TECHNICAL MANUAL

BVR1

Base Vectoring Rover

Revision 1.0   January 2026

Municipal Robotics
Cleveland, Ohio
muni.works

Contents

About This Manual

This manual is written by the people who built and operate BVR rovers. It's not a marketing document or a wish list: it's the real procedures we use, with the mistakes we've made and the lessons we've learned.

If something is unclear, wrong, or missing, let us know. This is a living document that improves with every build.

Revision History

Rev	Date	Changes
1.0	January 2026	Initial release (based on BVR0 manual)

What's New in BVR1

BVR1 builds on the BVR0 platform with several upgrades:

- **Larger wheels**: 8″ wheels (vs 6.5″ in BVR0) for better ground clearance and obstacle handling
- **Motor brackets**: Bicycle-style mounting brackets for easier wheel service and alignment
- **Custom battery pack**: 13S4P 21700 cells in a dedicated tray (vs downtube battery in BVR0)
- **Lighting**: Integrated headlights and tail lights for visibility and low-light operation
- **Improved sensor mast**: Reinforced design with cable routing channels

Most assembly procedures are identical to BVR0. This manual highlights BVR1-specific differences.

Document Conventions

Throughout this manual you'll see:

"We learned…"	Lessons from real build experience
⚡ COMMON MISTAKE	Errors we've seen (and made)
●●○	Difficulty rating (1-3)
15 min	Estimated time for procedure

> ℹ **NOTE** This is a living document. Report errors or suggestions at github.com/muni-works/muni.

BVR0 Cheat Sheet

Print this page. Laminate it. Tape it to your workbench.

Emergency Stop

1. Red button on rover
2. Spacebar on controller
3. Guide button (gamepad)
4. Connection loss (auto)

CAN Bus IDs

0	VESC Front Left
1	VESC Front Right
2	VESC Rear Left
3	VESC Rear Right
10+	Tool Attachments
0x0B00	LED Controller

Battery Voltages

Full charge	**54.6V**
Nominal	48V
Low warning	42V
Cutoff	**39V**
12V rail	11.5-12.5V

Torque Specs

Frame (M5)	**4 Nm**
Motor mounts (M5)	**4 Nm**
Electronics (M3)	**0.5 Nm**
Wheel axle	Hand tight

Wire Colors

- Orange: 48V Power (+)
- Black: Ground (-)
- Red: 12V Power
- Blue: Motor Phase A
- Green: Motor Phase B
- Yellow: Motor Phase C
- Purple: CAN High
- Cyan: CAN Low

LED Status Codes

- Solid Ready
- Pulse Teleop
- Pulse Autonomous
- Blink Low Battery
- Solid E-Stop
- Fast Fault
- Off No Power

CLI Commands

muni status	Health
muni can scan	Devices
muni motors test	Spin
muni leds set idle	Reset
muni logs -f	Live logs
systemctl restart bvrd	Restart

Network Ports

Hostname	bvr-XX
SSH	22
WebSocket	8080
Video	5600
Metrics	8086

Pre-Flight (2 min)

- ☐ Battery > 42V
- ☐ E-Stop released
- ☐ Wheels spin free
- ☐ Wheel bolts tight
- ☐ Connectors secure
- ☐ Camera/LiDAR clean
- ☐ Controller paired

Quick Troubleshooting

No power
→ Check breaker, battery

Motors not responding
→ Release E-Stop, muni can scan

Erratic movement
→ Check motor IDs, phase order

Video lag
→ Check WiFi, reduce resolution

GPS no fix
→ Open sky, check antenna

Dimensions

Frame L × W	60 × 50 cm
Height	45 cm
Wheelbase	45 cm
Track width	55 cm
Clearance	8 cm
Weight (empty)	15 kg

Support

Web	muni.works
Docs	muni.works/docs
GitHub	github.com/muni-works

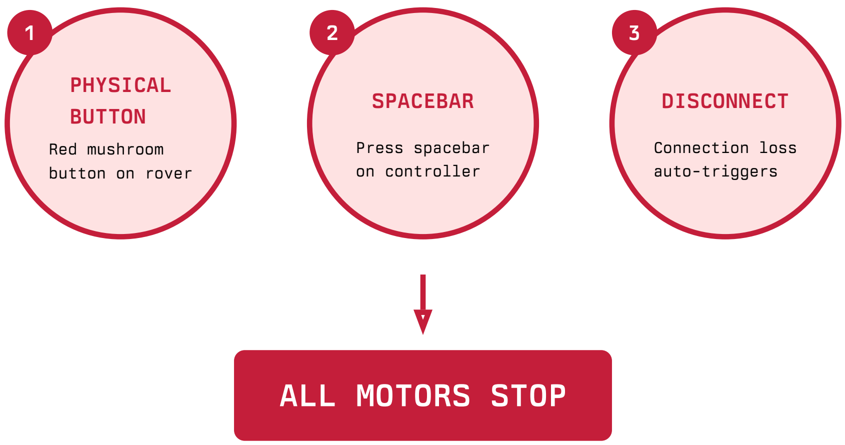
Serial: ____ Build: ____

Quick Reference

These three pages are the ones you'll use daily. Memorize the e-stop methods. Run the pre-flight checklist every time. Keep the controls layout in your head. Everything else in this manual is for building and fixing. This section is for operating.

Emergency Stop

⚠️ **DANGER** **Know this page.** If anything goes wrong, use one of these three methods immediately.



When to E-Stop:

- Person in path of rover
- Unexpected movement
- Smoke, sparks, or fire
- Loss of control
- Any doubt about safety

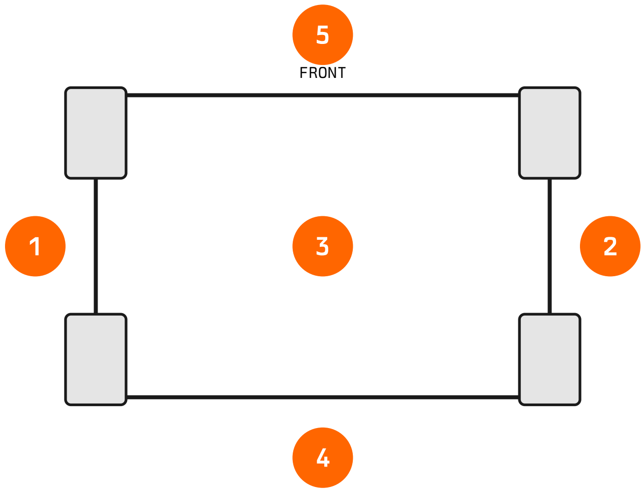
To resume after E-Stop:

1. Resolve the cause
2. Release physical button (if used)
3. Reconnect controller
4. Verify telemetry on dashboard
5. Resume operation

Pre-Flight Checklist

Daily inspection before operation

2 min



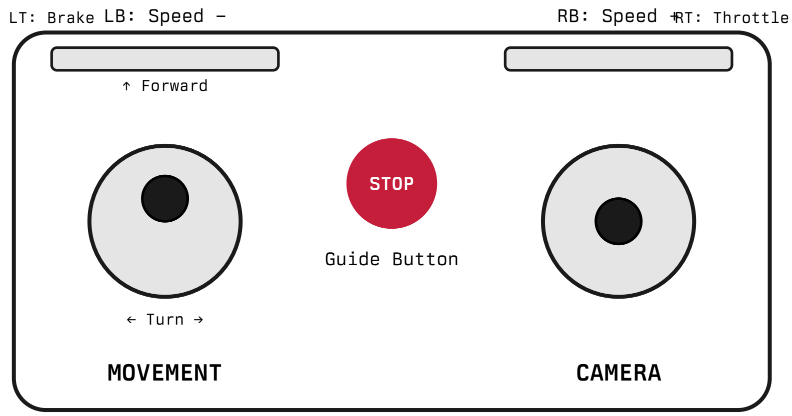
- [ ] **1** Wheels spin freely, no debris
- [ ] **2** All wheel bolts tight
- [ ] **3** E-Stop button not stuck
- [ ] **4** Battery voltage > 40V
- [ ] **5** Camera and LiDAR clean
- [ ] **6** All connectors secure

i **NOTE** If any check fails, do not operate. Resolve the issue first.

"We learned this the hard way:" We once operated with a loose wheel bolt. 10 minutes in, the wheel nearly came off mid-turn. The 2-minute checklist beats a 2-hour field repair.

Controls

Controller mapping reference 1 min read



Input	Action
Left Stick Up/Down	Forward / Reverse
Left Stick Left/Right	Turn left / right
Right Stick	Pan camera view
Left Bumper (LB)	Decrease max speed
Right Bumper (RB)	Increase max speed
Left Trigger (LT)	Brake / slow down
Right Trigger (RT)	Throttle (overrides stick)
Guide Button (center)	**Emergency Stop**
Spacebar (keyboard)	**Emergency Stop**

Before You Begin

This section explains what you're building, what you'll need, and how long it takes.

What You're Building

The BVR0 is a four-wheeled skid-steer rover with hub motors, a 48V power system, and onboard compute. It's designed for outdoor municipal work (snow clearing, mapping, patrol) but the base platform is general-purpose.

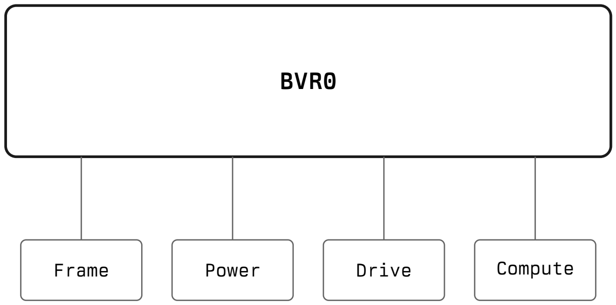


Figure 4: Four subsystems: mechanical frame, power distribution, drivetrain, and compute/sensors.

Prerequisites

Skills needed:

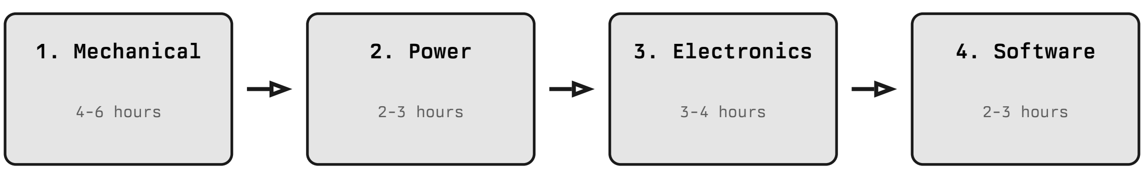
- Basic hand tools (hex keys, screwdrivers, wrenches)
- Wire stripping and crimping
- Soldering (through-hole level)
- Comfort with Linux command line
- Ability to read wiring diagrams

You do NOT need:

- CNC or machining (parts are outsourced or hand-cut)
- PCB design (all boards are off-the-shelf)
- Deep embedded programming (firmware is pre-built)

Build Phases

The build has four phases. Complete each before starting the next.



Total: 12-16 hours (split across 2-3 days recommended)

Recommended Order

Day	Tasks	Time
1	Cut extrusions, assemble frame, mount motor brackets	4-5 hr
2	Install motors, wire power system, mount electronics plate	4-5 hr
3	Wire VESCs and CAN bus, flash Jetson, configure and test	4-5 hr

✓ **TIP** Don't rush. A clean build with good cable management saves hours of debugging later.

