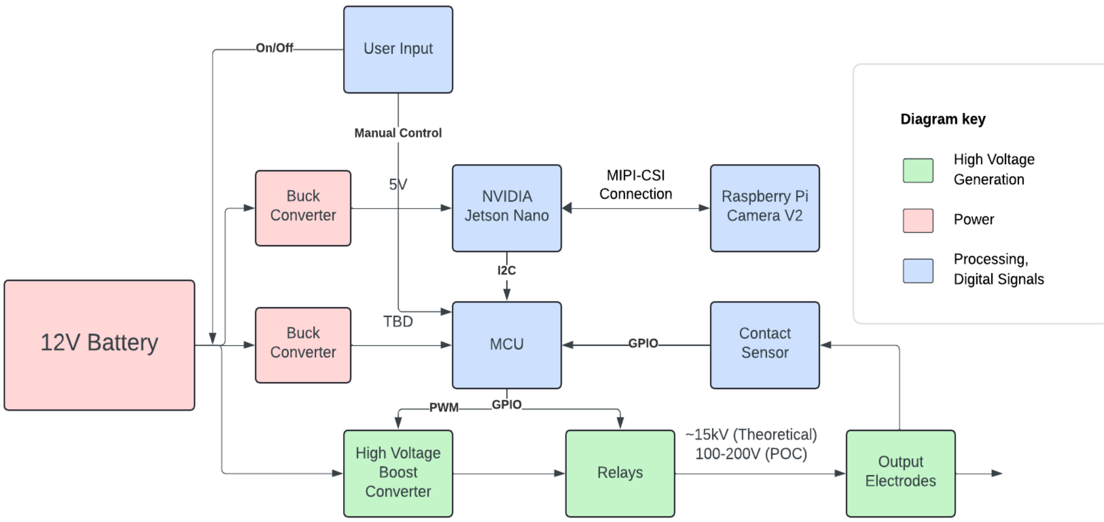

Figure 1: Electrical Interface Diagram

5.1. Primary Input Power

The power for the WIZARD system will come from a 12V battery, ideally from a tractor. This 12V input will be converted to the necessary voltage levels to power the components such as the NVIDIA Jetson Nano and the MCU using onboard buck converters. This power supply will also be directly boosted to the desired impulse voltage.

5.2. Voltage and Current Requirements

Component	Input Voltage Requirement	Input Current Requirement
NVIDIA Jetson Nano	5V	2A Minimum
MCU	TBD	TBD
High Voltage Boost Converter	12V	TBD

Table 4: Voltage and Current Requirements

5.3. Signal Interfaces

5.3.1. Internal Control Signals

GPIO pins on the MCU will control the high voltage processes, including relays, PWM, and contact sensing.

5.3.2. User Input

The user will be able to switch the system on and off using a physical switch. Also, the user will be able to toggle between automatic and manual operation using a physical switch, and in manual operation, there will be a button to discharge the high voltage impulse. The automatic/manual operation signals will be handled by the MCU.

5.4. Outputs

The primary output of the system will be the high voltage impulse, discharged into the targeted weed. For the user, there will be LEDs indicating the status of the systems within the module. These will include a power indicator, a contact indicator, and an operation mode indicator.

6. Communications / Device Interface Protocols

6.1. Embedded Systems Communication

Communication between the NVIDIA Jetson processor and the MCU will occur via I^2C protocol. This will be used to deliver information about the existence of weeds from the computer vision model to the high voltage system.

Weed Identification and Zapping via Autonomous Robot Device (WIZARD)

Will Fenno
Conner Mullen

EXECUTION PLAN

REVISION – 3.0
28 April 2025

1. ECEN 403 Execution Plan:

WIZARD Project Schedule																
	AUG		SEP				OCT					NOV				DEC
Deliverable/Task	8/20	8/27	9/3	9/10	9/17	9/24	10/1	10/8	10/15	10/22	10/29	11/5	11/12	11/19	11/26	12/3
Project Assigned 08/20																
Meet With Sponsor, German Team																
Preliminary Research																
Assign Subsystems																
Power Conversion Research																
Software Installation & Virtual Environment Setup																
Identify Species of Both Crop and Weed																
Create Image Dataset for Crops / Weeds																
ConOps First Draft, Send to Sponsor																
ConOps Revisions																
ConOps Report Due 09/15																
High Voltage Schematics and Simulations																
Label Images and Clean Data																
Set Milestones for Rest of Semester																
FSR, ICD, Validation Plan First Draft, Send to Sponsor																
FSR, ICD, Validation Plan Revision																
Midterm Presentation 09/23																
FSR, ICD, Milestones, Validation Plan Due 09/26																
High Voltage Component Research and Selection																
Build Object Detection Model																
Train & Test Model																
High Voltage PCB Design																
Status Update Presentation 10/14																
High Voltage PCB Layout Review																
Order Parts and PCB																
PCB Assembly and Smoke Test																
PCB Validation																
Improve Model Accuracy & Edit Hyperparameters																
Real Time Detection Testing																
Final Presentation 11/11																
Final Report First Draft, Send to Sponsor																
Final Demo Due 11/26																
Final Report Revisions																
Final Report Due 12/05																
Annotations		Not Started														
		In Progress														
		Completed														
		Behind Schedule														

2. ECEN 404 Execution Plan :

WIZARD Project Schedule																
	JAN			FEB				MAR					APR			
Deliverable/Task	1/12	1/19	1/26	2/2	2/9	2/16	2/23	3/2	3/9	3/16	3/23	3/30	4/6	4/13	4/20	4/27
Complete Code Transfer to Jetson																
Set up Jetson & Install Software/Packages																
Integrate CSI Camera with Jetson																
Status Update Presentation #1 (01/22)																
Test ML Code on Jetson & Fix Potential Issues																
Update Schematics and PCB Layout																
Order PCB and Parts																
Adjust Power Supply Component Values																
Computer Vision Subsystem Ready for Integration																
Status Update Presentation #2 (02/05)																
Assemble Revised PCB, Quick Validation																
Begin Subsystem Integration																
High Voltage Subsystem Complete for Integration																
3D Model/Print Casing for Electronics																
Status Update Presentation #3 (02/19)																
Troubleshoot Any Integration Problems																
Status Update Presentation #4 (03/05)																
Meet with Sponsor and Team in Germany																
Make Small Changes from Sponsor Feedback																
Design Blitz																
Status Update Presentation #5 (03/26)																
Integrated System Validation																
Final Presentation 04/09																
Implement Necessary Project Adjustments																
Generate Detailed Documentation																
Send Final Report Draft to Sponsor, Make Revisions																
Final Demo 04/24																
Final Report 04/28																
Annotations	Not Started															
	In Progress															
	Completed															
	Behind Schedule															

Weed Identification and Zapping via Autonomous Robot Device (WIZARD)

Will Fenno
Conner Mullen

VALIDATION PLAN

REVISION – 3.0
28 April 2025

1. Validation Plan

Paragraph #	Test Name	Success Criteria	Methodology	Status	Owner
3.2.1.1.	Capacitor Charge and Discharge Time	Time between start of charge up and end of discharge is less than 8 seconds	Measure voltage across output electrodes throughout a charge and discharge cycle, calculate time delta	COMPLETED	Conner Mullen
~~3.2.1.2.~~	~~Electrode Discharge Mode~~	~~Electrodes are only connected to high voltage output after contact is detected~~	~~With no contact: confirm that the voltage across electrodes is low~~ ~~With contact: confirm that indicator LED is on, and that the voltage across electrodes is high~~	~~TO BE TESTED~~	~~Conner Mullen~~
3.2.1.3.	False Positive Rate	FPR of less than 5% to prevent unintended crop damage	Conduct image classification test using a validation set with known crop and weed labels. Track the number of images where crops are incorrectly identified and calculate results	COMPLETED	Will Fenno
3.2.1.4.	False Negative Rate	FNR of less than 5% to prevent missed weeds	Conduct image classification test using a validation set with known crop and weed labels. Track the number of images where weeds are incorrectly identified and calculate results	COMPLETED	Will Fenno
3.2.1.5.	Camera Field of View	System detects objects at a range of 62.2 degrees horizontally and 48.8 degrees vertically	Measure the system's response to objects placed inside and outside the specified field of view	COMPLETED	Will Fenno
~~3.2.2.1.~~	~~Electrode Placement~~	~~Arcing does not occur across electrodes~~	~~Charge system to maximum voltage, visually confirm that no arc forms~~	~~COMPLETED~~	~~German Students~~
3.2.2.2.	Mounting	All components are secured properly	Visually inspect all connections to the robot or other platform, then attempt to move mounted components around to test strength of mounts	COMPLETED	Full Team
3.2.4.1.	Power Source	12V DC is converted to 5V, capable of 2A	Before powering on: Perform continuity test for all 12V points Power on board with 12V DC source and test voltage at output of power converters	COMPLETED	Conner Mullen
3.2.4.2.	Inputs	All control signals work as expected, as indicated by LEDs and relay clicking	Power system on, set to each combination and confirm that the proper LED indicators are on and listen for relay clicking	COMPLETED	Conner Mullen
3.2.4.3.	Outputs	LEDs all light up under correct circumstances Energy discharges through electrodes	Verify that proper LEDs light up under proper circumstances Voltage at electrodes reaches 80V	COMPLETED	Conner Mullen
3.2.4.4.	Interface Between Processor and Electronics	I2C signal sent from processor is received by MCU, correct output is observed (specific output and input signals will be updated as we finalize designs)	Send I2C commands from processor to microcontrollers, verifying that every necessary function is initiated properly	COMPLETED	Full Team
3.2.5.1.	Temperature (Thermal Resistance)	System functions in complete range of temperatures (10C to 45C)	Low end of temperature range exists outside in Texas, high end will be created with temperature chamber	COMPLETED	Full Team
3.2.5.2.	External Contamination	Large particles are kept out of the electronics casing	Bombard empty casing with dirt, grass, and other particles; open casing and visually inspect inside	COMPLETED	Full Team
3.2.6.1.	Built-In Test (BIT)	The system will activate a red LED in the case of camera failure during the startup process	Intentionally simulate camera failure via disconnection to verify LED activation response	COMPLETED	Will Fenno
3.2.6.2.	Isolation and Recovery	In the case of a BIT fault, the system will be reset and restore normal operations	Conduct a reset test in response to a camera detection failure	COMPLETED	Will Fenno

