3D Inspection Rover

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Midterm Report

REVISION – Draft

February 23, 2022

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B.O.B The Tomato Inspector

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CONCEPT OF OPERATIONS

REVISION – Draft
09 January 2022

CONCEPT OF OPERATIONS
FOR
3D Inspection Rover

TEAM 08

APPROVED BY:

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Project Leader Date

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Prof. Kalafatis Date

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T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
1.0	[02/09/2021]	[Dumont, Hines, Waters, Villegas]		Draft Release

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1. Executive Summary

To increase Texas' tomato production, greenhouses are being utilized to lengthen the tomato growing season. However, this is costly due to large material and man-hour expenses, as well as a lack of automation which could reduce these expenses. We will be creating an autonomous option to inspect and predict the optimal time to collect produce, which will decrease the man-hours needed in the harvest of tomatoes. The rover will navigate the aisles of the greenhouse, going from plant to plant ensuring all plants are examined and avoiding any obstacles encountered. Using a depth-sensing camera to capture and analyze images of the produce, B.O.B. will be capable of determining ripeness via visual indicators such as sugar level, color, and size. Through these techniques, B.O.B. will help improve the efficiency of the harvesting process of tomatoes.

2. Introduction

This document introduces a 3D inspection rover, a system capable of monitoring produce in a greenhouse, and informing farmers of the inspected plant's yield and health. To gain optimal production, the B.O.B. will serve as an inspector to help farmers identify which product has the desired characteristics while navigating around any obstacles it may face in aisles while inspecting.

2.1. Background

Related projects and research have been attempted before such as by using histograms of oriented gradients (HOG) which had a precision rate of 94% for telling if a tomato was ripe or not. B.O.B. will add to this process by determining if the tomato has a disease. This system will efficiently and autonomously identify and organize every image of produce to simplify the task for a human operator to go through the greenhouse and remove problem produce and pick ripe produce.

2.2. Overview

The farmer activates the rover to begin traversing and documenting. The rover will stop at every plant within the greenhouse and take detailed pictures of each. The on-board computer will then process these images by identifying each tomato, determine if it is ripe, unripe, or sick and assign them into the appropriate category which the farmer will use to efficiently harvest the tomatoes.

2.3. Referenced Documents and Standards

Document Name	Revision/Release Date	Publisher
Learning Python	4th Edition	O'Reilly
Image Processing	2nd Edition	John Wiley & Sons
2022 Complete Python Bootcamp Form Zero to Hero Python	2022	Udemy
Feature Extraction and Image Processing	2013	Safari, an O'Reilly Media Company

Table 1: Reference documents

3. Operating Concept

3.1. Scope

The B.O.B is designed for greenhouses to identify and sort produce, tomatoes in this case, into separate sections depending on their ripeness or if they are sick. This system is designed to decrease the cost of farmers operating large greenhouses by cutting out unnecessary labor time that would typically be used to employ a person to walk through the greenhouse and manually document the mentioned specifications.

3.2. Operational Description and Constraints

An operator will first plug in the raspberry pi and wait for it to go through its boot-up process. The operator will then connect their laptop to the raspberry pi and execute the proper command to make the machine begin the process of moving and collecting data. At this point B.O.B will be operating autonomously, locating every tomato plant and classifying it.

Constraint	Reasoning
Storage	The raspberry pi has limited onboard storage, so there is a limit to how many photos can be saved and processed. The use of an external SSD or cloud storage will help solve this problem; although cloud storage may also not be possible due to a lack of wifi within a greenhouse.
Terrain	The ground in the greenhouse, if it is dirt, could become muddy due to the irrigation system. If the ground gets too muddy the rover will not be able to drive around and operate smoothly.
A.I. Ability	Due to limited time and budget, the machine learning software will be restricted in how much training it receives for each category of tomato. Because of this, false negatives/positives are inevitable.
Battery Life	There is limited size and room for the rover to operate in, this leads to a constraint on battery size. The effect this will have is that it will limit the size of a greenhouse the rover can scan in one charge.

Table 2: Constraints of B.O.B and reasonings

3.3. System Description

The motors will be driven to traverse the greenhouse, powered by an integrated battery system. The camera positioning will be controlled by more precise computer guided motors. The on-board computer systems and camera will be powered by a separate battery system to better manage power needs. The computer will take pictures through an on-board camera; the picture will be sent to a processing program to sort the tomato state and store it properly. Finally, the computer will move the rover to the next plant and repeat the process.