Tools Required

Essential:
- Hex key set (2, 2.5, 3, 4, 5 mm)
- Phillips screwdriver
- Wire strippers (10-22 AWG)
- Crimping tool (for ferrules)
- Soldering iron + solder
- Multimeter
- Heat gun or lighter (heat shrink)

Helpful:
- Torque wrench (4 Nm range)
- Miter saw or hacksaw (for extrusions)
- Deburring tool
- Cable tie gun
- Label maker
- Helping hands (for soldering)

Materials Checklist

Before starting, verify you have:

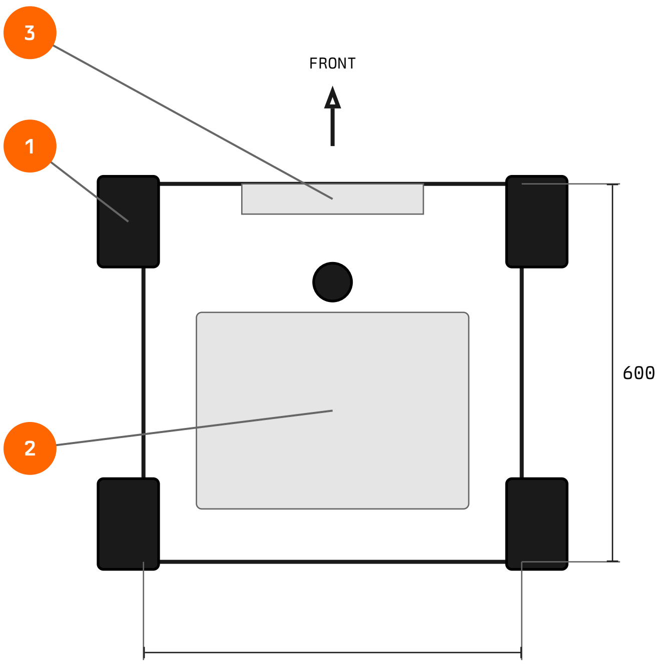
- [ ] All BOM items received and inspected
- [ ] Extrusions cut to length (or stock to cut)
- [ ] Motor brackets fabricated (or ordered)
- [ ] Electronics plate fabricated (or ordered)
- [ ] Battery charged to 50%
- [ ] Jetson flashed with JetPack

See **Appendix A: Bill of Materials** for the complete parts list with vendors.

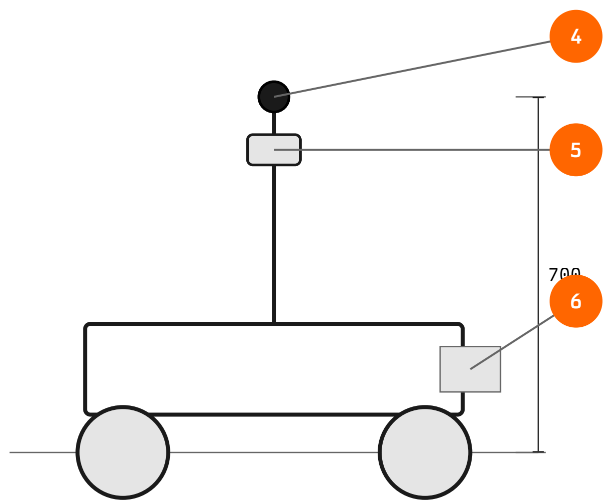
Overview

The BVR0 is the first rover in the Muni fleet. It's intentionally simple: a rigid aluminum frame, four hub motors, and enough compute to handle autonomy. No suspension, no steering linkages, no complex mechanisms. Everything that can break has been removed.

The design philosophy is "municipal-grade": it needs to survive Cleveland winters, sidewalk salt, and the occasional collision with a park bench. The 2020 aluminum extrusion frame can be rebuilt with hardware store parts. The hub motors are the same units used in hoverboards and e-scooters (proven, cheap, replaceable). The electronics are mounted on a single plate that slides out for service.



TOP VIEW



SIDE VIEW

Components

1 Hub motor wheels (×4)
2 Electronics bay
3 Tool mount
4 360° camera
5 LiDAR sensor
6 Tool attachment

Key Specifications

Dimensions	600 × 600 × 700 mm
Weight	30 kg with battery
Speed	1.0–2.5 m/s
Runtime	4 hours
Temp range	−20°C to +40°C

Specifications

These are the target specifications for a standard BVR0 build. Your rover may vary slightly depending on component sourcing and local modifications.

Mechanical

Footprint	600 × 600 mm
Height	700 mm (with mast)
Weight	30 kg
Ground clearance	50 mm
Wheel diameter	160 mm
Frame	2020 aluminum extrusion

Electrical

Main battery	48V 20Ah (960 Wh)
Chemistry	13S LiPo
Voltage range	39–54.6V
Accessory rail	12V 10A
Main fuse	100A

Drivetrain

Motors	4× 350W hub motors
Controllers	4× VESC 6.7
Drive type	Skid-steer
Max speed	2.5 m/s
Cruise speed	1.0 m/s

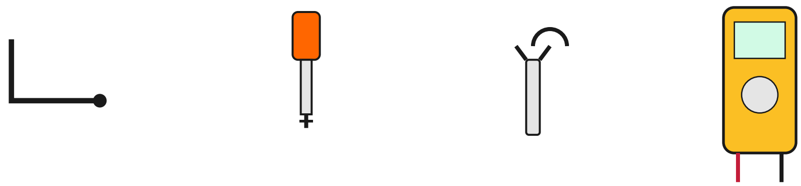
Perception

LiDAR	Livox Mid-360
Camera	Insta360 X4 (360°)
GPS	RTK-capable (optional)

Compute

Main computer	Jetson Orin NX 16GB
Connectivity	LTE + WiFi
CAN bus	500K baud

Required Tools



Hex Keys — 2.5, 3, 4, 5 mm

Screwdriver — Phillips 2

Wrenches — 8, 10, 13 mm

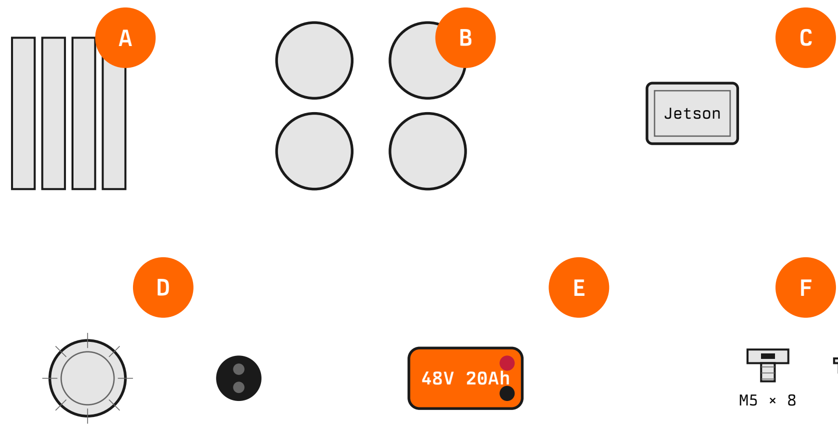
Multimeter — V / Ω / Continuity

Required
- Hex key set (metric: 2.5, 3, 4, 5 mm)
- Phillips screwdriver (2)
- Adjustable wrench or socket set (8, 10, 13 mm)
- Multimeter (voltage, resistance, continuity)
- Wire strippers (20-12 AWG)
- Soldering iron (40W+) and solder
- Heat shrink assortment
- Miter saw or hacksaw (for extrusions)

Recommended
- Torque wrench (4 Nm for M5)
- Drill and drill bits (3.2, 4.2, 5 mm)
- Tap set (M4×0.7, M5×0.8)
- Deburring tool
- Cable ties (assorted sizes)
- Label maker
- Work mat
- Helping hands / PCB holder

> ℹ **NOTE** All M5 bolts should be torqued to 4 Nm. Over-tightening can strip aluminum threads.

Parts List



Parts

A	Chassis: extrusions, brackets, plate	$150
B	Drivetrain: motors, VESCs	$830
C	Electronics: Jetson, CAN, LTE	$900
D	Perception: LiDAR, camera, pole	$1,800
E	Power: battery, DC-DC, fuse, E-stop	$400
F	Hardware: bolts, T-nuts, wire	$100

Cost Summary

Chassis	$150
Drivetrain	$830
Electronics	$900
Perception	$1,800
Power	$400
Hardware	$100
Total	**$4,180**

All parts commercially available.

Full BOM with links:
docs/hardware/bom.md

Where to Buy:

Category	Primary Source
Notes	Extrusions
Amazon, Misumi	2020 V-slot or T-slot
Motors	AliExpress
Search “hoverboard hub motor 350W”	VESCs
Flipsky	VESC 6.6 or 6.7
Jetson	NVIDIA, Arrow, Seeed
Orin NX 16GB + carrier	LiDAR
Livox / DJI Store	Mid-360, 1 week ship
Camera	Amazon, B&H
Insta360 X4	Custom cuts
SendCutSend	Upload DXF, 3-5 day turnaround

Custom Fabricated Parts

BVR0 requires **zero** custom fabricated parts.

No custom parts needed

How BVR0 avoids custom fabrication:

Component	BVR0 Approach
Alternative (BVR1)	Motor mounting
Direct bolt to 2020 T-slot	Custom brackets
Battery	Downtube e-bike battery
Custom pack + tray	Electronics
Tape/zip-tie to chassis	Custom plate

> ℹ **NOTE** BVR0 is intentionally scrappy. The goal is to get a working rover with parts you can order today and assemble this weekend. No waiting for laser cutting, no CAD required.
> Once you've proven the concept, BVR1 introduces custom parts for a cleaner, more serviceable build.

Hardware Reference

Standard fasteners and hardware used throughout the build.

Bolts

Size	Use
M3×8	Electronics mounting
M5×8	T-nut, light duty
M5×10	T-nut, standard
M5×12	Motor to frame
M5×16	T-nut, through plate

T-Nuts

Type	Use
M5 drop-in	Post-assembly insertion
M5 slide-in	Pre-assembly (easier)
M6 drop-in	Heavy-duty mounts

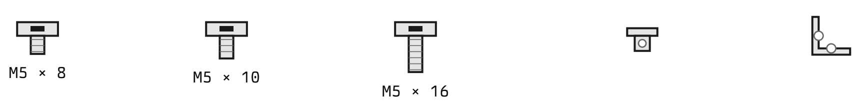
Connectors

Type	Rating
Use	XT90
90A	Battery main
XT60	60A
Motor phase	XT30
30A	12V power
JST-PH	3A
CAN bus, signals	DT 4-pin
25A	Tool connector

Wire Gauge

AWG	Use
8 AWG	Battery to bus
10 AWG	Bus to VESCs
14 AWG	12V power
22 AWG	CAN bus, signals

Common Hardware (actual size)



M5×8 M5×10 M5×16 M5 T-Nut Corner

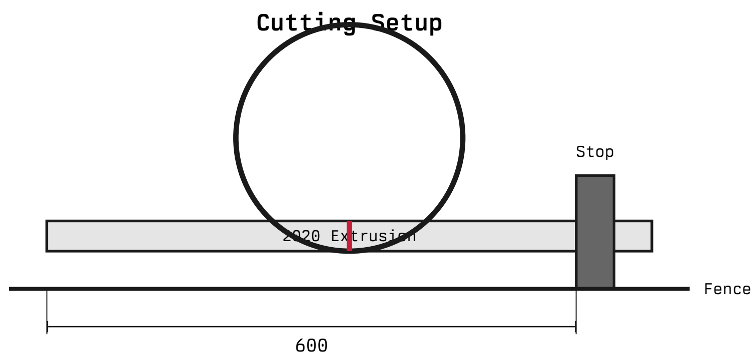
Chassis Assembly

The chassis is the skeleton of the rover. It's built from 2020 aluminum extrusion, the same stuff used in 3D printer frames and CNC machines. The T-slot design means you can mount anything anywhere, and if you mess up a hole, just slide the T-nut to a new position.

The frame goes together like adult LEGO. No welding, no precision machining. If you can use a saw and a hex key, you can build this chassis.