Weed Identification and Zapping via Autonomous Robot Device (WIZARD)

Will Fenno
Conner Mullen

SUBSYSTEM REPORTS

REVISION – 3.0
28 April 2025

SUBSYSTEM REPORTS

FOR

WIZARD

TEAM <72>

APPROVED BY:

Project Leader Date

Prof. Kalafatis Date

T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
0.0	09/15/2024	William Fenno Conner Mullen		Draft Release
1.0	09/26/2024	William Fenno Conner Mullen		Revision 1
2.0	12/05/2024	William Fenno Conner Mullen		Revision 2
3.0	04/28/2025	William Fenno Conner Mullen		Revision 3

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1. Introduction

This document is a combined progress report for ECEN 403/404. It includes an in-depth description of the computer vision subsystem completed by Will Fenno and the high voltage subsystem completed by Conner Mullen. This document will show that both subsystems have been validated and are ready for integration.

2. Computer Vision Subsystem Report - Will Fenno

2.1. Subsystem Introduction

The Computer Vision subsystem is responsible for developing a machine learning model capable of real time classification and detection of invasive weeds in soybean crop fields. This model evaluates live video footage from the robot's onboard camera as it navigates through the crop field row spacings. Upon confidently identifying a weed, a predicted bounding box with a confidence score and a center point is created around the weed for visual localization. After two consecutive stable predictions, a signal is sent to the high voltage subsystem to charge an electrical impulse for weed termination.

2.2. Subsystem Details

2.2.1. Data Preprocessing

The original dataset was created by downloading approximately 400 images from the internet, and organizing them into three classes: Crop (soybean), Weed (redroot pigweed), and Background (soil/grass). Using a labelling software called Labelme, each image was annotated with bounding boxes and class labels.

To enhance the dataset, an image augmentation library called Albumentations was used to change the properties of each image such as brightness contrasts, RGB/gamma shifts, and bidirectional flipping. This process increased the dataset to around 8,000 images and respective labels, providing more diversity for robust training.

The augmented data was divided into training, testing, and validation sets, following a 70%-15%-15% split. After loading both the augmented images and labels to the dataset, the two were combined into a single dataset ready for utilization.

2.2.2. Machine Learning Model

The current state of the WIZARD model uses the VGG16 model architecture as a base for fine-tuned feature extraction. Our model has two heads for dual output:

1. Classification Head: Predicts the class of each detected object as either Crop (0), Weed (1) , or Background (2). This head is redesigned into a probability distribution over each class using a softmax activation. A Categorical Cross-Entropy loss function was used to calculate the loss between the predicted and true class labels.

2. Localization Head: Predicts the bounding box coordinates for each detected object. This head uses a sigmoid activation to output the coordinates as normalized values between 0 and 1. A Huber loss function was used to compute the difference between the predicted and true bounding box coordinates.

The full model overview, including the two output heads, is shown in *Figure 1* below:

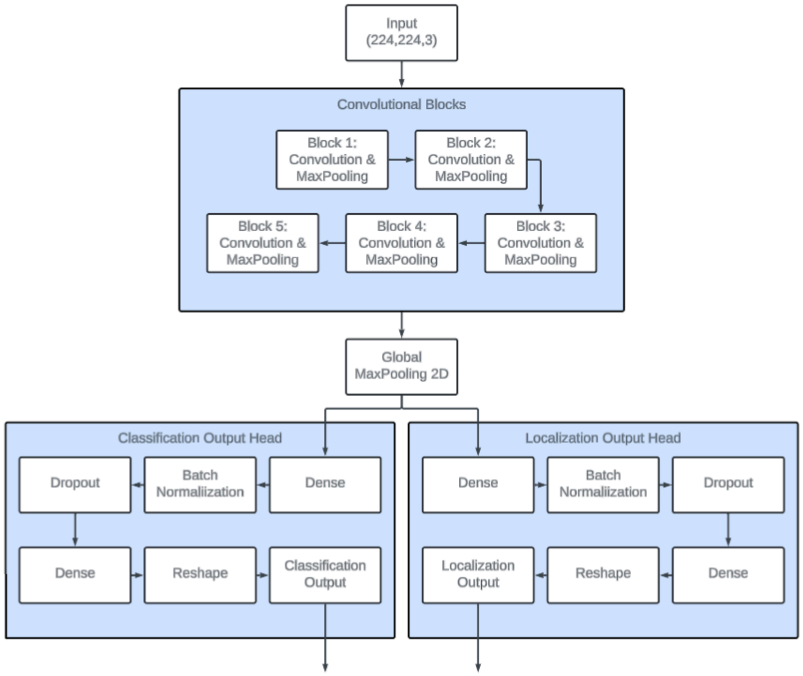

Figure 1: WIZARD Model Architecture Overview

Hyperparameters and regularization techniques (Dropout, Batch Normalization, L1/L2 Kernel Regularization) were applied to both heads of the model to reduce overfitting issues. The model is compiled using the Adam optimizer, with weights changing throughout training depending on the gradients computed from classification and localization losses. This method improves the model's ability to classify objects and predict bounding box locations with high accuracy. NMS and confidence thresholds are employed to polish predictions and minimize false positives.

2.2.3. Real-Time Detection Testing

The WIZARD model was applied to real time detection testing differently based on the semester. In ECEN 403, testing was done on a laptop with a webcam; whereas in ECEN 404, testing was conducted using the Raspberry Pi Module V2 camera attached to the Nvidia Jetson Nano processing unit (details provided in the section 2.2.5). In each case, after a frame is preprocessed, both class labels and confidence scores are produced for detected objects, with bounding boxes being drawn around weeds. Non-Maximum Suppression (NMS) was applied to reduce unnecessary overlapping boxes, and a confidence threshold of 85% was set to eliminate low-confidence predictions. Testing was performed both at home and in the FEDC so that the accuracy could be evaluated in different locations and lighting conditions.

2.2.4. WIZARD Model Results

The current version of the WIZARD model was trained for 20 epochs on training data for learning and validation data for tuning. The combination of classification and localization loss (Total Loss) decreased throughout training to nearly 0% on the training data, and to nearly 11% on validation data. The model's accuracy converged to 100% on the training data, and ended at roughly 89% on the validation data.

