RIGOROUS LLC

January, 2022

High Tunnel Gantry System

Critical Design Review

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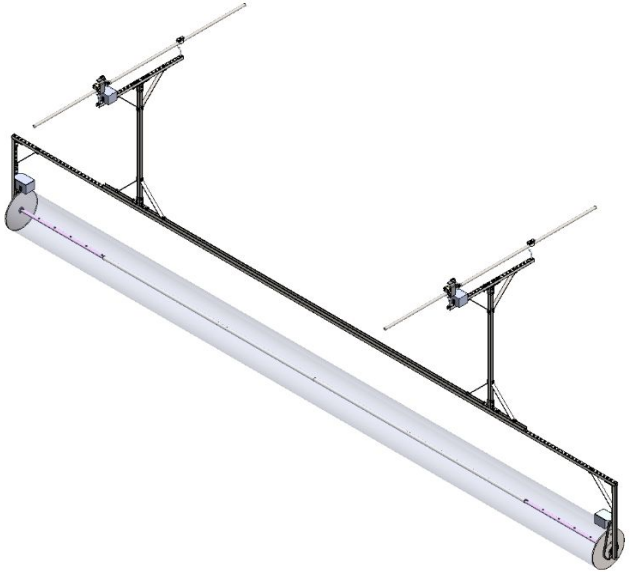
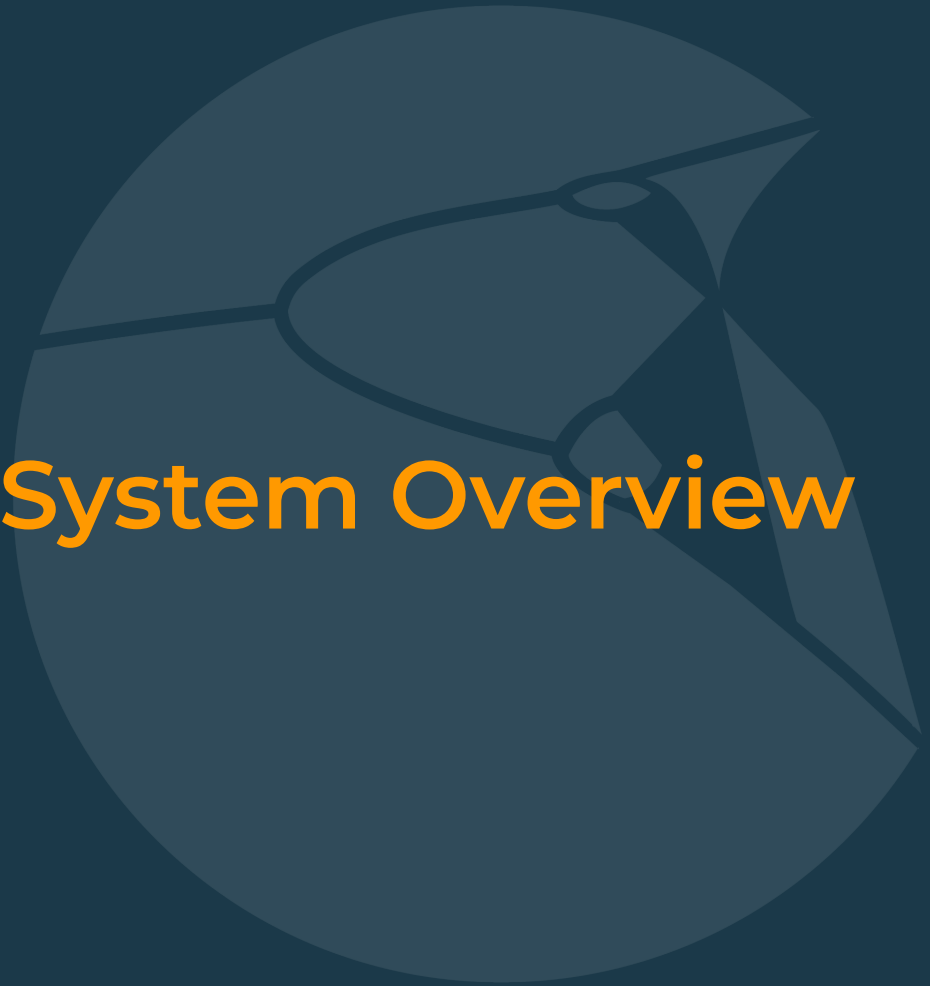
Agenda

1. System Overview
2. Updated Designs
   a. Transport Cart
   b. Toolbar
   c. Trolley Car
   d. ARCS
   e. Software
3. Bill of Materials
4. Labor Studies
5. Outreach





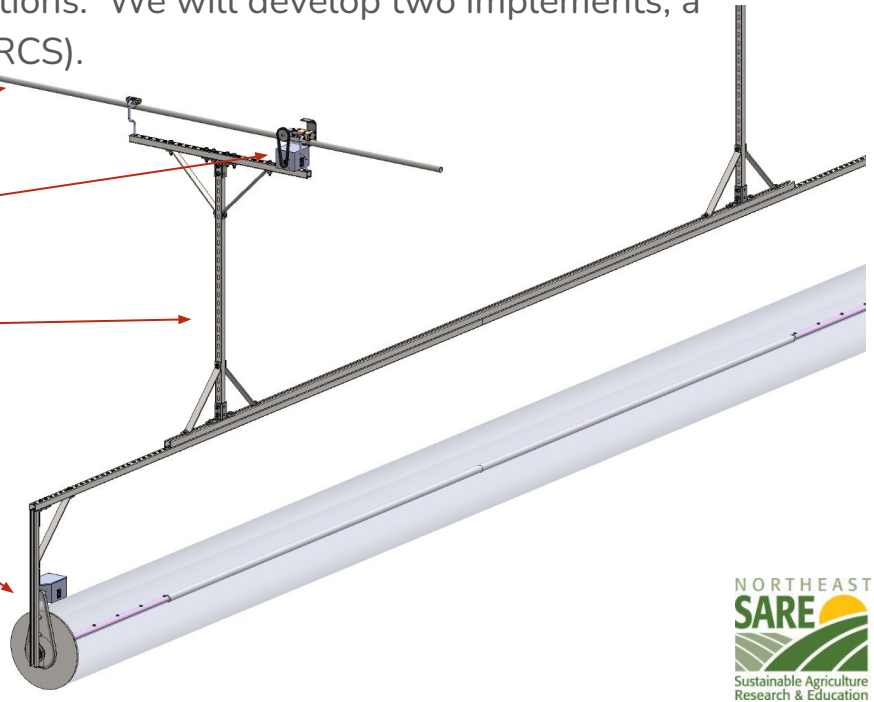
System Overview

System Overview

The High Tunnel Gantry System (HTGS) consists of one or more overhead rails, used as a monorail or together with a toolbar. Like a tractor, the toolbar works with interchangeable implements. A Trolley Car moves the implements along the rails to precise locations. We will develop two implements; a Transport Cart and an Automated Row Cover System (ARCS).