Cutting Extrusions

Cut aluminum stock to length 20 min



Procedure:

1. Clamp stop block at 600mm from blade
2. Place extrusion against fence and stop
3. Cut slowly to prevent burrs
4. Rotate 90° and re-cut if needed for square ends
5. Deburr all cut edges with file or deburring tool

Cut List (BVR0 standard):

Qty	Length
Purpose	4
600mm	Base frame
4	600mm
Top frame	4
250mm	Vertical posts

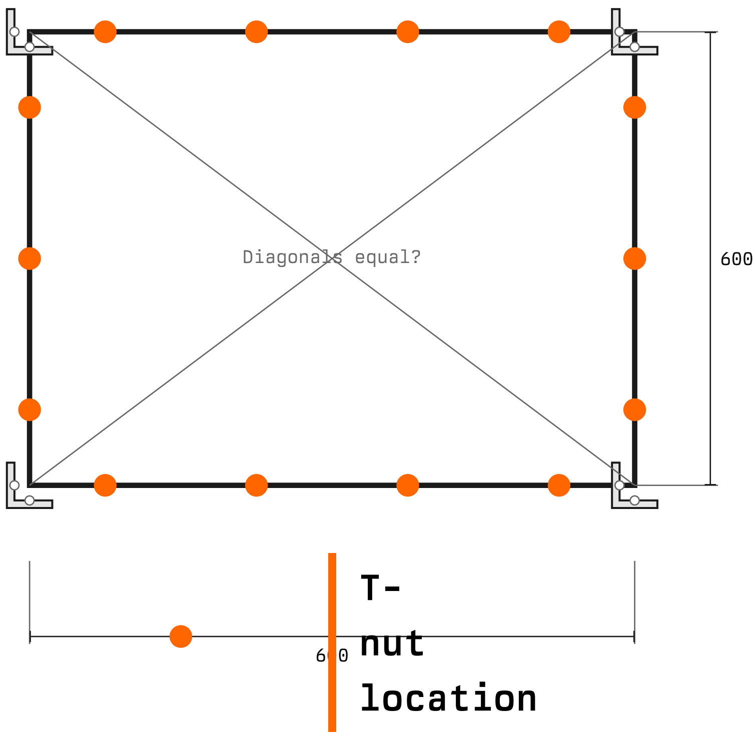
Total: 5.8m of 2020 extrusion needed.

⚠️ **WARNING** Aluminum chips are sharp. Wear safety glasses. Clean chips from T-slots before assembly.

⚡ **COMMON MISTAKE** Cutting too fast causes burrs that jam T-nuts. Slow cuts with a fine-tooth blade save deburring time.

Base Frame Assembly

Assemble the base frame square 15 min



Assembly Steps:

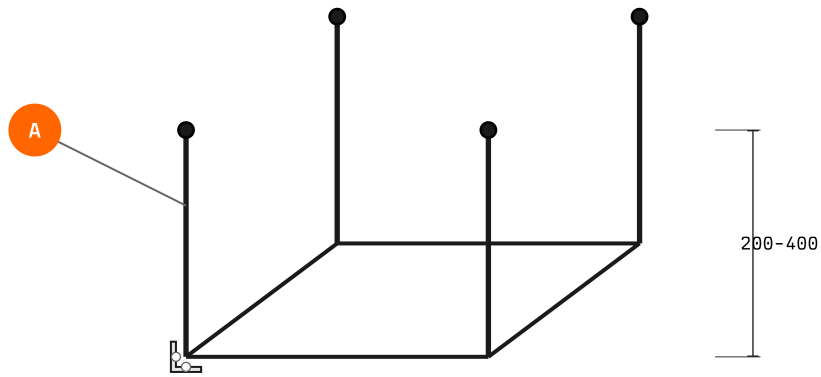
1. **Pre-insert T-nuts** into all extrusion channels (8 per extrusion, 32 total for base)
2. **Dry-fit** all four extrusions in a square, corners aligned
3. **Attach corner brackets** loosely (finger-tight M5×10 bolts)
4. **Check squareness:** measure both diagonals. They must be equal (±1mm).
5. **If not square:** tap the long diagonal corner with a mallet to adjust
6. **Tighten all bolts** to 4 Nm in a star pattern

> ℹ **NOTE** Leave extra T-nuts in channels for later mounting. Easier now than adding drop-in nuts later.

> *"We learned this the hard way:" The first build had exactly enough T-nuts. Adding the electronics plate later meant disassembling half the frame. Now we pre-load 30% more than the BOM says.*

Vertical Posts

Install corner vertical posts 10 min



Mounting Method A: Corner Bracket

Use 90° corner brackets at each post base.

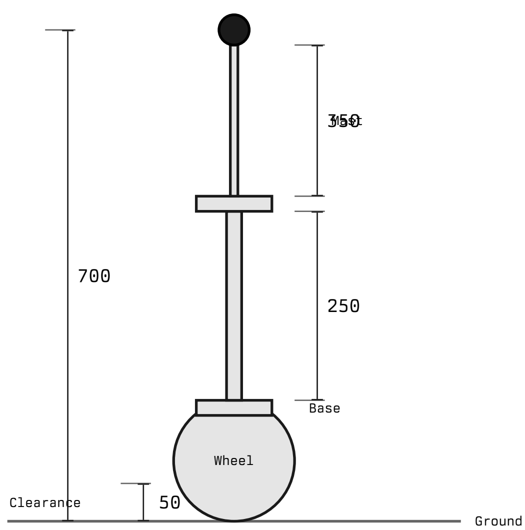
- 2× M5×10 bolts per bracket
- Insert T-nuts in both base and post
- Tighten to 4 Nm

Mounting Method B: Blind Joint

Use blind joint connectors for cleaner look.

- Drill 5mm access hole in base extrusion
- Thread M5×25 bolt through into post
- Hidden hardware, harder to adjust

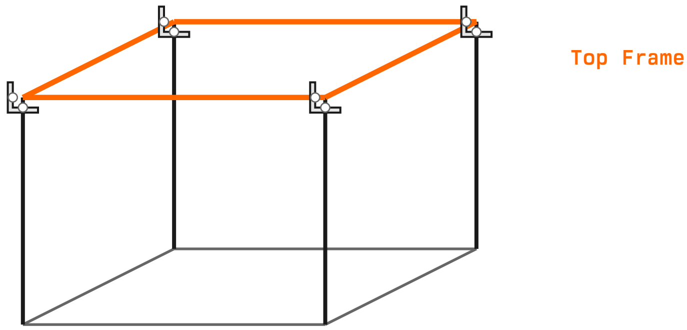
Height Calculation:



Component	Height
Cumulative	Wheel radius
80mm	80mm
Ground clearance	50mm
-	Base to top frame
250mm posts + 40mm	370mm
Sensor mast	330mm
700mm	

Top Frame

Complete the box frame 15 min



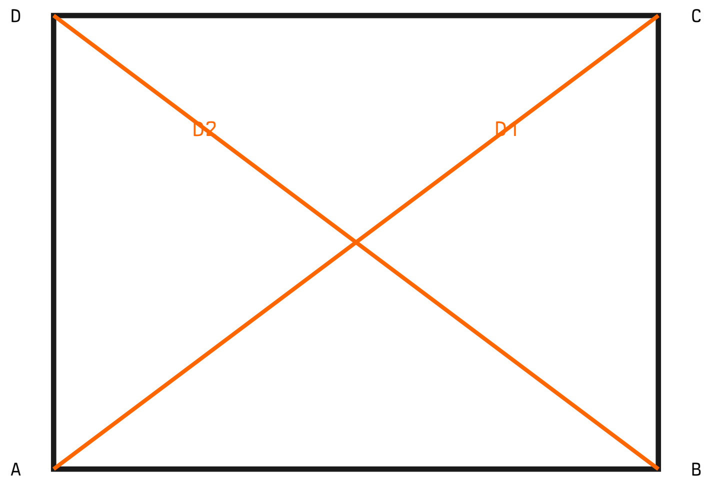
Assembly:

1. Attach corner brackets to top of each vertical post (loosely)
2. Place top frame extrusions onto brackets
3. Align extrusions flush with vertical posts
4. Check that top frame is level (use spirit level)
5. Tighten all connections to 4 Nm

> i **NOTE** The top frame provides mounting points for the electronics plate, sensor mast, and protective covers.

Squareness Check

Verify frame geometry 5 min



D1 = D2 ± 1mm

Squareness Test:

1. Measure diagonal A→C (D1)
2. Measure diagonal B→D (D2)
3. Compare: D1 should equal D2 within 1mm
4. If not equal: loosen corners, tap long diagonal, re-tighten

Rigidity Test:

1. Grip opposite corners
2. Try to twist the frame
3. Frame should not flex or rack
4. If loose: check all bolt torque, add corner braces if needed

Final Checklist:

- [ ] All corners have brackets installed
- [ ] All bolts torqued to 4 Nm
- [ ] Diagonals equal within 1mm
- [ ] Frame does not rack or twist
- [ ] All T-slots clear of debris
- [ ] Extra T-nuts in channels for later use

✓ TIP Take a photo of the diagonal measurements. Useful reference if the frame gets knocked out of square later.

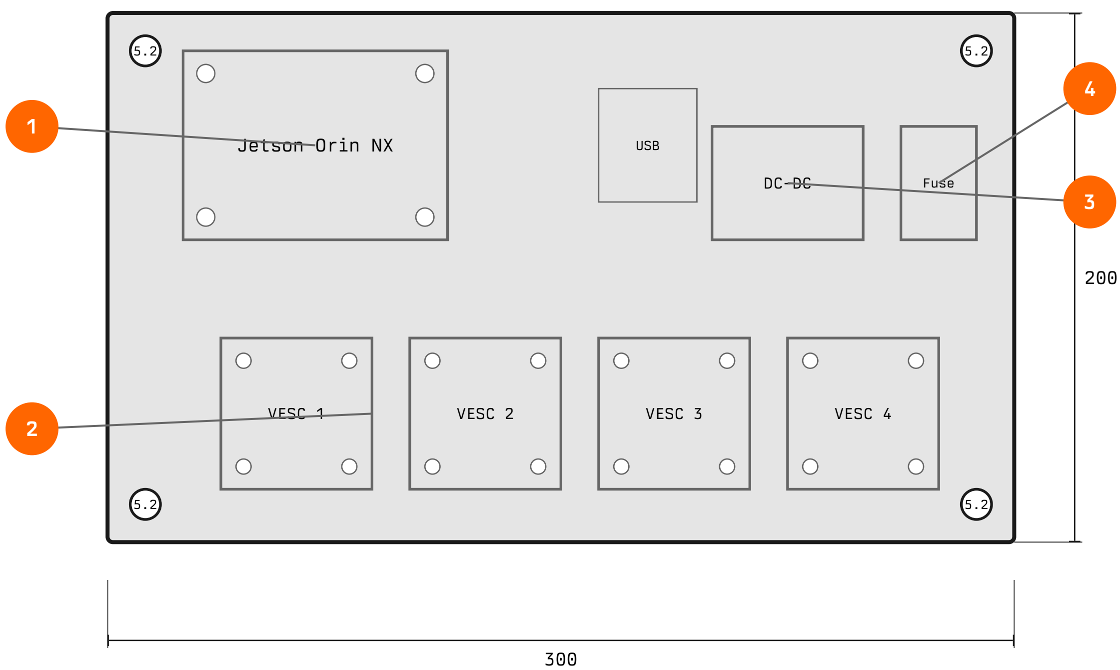
Electronics Plate

All the brains live on one removable plate. The Jetson compute module, four VESC motor controllers, DC-DC converter, and fusing all mount here. When something goes wrong (and eventually it will), you can unbolt four screws, slide the plate out, and work on it at a bench.

The layout is designed for airflow and serviceability. VESCs go near the edges where they can radiate heat. The Jetson sits in the middle with space around it for convection. Connectors face outward so you can plug and unplug without removing the plate.