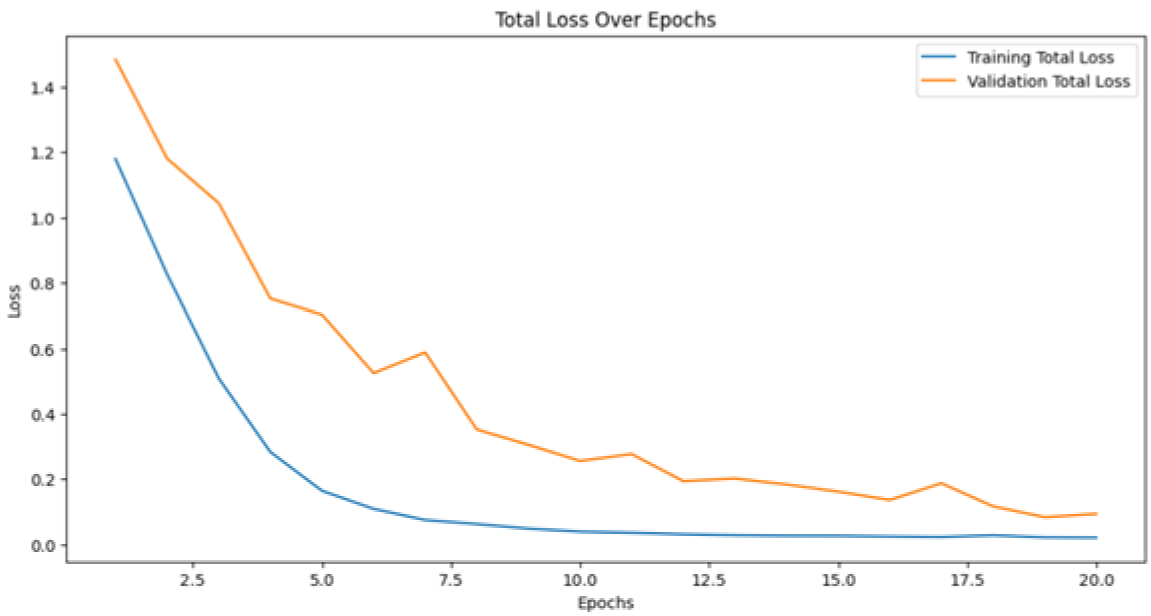

Figure 2: Total Loss Curve for WIZARD Model

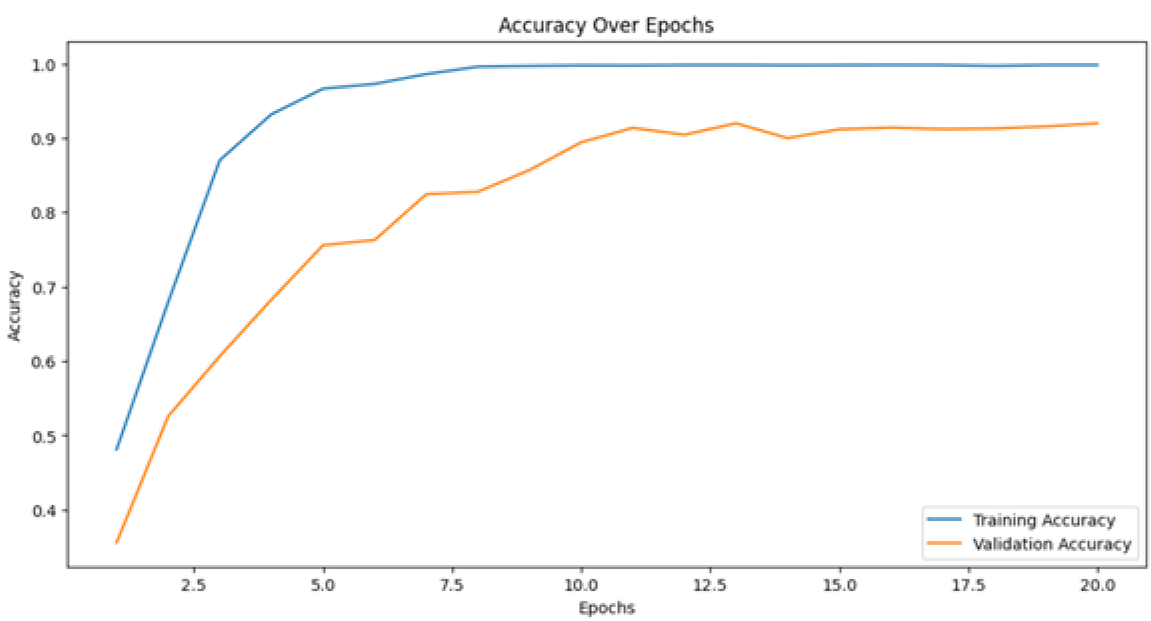

Figure 3: Accuracy Curve for WIZARD Model

2.2.5. NVIDIA Jetson Nano Setup

At the end of ECEN 403, the machine learning model and the python code created were uploaded to our GitHub repository. Once the Jetson was initialized, the repo was cloned onto it for use. I then configured the Jetson by installing all the necessary softwares and dependencies needed for the model to run. A virtual environment was created with Python 3.9.6 with the main IDE being JupyterLab. Tensorflow 2.10.1 with Keras applications was installed for loading and applying the WIZARD model, while OpenCV with GStreamer support was installed to access feed from the attached camera.

Parallel threading was implemented after observing slow model predictions and frame rate while running the model on the Jetson. In this solution, a main thread continuously captures the frames from the camera, and in a separate thread, a frame is taken and model predictions are generated and displayed back on the main thread in a loop. This workaround increased the camera frame rate, decreased prediction intervals, and made running the model more viable.

2.3. Subsystem Validation

The screenshots shown below were captured during testing from my laptop webcam and the Raspberry Pi camera. As presented in *Figure 4* and *Figure 5*, weeds are confidently detected and enclosed within bounding boxes that dynamically adjust to roughly fit their shape every frame. The model consistently classifies weeds with high accuracy both in congested and isolated locations.

Figure 4: Real-Time Prediction for Weed #1

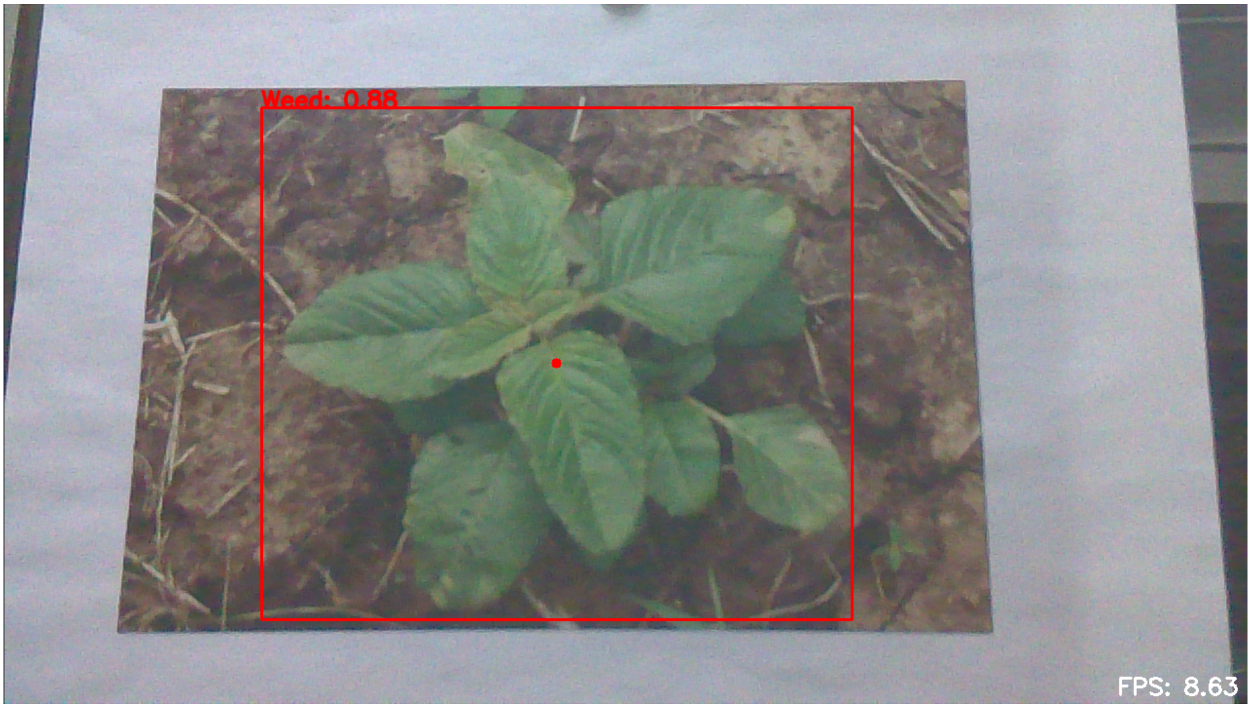

Figure 5: Real-Time Prediction for Weed #2

When images of soybeans were presented, the model accurately identified them as crops, displaying the confidence score on the bottom-left corner of the screen. Both multiple and single crop cases are shown below in *Figure 5* and *Figure 6* respectively.

Figure 6: Real-Time Prediction for Crop #1

Figure 7: Real-Time Prediction for Crop #2

The high accuracy in classifying objects as weeds or not (crop/background) validates the WIZARD model's functionality for real-time conditions. Live testing predictions performed as expected, with zero false positives and very minimal false negatives. In a testing batch of 25 combined weeds, crops, and background terrain, only one weed was wrongly classified as a crop which validates the criteria of a false negative rate of less than 5%.

2.4. Subsystem Conclusion

The computer vision subsystem successfully distinguishes between detected weeds and crops, generating bounding boxes around confidently identified weeds to later guide electrode placement for precise elimination of the weed's stem. In preparation for integration, the machine learning model and detection code has been successfully transferred to the NVIDIA Jetson Nano and, with the implementation of parallel threading to increase the overall subsystem performance.

3. High Voltage Subsystem Report - Conner Mullen

3.1. Subsystem Introduction

The high voltage subsystem is responsible for delivering the high voltage impulse upon instruction from the computer vision subsystem. This subsystem is capable of receiving I^2C signals to read from and write to a series of GPIO pins to control the high voltage delivery. The high voltage impulse is generated using a Cockroft-Walton (C-W) generator that boosts the source voltage (12V) up to 86V as a proof of concept. The high voltage subsystem includes an option to detect when the current through the electrodes is higher than a threshold chosen by the user. The high voltage subsystem is also responsible for providing sufficient power to the NVIDIA Jetson Nano, so it includes a buck-boost converter designed to convert 12V into 5V for a 2A load. The design and implementation of this subsystem involved the design and assembly of a PCB with all necessary inputs, outputs, and components.

3.2. Subsystem Details

3.2.1. Communication with Computer Vision Subsystem

The high voltage subsystem is controlled by an I^2C signal from the NVIDIA Jetson Nano. This I^2C signal is read by a TCA9554PWR GPIO Expander Integrated Circuit (I^2C Address 0x20), which has 8 configurable GPIO pins. 4 were used in this iteration of the subsystem. Information on the 4 control signals is listed in the table below.