Primary Subsystems

- Rail System
- Transport Cart
- Trolley Car
- Toolbar
- Automated Row Cover System (ARCS)



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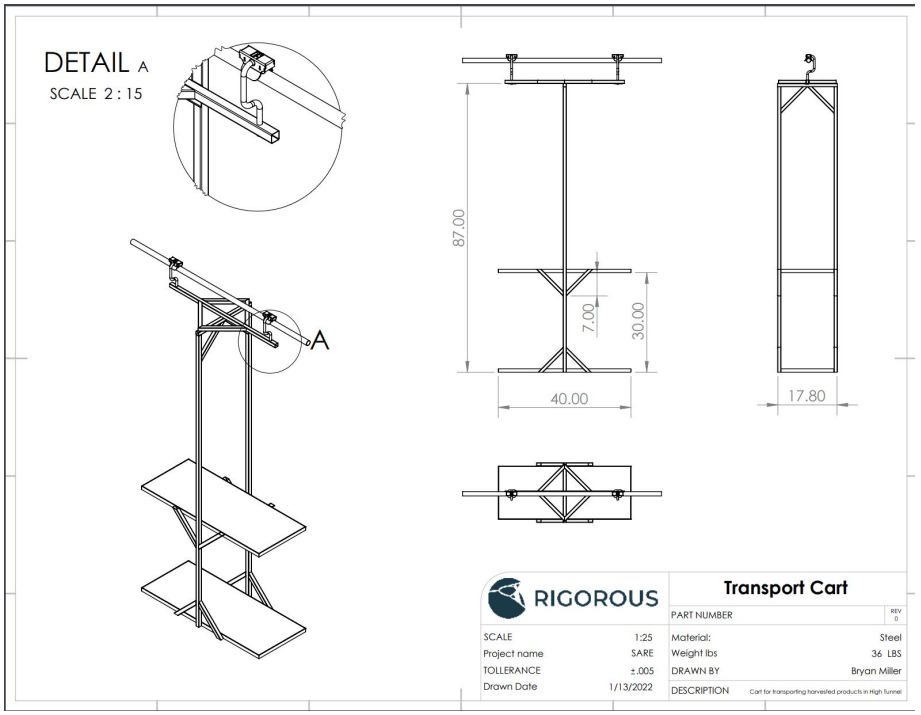
Transport Cart

- Keep cart weight < 55 lbs
- Easy on/off of rail without accidental dismounting
- 1” Steel square tubing, accessible and easy to weld
- Fits standard bins
- Cannot be significantly overloaded



Rimol Gothic Style High Tunnel 30’ x 96”

- Truss style supports are necessary to support estimated loads (300lbs per rail)
- Space between outside bed and sidewall - 18”
- Width of beds, inside baseboard to baseboard - 29’ 10”
- Hipboard height - 6’
- Crossbar height - 9’8” - 9’10”
- Distance between crossbars - 16’7”

Updated Designs

Rail System

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Rail System - Overview

The Rail System is the track for the gantry system. The rails are placed above the rows in the high tunnel, allowing the passage of tooling throughout the season. Gantry tools use the rails for transportation throughout the high tunnel. The rails are made from SS20 round pipe used for fence top rails and hung with U-bolt hangers. Rails are connected by swaged fittings and screws.

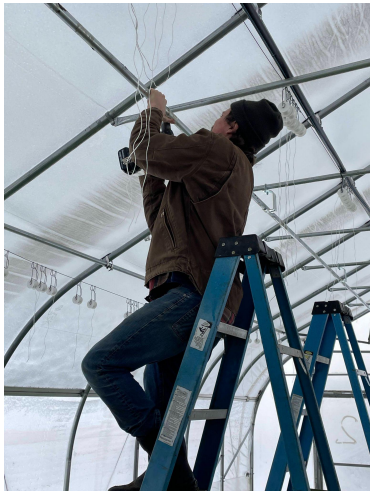
Subsystems

- Rail - Round tube that creates a track for the gantry system.
- Hangers - U shaped hanger to support the rail and allow trolley passage.
- Rail Connections - Swaged ends plus screws.

Hanger

Rail Connector

Rail



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Rail System - Rail

The rail is a 1 3/8” SS20 fence top rail that is hung from the high tunnel cross bars to act as a track for the gantry system. Fence top rail is readily available and can typically be purchased locally to mitigate shipping costs.

Functions

- Gantry Track - All HTGS implements utilize the rail as a track for trolley passage.

Key Requirements

- Load: 300 lbf
- Easy passage of hanging trolleys

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Rail System - Rail Connectors

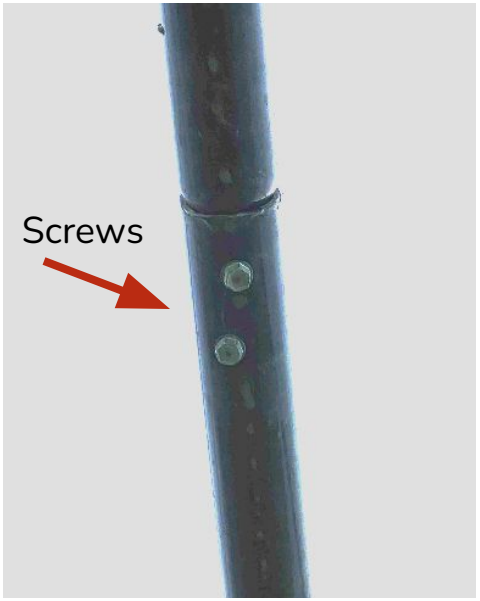
The rails have a swaged end and an open end. The rails are connected by inserting the swaged end into the next rail's open end. The connection is secured with screws.

Functions

- Swaged Fitting - Swage fittings allow easy for easy installation.
- Screw Fastener - Two screws prevent the rails for seperating.

Key Requirements

- Trolley Passage - Connections need to be smooth on the upper portion of the rail to allow smooth trolley passage.



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Rail System - Hangers

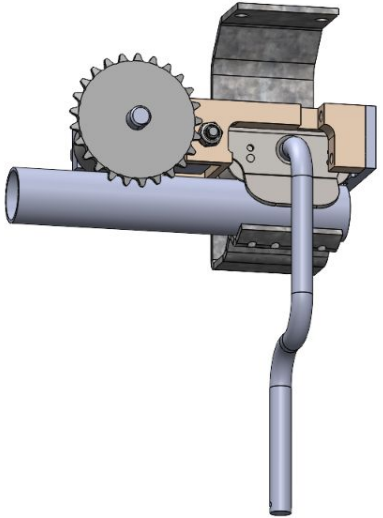
The hangers attach to the high tunnel cross bars with a U-bolt. A C-bracket hangs below with a mounting location for the rail. The rail is bolted to the bottom of the C-bracket.

Functions

- Rail Hanger - U-Bolt hanger with C-Bracket and mounting location for rail

Key Requirements

- Vertical Clearance - 5.5 inches
- Horizontal Clearance - 2 inches



Transport Cart

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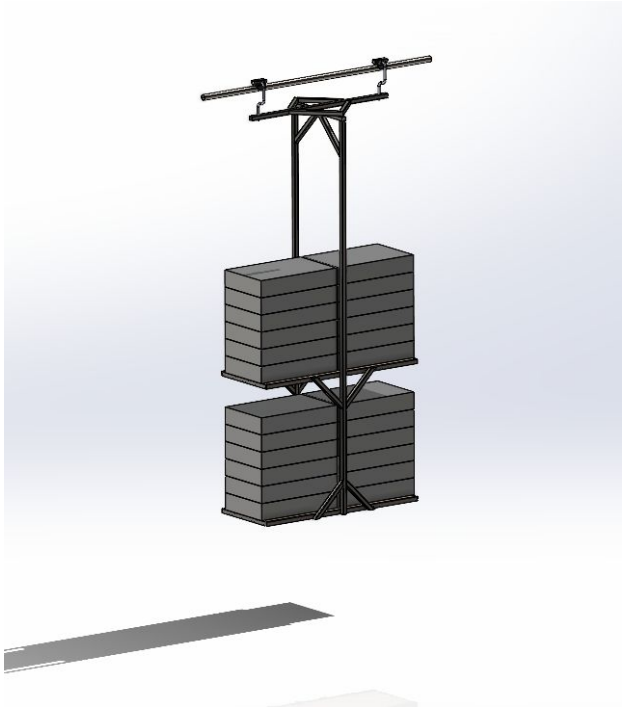
Transport Cart

The Transport Cart is a hanging cart used to move objects throughout the high tunnel. The cart includes built shelves and trolleys to attach to the rail. The cart hangs from a single rail and is pushed down a row or can be attached to the motorized Trolley Car. The cart can be lifted from the rail and moved between rows.



Subsystems

- Frame - Support structure for the transport cart.
- Trolleys - Two hanging trolleys to hang the frame from the rail.
- Shelves - Two shelves to place objects for transport.