Electronics Plate Layout

Reference: plate fabrication outsource or 1 hr



Components:

1 Jetson Orin NX + CAN board
2 VESC 6.7 ×4 (60×40mm each)
3 DC-DC 48V→12V
4 100A fuse holder

Plate Material:

- 6mm (1/4″) 6061-T6 aluminum (recommended)
- Or: 5mm acrylic (lighter, less heat dissipation)
- Or: 3mm FR4/G10 (good insulator)

CAD File: bvr/cad/exports/electronics_plate.stl

Drilling Guide

Drill mounting holes 30 min

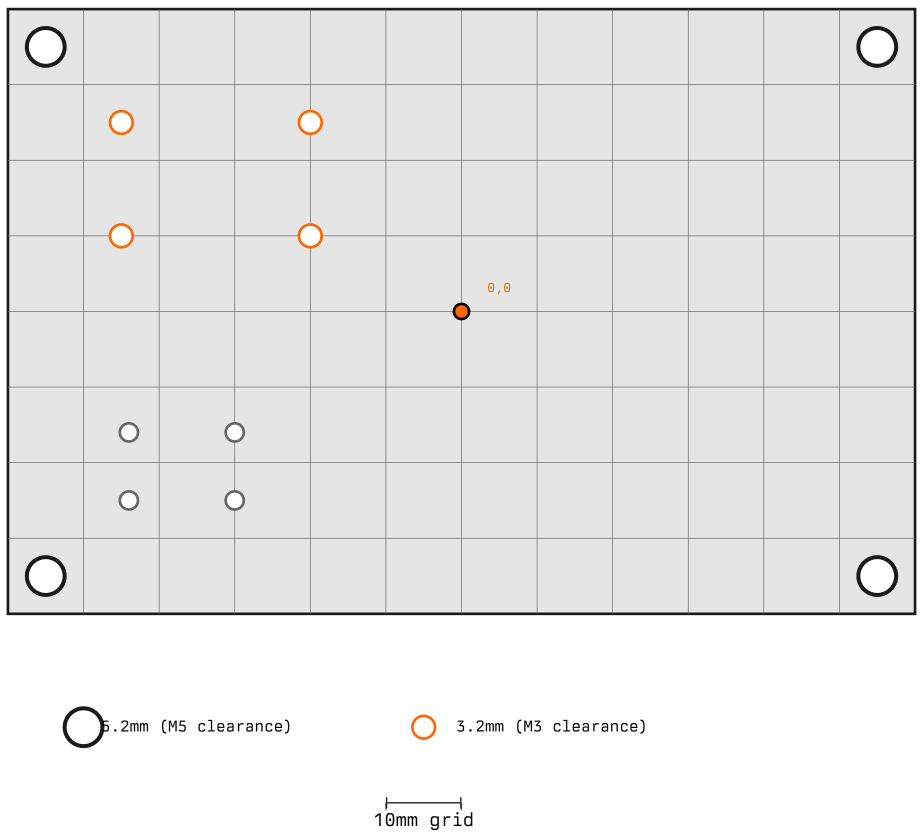


Figure 18: Hole positions. Grid squares = 10mm. Origin at plate center.

Drill Sizes:

Hole Type	Drill Size
Purpose	M5 clearance
5.2mm	Plate mounting to frame
M3 clearance	3.2mm
Electronics mounting	M3 tap
2.5mm	If threading aluminum
M4 clearance	4.2mm
Larger components	

Plate Mounting

Mount plate to frame 15 min

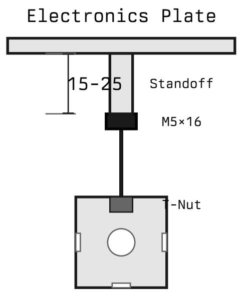


Figure 19: Cross-section: standoff mounting provides airflow under plate.

Mounting Hardware (per corner):

- 1× M5×16 or M5×20 bolt
- 1× M5 T-nut (drop-in or slide-in)
- 1× M5 standoff (15-25mm height)
- 1× M5 nut or second standoff

Standoff Height:

- 15mm: Minimal, tight fit
- 20mm: Recommended (good airflow)
- 25mm: Maximum cable clearance

Use same height at all 4 corners.

Installation:

1. Insert T-nuts into top extrusion slots
2. Thread M5 bolts through standoffs
3. Position plate on standoffs
4. Align with T-nuts
5. Tighten to 4 Nm

i **NOTE** Leave plate loose until all electronics are mounted. Easier access.

Drivetrain

The BVR1 uses skid-steer drive: four independent hub motors, one in each wheel. To turn, the left and right sides spin at different speeds (or opposite directions). It's the same principle as a tank or a Roomba.

Hub motors eliminate chains, belts, gearboxes, and axles. The motor **is** the wheel. This means fewer parts, less maintenance, and no drivetrain to align. The tradeoff is that hub motors are heavier than outrunner motors with belt drive, but for a utility rover that's not a problem.

BVR1 uses 8″ hub motors (larger than BVR0's 6.5″ hoverboard motors) for improved ground clearance and obstacle handling. These mount via custom brackets rather than directly to the frame, making wheel service easier.

Motor Bracket Design

Reference: bracket fabrication — outsource or 1 hr

The BVR1 motor brackets use a bicycle-style design: an L-shaped aluminum bracket bolts to the frame, and the motor axle clamps into the bracket's slot. This allows quick wheel removal without disturbing the frame.

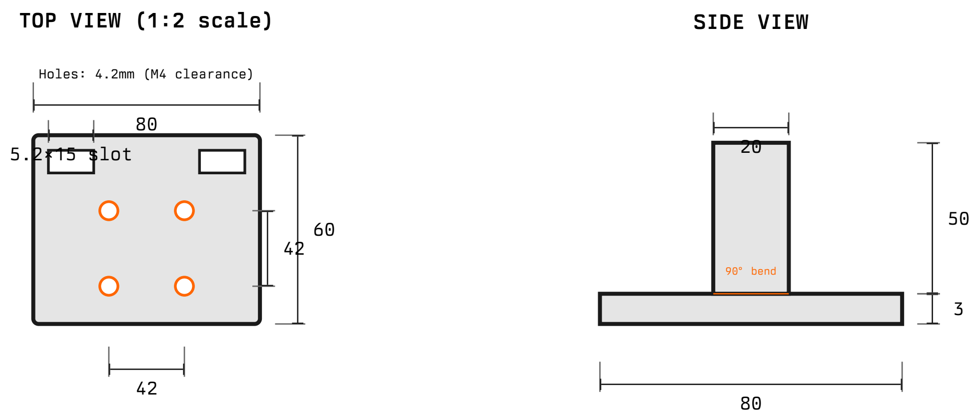


Figure 20: Motor bracket dimensions. Material: 3mm 6061-T6 aluminum.

Bracket Specifications:
- Material: 3mm 6061-T6 aluminum
- Overall: 80mm × 60mm flat, 50mm vertical
- Frame slots: 5.2mm × 15mm (M5 adjustment)
- Motor holes: 42mm × 42mm square pattern
- Drill: 4.2mm (M4 clearance)
- Bend: 90° along 80mm edge

CAD Files: Available at bvr/cad/exports/:
- motor_mount_8in.stl (3D model)
- motor_mount_plate_8in.stl
- motor_mount_tab_8in.stl

SendCutSend accepts DXF/STEP files for laser cutting and bending.

> i **NOTE** The 42mm hole pattern fits standard 8″ hub motors. Verify your motor's bolt pattern before cutting.

Motor Bracket Mounting

Mount brackets to frame 15 min

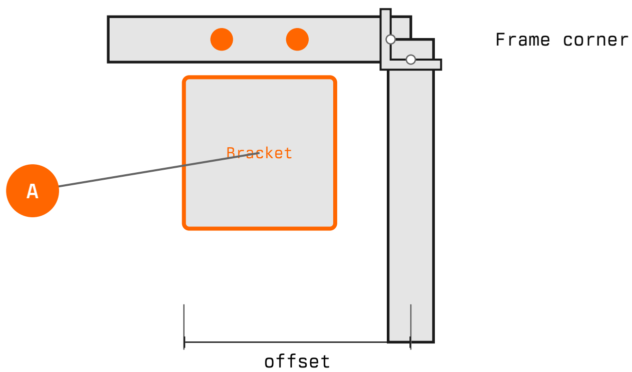


Figure 21: Motor bracket position at frame corner. All 4 corners mirror this layout.

Mounting Procedure:

1. Slide T-nuts into bottom extrusion channel
2. Position bracket with motor axle aligned to wheel position
3. Insert M5×10 bolts through bracket slots into T-nuts
4. Leave bolts finger-tight for adjustment
5. Verify bracket is perpendicular to extrusion
6. Tighten to 4 Nm

Bracket Positions:

Corner	Offset from corner
Front Left	50mm
Front Right	50mm
Rear Left	50mm
Rear Right	50mm

Alignment Check:

- Motor axles should be parallel
- Equal distance from frame edges
- Perpendicular to travel direction

Hub Motor Installation

Install hub motors 30 min

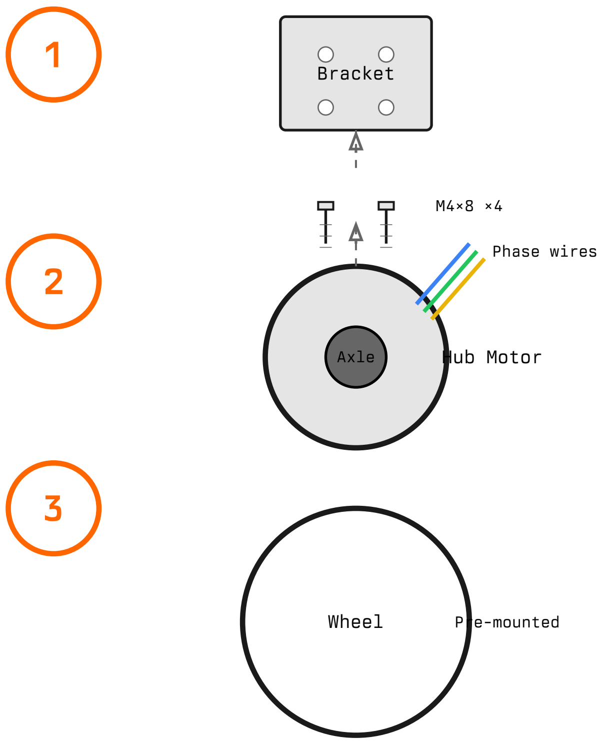


Figure 22: Motor installation sequence. Wheels typically come pre-mounted on hub motors.

Installation Steps:

1. Align motor mounting holes with bracket holes
2. Insert M4×8 bolts through bracket into motor
3. Tighten in cross pattern to 2 Nm
4. Route phase wires toward electronics bay
5. Secure wires with cable ties (leave slack for wheel movement)

⚠️ **WARNING** Do not pinch phase wires between motor and bracket. This can cause shorts.

"We learned this the hard way:" The first motor install was tight. Really tight. We cross-threaded an M4 bolt and stripped the motor housing. Now we hand-thread every bolt first before using a driver.

Wheel Alignment

Check and adjust wheel alignment 15 min

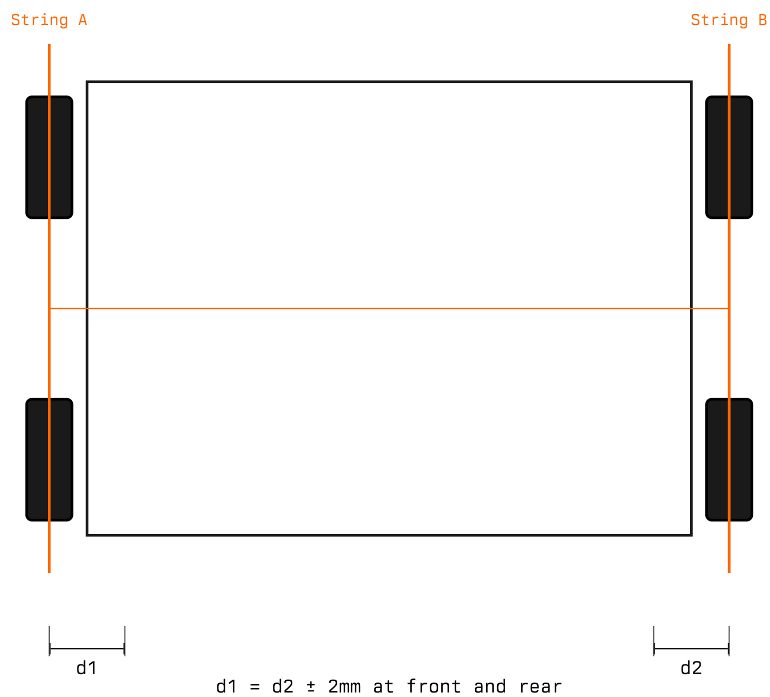


Figure 23: String alignment method. Stretch strings parallel to frame sides.