Signal	I/O	Pin	Description
555RESETB	OUT	0	When low, turns off function of 555 oscillator
ZAP_ON	OUT	1	When low, C-W generator is disconnected from 12V (relay)
CURRENT_MEASURE	OUT	2	When low, current through electrodes is not measured (relay)
CURRENT_HIGH	IN	3	Indicates whether current through electrodes is above threshold (chosen by potentiometer)

Table 1: High Voltage Subsystem Control Signals

The states of the output signals can be altered by writing to the IC’s output register (0x01), and the CURRENT_HIGH input signal can be read by reading the IC’s input register (0x00), then ANDing the result with an 0x08 mask, as this signal is in the 2^3 bit of the data byte. As an example, to turn on the high voltage impulse with current detection on, the Jetson would set the output register to 0x07 (555 oscillator on, 12V connected, current detection on).

The ZAP_ON and CURRENT_MEASURE signals control mechanical relays, and those relay coils are driven by BJT transistors that are activated by the control signals at the base. There are also diodes across the coils (inductors) to block any flyback.

3.2.2. High Voltage Generation

The high voltage that will be used to kill the weeds is generated using a Cockroft-Walton generator (*Figure 7*), a repeatable voltage multiplier that produces a high DC voltage from an alternating input voltage. For the purposes of ECEN 403, this voltage had a hard cap at 100V due to safety concerns and limits on the instruments in the FEDC. Because of this, I chose a theoretical maximum of 96V, accomplished using an 8-stage C-W generator. However, as our German partners complete their research, we will have a better idea of what is required to kill a weed and we will have access to their high voltage test laboratory, so the 404 version of this subsystem will be designed with the actual specifications in mind. The time it takes to reach the target voltage in this simulation is negligible (11ms), but as we are required to reach significantly higher voltages to kill a weed, this time will become an issue that could limit how frequently we turn on and off the C-W generator.

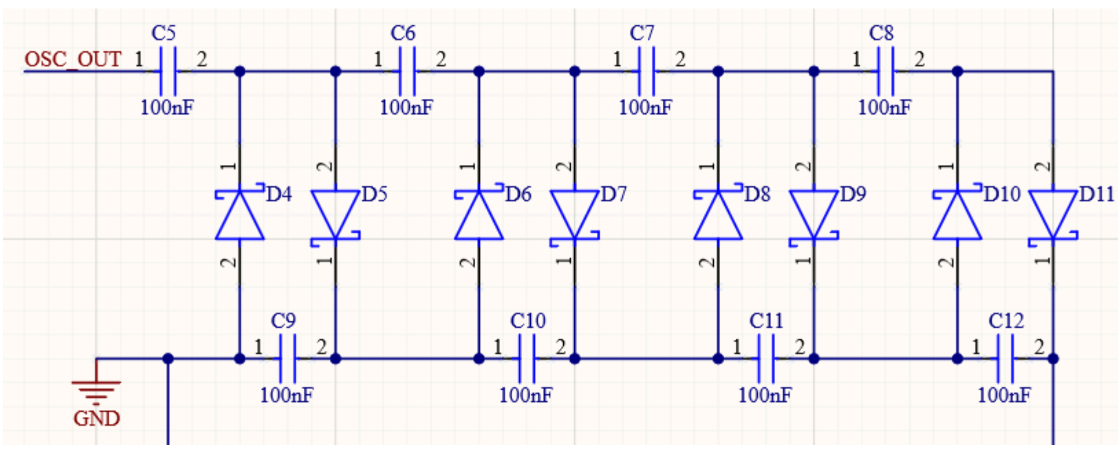

Figure 8: Cockroft-Walton Generator

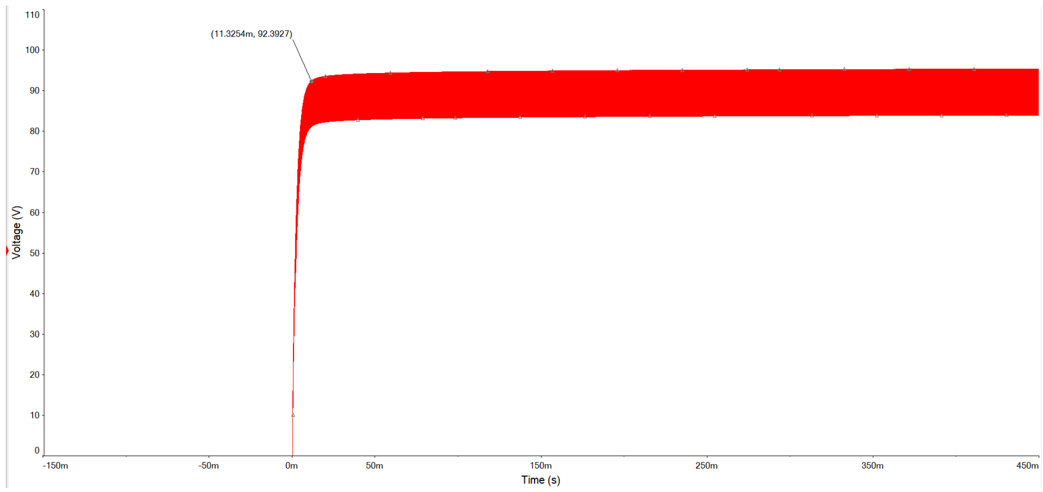

Figure 9: Output of the 8-stage Cockroft Walton Generator

An n-stage C-W generator takes an input voltage that alternates between $-V_{in}$ and $+V_{in}$, and outputs a $+nV_{in}$ DC voltage (not including voltage drops across diodes). A simple H-bridge configuration (*Figure 9*) is used to produce the alternating input from our 12VDC source. The output doesn't reach +12V or -12V because of the voltage drop across the transistors. The H-bridge requires two 0-12V "clock" signals offset by 180°, and these are generated with a 555 timer IC in an astable configuration and a BJT transistor in an inverting configuration. The frequency that all of this oscillates at is not particularly important, so I chose 10kHz.

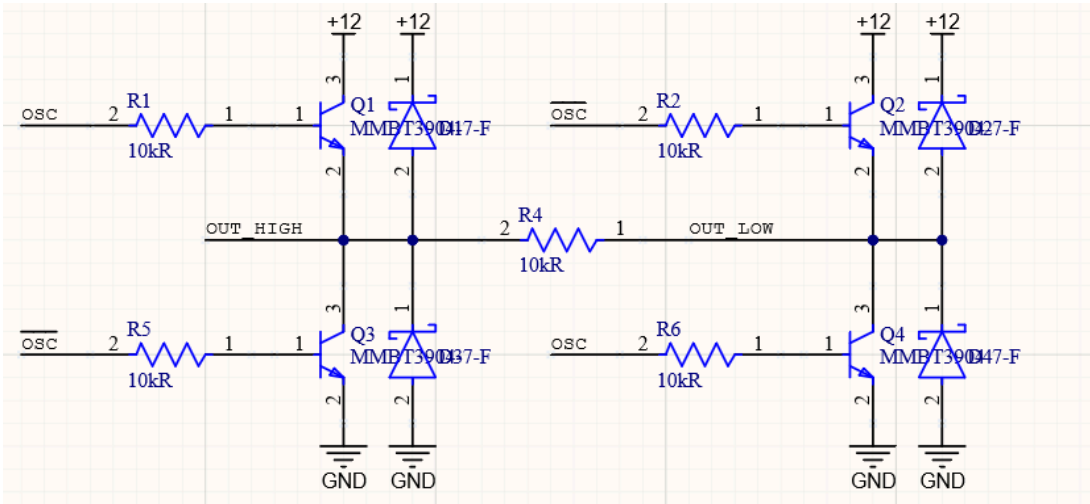

Figure 10: H Bridge Oscillator

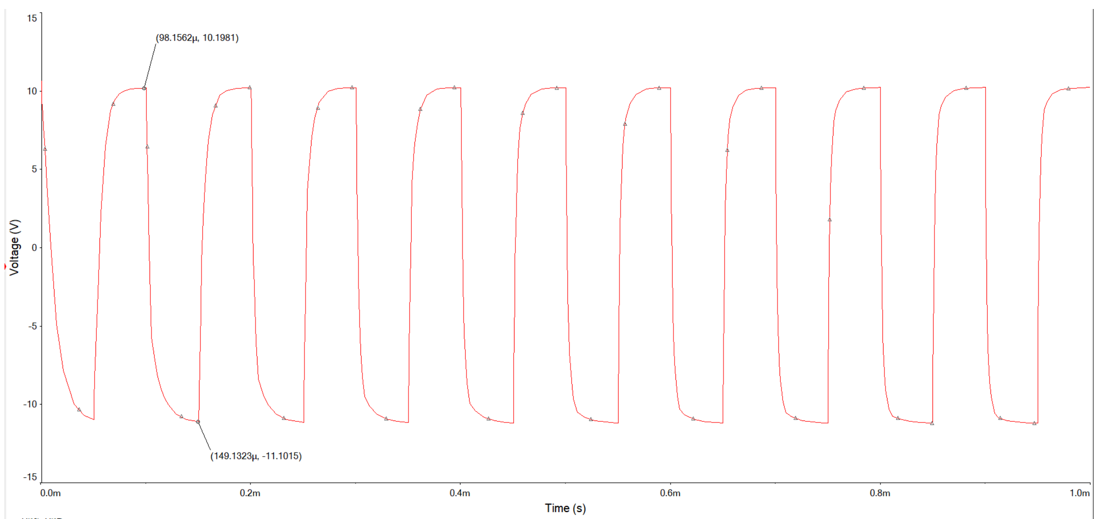

Figure 11: Output of H Bridge Oscillator

3.2.3. High Current Detection

One of the most important parameters of killing a weed with a high voltage impulse is the duration of the impulse. The German members of our team are actively conducting research to determine this parameter, but another possible approach to determining the duration of the impulse could be the biology of plants. If a plant is exposed to a high voltage impulse, its electrical resistance decreases over time, which would increase the current through the plant, per Ohm's Law. The high current detection module of this subsystem is a simple comparator that takes the voltage across a resistor in series with the plant (determined by the current through the plant) and compares it to a reference voltage controlled by a potentiometer. The output is the control signal CURRENT_HIGH (shown by an LED indicator on the PCB), and this feature can be toggled on and off by the CURRENT_MEASURE signal.