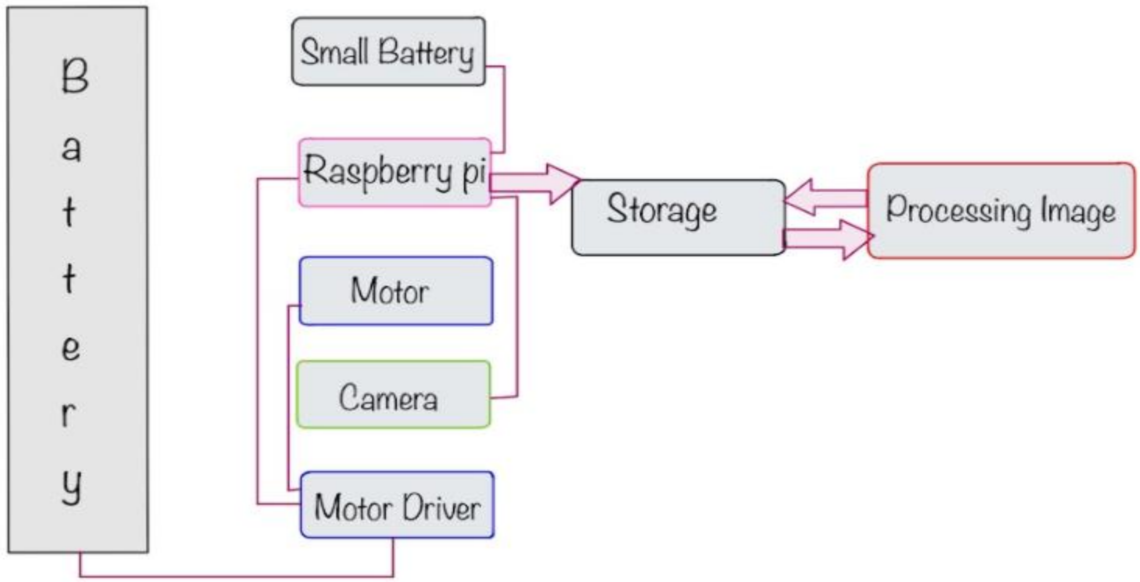

Figure 1. System Overview Block Diagram

3.4. Modes of Operations

The B.O.B will only have one mode of operation, which is completely autonomous. In this mode, the rover will simply need to be turned on and an external user will need to run the program that will be written on a raspberry pi before the rover will begin patrolling the greenhouse examining every tomato in the building. The image will then be processed in real-time and placed into separate labels to be accessed by humans at a later date. Then returning to where it started to be charged at the end of the day.

3.5. Users

The rover will be marketed toward both small and large-scale farmers who plan on growing produce inside of a greenhouse. This will help to lessen man-hours needed to monitor the produce and require fewer people to monitor large areas.

The B.O.B can also be modified to work outdoors simply which would increase the number of farmers it can benefit. This could save farmers everywhere a large sum of money since there will need to be fewer people monitoring the fields looking for sick produce and determining time until ripe.

3.6. Support

Information on how to make basic repairs will be provided in the form of a user manual. Also included in the manual will be a list of every part and how it contributes to the operation of the rover. B.O.B will come with all necessary software pre-installed along with detailed instructions on how to connect the operating software to a laptop so that data can be accessed at the end of the day and the rover can be started at the beginning of the day.

4. Scenario(s)

4.1. Ripe Tomato

In this scenario, the tomato is ripe and ready to be picked. The tomato should be bright red and round and from there the processor should sort the tomato into the ‘ripe’ category so that the farmer can mark it for harvesting.

4.2. Unripe Tomato

In this scenario, the tomato is not ripe and shouldn’t be picked. The tomato is likely a shade of green and egg-shaped. The processor will recognize this and sort the tomato into the ‘Unripe’ category so that the farmer knows to wait and check back later.

4.3. Sick Tomato

In this scenario, the tomato is sickly and should be discarded. The tomato could be discolored, rotten, or have any other signs of sickness. From there the processor should sort the tomato into the “sick” category so that the farmer can mark it to be discarded or composted.

5. Analysis

5.1. Summary of Proposed Improvements

Possible areas of improvement provided by B.O.B include:

- Automation of produce classification
- Recognition of diseased plants
- Lower cost to farmer
- Higher quality produce for the public
- More accurate and accessible information for the farmer

5.2. Disadvantages and Limitations

Disadvantages include a constant chance of error that is inherent with machine learning in any scope. Additionally, there are strict budget and time limitations that prevent the machine from having top-of-the-line parts and programming. These limitations act together to affect overall accuracy and quality.

5.3. Alternatives

An alternative to this solution would be to put the rover on a track system much like a train. This would simplify the autonomous motion needed to drive the rover around since no steering programming would be needed. This could lead to issues such as the track being wet and the machine sliding past where it was supposed to stop or possibly jumping off the track if something would be sitting on it.

There is also a variety of other programming languages that could be used instead of python as well as other microcontrollers beside the raspberry pi that will have strengths and weaknesses.