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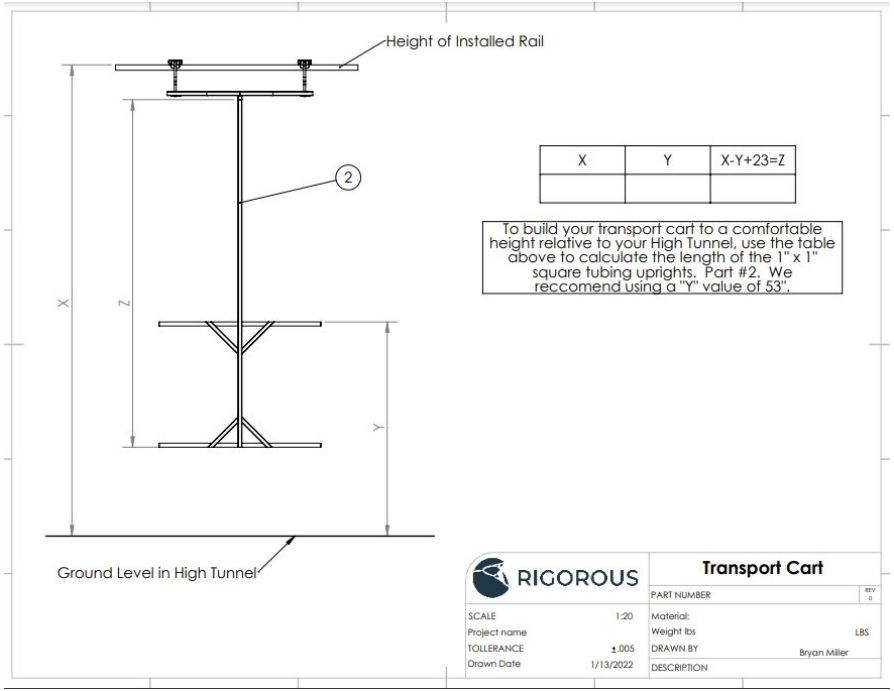
Transport Cart - Frame

We have updated the Transport Cart to better meet the requirements of the system, including narrowing the width and allowing for easy front and back loading.

We considered making the height adjustable, but found there were strength, weight, and complexity tradeoffs. We decided to move forward with a model that can be easily updated according to desired height, but not adjustable once it is built.

Our design is made out of aluminum, but can easily be fabricated in the same geometry with steel.

The frame hangs off of two Railex trolleys (RTP 514) which can support up to 125 lbs each, so 250 lbs combined.



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Transport Cart - Shelves

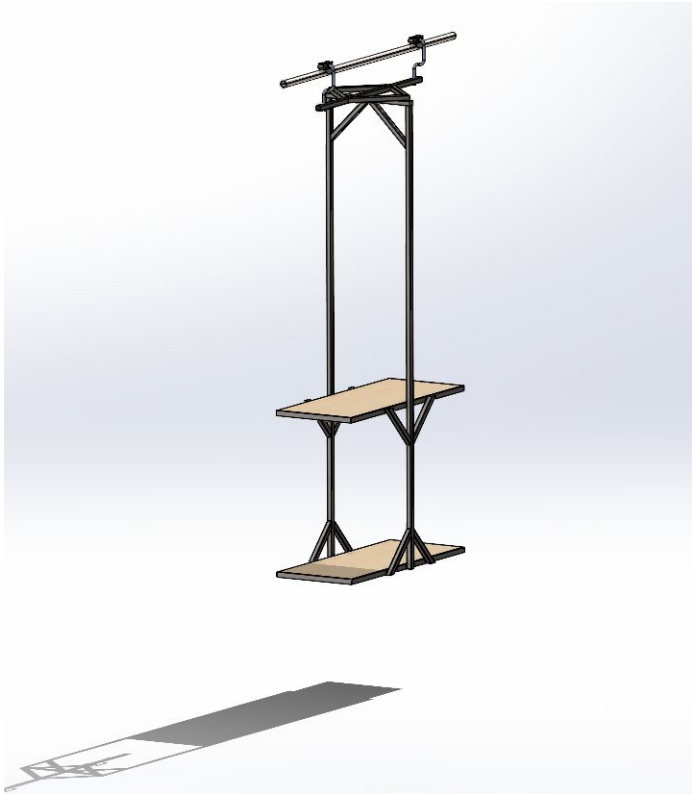
The ¾” plywood shelves are designed to support a variety of popular tray, crate, and carton sizes. We opted to make the shelves narrower to better fit between rows rather than support wider containers such as bread trays.

Functions

- Shelf Base - Plywood insert for the shelf base.
- Supported Containers:
  - 10# Tomato Cartons (13”W x 20”L x 3.75”D) (2-wide)
  - 15# Tomato Cartons (16”W x 23.5”L x 4.5”D) (2-wide)
  - Plastic 10# Tomato Tray (13.25”W x 19”L x 5”D)
  - 1020 Plant Trays (10.94”W x 21.44” L x 2.44”D)
  - Stackable Crate (23.75”W X 18”L X 11.5” D) - top shelf only

Key Requirements

- Number of Shelves - 2
- Strong enough to hold 300 lbs



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Transport Cart - Load Capacity

Tray Name	Tray Size	Cart Capacity	Stack Size	Weight
10# Tomato Cartons	13”x20”x3.75”	20	5	200 lbs
15# Tomato Cartons	16”x23.5”x4.5”	14	3/4	210 lbs
1020 Trays	11”x21.5”x2.5”	7	1	n/a
Stackable Crate	23.75”W X 18”L X 11.5” D	4	2 (top shelf only)	160 lbs

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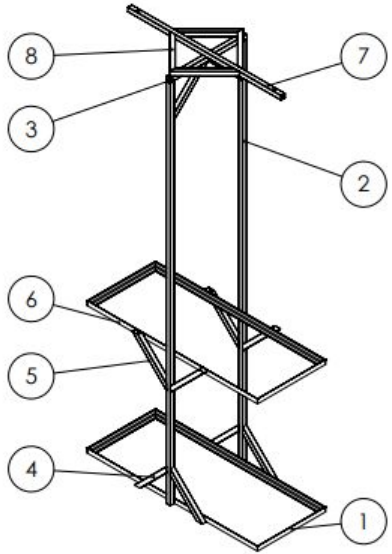
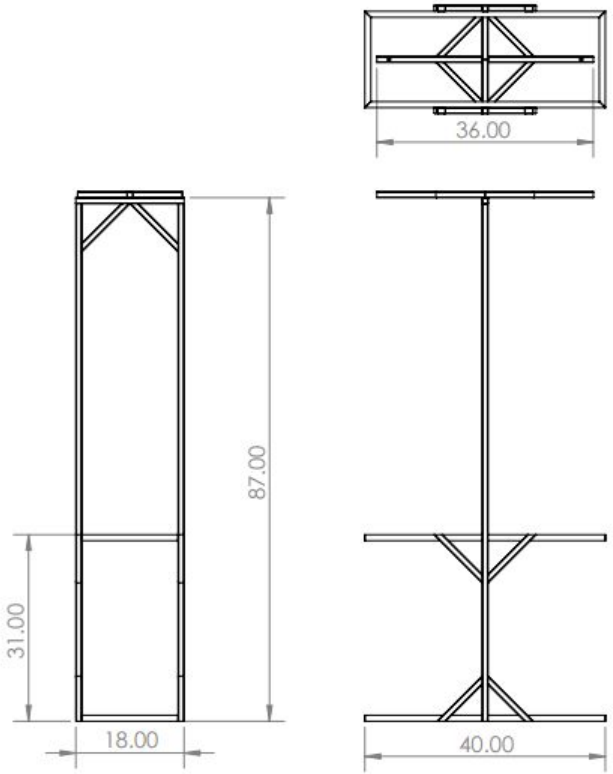
ITEM NO.	QTY.	DESCRIPTION	LENGTH
1	4	L 1.00 X 1.00 X .125	16
2	2	1" x 1" Square Tubing	86
3	1	1" x 1" Square Tubing	18
4	4	1" x 1" Square Tubing	10.6066
5	6	1" x 1" Square Tubing	11.3137
6	4	L 1.00 X 1.00 X .125	40
7	1	1" x 1" Square Tubing	36
8	4	1" x 1" Square Tubing	11.6066