Alignment Procedure:

1. Stretch two parallel strings along frame sides
2. Measure gap from string to front wheel edge
3. Measure gap from string to rear wheel edge
4. Gaps should be equal (±2mm) on each side
5. If not equal: loosen bracket, adjust, re-tighten

Common Issues:

Symptom	Cause
Fix	Rover pulls left
Right wheels toe-in	Adjust right brackets outward
Rover pulls right	Left wheels toe-in
Adjust left brackets outward	Excessive tire wear
Wheels not parallel	Realign all brackets
Vibration at speed	Wheel out of round
Replace tire or motor	

Power System

The rover runs on 48V nominal (13S lithium). This voltage is high enough to be efficient (less current means thinner wires and less heat) but low enough to avoid the regulatory complexity of “high voltage” systems.

BVR1 uses a custom battery pack instead of an off-the-shelf downtube battery. This allows for a form factor optimized for the rover’s layout and higher capacity cells.

The power path is simple: battery → fuse → e-stop relay → distribution bus → loads. Every component can be isolated, and the e-stop cuts power to everything downstream instantly.

Respect the battery. A 48V 20Ah pack stores nearly 1 kWh of energy. That’s enough to weld metal if shorted, or start a fire if punctured. The safety section covers handling in detail.

Battery Pack

Install custom battery pack 20 min

BVR1 uses a custom 13S4P battery pack built with 21700 cells. The pack mounts in a dedicated tray with integrated BMS and Anderson PowerPole connectors.

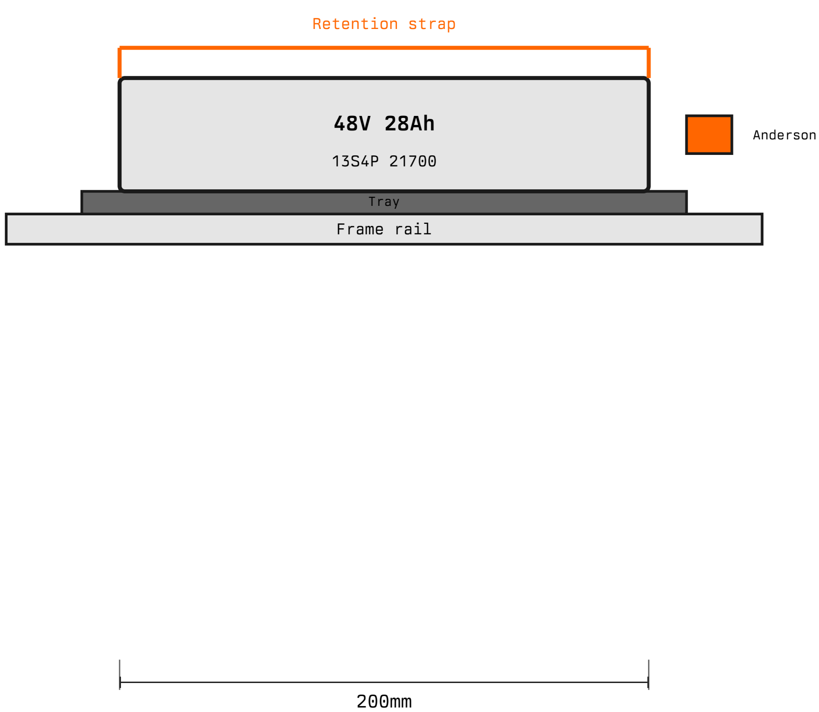


Figure 24: Custom battery pack mounted in tray with retention strap.

Pack Specifications:

- Configuration: 13S4P (48V nominal)
- Cells: Samsung 50E or Molicel P42A
- Capacity: 28Ah (1,344 Wh)
- Max discharge: 80A continuous

Tray Construction:

- Material: 2mm 6061-T6 aluminum
- Flat size: 240mm × 180mm
- Bend: 15mm lip on all 4 sides (90°)
- 10mm EVA foam padding (bottom)

- BMS: 13S 100A with balancing
- Connector: Anderson SB50 or similar
- Retention: 25mm nylon strap + cam buckle

CAD File: bvr/cad/battery-tray.dxf

> ⚠️ **WARNING** Battery must not shift during operation. Loose batteries can short on frame, causing fire.

Fuse and E-Stop

Wire safety disconnect

20 min

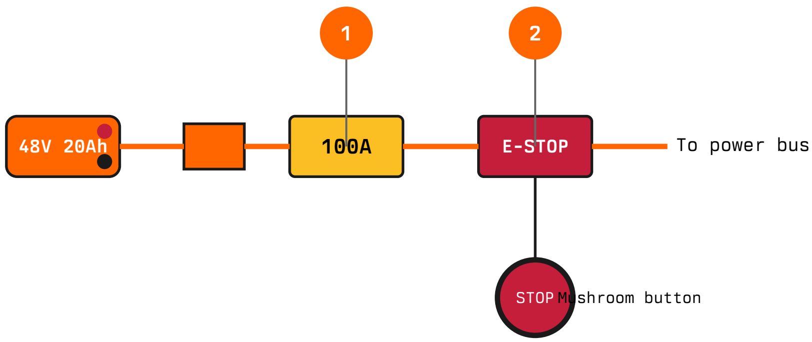


Figure 25: Power flows: Battery → Connector → Fuse → E-Stop relay → Power bus

1 Fuse (100A):

- ANL or MIDI style fuse
- Inline fuse holder with ring terminals
- Mount accessible for replacement
- Size: protects wiring, not electronics

2 E-Stop Relay:

- Normally-open contactor (closes when safe)
- 12V coil, controlled by Jetson GPIO
- 100A+ contact rating
- Fails safe: power loss = stop

Wiring:

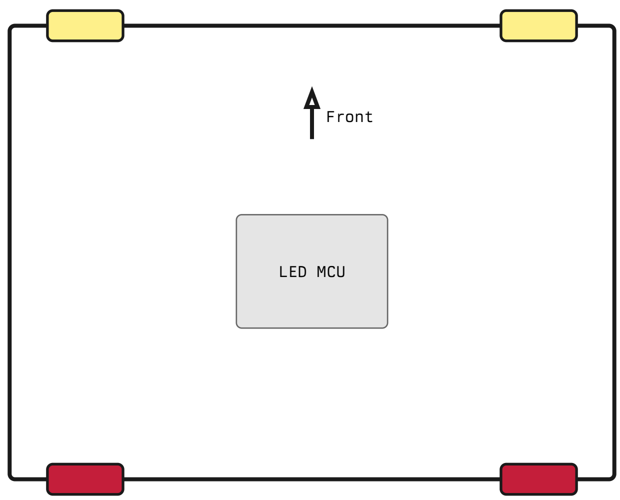
- Use 8 AWG wire for main power path
- Ring terminals with heat shrink
- Keep runs short between fuse and relay

Lighting System

Install headlights and tail lights 30 min

BVR1 includes integrated lighting for visibility and safety. Headlights illuminate the path ahead for camera perception in low light. Tail lights provide visibility to pedestrians and vehicles.

Headlights (white)



Tail lights (red)

Figure 26: Light positions: white headlights front, red tail lights rear.

Headlights:
- 2× high-power white LED modules
- 12V, 5W each
- Wide beam for path illumination
- Mount to front frame rail
- Controlled via CAN bus from MCU

Tail Lights:
- 2× red LED strips or modules
- 12V, 2W each
- Always on when rover is powered
- Mount to rear frame rail
- Can flash during reversing

Wiring:
- Lights connect to LED MCU (RP2350)
- MCU receives commands over CAN bus
- 12V power from DC-DC converter
- Use 18 AWG wire for light circuits

Light States:

State	Headlights
Tail Lights	Idle
Off	Dim (10%)
Teleop	On
On	Autonomous
On	On
Reversing	On
Flashing	E-Stop

Off	Fast flash

DC-DC Converter

Install voltage regulator 10 min

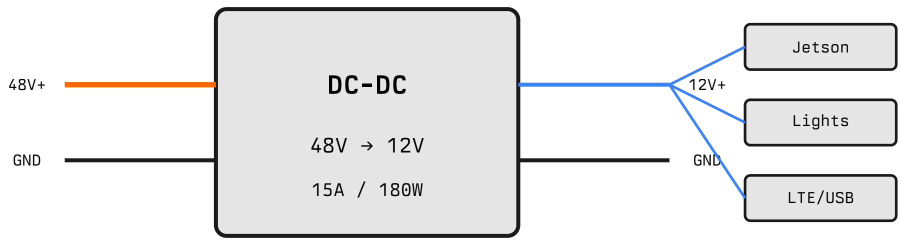


Figure 27: DC-DC powers all 12V devices including lighting.

Specifications:

Parameter	Value
Input voltage	36-60V (fits 13S LiPo range)
Output voltage	12V regulated
Output current	15A continuous
Efficiency	>90%
Mounting	M3 holes, heatsink on bottom

12V Load Budget:

Device	Current
Jetson Orin NX	5A peak, 3A average
Headlights	1A
Tail lights	0.5A
LTE modem	1A
USB hub	0.5A
Accessories	1A reserve
Total	**8A typical, 12A max**

> i **NOTE** BVR1 uses a 15A DC-DC (vs 10A in BVR0) to handle the additional lighting load.

Power Distribution

Wire power bus 45 min

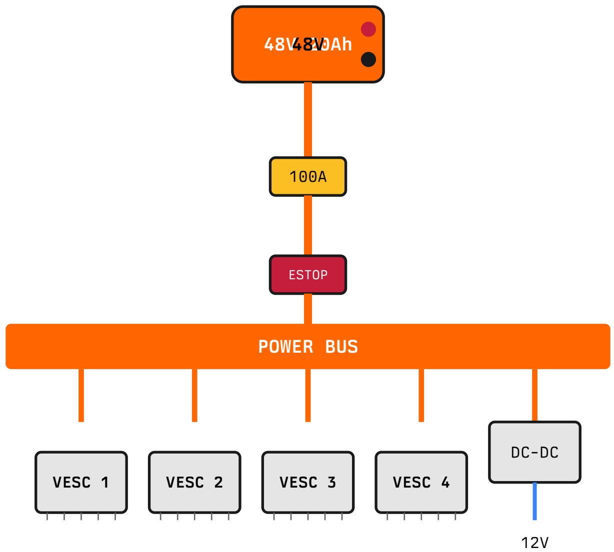


Figure 28: Power distribution topology. All 48V loads connect to central bus.

Bus Options:

Bus Bar (recommended):

- Solid copper bar with tapped holes
- Clean, low resistance
- Easy inspection

Splitter Cable:

- Anderson to 4× XT60
- Simpler for prototypes
- Higher resistance

Electronics

The electronics are the nervous system: motor controllers that translate commands into wheel motion, a compute module that runs the autonomy stack, and a CAN bus that ties everything together.

We use VESC motor controllers because they're open-source, powerful, and have a decade of real-world use in electric skateboards and robotics. The Jetson Orin NX handles perception and planning. It's overkill for teleoperation, but essential for autonomous operation.

VESC Mounting

Mount motor controllers 20 min

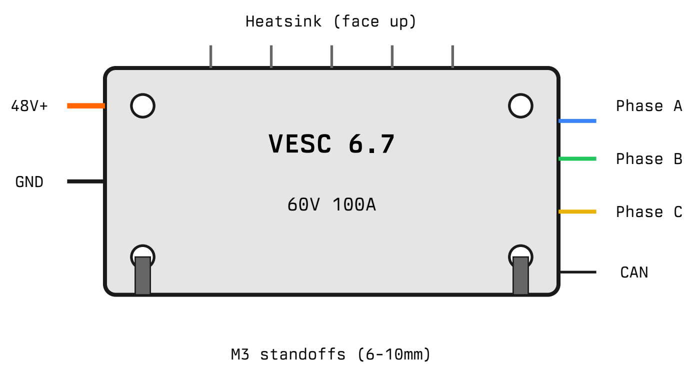


Figure 29: VESC mounted on standoffs for airflow. Heatsink faces up.

Mounting:

- M3×6 standoffs at all 4 corners
- M3×8 bolts through plate into standoffs
- Thermal pad between VESC and plate (optional, for heat transfer)

Power Connections:

- 10 AWG wire for 48V input
- XT60 connectors recommended
- Keep power wires short

> ⚡ **COMMON MISTAKE** VESCs generate serious heat under load. Without standoffs for airflow, thermal throttling kicks in after 3 minutes of hard driving.