5.4. Impact

The impact of this project is to save farmers money by not having to employ as many farmhands. This will have a positive environmental impact since there will be less people commuting to and from the farm, cutting down on greenhouse gas emissions. It will also improve the quality of life to everyone that the farm provides produce to by increasing the quality of produce and since the operating cost is lower to the farmer, the produce can be sold for less, further benefiting the consumer. There are ethical concerns that come with automation taking the jobs of people, but these do not apply to the B.O.B rover as it is made to aid those workers by automating a tedious and time consuming task, freeing them for other work.

3D Inspection Rover

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Celeste Waters

FUNCTIONAL SYSTEM REQUIREMENTS

REVISION – 1
23 February 2022

FUNCTIONAL SYSTEM REQUIREMENTS
FOR
3D Inspection Rover

PREPARED BY:

Chris Dumont

Author Date 02/23/2022

APPROVED BY:

Chris Dumont

Project Leader Date 02/23/2022

Kevin Nowka, P.E. Date 02/23/2022

T/A Eric Robbles Date 02/23/2022

Change Record

Rev.	Date	Originator	Approvals	Description
1	[02/23]	3D Inspection rover	Robbles, Nowka	Revision 1

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1. Introduction

1.1. Purpose and Scope

The capability of farmers to receive information accurately and reliably about their produce is paramount when it comes to running a profitable farm. In place of having a worker classify the greenhouse one tomato at a time our goal is to provide an automated rover that will classify every tomato by type. The B.O.B. will achieve this through a machine learning program that will sort images taken by an onboard camera. With the data achieved through the program, useful charts and graphics can be generated to inform the farmer of problem tomatoes, expected yield, and percentage of ripe to unripe tomatoes. This will allow the farmer to focus on other parts of the farm, saving them time and money. Our system will reduce overall man hours needed and is scalable to larger products by simply adding a larger battery onboard. It will also decrease the likelihood of a tomato being damaged during the inspection process because the rover will have no need to touch it which could potentially knock it off the plant and damage it.