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Cart Frame

PART NUMBER	CartFrame001	REV	D
SCALE	1:20	Material:	AISI 1020 Steel, Cold Rolled
Project name	ARCS	Weight lbs	33.9100 LBS
TOLLERANCE	±.005	DRAWN BY	Bryan Miller
Drawn Date	1/13/2022	DESCRIPTION	Hangs from Rollex roller, platform sets inside frame

Toolbar

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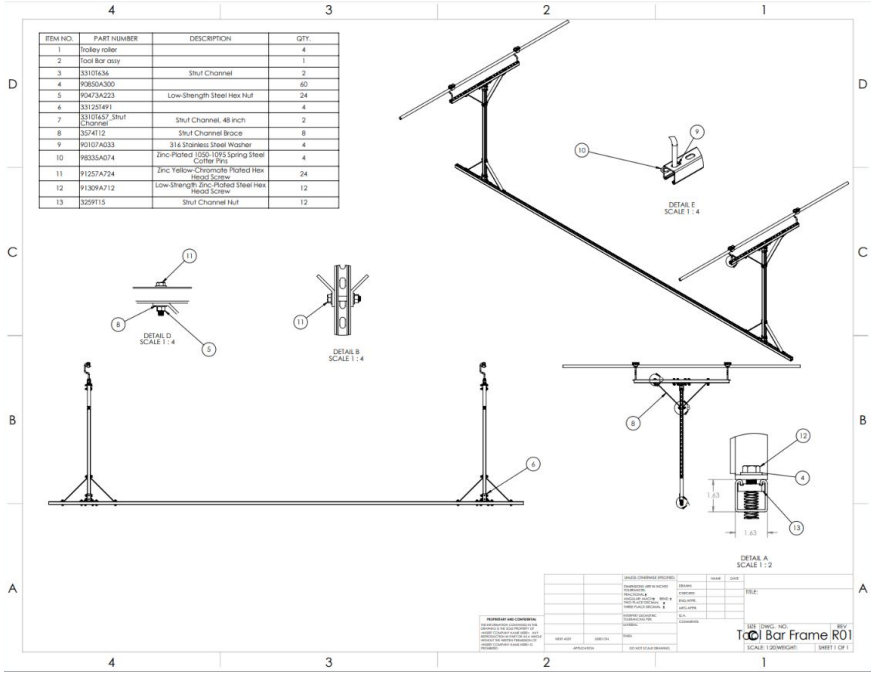
Toolbar - Overview

The Toolbar serves as a generic attachment to connect implements and tooling. The toolbar is designed to span multiple rails and be driven by multiple Trolley Cars. The toolbar includes passive Trolleys to hang from the Rail System.

Subsystems

- Frame - Support Structure for the Toolbar.
- Adjustable Height - System to adjust the height of the tool bar.
- Attachment Point - System to attach tooling to the toolbar.
- Trolleys - Four hanging trolleys to hang the frame from the rail. This is the same trolley used for the Transport Cart.



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Toolbar - Frame

The Toolbar Frame is designed to hang from Trolleys on the Rail System. The Frame will include rigid bars from the Trolleys to a spanning bar for Tooling Attachments. The Frame must support the ARCS load weight and torque applied during spooling operations.

Functions

- Trolley Attachment Point - Unistrut Bar with holes for trolley pin and fastener connection.
- Vertical Hanging Bar - Vertical bars to lower toolbar from Rail System.
- Horizontal Toolbar - Primary toolbar with Unistrut for Tooling Attachments.
- Truss System - Support structure for the Horizontal Toolbar.

Key Requirements

- Load: 250 lbf

Trolley Car

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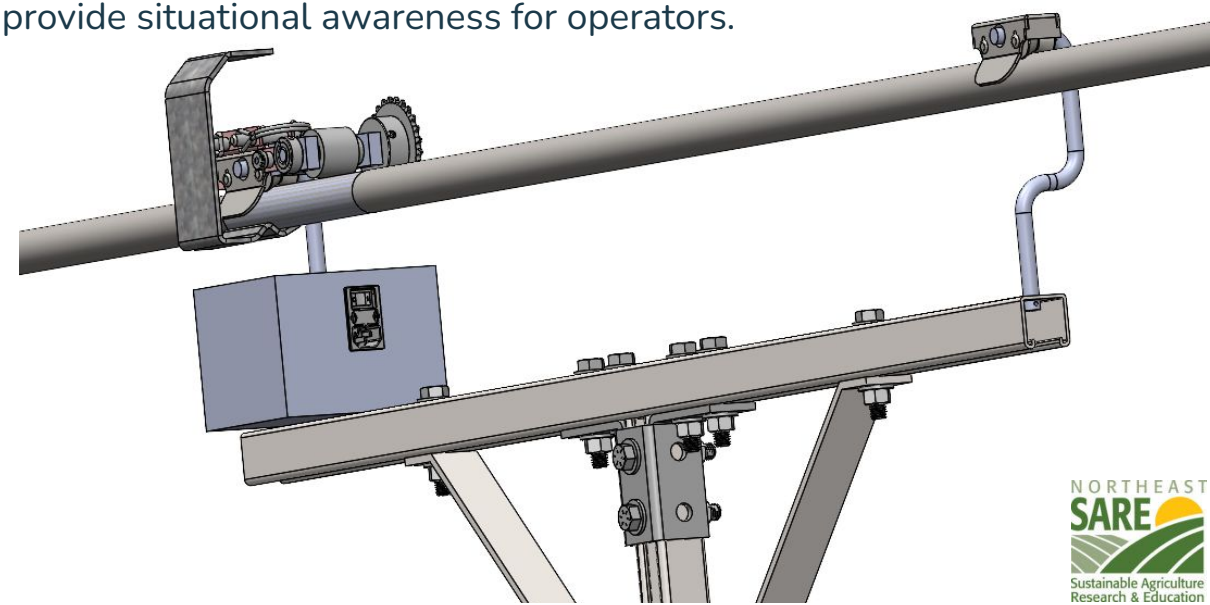
Trolley Car - Overview

The Trolley Car is a motorized trolley that connects to the toolbar and moves implements on the Rail System. The Trolley Car has one drive wheel connected to a drive motor to move the trolley down the rail. The system will calculate the position of the Trolley car along the track using motor position feedback. An internal control system will manage the movement and process external motion commands. Trolley Cars can operate independently or together in coordinated motions. A bottom facing camera will record crow imagery and provide situational awareness for operators.

Subsystems

- Enclosure
- Hitch
- Traction System
- Drive System
- Trolley Control System
- Vision System



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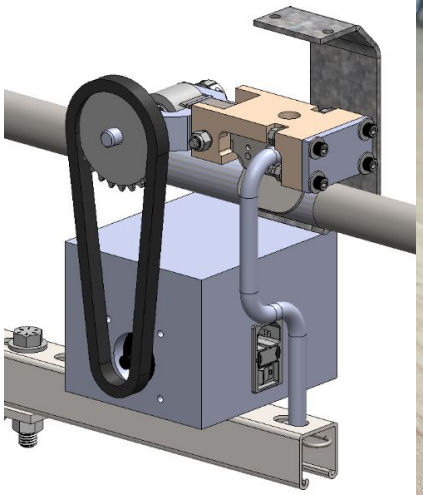
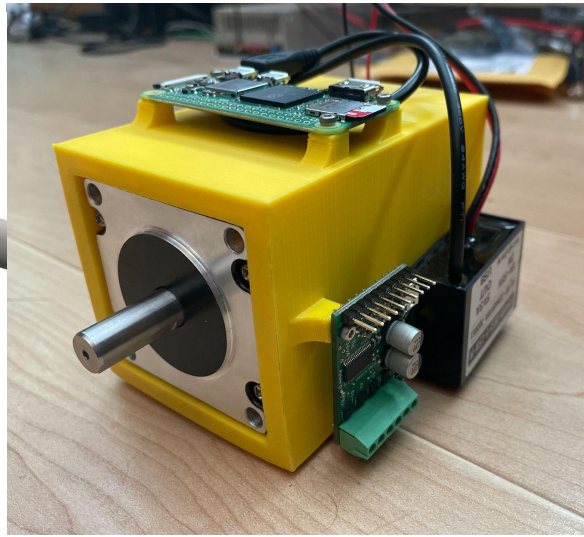
Trolley Car - Enclosure

The enclosure houses the electrical system, drive system, and computing system for the Trolley Car. The enclosure can be quickly moved between rails and attaches to implements using the integrated hitch.