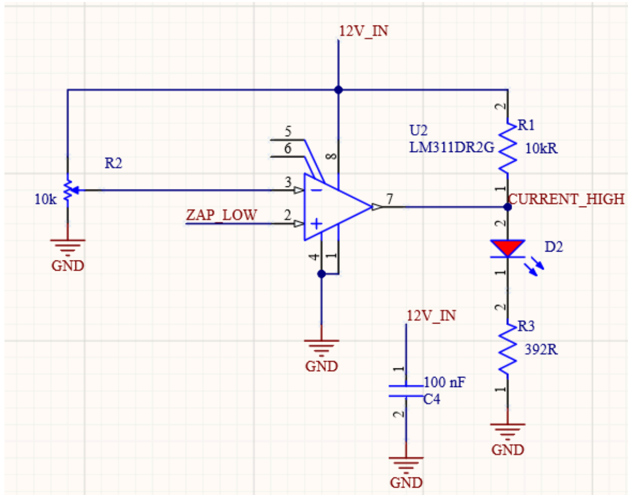

Figure 12: Comparator-Based High Current Detector

3.2.4. 5V Power Supply

The NVIDIA Jetson Nano requires a 5V power supply capable of supplying 2A at maximum power draw. To produce this, a LM22673MRE-5.0/NOPB IC was used in the circuit shown in *Figure 12*. This IC is rated for 3A and regulates the voltage around 5V for any input voltage between 4.5V and 42V, and all the peripheral components are rated for at least 3A. Component values were all chosen based on the information from the IC datasheet.

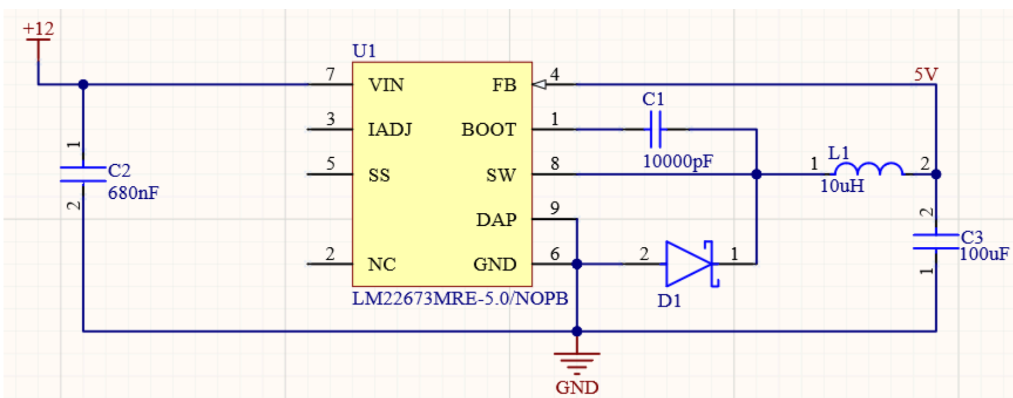

Figure 13: 5V Power Supply

3.2.5. Changes for Integration

During the integration process, there were two changes that needed to be made. The first change was to add a level shifter between the NVIDIA Jetson and the WIZARD hardware to allow 3.3V I^2C to communicate with 5V I^2C. This was done on a separate PCB that connects directly to the Jetson GPIO pins. The second change was to increase the output voltage of the buck converter in *Figure 12* from 5V to 5.1V. This was accomplished by disconnecting the feedback pin of the buck converter (pin 4) from the output. This was replaced by a voltage divider consisting of a 1kΩ resistor between ground and pin 4 and a 39Ω resistor between pin 4 and the output. This was done to increase the minimum voltage to stay above the minimum threshold supply voltage of the Jetson.

3.3. Subsystem Validation

3.3.1. Communication with Computer Vision Subsystem

The I^2C communication with this PCB was validated using an Arduino acting as the I^2C master. The master sent I^2C signals changing I/O configuration of the GPIO pins and changing the state of each of the output signals. The success of these commands was verified using a multimeter to probe the voltage at each of the output pins to verify that the GPIO Expander IC was properly receiving and interpreting the commands. The switching of the relays was verified audibly, as the mechanical relays make a loud clicking sound when they are changing states. The input CURRENT_HIGH signal was set to both 0 and 1 using the methods described in section 3.3.3, and the master read the input register of the GPIO Expander for both cases. In both cases, the 8's bit was read as the proper value, confirming that the I^2C signals are working as intended.

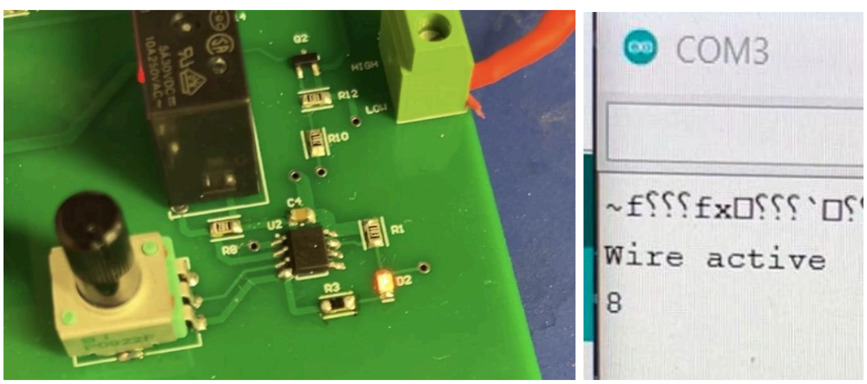

Figure 14: LED D2 showing CURRENT_HIGH = 1, and I^2C master reading value of 8 ($1x2^3$)

3.3.2. High Voltage Generation

The C-W generator reaches 80V in a fraction of a second. The reason it only reaches 80V and not the 96V described above is the voltage across the diodes. With real world imperfections taken into account, the C-W generator works as expected under no load. The output voltage decreases with decreasing loads as expected, but the voltage decrease at the resistance of a weed is not significant. This means that when the electrodes are contacting the weed, the voltage will not drop significantly.

Load	Voltage
Open	85.6V
1.04MΩ	79.3V
940kΩ	78.9V
870kΩ	78.5V
470MΩ	75.4V

Table 2: Electrode Voltages Under Various Resistive Loads

3.3.3. High Current Detection

The high current detection module works as intended. By connecting 6V to the lower electrode, it can be seen that when the potentiometer is oriented with the notch on top, indicating the reference voltage is greater than 6V (12V / 2), the indicator LED is off. When the potentiometer is rotated so that the notch is towards the bottom (reference voltage < 6V), the LED indicator is on.

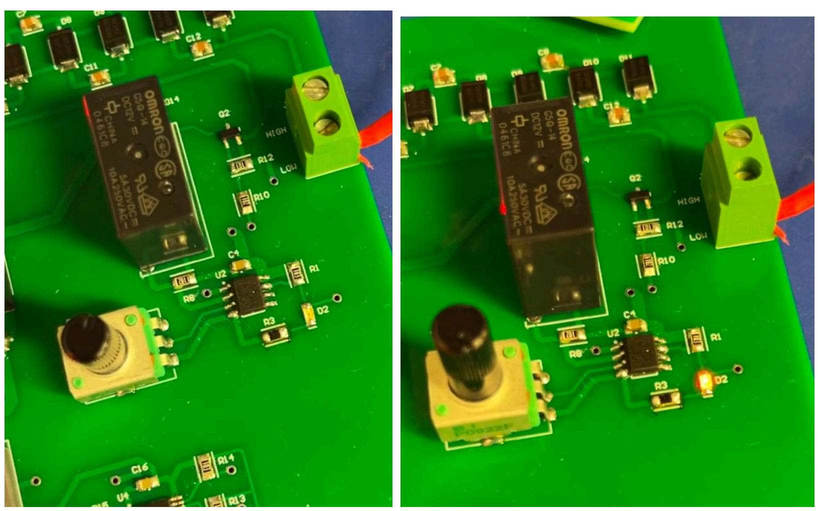

Figure 15: Threshold is not reached (left) and threshold is reached (right)

3.3.4. 5V Power Supply

The 5V power supply was tested using an electronic load to simulate a load up to 2A. With no load, the output voltage was 4.98V with less than 10mV of noise. Under the maximum 2A load, the output voltage was 4.88V with roughly 200mV of noise. This noise will need to be decreased before the next iteration, and I plan on revisiting the component value selections I made based on the IC datasheet. This noise can also be a result of a very noisy input voltage from the bench power supply, but that will likely exist for the 12V car battery as well, so it will need to be addressed in ECEN 404.