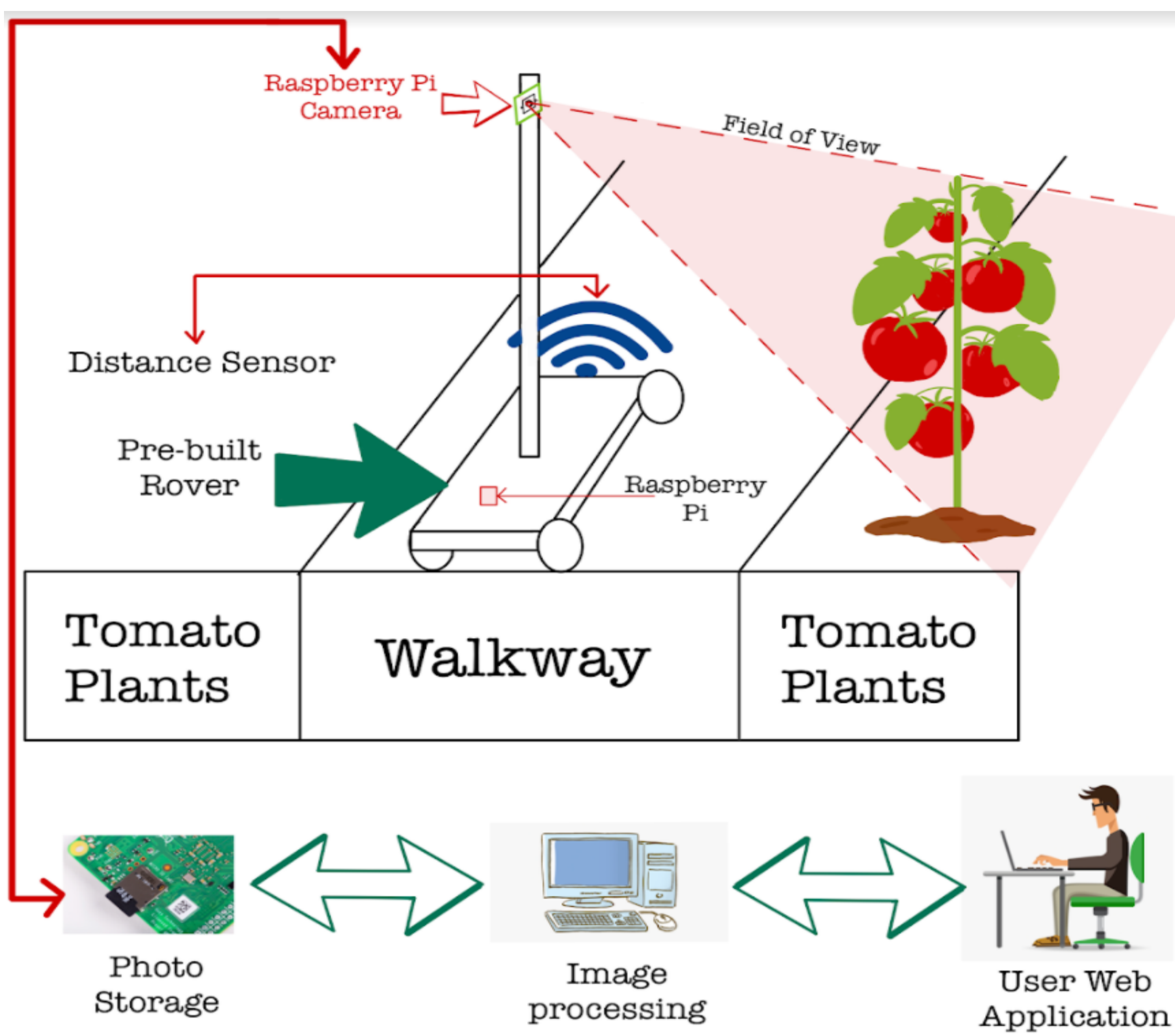

Figure 1. Your Project Conceptual Image

1.2. Responsibility and Change Authority

Chris Dumont, the team leader, is responsible for ensuring all requirements of the project are met.These requirements can only be changed by approval of the team leader and Professor Kevin Nowka.

Subsystem	Responsibility
Autonomous Navigation	Chris Dumont
Camera Positioning	Dalton Hines
Image Classification	Felipe Villegas
Data accessibility and organization	Celeste Waters

Table 1: Subsystem Leads

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
SH-16586-07-06-F-36	2007	Electrical Safety: Participant Guide
STD-112-1996	Revision-2004	IEEE Standard Test Procedure for Polyphase Induction Motors and Generators
1926.756	2001	Beams and Columns: Safety and Health Regulations for Construction

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
1	2002	National Electrical Code Allowable Ampacities of Insulated Conductors Rated 0-2000V
1	1999	Structural Steel Design: Structural Engineering Handbook

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 3D Inspection Rover is a replacement for humans when the task at hand is classifying tomatoes as they grow in a greenhouse. It allows for reduced man hours and thus a lower operating cost to the farmer. The 3D Inspection Rover has four subsystems: Autonomous Navigation, Camera Positioning, Image Classification, and Data Accessibility/Organization.

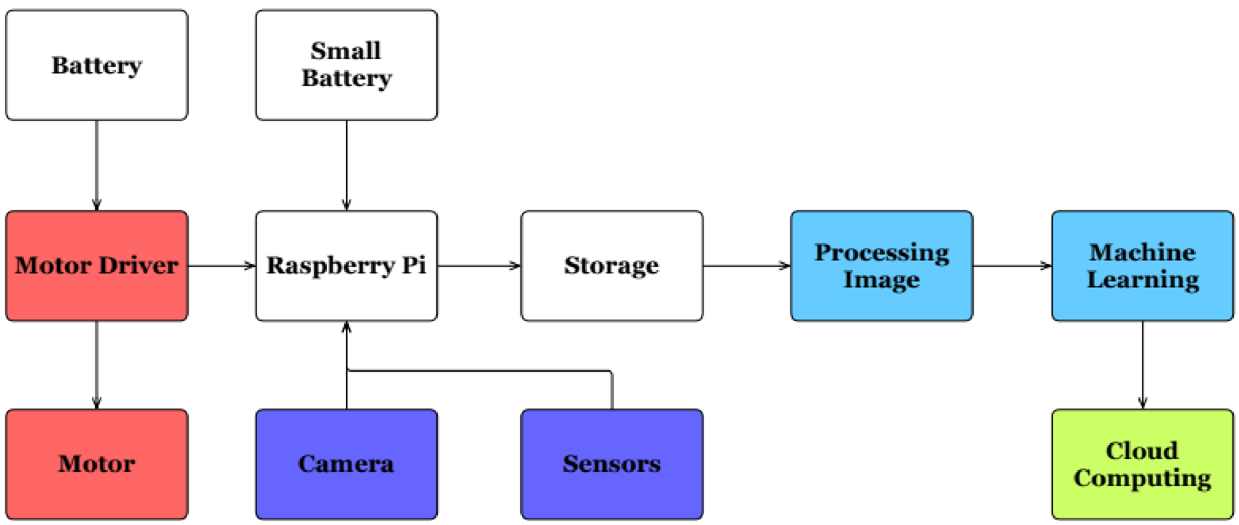

Figure 1. Block Diagram of System

There will be two on board batteries, one for driving the motors, the other for powering the computer, camera, and distance sensors. These batteries will need to be recharged at the end of every operating cycle. The camera and distance sensors will provide input information to the computer which will be running an obstacle detection and image tracking program to determine the best route to the nearest plant. Once at the plant the motors will stop moving and allow the camera positioning system to take multiple pictures of the plant to be sent for further processing from the machine learning program. The camera will be plugged directly into the computer to reduce the need of a transmitter. The machine learning program will then sort the tomatoes by location, ripe, unripe, and sick. Once the computer has this information it will be uploaded to a cloud server which will use it to create useful graphics for the farmer.