Functions

- Integrated Mounting Features - Built in standoffs to mount the following system components:
  - **Traction System:** Bearings, Shaft, Drive Wheels
  - **Drive System:** Motor, Motor Controller
  - **Power Electronics:** AC Receptacle w/ Fuse & Power Switch, 48VDC Converter, 5 VDC Converter
  - **Computing System:** Computer, Camera
- Trolley Hitch - Hitch to attach trolley to implements including the toolbar.



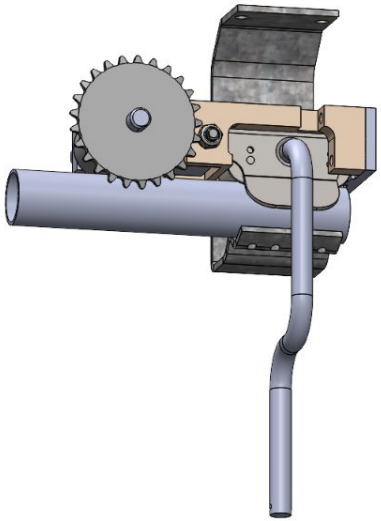


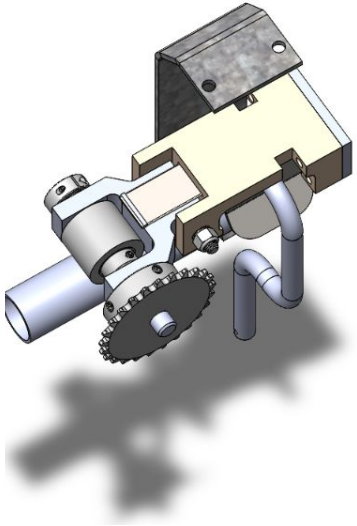
Key Requirements

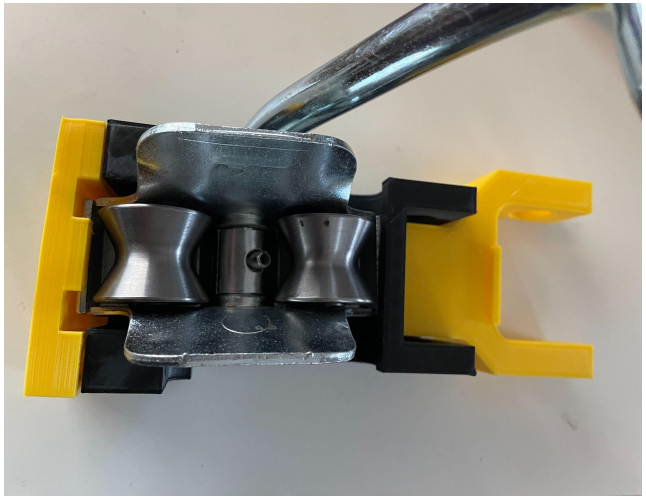
- Water and Dust Resistant - All system components will be fully enclosed without gaps in the lids.

Trolley Car - Hitch

The hitch is made up of 3D printed components, a spring, and hardware. It clamps over the trolleys (one per rail) with a built-in system that will drive the components.







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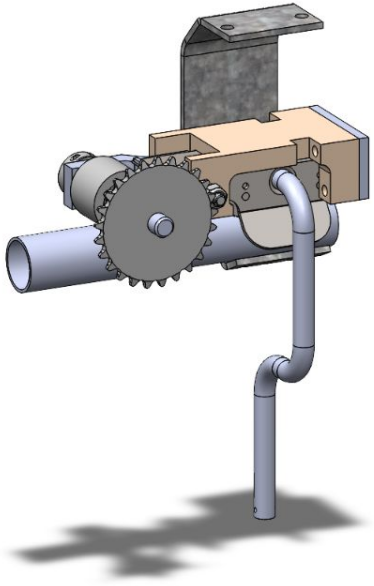
Trolley Car - Traction System

The Traction System converts the motors rotational motion into linear motion along the rail.

The weight of the toolbar and implements are the normal force applied to the wheel for traction along the rail. The drive wheel is attached by a drive shaft and chain & sprocket to the motor.



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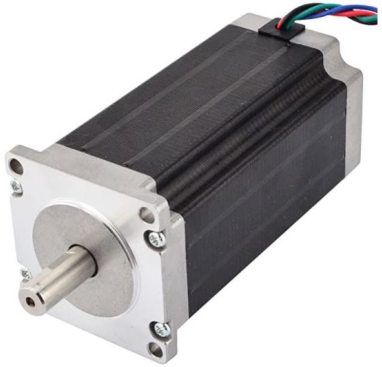
Trolley Car - Drive system

The Drive System provides the power for the Traction System. A stepper motor drives a sprocket connected to the Traction System. A motor controller provide powers and control for the Trolley Car.

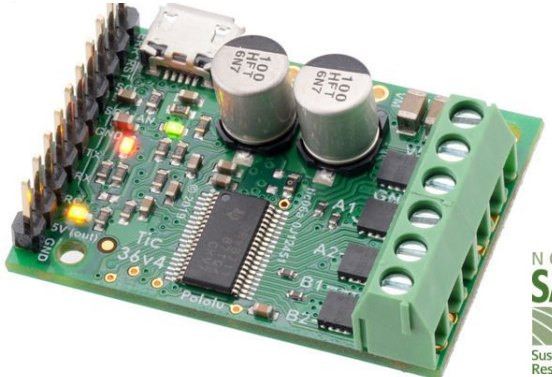
Functions

- NMEA 23 Stepper Motor - Motor for driving traction system. Motor position output used for relative positioning.
- Motor Controller - Power and controller for the stepper motor. Digital interface for status and control.



Key Requirements

- Motor Torque: 425 oz. in.
- Motor Voltage: 48 VDC
- Motor Current: 4 Amps



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Automated Row Cover System (ARCS)

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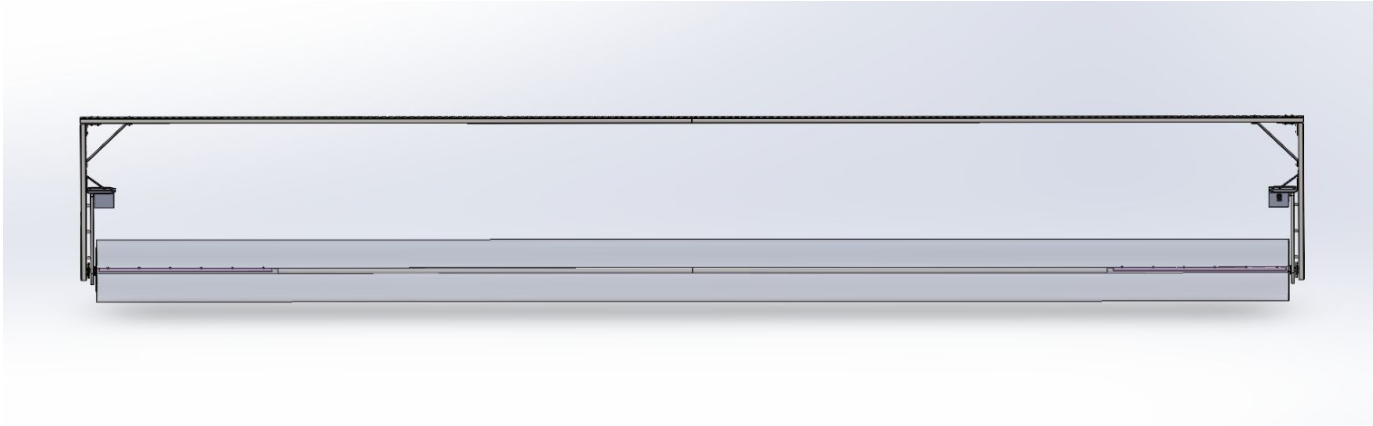
ARCS - Overview

The Automatic Row Cover System (ARCS) is designed to automatically spool row cover. The system will span the width of the high tunnel and will attach to the toolbar. The Trolley Car will automatically move the system down the high tunnel during spooling operations. The ARCS will include spooling motors and control system to automatically manage row cover.