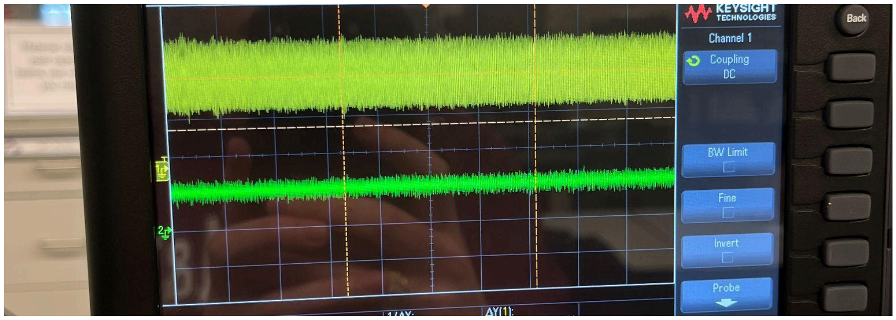

Figure 16: Oscilloscope reading of input (yellow) and output (green) to 5V power supply

This module was also tested across a range of input voltages from 9V-14V. The output voltage remained at 4.88V under a 2A load, although with slightly more noise. This is because the peripheral components were chosen with an input voltage of 12V in mind, so they don't work as well at other voltages.

3.4. Subsystem Conclusion

The high voltage subsystem successfully takes I^2C input and interprets those signals to control its modules. It produces a high voltage in a short amount of time, showing that the C-W generator is a viable option for reaching high DC voltages. The 5V power supply needs to be improved because of its noise, but it is capable of withstanding the necessary load of 2A. The high current sensor works as intended, with no improvement needed. Before the next iteration of this subsystem, the testing in Germany will be finished, and we will know the requirements for the high voltage impulse, and the C-W generator will be modified to meet those requirements. These modifications will likely include a transformer to boost the output of the H-Bridge and a more modular design, so one single design can be tested in Texas at a lower voltage and in Germany at full power.

Weed Identification and Zapping via Autonomous Robot Device (WIZARD)

Will Fenno
Conner Mullen

SYSTEM REPORT

REVISION – 3.0
28 April 2025

System Report
for
WIZARD

Team <72>

Approved by:

Project Leader Date

Prof. Kalafatis Date

T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
0.0	09/15/2024	William Fenno Conner Mullen		Draft Release
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2.0	12/05/2024	William Fenno Conner Mullen		Revision 2
3.0	04/28/2025	William Fenno Conner Mullen		Revision 3

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1. Overview

Our sponsor, Dr. Markus Zink, requested an alternative solution for weed control in organic farms that does not use chemical herbicides. WIZARD will become an automated robotic platform that will recognize redroot pigweeds growing in soybean crop fields using machine learning to locate then deliver a high voltage electrical impulse to kill weeds. With the German team working on the robotics portion as well as the electrode placement and high voltage testing, we are in charge of creating a machine learning model that, upon confident and stable weed detection, will charge a zap under 100V as a proof of concept due to the lack of equipment here to reach 15kV safely. The culmination of our system can be seen in *Figure 1*, providing labels for each major component and arrows for connections between the two subsystems.

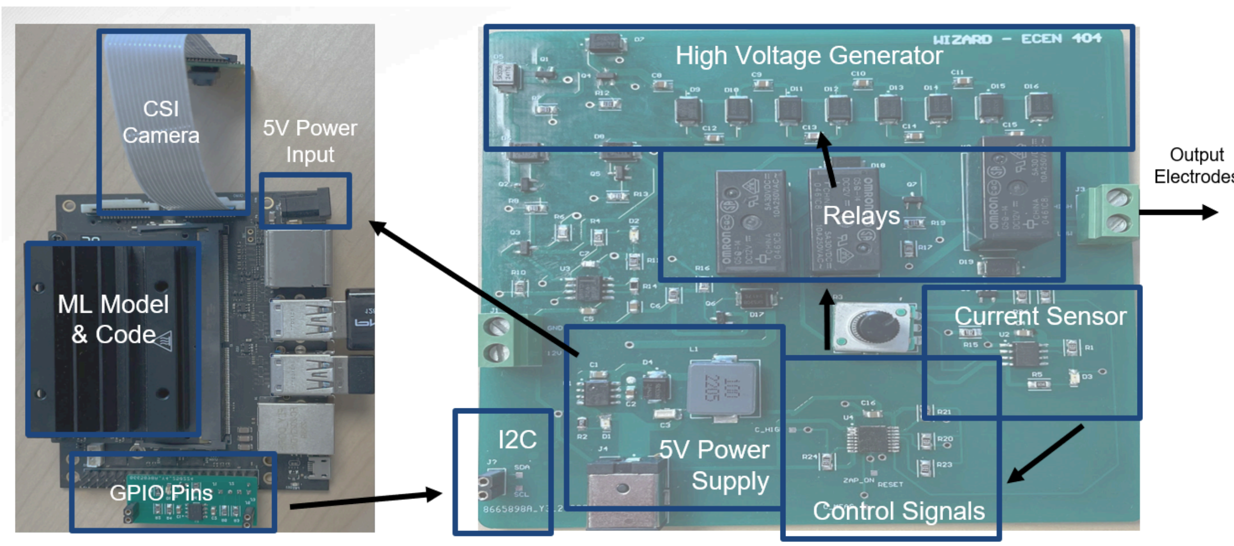


Figure 1: Integrated Project Diagram

2. Development Plan & Execution

2.1. Design Plan

Figure 2 outlines the original plan for the breakdown of the WIZARD system. The individual subsystems were designed and validated independently in the first semester, and the results from those tests are outlined in the *Subsystem Reports*.

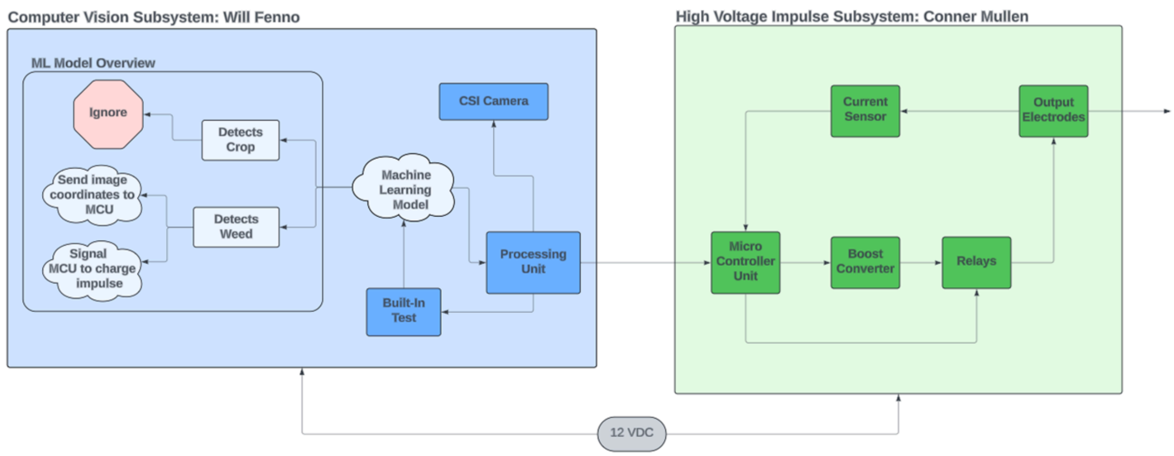


Figure 2: WIZARD Subsystem Diagram

The final iteration of the WIZARD system remains very similar to the subsystems completed in the first semester. However, as we started integrating the two subsystems, some changes needed to be made in order to produce a working system. These changes are outlined in the following sections.

2.1.1. Design Change: Parallel Threading

As mentioned in the *Computer Vision Subsystem Report*, parallel threading was implemented within the detection code after observing slow frame rate along with long generated prediction intervals while running the model on the NVIDIA Jetson Nano in its native state. In this solution, a main thread continuously captures the frames from the camera, and in a prediction thread, a frame is taken, model predictions are generated and then displayed back on the main thread in a loop. This method increased overall performance on the Jetson while decreasing the amount of time it takes to run a model prediction.

2.1.2. Design Change: I^2C Level Shifter

While the Jetson was capable of sending the correct I^2C signals and the WIZARD hardware was capable of receiving and interpreting the correct signals (tested with Arduino), they were not able to communicate with each other. We found that the Jetson uses 3.3V as its high level, while the WIZARD hardware uses 5V as its high level, which were incompatible with each other. To fix this issue, a level shifter was added that bridged the gap between the two incompatible signals.

2.1.3. Design Change: Buck Converter Output Voltage

The buck converter from the first semester successfully produced an RMS (root mean square) of 5V under maximum load. However, it did drop below the minimum voltage requirement of 4.75V that the Jetson needs to stay on. In order to fix this, the feedback pin of the buck converter controller was disconnected from the output of the converter. This was replaced by a voltage divider that kept the output around 5.1V when the feedback pin was stable at 5V. This simply increased the level of the voltage produced, so the output voltage remained above the minimum threshold, powering the Jetson with no issues.