3.2. Characteristics

3.2.1. Functional / Performance Requirements

3.2.1.1. Plant Detection Pass Rate

The system is expected to recognize 75-80% of the plants

Rationale: The system is subject to very strict budget restrictions; this limits the quality of camera we can use and results in less than perfect data.

3.2.1.2. Tomato Classification Pass Rate

The Machine learning program will accurately classify tomatoes 60-80%

Rationale: Like the previous rationale the lower quality camera results in messy images. The limited time frame for the project also limits the amount of time the machine learning algorithm can be trained in tomato recognition.

3.2.2. Physical Characteristics

3.2.2.1. Height

The height of the rover's camera lifting mechanism must be at least 8 ft tall.

Rationale: This requirement was specified by the sponsor because the highest that a tomato plant will be is 8ft tall and we need to be able to document the entire plant.

3.2.2.2. Run Time

The rover needs to be able to run long enough to document every tomato in the greenhouse on one charge.

Rationale: This is important to reduce the number of incomplete runs as well as having to locate the rover if it dies.

3.2.2.3. Width

The rover is currently 2.5 ft wide and needs to stay as such. Nothing we add may make it wider.

Rationale: This is because there is limited aisle space for the rover to navigate.

3.2.2.4. Length

The rover is currently 3 ft long, we may increase the length slightly with our sensors if need be.

Rationale: The rover still needs to make tight turns around the greenhouse so keeping the length limited is important.

3.2.3. Electrical Characteristics

3.2.3.1. Inputs

The lack of any input shall not damage the microcontroller in any way. Similarly multiple inputs from one sensor, nor any combination of inputs will damage the microcontroller, or reduce it's life expectancy in any way.

Rationale: We do not want the microcontroller to break because operation would come to a standstill until it is replaced.

3.2.3.1.1 Power Consumption

The maximum peak power of the motors shall not exceed 144 watts. The maximum peak power of all other systems shall not exceed 15 watts

Rationale: This is because we want both batteries to have a similar life expectancy.

3.2.3.1.2 Input Voltage Level

The input voltage level for the motors shall be +24 volts, while the input voltage for all other systems shall be no more than +3.3 to +5 volts.

Rationale: This is because the pieces are rated for these values.

3.2.3.1.3 Input Current Level

The output current from the large battery is not to exceed 25 Amps, while the output voltage for the small battery is not to exceed 3 Amps.

Rationale: The motor driver is rated for 25 amps while the Raspberry Pi is rated for 3 amps.

3.2.3.2. Outputs

No outputs created by the system will be capable of damaging the system.

Rationale: This is so the rover is not capable of damaging itself under any circumstances.

3.2.3.2.1 Data Output

The system will be capable of uploading data to a cloud computing site.

Rationale: This allows the data to be stored and computed more effectively since there is limited onboard storage space as well as computing power.

3.2.3.2.2 Raw Video Output

The system will hold pictures of problem tomatoes to be sorted later by a human, as well as an image of sick tomatoes so the farmer may remove it manually later.

Rationale: This is important because there is a lack of internet in a greenhouse as well as allowing the farmer to view the problem tomatoes.

3.2.3.3. Connectors

The microprocessor will have a removable SD card, that can be plugged into any viable computer

Rationale: The system requires this because there is a lack of wifi in greenhouses.

3.2.3.4. Wiring

The wiring used will follow IEEE and NEC standards for the expected power levels.

Rationale: The system uses this because it is important for the safety of people and property.

3.2.4. Environmental Requirements

While the system is operating water sprinklers will need to be shut off. All other environmental requirements will be met by the rover.

Rationale: The rover is not waterproof so there could be a safety hazard as well as system failure.

3.2.4.1. Thermal

The onboard computer is rated for 0 degrees Celsius to 85 degrees Celsius, All other systems will also operate within this range.

Rationale: The computer can only operate within a limited range to prevent damage.

3.2.4.2. Water Sprinklers

Sprinklers will have to be shut off during machine operation.

Rationale: The rover is not waterproof so there could be a safety hazard as well as system failure.

3.2.4.3. Humidity

Humidity will need to be low during machine operation, below 70%

Rationale: The humidity could cause short circuiting to occur so keeping within the limits is important for operational effectiveness and safety.