Subsystems

- Frame
- Spool Drive System
- Motor Module
- ARCS Controller
- ARCS User Interface



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ARCS - Frame

The ARCS frame will attach to the Toolbar. The frame will provide support and mounting for the main spool and row cover spooling system. The spool must span the distance of the high tunnel, maximizing wall to wall coverage. The width of the frame is dictated by the width of the high tunnel at the height of the toolbar. To maximize potential width, we narrowed the height of the ARCS frame and lowered the toolbar.

Functions

- Toolbar Attachment - Attachment from the ARCS Frame to the Toolbar.
- Main Spool Mounting - Structure and bearing to support a fully loaded spool.
- Drive System Mounting - Mounting for the motors and drive system.
- Spool - Shaft to load row cover.

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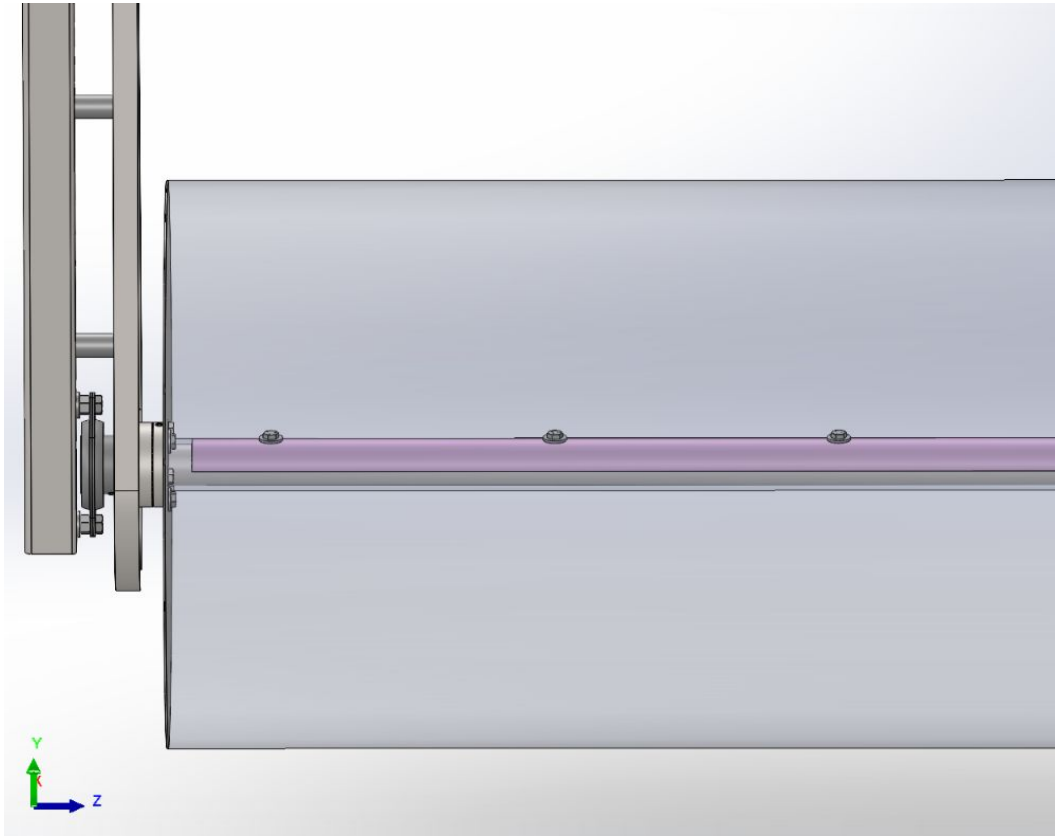
ARCS - Row Cover Roll

- Remay size 30’ x 100’
- Targeting 27’10” (down from 28’6”) wide remay on the roll
- Typar T-518 Row Cover
- PVC clip to attach to bar



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ARCS - Spool Drive System

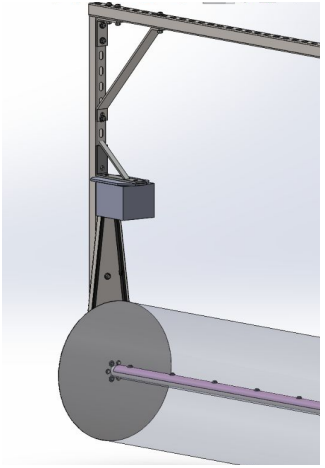
The Row Cover Spooling System is the main drive mechanism for spooling row cover. The spooling system includes drive motors to rotate the spool in both directions. The drive mechanism transfers rotational power from the motors to the main spool.

Functions

- Spooling Motors - Two motor modules to drive both sides of the spool.
- Drive Mechanism - Sprocket and chains to drive the spool.

Key Requirements

- NEMA 23 Motor Module - Utilize the components from Trolley Car.



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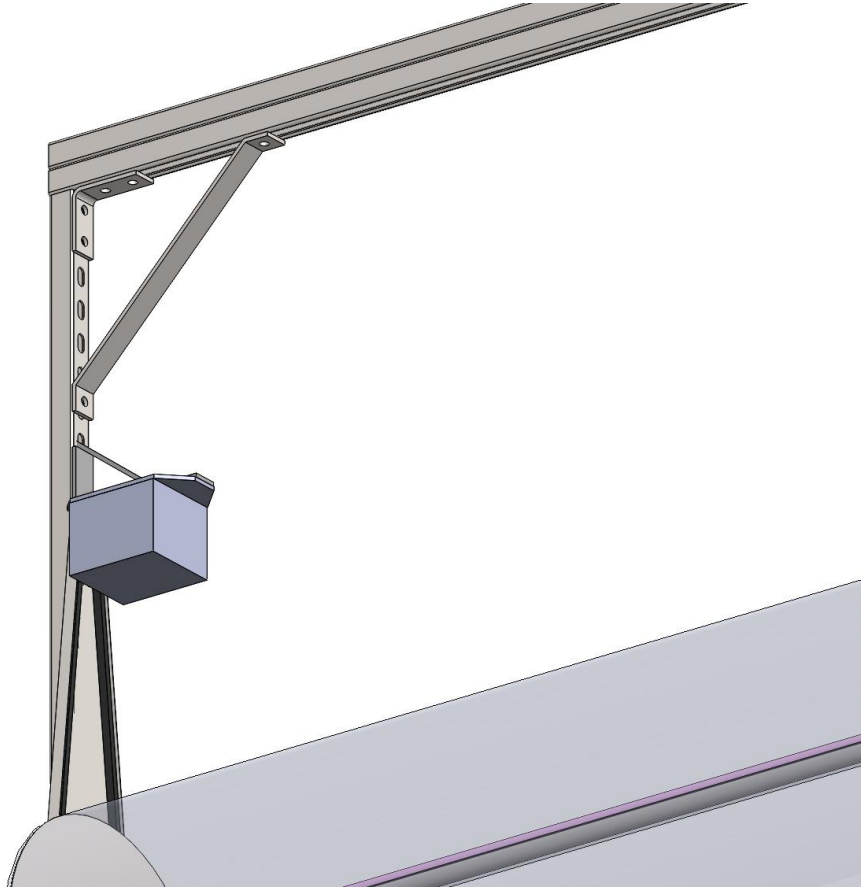
ARCS - Attachment Point

The Unistrut allows for various attachment points to provide a mechanism to attach tools and implements to the Toolbar.

We shortened the vertical struts of the ARCS to 3’ (down from 4’). This provided enough horizontal clearance to allow for a 27’10” roll of row cover.

Functions

- Off-the-shelf attachment system.
- Non-permanent attachment for implements.
- Supports 30’ span, anticipates bend in metal.