VESC Configuration

Set CAN IDs and motor parameters

10 min per VESC

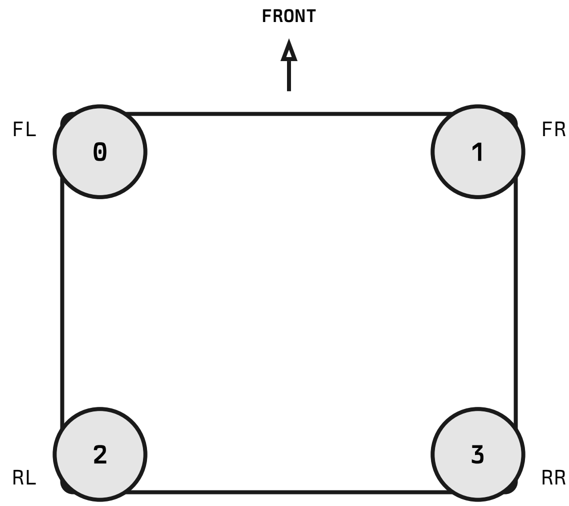


Figure 30: CAN ID assignment. ID 0-3 for wheels, ID 10+ for tools.

VESC Tool Configuration:

Parameter	Value
Controller ID	0, 1, 2, 3 (unique per VESC)
CAN Mode	VESC
CAN Baud Rate	CAN_500K
Send CAN Status	Enabled
CAN Status Rate	50 Hz
Motor Type	BLDC or FOC (depends on motor)
Current Limit	30A (per motor)

Motor Detection:

1. Connect VESC to computer via USB
2. Open VESC Tool
3. Run Motor Detection wizard
4. Save configuration to VESC
5. Disconnect USB, connect CAN

Jetson Mounting

Install compute module 15 min

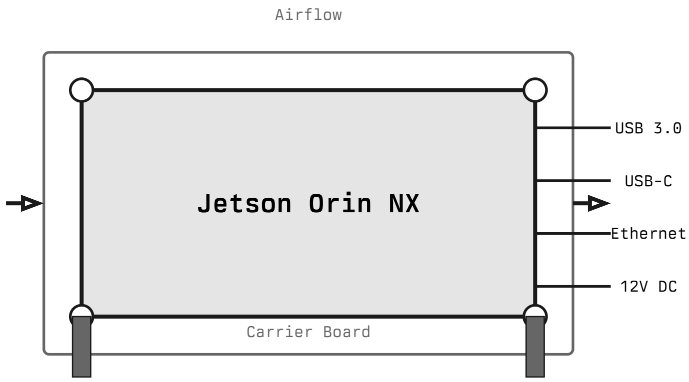


Figure 31: Jetson mounted on standoffs. Ensure airflow around heatsink.

Connections:

Port	Connection
USB 3.0 1	USB-CAN adapter
USB 3.0 2	USB hub (camera, LTE)
12V DC	From DC-DC converter
GPIO	E-Stop relay control

Software:

- JetPack 6.0 or later
- bvrd daemon (auto-start on boot)
- Insta360 SDK for camera

▶ Jetson Setup Guide

GPIO Pinout

Wire E-Stop relay 10 min

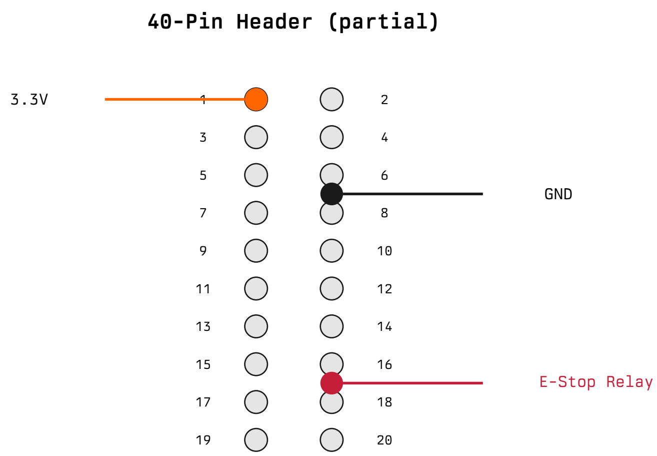


Figure 32: GPIO header. Only pins used by BVR0 are highlighted.

GPIO Assignments:

Pin	GPIO
Function	**Direction**
Notes	32
GPIO12	E-Stop Relay
Output	High = relay closed = power on
6	GND
Relay ground	-
Common ground	1
3.3V	Status LED
Power	Optional status indicator

E-Stop Relay Wiring:

```
Jetson Pin 32 (GPIO12) ──┬── Relay coil (+)
                         │
Relay coil (-) ──────────┴── Jetson Pin 6 (GND)
```

The relay is a normally-open (NO) type. When GPIO12 is LOW (default at boot), the relay is open and power is cut to motors. Software must explicitly set GPIO12 HIGH to enable motor power.

> *"We learned this the hard way:" The first prototype used a normally-closed relay. Boot glitch meant motors got power before software loaded. Now we always use normally-open for fail-safe.*

USB-CAN Adapter

Connect CAN bus interface 5 min

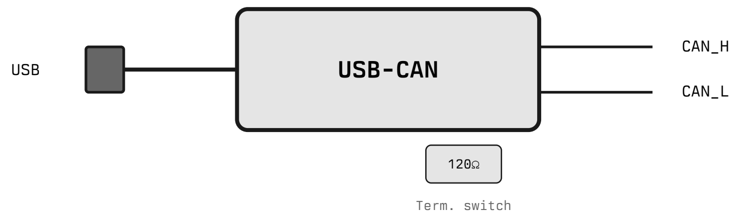


Figure 33: USB-CAN adapter provides CAN bus access from Jetson.

Recommended Adapters:
- Canable Pro (open source)
- PEAK PCAN-USB
- Innomaker USB-CAN

Configuration:

```
# Set up CAN interface
sudo ip link set can0 type can bitrate 500000
sudo ip link set can0 up

# Test with candump
candump can0
```

Termination:
- If adapter is at end of CAN bus: enable 120Ω termination
- If adapter is in middle of chain: disable termination
- Total bus should have exactly 2 termination resistors

> ⚡ **COMMON MISTAKE** Three termination resistors = 40Ω total = signal reflections = random VESC dropouts. Use a multimeter to verify 60Ω across CAN_H/CAN_L (two 120Ω in parallel).

Sensor Mast

The sensor mast is the rover's eyes. It elevates the LiDAR and 360° camera above the chassis to get an unobstructed view of the world.

Height matters. Too low and the sensors see mostly wheels. Too high and the mast becomes a sail in the wind and a lever arm for tip-overs. We settled on 700mm total height (from ground to camera) as a good compromise for sidewalk-scale operation.

The mast is intentionally simple: a tube, a clamp, and some brackets. If it gets bent (it will), you can straighten it or replace it in minutes.

Sensor Mast Assembly

Build sensor pole 20 min

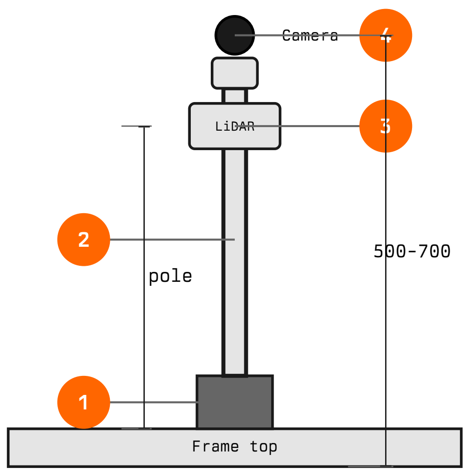


Figure 34: Sensor mast with LiDAR below camera for unobstructed 360° view.

Components:

1 Pole mount bracket
2 Carbon fiber or aluminum tube
3 LiDAR mount plate
4 Camera mount (1/4-20)

Pole Specifications:

- Diameter: 25-30mm OD
- Material: Carbon fiber (light) or 6061-T6 aluminum
- Length: 400-600mm depending on design
- Wall thickness: 2mm minimum

LiDAR Mounting

Mount LiDAR sensor 15 min

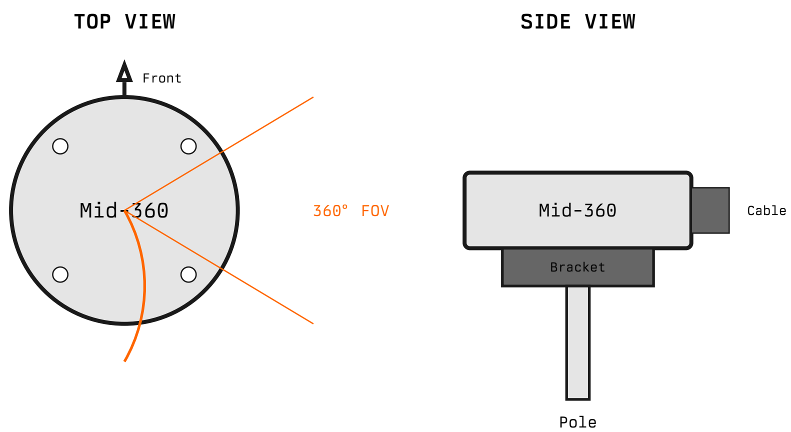


Figure 35: LiDAR mounted level with 360° horizontal FOV. Cable routes down pole.

Installation:

1. Attach LiDAR to mount plate with M3 bolts
2. Level the mount plate (use spirit level)
3. Secure mount plate to pole with hose clamps or bolts
4. Route cable inside pole or along outside with ties
5. Connect to Jetson via Ethernet

Orientation:

- LiDAR “front” should face rover front
- Ensure level within ±1°
- No obstructions in 360° view

Camera Mounting

Mount 360° camera 10 min

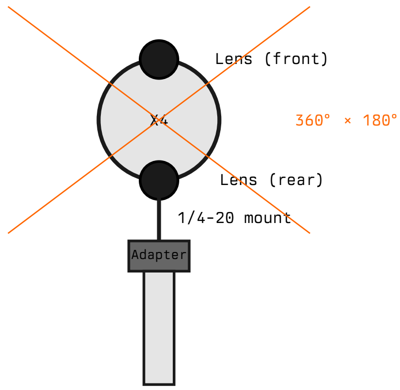


Figure 36: Camera at mast top. Dual lenses capture full spherical view.

Mount Options:
- 1/4-20 threaded insert in pole top cap
- GoPro-style mount adapter
- Custom 3D-printed adapter

Cable Routing:
- USB-C cable to Jetson
- Route inside pole if possible
- Secure with cable ties
- Leave strain relief loop at camera

Camera Settings:

Setting	Value
Mode	Live streaming (H.265)
Resolution	4K or 5.7K
Frame rate	30 fps
Stabilization	FlowState (on)

Wiring

Wiring is where builds go wrong. A loose connection causes intermittent failures. A reversed polarity destroys components. A pinched wire works fine until it doesn't.

Take your time here. Label every wire. Double-check polarity before applying power. Use the correct gauge wire for the current it carries. The extra hour spent on clean wiring saves days of debugging later.

The schematic on the next page shows the complete system. Study it before you start, and refer back to it often.