3.2.5. Failure Propagation

The B.O.B shall not allow propagation of faults beyond the subsystem it originated in.

3.2.5.1. Failure Detection, Isolation, and Recovery (FDIR)

The B.O.B. will have failure detection in the form of a system check at the beginning of operation. It will test motor control as well as sensor and camera operation. Every day when the system starts up, it will request a picture from the camera as well as a reading from each distance sensor. During operation all of these items will be in use constantly, so if one fails during operation it will instantly be known by the system. If a sensor fails to operate the user will be notified so that the problem device can be replaced or repaired. The B.O.B. may also have a power detection to alert the user of low power, and current location, so the rover may be recovered.

3.2.5.1.1 Built In Test (BIT)

The B.O.B. may have an internal subsystem that will generate test signals and evaluate the B.O.B. responses and determine if there is a failure.

3.2.5.1.1.1 BIT Critical Fault Detection

The BIT shall be able to detect a critical fault in the B.O.B. 90 percent of the time.

Rationale: This is a requirement specified by our customer due to constraints of their system in which the B.O.B is integrating.

3.2.5.1.1.2 BIT False Alarms

The BIT shall have a false alarm rate of less than 10 percent.

Rationale: This is a requirement specified by our customer due to constraints of their system in which the B.O.B. is entering.

3.2.5.1.1.3 BIT Log

The BIT shall save the results of each test to a log that shall be stored in the B.O.B. for retrieval and clearing by maintenance personnel.

Rationale: This is a requirement specified by our customer due to constraints of their system in which the Search and Rescue System is integrating.

3.2.5.1.2 Isolation and Recovery

The B.O.B. should provide for fault isolation and recovery by enabling subsystems to be reset or disabled based upon the result of the BIT.

Rationale: This is a requirement specified by our customer due to constraints of their system in which the Search and Rescue System is integrating.

4. Support Requirements

The B.O.B. only requires that it be charged at the end of every use session. Once it has scanned all tomatoes it will require a person to plug the SD card into a computer so that it's information may be uploaded to the cloud computing software. The information will be easy to upload through a website, then all the work will be done for the farmer.

Appendix A: Acronyms and Abbreviations

Below is a list of common acronyms and abbreviations, update based upon your project….

A	Amp
BIT	Built-In Test
CCA	Circuit Card Assembly
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EO/IR	Electro-optical Infrared
FOR	Field of Regard
FOV	Field of View
GPS	Global Positioning System
GUI	Graphical User Interface
Hz	Hertz
ICD	Interface Control Document
kHz	Kilohertz (1,000 Hz)
LCD	Liquid Crystal Display
LED	Light-emitting Diode
mA	Milliamp
MHz	Megahertz (1,000,000 Hz)
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
mW	Milliwatt
PCB	Printed Circuit Board
RMS	Root Mean Square
TBD	To Be Determined
TTL	Transistor-Transistor Logic
USB	Universal Serial Bus
W	Watt
V	Volt
VME	VERSA-Module Europe

Appendix B: Definition of Terms

Fault Isolation: Process of identifying a fault in a system and preventing it from propagating to other subsystems.

Humidity: amount of water vapor in the air, expressed as a percentage of the maximum amount of water vapor the air can hold at the same temperature.

3D Inspection Rover

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Celeste Waters

INTERFACE CONTROL DOCUMENT

REVISION – Draft
February 23, 2022

INTERFACE CONTROL DOCUMENT
FOR
3D Inspection Rover

PREPARED BY:

Dalton Hines and Felipe Villegas

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Author Date 02/23/2022

APPROVED BY:

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Project Leader Date 02/23/2022

Kevin Nowka

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Kevin Nowka, P.E. Date 02/23/2022

Eric Robbles

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T/A Eric Robbles Date 02/23/2022

Change Record

Rev.	Date	Originator	Approvals	Description
1	[02/23]	[3D Inspection Rover]	Nowka, Robbles	Revision 1

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1. Overview

This document provides information about various characteristics of the rover as well as how the various components will be placed and interact with one another. The main details explored include the physical characteristics, head dissipation, electrical system, and communications of the rover and its components.

2. References and Definitions

2.1. References

Refer to section 2.2 of the Functional System Requirements document.