Software

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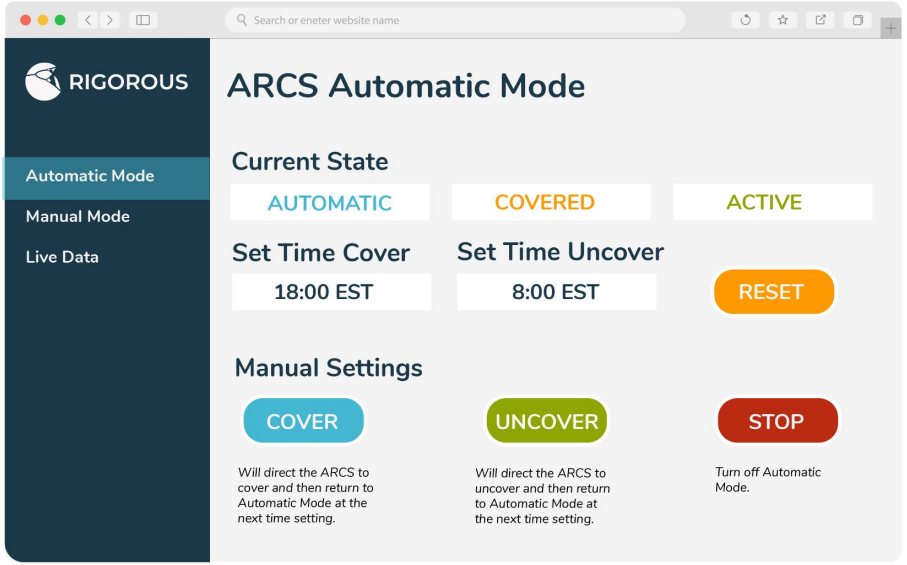
Software - Overview

The software system provides ARCS operators with the ability to control and receive status from the system. The system uses distributed Raspberry Pi computers to control individually control each ARCS motor. Additionally the system includes a system controller to coordinate the 4 motors for ARCS operators. Finally there is a local website that allows operators to view status, configure, and control the ARCS. All software is written in Python and will be running on embedded computers.

Subsystems

- Motor Control
- ARCS Control
- ARCS User Interface



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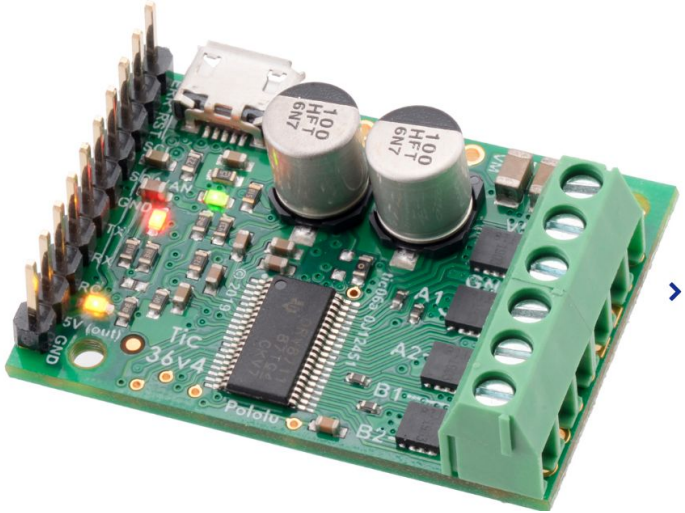
Software - Motor Control

We are using a Pololu stepper motor controller for all motor enclosures. Each motor enclosure includes a control computer that will run a dedicated motor control application. The application will manage motor motion and collect motor controller status information.

Functions

- Motor Control
  - Enable State
  - Relative Position Control
- Motor Status
  - Enable State
  - Motor Current
  - Relative Position



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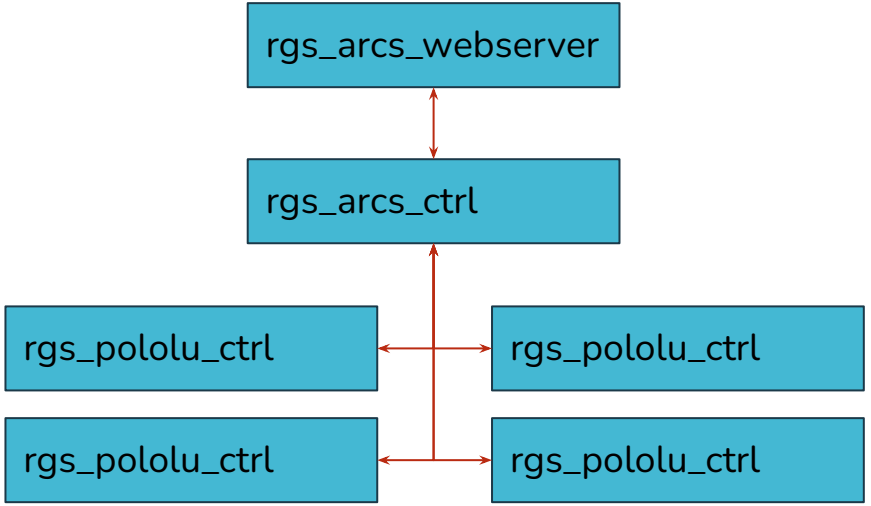
Software - ARCS Control

The ARCS controller will communicate with all motor controllers to coordinate them for row cover management. The controller will monitor each motors relative position and create an absolute position along the rail. Additionally manual function will be included for system maintenance and testing.

Functions

- Motion Control
  - Control Modes: Automatic, Manual, Stop
  - Trolley Motion Synchronization System
  - Spooling Synchronization System
  - Automatic Cover Time Settings
- Status Monitoring
  - Excessive Power Fault
  - Subsystem Communications
- Absolute Rail Positioning
  - Homing Routine
  - Position Monitoring



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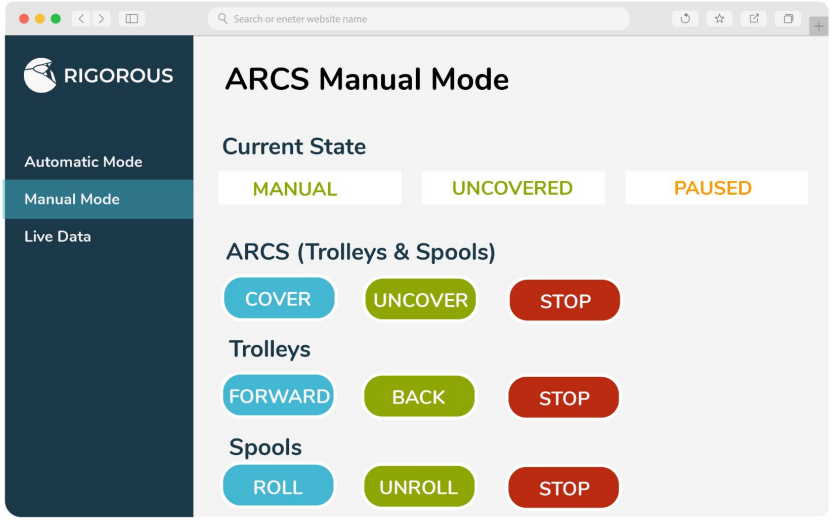
Software - ARCS User Interface

The ARCS user interface is a locally hosted website on the ARCS that provides system status and control. The user interface will communicate directly with the ARCS controller to view system data and set configurations for automatic controls.

Functions

- System Controls
  - Mode Selection
  - Cover Time Configurations
  - Temporary Automatic Cover Override
  - Manual System Controls
- System Status
  - System Mode
  - State of Row Cover (Covered/Uncovered)
  - ARCS Rail Position
  - Individual Motor Status



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Potential Issues

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Potential Issues

Issue	Solution(s)
Unlevel high tunnel / rail	Braking System
	Level the rail
ARCS too narrow	Two systems run on three rails
	Hooped or angled attachment to toolbar

Bill of Materials

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Sub System	Spent Thus Far	Not Included
Rail (200 ft)	$1,335.25	*End caps
Toolbar (x2)	$464.05	*Strut Channel
Trolley Car (x2) & Enclosures (x2)	$493.77	*Braking system (optional)
Motor Box (x4)	$887.17	
ARCS Frame	$1,484.20	*Strut Channel *Pipe for Spool *PVC Clips
Transport Cart	$524.28	*Shelf inserts
Total	$5,188.72	

Labor Studies

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ARCS

Currently, the Jericho Settlers team are logging labor time to move row cover in a comparable high tunnel to where the ARCS will operate for testing. Due to delays in our schedule, we opted to separate the time logging from the system testing to capitalize upon the time period when the row cover would need to be managed regularly based on the planting schedule.