System Wiring Schematic

Reference: complete wiring diagram reference

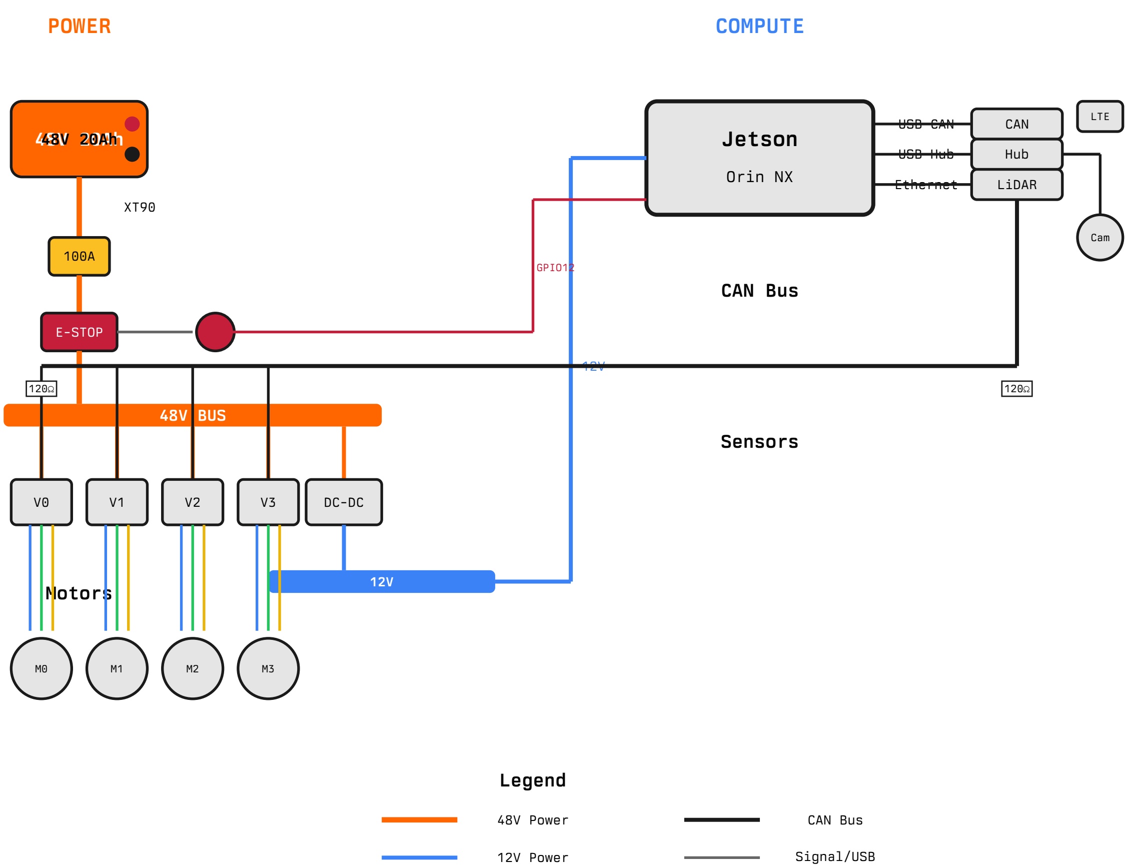


Figure 37: Complete system wiring. Power flows left, compute/sensors right.

CAN Bus Wiring

Wire CAN bus network 30 min

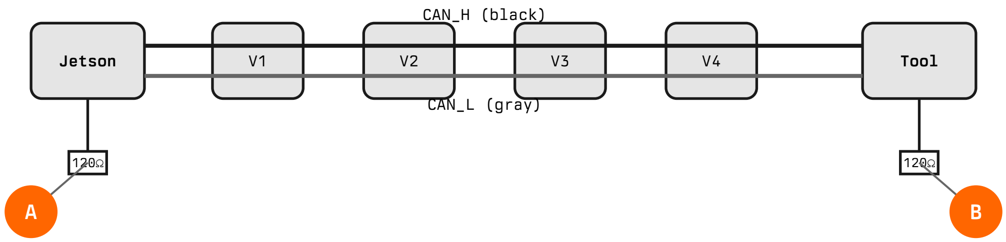


Figure 38: CAN bus with 120Ω termination at each end (A and B).

Wiring Rules:

- Use twisted pair wire (22 AWG)
- CAN_H to CAN_H, CAN_L to CAN_L at each device
- Maximum total bus length: 40m at 500K baud
- Exactly 2 termination resistors (one at each end)
- Keep CAN wires away from motor phase wires

JST Connector Pinout:

Pin	Signal
Color (typical)	1
GND	Black
2	CAN_L
Gray or White	3
CAN_H	Orange or Yellow
4	+5V (optional)
Red	

Motor Phase Wiring

Connect motor phase wires 15 min per motor

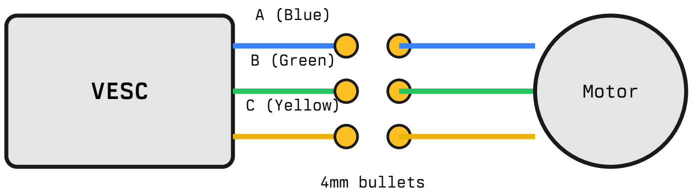


Figure 39: Phase wires connect VESC to motor via bullet connectors.

Connection Notes:

- Motor wire colors may not match VESC colors
- If motor spins wrong direction: swap any two phase wires
- Use 4mm gold bullet connectors (60A rated)
- Solder connections, use heat shrink
- Keep phase wires away from signal wires (EMI)

Wire Lengths:

Motor Position	Approx. Length
Front Left	400mm
Front Right	500mm
Rear Left	300mm
Rear Right	400mm

i **NOTE** Add 50mm extra for service loops. Too tight = strain on connectors.

⚡ **COMMON MISTAKE** Phase wire order doesn't matter for direction (any two can be swapped). But inconsistent colors across all 4 motors makes troubleshooting a nightmare. Pick a convention and stick to it.

Signal Wiring

Route USB and signal cables 20 min

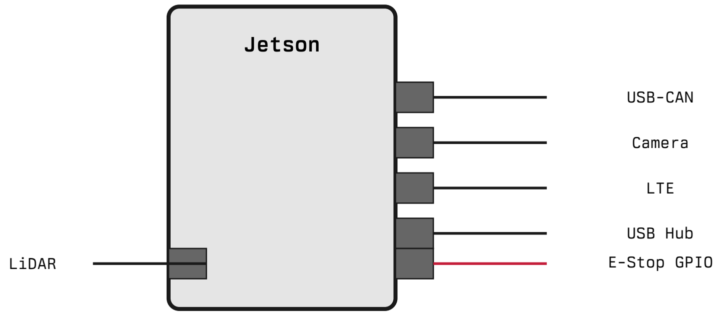


Figure 40: Jetson connections. USB for peripherals, GPIO for E-Stop, Ethernet for LiDAR.

USB Allocation:

Port	Device
Cable	USB 3.0 1
USB-CAN adapter	USB-A to adapter
USB 3.0 2	USB Hub
USB-A to hub	Hub Port 1
Insta360 X4	USB-C
Hub Port 2	LTE modem
USB-A	

GPIO:

- Pin for E-Stop relay control
- Active-high: GPIO high = relay closed = power on
- On Jetson startup: default low = safe state

Cable Management

Secure and organize all wiring 30 min

Frame interior (top view)

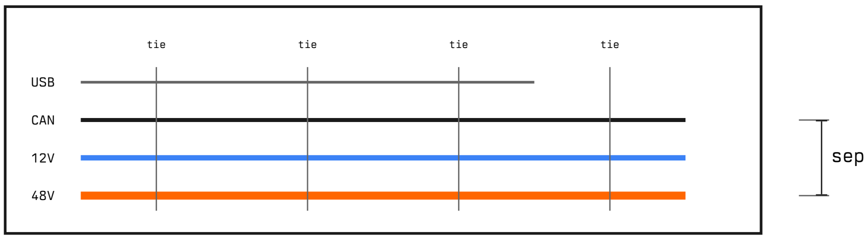


Figure 41: Route power and signal cables separately. Secure every 150mm.

Routing Rules:

- Separate power (48V) from signals by at least 25mm
- CAN bus twisted pair reduces interference
- Use cable ties every 100-150mm
- Leave service loops at connectors
- Label both ends of each cable

Cable Tie Points:

- Frame corners
- Near each connector
- Before/after bends
- At entry to electronics bay

- [ ] No cables in wheel path
- [ ] No cables near hot components (VESCs)
- [ ] All connectors accessible
- [ ] Service loops at key points
- [ ] Labels on power cables

> *"We learned this the hard way:" Beautiful cable management is great until you need to replace a VESC. Leave enough slack to pull components 10cm out for service without disconnecting everything upstream.*

Testing

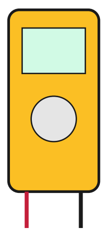
This is the moment of truth. You've built the mechanical system, wired the electronics, and configured the software. Now you find out if it all works together.

Go slow. The pre-power checks exist because we've made every mistake in this section at least once. A reversed connector, a missed termination resistor, a VESC with the wrong ID, these are easy to fix **before** you apply power and much harder after.

The first power-up should be anticlimactic. If you smell burning, hear crackling, or see smoke: power off immediately. Something is wrong, and continuing will make it worse.

Pre-Power Checks

Verify connections before first power-on 10 min



Multimeter Tests

Continuity Tests (power OFF):

Test	Probe Points
Expected	48V+ to GND
Battery connector pins	Open (no beep)
12V+ to GND	DC-DC output
Open (no beep)	CAN_H to CAN_L
CAN connector	60Ω (two 120Ω in parallel)
Phase A to B	Motor connector
Low resistance (motor windings)	

Visual Inspection:

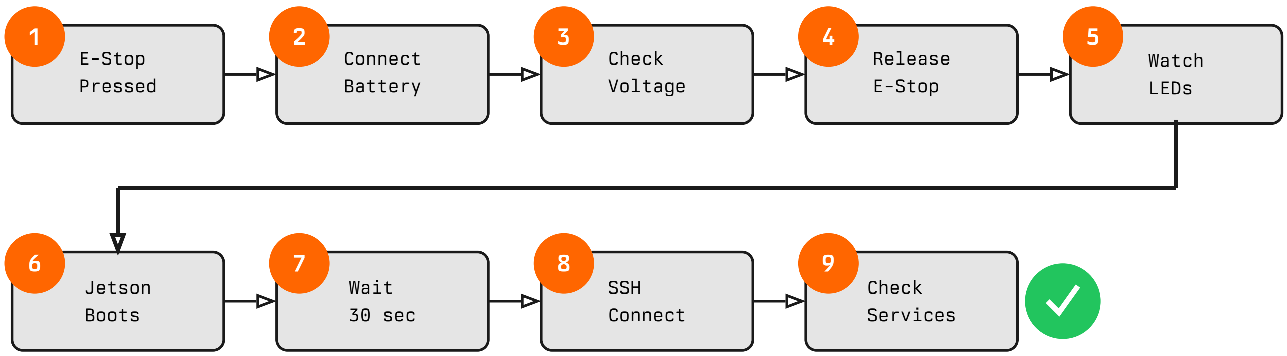
- [ ] No exposed wire or bare conductors
- [ ] All connectors fully seated
- [ ] Polarity correct (red to +, black to -)
- [ ] No pinched wires
- [ ] Fuse installed and correct rating
- [ ] E-Stop button in pressed (safe) position

⚠️ **DANGER** If any continuity test shows a short (beep) between power and ground, DO NOT APPLY POWER. Find and fix the short first.

> *"We learned this the hard way:" A reversed XT60 connector on the DC-DC input fried a $35 converter instantly. The 30-second continuity check would have caught it.*

First Power-Up

Initial power-on sequence 5 min



What to Watch:

Indicator	Normal
Problem	VESC LEDs
Solid green	Red = fault, none = no power
Jetson LED	Solid then blinking
None = power issue	DC-DC LED
Green (if equipped)	None = input voltage issue
Smell	None
Burning = immediate power off	Sound
Quiet hum	Buzzing = loose connection

VESC Configuration

Configure motor controllers 15 min per VESC ●●●

Configure motor controllers using VESC Tool.

▶ VESC Setup Walkthrough

Connection:

1. Connect laptop to VESC via USB
2. Open VESC Tool
3. Select serial port, click Connect

Motor Wizard:

1. Navigate to Motor → Motor Wizard
2. Select motor type (usually "Large outrunner")
3. Run detection: VESC will spin motor briefly
4. Review detected parameters
5. Write configuration to VESC

CAN Configuration:

1. Navigate to App → CAN Status
2. Set unique Controller ID (0, 1, 2, 3)
3. Set CAN Baud to 500K
4. Enable "Send CAN Status"
5. Write configuration

Per-VESC Settings:

VESC	ID
Motor Direction	Front Left
0	Forward = CCW
Front Right	1
Forward = CW	Rear Left
2	Forward = CCW
Rear Right	3
Forward = CW	

ℹ **NOTE** Left and right motors spin opposite directions for forward motion in skid-steer.