2.2. Definitions

CCA	Circuit Card Assembly
mA	Milliamp
mW	Milliwatt
MHz	Megahertz (1,000,000 Hz)
TBD	To Be Determined
TTL	Transistor-Transistor Logic
VME	VERSA-Module Europe

3. Physical Interface

3.1. Weight

3.1.1 Weight of Rover Body.

Component	Weight	Number of Items	Total Weight
Body	TBD	1	TBD
Wheels	TBD	4	TBD
Battery	TBD	3	TBD
Motors	TBD	4	TBD
Motor Driver	TBD	1	TBD
Raspberry Pi	TBD	1	TBD

Table 1: Weight of Rover Body

3.1.2. Camera System

Component	Weight	Number of Items	Total Weight
Angle Iron	TBD	1	TBD
Camera	TBD	1	TBD
Lens	TBD	1	TBD
Gimbal	TBD	1	TBD
Motor Driver	TBD	1	TBD
Motor	TBD	1	TBD

Table 2: Weight of Components External to the Rover Body

3.2. Dimensions

3.2.1. Dimension of Rover Body

The subsystems of the rover will be contained within the body of the rover itself which is 29.5 inches long, 27.5 inches wide, and 6 inches tall. The motors are 6.5 x 2 inches, the battery unit is 14 ⅛ x 6 inches, and the raspberry pi is 3 x 2.5 inches.

3.3. Mounting Locations

3.3.1 Rover Operation Setting

The inspection rover will be deployed in a greenhouse, organized in aisles, and with a greenhouse fabric terrain. The aisles should be free of obstacles in ordre to allow the rover to traverse smoothly. The rover should receive minimal water exposure in order to preserve the electronics onboard.

3.3.2 Placement of Units in the Rover Body

The rover’s body will contain the motors, motor drivers, batteries, and computer system so that the total size of the rover is minimized, and the center of mass can be lowered. Rover size should be minimized for ease of transportation to and from greenhouses and a low center of mass will allow the rover to operate in rough terrain without worry of tipping over.

3.3.3 Mounting of Camera

The camera will be mounted above the rover on a gimbal, which would in turn be placed on an angle iron that is mounted on the rover. This will give the camera an adequate field of view to successfully analyze the plants.

4. Thermal Interface

The rover will not produce enough heat to warrant a cooling system to help manage heat. The air surrounding the rover will be cool enough to allow for the heat to dissipate away without harming the rover and its components.

5. Electrical Interface

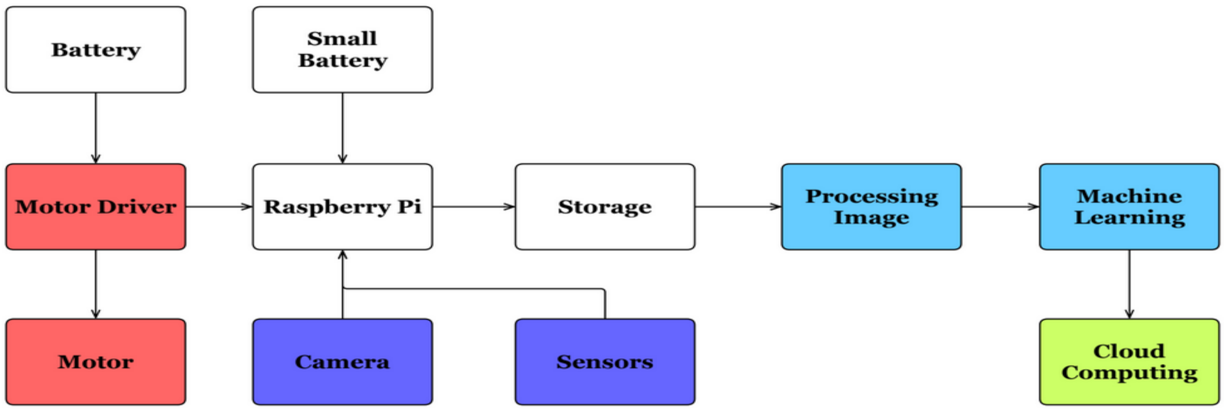

Figure 1: Block Diagram of System

5.1. Primary Input Power

2x12 Volt batteries will be used to power the motors.

1x5 volt battery will be used to power the sensors.

5.2. Voltage and Current Levels

5.2.1 Maximum Values

Component	Voltage	Current	Power
12 V Battery	12 V	18 Ah	216 Wh
5 V Battery	5 V	6 Ah	30 Wh
Sensor	TBD	TBD	TBD
Raspberry Pi 4 B	5 V	16 mA	80 W
Pi camera	TBD	TBD	TBD
Motor	24 V	TBD	TBD
Motor Driver	TBD	TBD	TBD

Table 3: Maximum Powers of Each Device

5.3. Signal Interfaces

The Raspberry Pi will take input signals as well as output signals to and from sensors, camera, and serve as the overall control unit of the rover.

5.4. User Control Interface

There will be a website that the user will be able to interact with to look at data and the geolocation of plants within the greenhouse.