2.2. Execution

The execution plan for this project is in the *Execution Plan* section of this report. The first semester was dedicated to the development of our individual subsystems, which is detailed in the *Subsystem Reports*. The final semester of this project was dedicated to refining our subsystems and bringing them together to accomplish the whole mission of the project. During the first month of the semester, the primary focus was updating our subsystems to prepare for integration. For the rest of the semester, we brought the computer vision and high voltage together and tested the full functionality of the WIZARD system.

2.3. Validation

2.3.1. Validation Overview

Our validation points, outlined in *Figure 3*, can be split into three main functional groups. In white are the electrode validation points, which were moved under the German team's scope, as they are working on the high voltage testing and robotics. The rows highlighted in green are the points that are directly related to the primary function of the system (identification and elimination of weeds). The points highlighted in blue are the environmental and physical requirements.

Paragraph #	Test Name	Success Criteria	Methodology	Status	Owner
3.2.1.1.	Capacitor Charge and Discharge Time	Time between start of charge up and end of discharge is less than 8 seconds	Measure voltage across output electrodes throughout a charge and discharge cycle, calculate time delta	COMPLETED	Conner Mullen
~~3.2.1.2.~~	~~Electrode Discharge Mode~~	~~Electrodes are only connected to high voltage output after contact is detected~~	~~With no contact: confirm that the voltage across electrodes is low~~ ~~With contact: confirm that indicator LED is on, and that the voltage across electrodes is high~~	~~TO BE TESTED~~	~~Conner Mullen~~
3.2.1.3.	False Positive Rate	FPR of less than 5% to prevent unintended crop damage	Conduct image classification test using a validation set with known crop and weed labels. Track the number of images where crops are incorrectly identified and calculate results	COMPLETED	Will Fenno
3.2.1.4.	False Negative Rate	FNR of less than 5% to prevent missed weeds	Conduct image classification test using a validation set with known crop and weed labels. Track the number of images where weeds are incorrectly identified and calculate results	COMPLETED	Will Fenno
3.2.1.5.	Camera Field of View	System detects objects at a range of 62.2 degrees horizontally and 48.8 degrees vertically	Measure the system's response to objects placed inside and outside the specified field of view	COMPLETED	Will Fenno
~~3.2.2.1.~~	~~Electrode Placement~~	~~Arcing does not occur across electrodes~~	~~Charge system to maximum voltage, visually confirm that no arc forms~~	~~COMPLETED~~	~~German Students~~
3.2.2.2.	Mounting	All components are secured properly	Visually inspect all connections to the robot or other platform, then attempt to move mounted components around to test strength of mounts	COMPLETED	Full Team
3.2.4.1.	Power Source	12V DC is converted to 5V, capable of 2A	Before powering on: Perform continuity test for all 12V points Power on board with 12V DC source and test voltage at output of power converters	COMPLETED	Conner Mullen
3.2.4.2.	Inputs	All control signals work as expected, as indicated by LEDs and relay clicking	Power system on, set to each combination and confirm that the proper LED indicators are on and listen for relay clicking	COMPLETED	Conner Mullen
3.2.4.3.	Outputs	LEDs all light up under correct circumstances Energy discharges through electrodes	Verify that proper LEDs light up under proper circumstances Voltage at electrodes reaches 80V	COMPLETED	Conner Mullen
3.2.4.4.	Interface Between Processor and Electronics	I2C signal sent from processor is received by MCU, correct output is observed (specific output and input signals will be updated as we finalize designs)	Send I2C commands from processor to microcontrollers, verifying that every necessary function is initiated properly	COMPLETED	Full Team
3.2.5.1.	Temperature (Thermal Resistance)	System functions in complete range of temperatures (10C to 45C)	Low end of temperature range exists outside in Texas, high end will be created with temperature chamber	COMPLETED	Full Team
3.2.5.2.	External Contamination	Large particles are kept out of the electronics casing	Bombard empty casing with dirt, grass, and other particles; open casing and visually inspect inside	COMPLETED	Full Team
3.2.6.1.	Built-In Test (BIT)	The system will activate a red LED in the case of camera failure during the startup process	Intentionally simulate camera failure via disconnection to verify LED activation response	COMPLETED	Will Fenno
3.2.6.2.	Isolation and Recovery	In the case of a BIT fault, the system will be reset and restore normal operations	Conduct a reset test in response to a camera detection failure	COMPLETED	Will Fenno

Table 1: WIZARD Validation Plan

In order to validate all of these points, we ran through several full system tests, outlined in the sections below, as well as some more specialized tests to validate the environmental and internal points. All of the full system tests were run with the input and output parameters that would be present in the real WIZARD system.

2.3.2. Weed Detected

The purpose of this test is to confirm that the WIZARD system will correctly identify a weed and deliver an impulse that fits the set parameters. *Figure 3* shows the computer vision and terminal outputs when a weed is in the field of view of the camera. Alongside these outputs, the WIZARD hardware delivered an ~89V impulse, shown in the images in *Figure 3*.

Figure 3: Weed Detection with Terminal Output

Alongside these outputs, the WIZARD hardware delivered an ~89V impulse, shown in the images in *Figure 4*. The impulse is delivered well within the time limit of 8 seconds, and the delivery of the impulse proves that the communication between the Jetson and WIZARD hardware works as intended. The duration of the impulse can be set by the user, but in this test, the impulse is shut off (voltage drops) within 1 second.

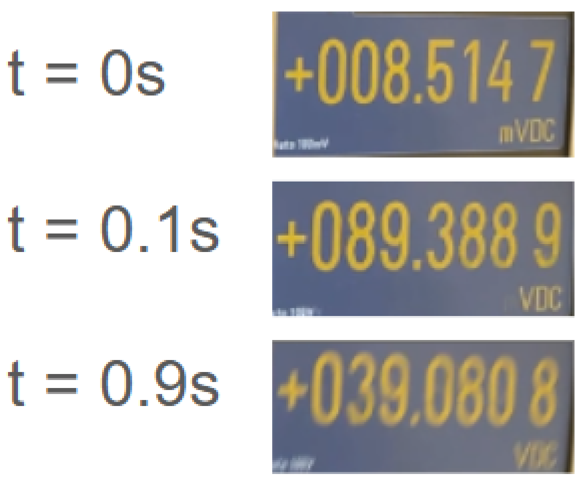


Figure 4: Voltage Across Electrodes at Times After Weed Detection

2.3.3. Crop Detected

The purpose of this test is to confirm that the WIZARD system will not deliver an impulse when there is not a weed within the camera field of view. No bounding box appears (*Figure 5*), indicating there is no weed detected, and therefore, the hardware remains idle.

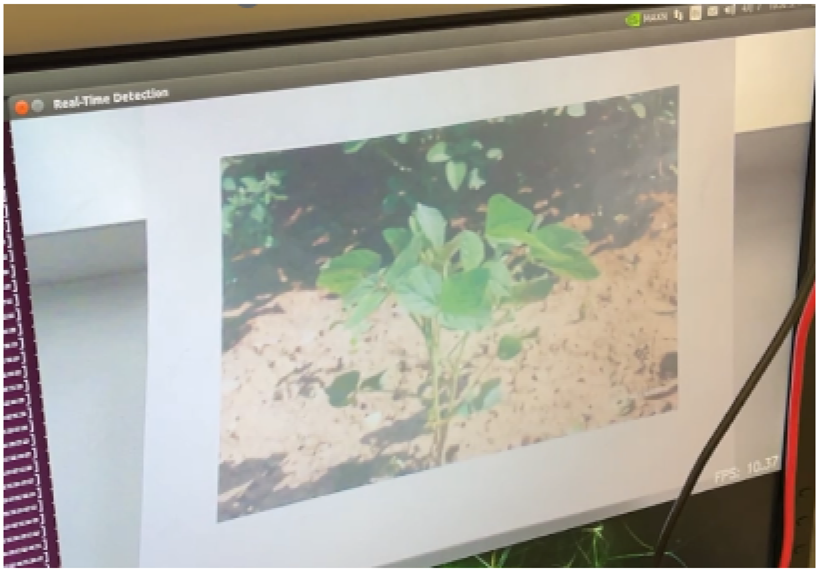
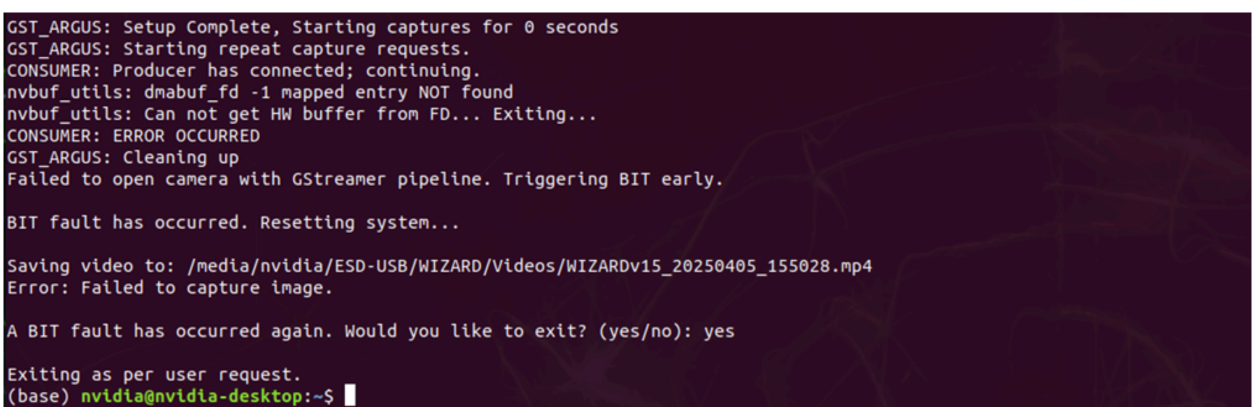


Figure 5: WIZARD Model Correctly Ignoring a Crop

2.3.4. Built-In Test

A Built-In Test (BIT) was created in the event of a camera fault. When the BIT is triggered, it will turn on a red LED on GPIO Pin #7 on the Jetson's carrier board to inform the user that a fault has occurred as well as perform a system reset to try and restore normal operations rather than run the detection code. After the reset, if there is another camera failure, it will once again trigger the BIT and turn on a red LED for a second time. After this second indication of a camera fault, it will prompt the user to exit the code so that the persisting issue can be resolved.