Goals

- Track the number of hours necessary to manage row cover in one house for a one-month period
- Extrapolate the monetary benefit of replacing that labor cost to determine the potential return on investment for the ARCS
- Determine and list additional benefits to the farmer

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Transport Cart

During peak tomato season, the JSF team will track harvest tomato hours. There will be one test bed, which contains the Transport Cart, and one control bed, which will be harvested with current methods. The JSF team will log the total number of flats, size of flats, and harvest time for 2 months.

Goals

- Track the number of hours necessary to harvest tomatoes with the cart and in a control environment without the cart
- Compare the time and weight-carry savings during the harvest periods

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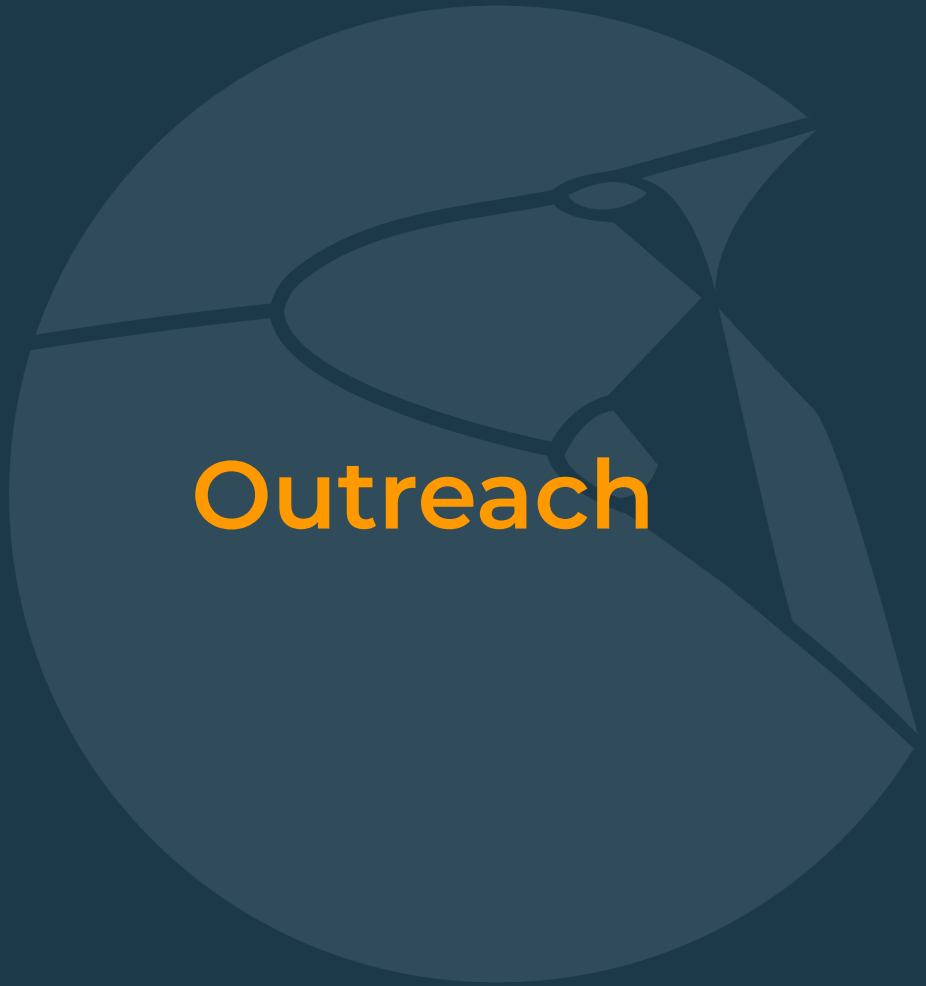

Outreach

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Direct Outreach

- 1:1 conversations with 20 Farmers in the Northeast to discuss functionality and desirability
- Design Review Board to meet twice during the design process for in depth knowledge and feedback
- Workshops
  - Winter/Spring workshop - ARCS
  - Summer workshop - Harvest Cart & Rail System
- Conferences
  - NOFA VT Winter 2023 (Feb)
  - NEVBGA Winter 2022 (Dec)

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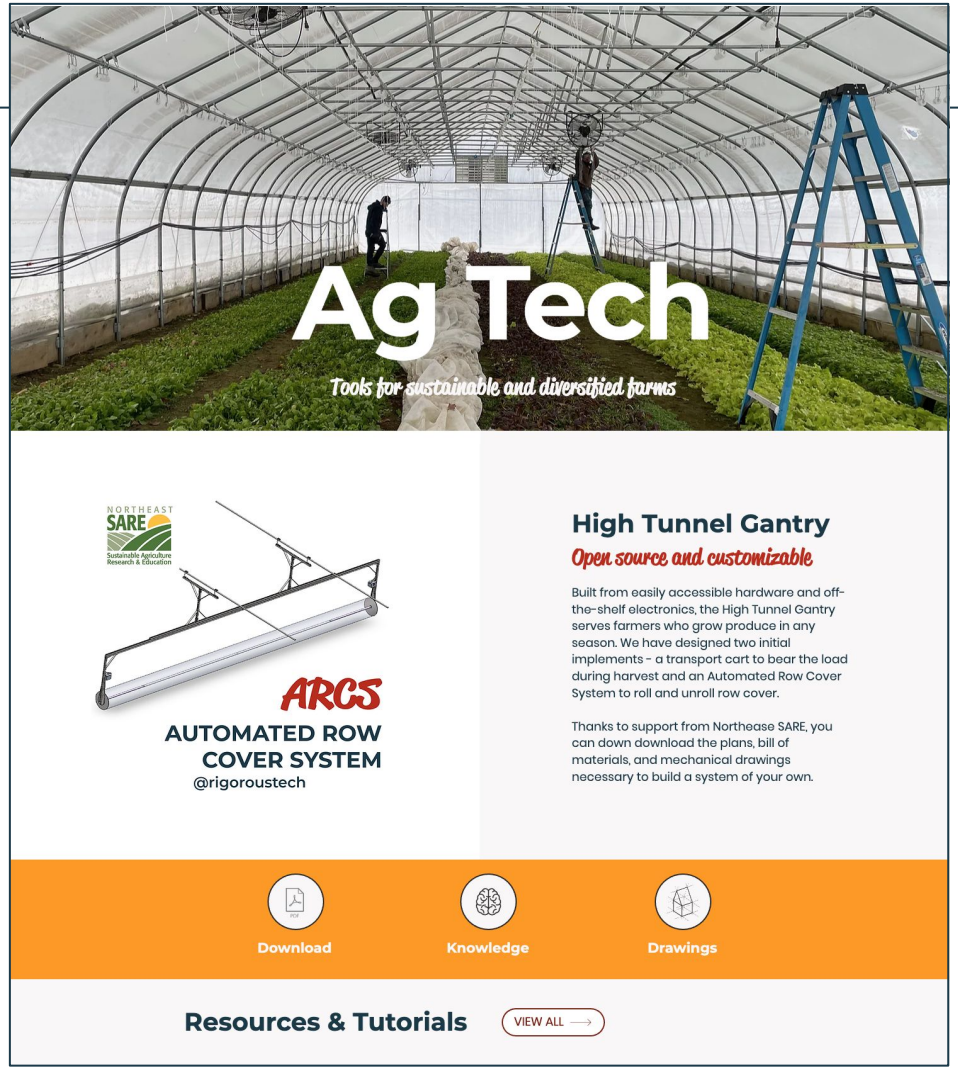
Digital Awareness

- Downloadable designs and digital resources
  - Rigorous website - downloadable designs, including drawings and bills of materials
  - Blog and video tutorials for how-to build (website and Youtube)
  - Instagram shorts to drive traffic
  - Upload designs to Farmhack.org



Thank You