6. Communications / Device Interface Protocols

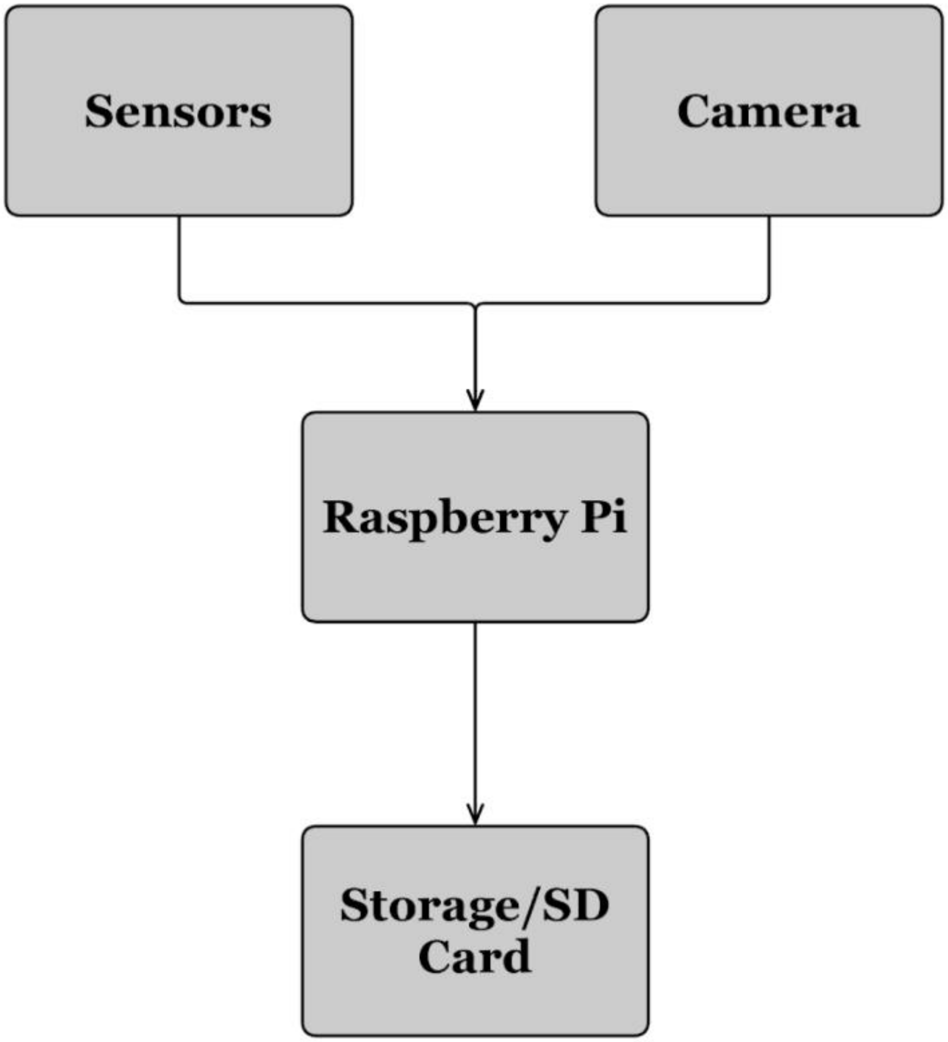

Figure 2: Peripheral Devices

6.1. Storage and Data Extraction

The Raspberry Pi will contain an SD card, which will store the results of the tomato analysis. This SD card will then be removed from the rover, inserted into a computer, and use the product accompanied website to extract the data and send it to the database.

6.2. Video Interface

The camera will be connected to the Raspberry Pi to provide the video and image feed.

6.3. Device Peripheral Interface

The rover will use distance sensors and a camera to track its current position and use this information to navigate to the next plant.

Execution and Validation Plan						
	Feb 21	Mar 7	Mar 21	Apr 4	Apr 18	May 2
Chris	Necessary Software installed on RPpi	Control of all 4 motors, with left and right motors working in conjunction	Setup and Understanding of Distance sensor outputs	Set up and understanding of color sensor outputs	Motor Response to distance sensors	Motor response to color sensors/Functioning Subsystem
Celeste	Server setup	Setup SQL database	Program to file and sort images	Populated Database	Refine and Testing	Output expected plant yield, health, and statistics
Dalton	Set-up Raspberry Pi for use with motors and camera	Control of motor for camera movement	Program Image Segmentation	Program Image Segmentation/ Accuracy testing for round objects	Integrate camera movement with Image Segmentation	Image flagging and storage
Felipe	Begin acquiring a dataset, labeling, and select ML model	Dataset and feature selection ready	Implement ML model and begin training	ML model validation and iteration	Finetune and optimize ML program	Final Testing and adjustments

Complete:

- Bill of Materials (BOM) submitted for approval
- Identification of needs for every subsystem