This precaution was implemented into the main() function of the detection code, with the terminal output shown below in *Figure 6* when a camera fault is simulated:



```
GST_ARGUS: Setup Complete, Starting captures for 0 seconds
GST_ARGUS: Starting repeat capture requests.
CONSUMER: Producer has connected; continuing.
nvbuf_utils: dmabuf_fd -1 mapped entry NOT found
nvbuf_utils: Can not get HW buffer from FD... Exiting...
CONSUMER: ERROR OCCURRED
GST_ARGUS: Cleaning up
Failed to open camera with GStreamer pipeline. Triggering BIT early.

BIT fault has occurred. Resetting system...

Saving video to: /media/nvidia/ESD-USB/WIZARD/Videos/WIZARDv15_20250405_155028.mp4
Error: Failed to capture image.

A BIT fault has occurred again. Would you like to exit? (yes/no): yes

Exiting as per user request.
(base) nvidia@nvidia-desktop:~$
```

Figure 6: Built-In Test Terminal Output

2.3.5. Environmental/Physical Validation

The environmental/physical validation points were all met using a 3D-printed casing, shown in *Figure 7*. This casing, along with mesh sidings (not pictured), protect the electronics from dirt and other debris present in farmland. The Jetson and WIZARD hardware are also secured within the mounting, which can be seen in *Figure 7*. The thermal limits were confirmed by running the system outside throughout the semester, allowing us to test across the desired temperature range. Along with this, the casing allows for airflow across the electronics, which will reduce the effects of the heat generated by the microprocessor.

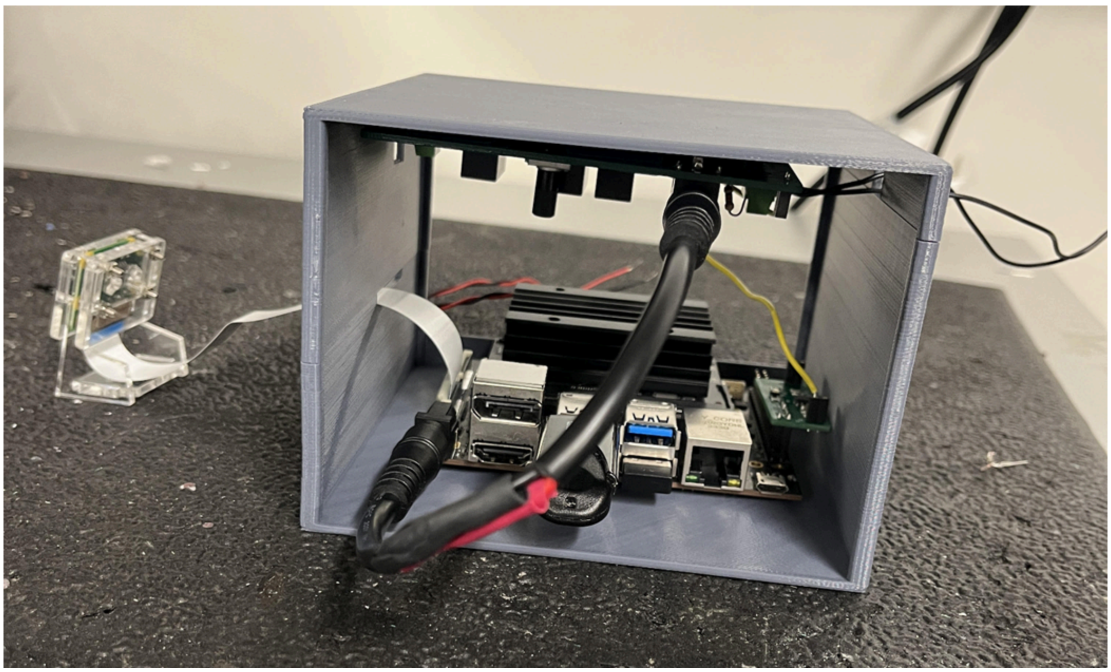


Figure 7: WIZARD 3D-Printed Casing

2.3.6. Internal Functions

The two internal validation points that were essential to the functionality of this system were the communication between the Jetson and the high voltage hardware and the buck converter that powers the Jetson. The initial validation for the communication is shown in 3.3.1 of the *Subsystem Reports* and was further validated after integration by running the full system tests outlined above. The buck converter was validated by using it to power the Jetson while running the WIZARD model for a variety of durations as long as 3 hours, and the Jetson remained functional. The output of the buck converter under maximum load is shown in *Figure 8*.

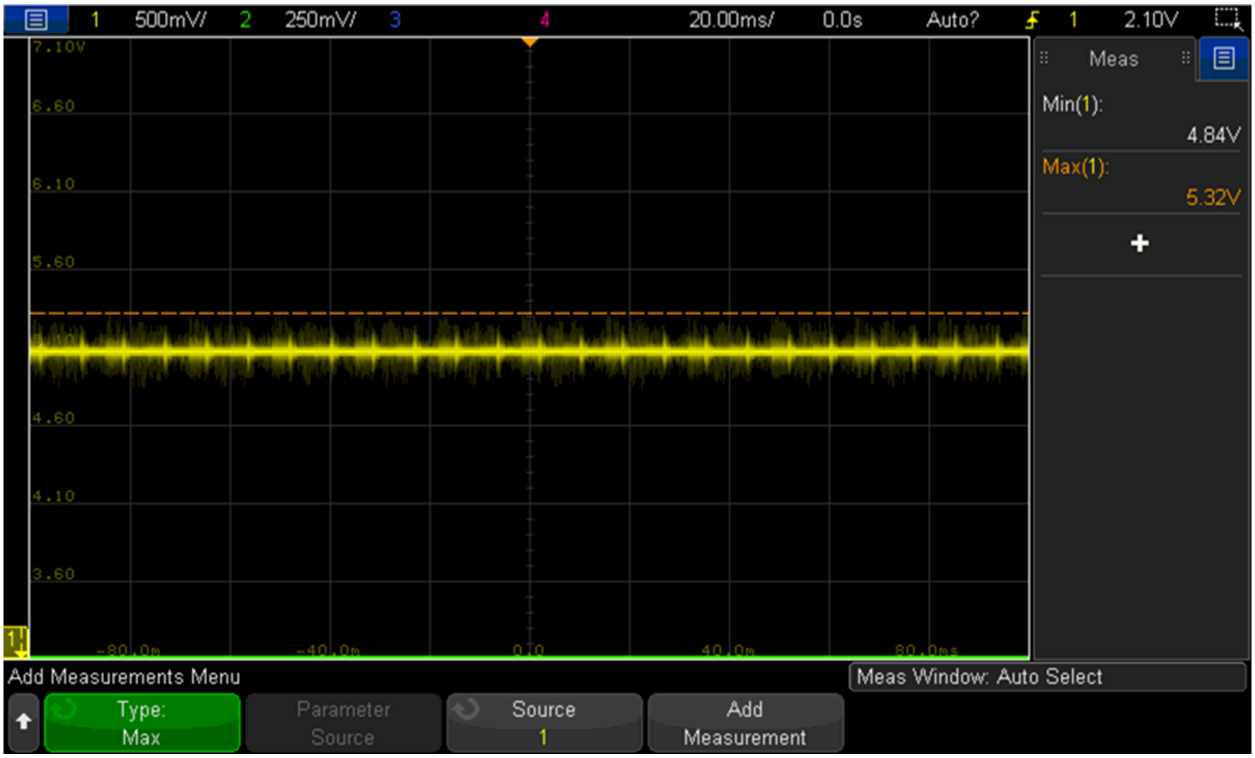


Figure 8: WIZARD Buck Converter Output Under Maximum Load

3. Conclusion

At the start of this project, we aimed to produce a system capable of identifying and eliminating weeds. Although our objective shifted into producing a proof of concept, the final WIZARD system is capable of identifying weeds with high accuracy and delivering a scaled down impulse that proves that the WIZARD concept could be viable.

3.1. German Collaboration

Although our report only consists of two subsystems and two team members, we were joined by three students in Germany learning under Dr. Zink. Throughout the semester, they conducted experiments to determine the optimal parameters for the high voltage impulse. They are also developing a robotic platform for the WIZARD system to operate on. As we conclude our work on this project, they will continue to work on using our proof of concept to bring the full vision of WIZARD to life.

3.2. Future Steps

This project will be continually developed by the German team over the next several months. They have access to the computer vision and hardware system that we developed, and they will be working to integrate our work into their robotic platform and high voltage equipment.