⚡ **COMMON MISTAKE** Swapping VESC IDs 0↔1 or 2↔3 makes the rover spin in circles instead of driving straight. The CAN ID diagram on the Quick Reference Card saves debugging time.

Motor Testing

Verify motor response 10 min

⚠ **WARNING** Elevate rover so all wheels are off the ground before motor testing.

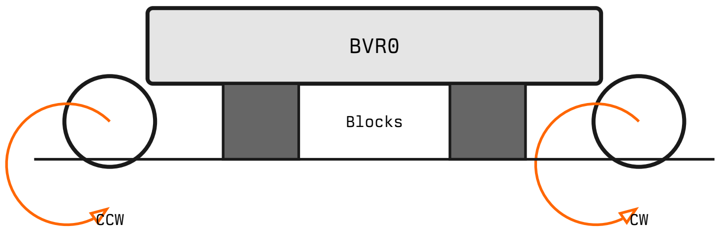


Figure 44: Test with wheels elevated. Verify each motor spins correct direction.

Test Procedure:

1. Elevate rover on blocks (all wheels free)
2. Power on, release E-Stop
3. Connect controller
4. Command forward slowly: all wheels should spin "forward"
5. Command reverse: all wheels should spin "backward"
6. Command left turn: right wheels forward, left wheels backward
7. Test E-Stop: press button, verify immediate stop

Direction Fix: If a motor spins wrong direction, swap any two phase wires on that motor.

- [ ] All 4 motors respond to commands
- [ ] Direction correct for each motor
- [ ] E-Stop stops all motors immediately
- [ ] No unusual sounds or vibration
- [ ] VESCs not overheating

"We learned this the hard way:" The first road test had the rover on flat ground. It took off at 2 m/s and hit a wall. Always test on blocks first, with throttle at minimum.

Operation

Operating the rover is straightforward once it's built and tested. The startup sequence takes about 3 minutes. Shutdown takes 1 minute. Most of that time is waiting for the Jetson to boot.

The key habit is consistency. Use the same startup sequence every time. Check the same indicators. Park in the same spot. Consistent routines catch problems early, when they're small and easy to fix.

Startup Procedure

Power on and connect 3 min

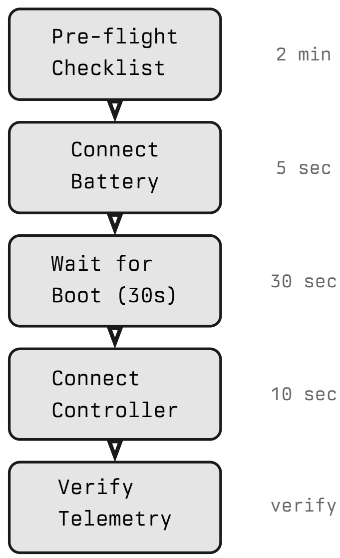


Figure 45: Startup takes approximately 3 minutes.

Detailed Steps:

1. **Pre-flight:** Complete checklist on page 2
2. **Battery:** Connect XT90 (hear click). E-Stop should be pressed.
3. **Boot:** Release E-Stop. Wait for Jetson to boot (30s). VESC LEDs turn green.
4. **Controller:** Power on controller. Connect to operator station.
5. **Telemetry:** Verify video feed, voltage reading, and mode indicator.

> i **NOTE** Do not operate if telemetry shows errors or video feed is absent.

Shutdown Procedure

Safe power-off sequence 1 min

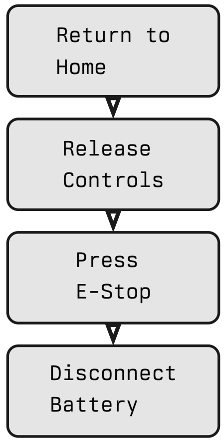


Figure 46: Always press E-Stop before disconnecting battery.

Shutdown Checklist:

- [ ] Rover parked in designated area
- [ ] Controller set down / powered off
- [ ] E-Stop button pressed (red button down)
- [ ] Wait 5 seconds for Jetson to save state
- [ ] Disconnect battery (pull XT90)
- [ ] Store battery properly (50-60% charge for long storage)

⚠️ **WARNING** Never disconnect battery while Jetson is running. This can corrupt the filesystem.

"We learned this the hard way:" One field test ended with a dead battery mid-session. The Jetson filesystem corrupted and needed a full reflash. Now we monitor voltage religiously and shut down at 42V.

Tool Attachment

Attach modular tools 2 min

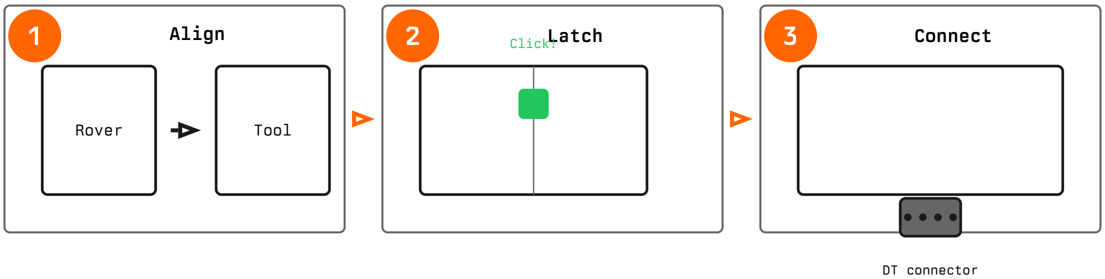


Figure 47: Tool attachment: align rails, latch, then connect electrical.

Attachment Procedure:

1. Power OFF rover (E-Stop pressed)
2. Align tool mounting rails with rover interface
3. Slide tool forward until latch clicks (audible)
4. Verify latch indicator shows green/locked
5. Connect DT electrical connector (power + CAN)
6. Power ON rover
7. Tool announces itself automatically on CAN bus
8. Operator UI shows tool status

Detachment:

1. Power OFF rover
2. Disconnect DT electrical connector first
3. Release latch lever
4. Slide tool rearward to remove

> i **NOTE** Always disconnect electrical before unlatching mechanical. Prevents arcing.

Safety

The BVR0 is a machine, and machines can hurt you. The hazards are real: spinning wheels that don't care about fingers, a battery that can catch fire, a 30kg robot that can pin you against a wall.

None of this is meant to scare you. These hazards are manageable with basic awareness and respect for the machine. The safety protocols in this section come from experience (some of it painful). Follow them.

Personal Protective Equipment

PPE requirements by task reference

Task	Required PPE
Cutting extrusions	Safety glasses, work gloves
Soldering / wiring	Safety glasses, fume extraction
Battery handling	Insulated gloves, safety glasses
Motor testing	Safety glasses, hearing protection
Operation	None required (stay clear of rover)

Safe Operating Distance:

- Operator: minimum 2m from rover during teleop
- Bystanders: minimum 5m from operating rover
- During charging: check every 15 min, do not leave unattended

Hazard Zones

Know the danger zones reference

⚠️ **DANGER** Stay clear of marked zones during operation. Serious injury possible.

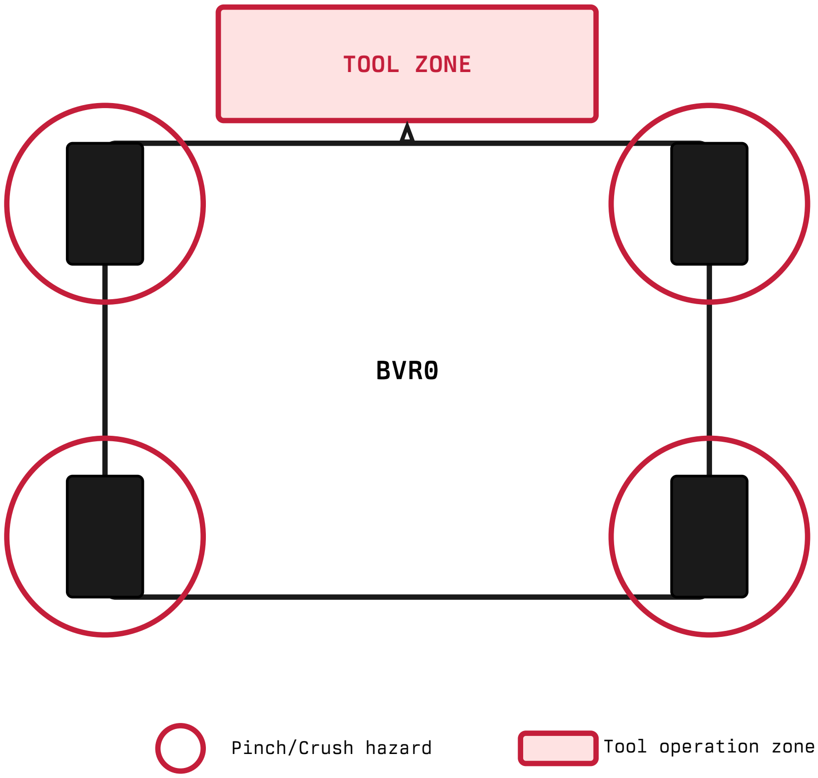


Figure 48: Keep hands, feet, and loose clothing clear of marked zones.

Hazard Types:

Zone	Hazard
Injury Type	Wheel areas
Rotating wheels, motor torque	Crush, pinch, friction burn
Tool zone	Rotating auger/blade
Laceration, amputation	Underside
50mm ground clearance	Crush if rover tips
Battery area	Electrical, thermal
Shock, burns	

Battery Safety

Handle lithium batteries safely reference

⚠️ **WARNING** Li-ion batteries can catch fire if damaged, punctured, or short-circuited.

DO		DON'T	
15-25°C	Store temp	No water	Keep dry
50-60%	Storage charge	No puncture	Protect case
Inspect	Before each use	No fire	Never burn

Signs of Battery Damage:

- Swelling or bulging
- Unusual heat
- Hissing or venting
- Visible damage to case
- Reduced capacity

In Case of Battery Fire:

1. **Evacuate** the immediate area (minimum 10m / 30ft)
2. Call fire department: **911**
3. If small and contained: use **CO2** or **ABC dry chemical** extinguisher
4. If large or spreading: **do not attempt to extinguish** (let professionals handle)
5. Ventilate area (toxic fluoride fumes)
6. Water in **large quantities** can cool adjacent cells and prevent spread, but small amounts can make it worse

⚠️ **WARNING** Li-ion fires re-ignite. Monitor for at least 1 hour after fire appears out. Do not move battery until cool.

⚠️ **DANGER** Never attempt to charge a damaged battery. Dispose at authorized battery recycling facility (Call2Recycle, Best Buy, etc.).

Firmware

The rover runs two firmware stacks: bvrd on the Jetson (the main brain), and embedded firmware on tool attachments (ESP32-based).

Most operators never need to touch firmware. It comes pre-flashed on shipped units, and updates are pushed over-the-air. This section is for those building from scratch or doing development work.

If you're comfortable with Linux command lines and embedded toolchains, this will be familiar. If not, follow the steps exactly, and don't skip the verification steps.

Initial Jetson Setup

Flash and configure Jetson 45 min ●●●

▶ Full Setup Walkthrough

1. Flash JetPack OS:

Download JetPack 6.0+ from NVIDIA. Flash using SDK Manager on Ubuntu host:

```
# On Ubuntu 20.04/22.04 host machine
sudo apt install nvidia-sdk-manager
sdkmanager  # GUI will launch
```

Select "Jetson Orin NX" and JetPack 6.0. Follow prompts to flash.

2. First Boot Configuration:

```
# Set hostname
sudo hostnamectl set-hostname bvr0

# Create muni user (if not done during setup)
sudo adduser muni
sudo usermod -aG sudo,dialout,video muni

# Enable SSH
sudo systemctl enable ssh
```

3. Install Dependencies:

```
sudo apt update && sudo apt upgrade -y
sudo apt install -y can-utils build-essential \
    libclang-dev pkg-config libssl-dev

# Install Rust
curl --proto '=https' --tlsv1.2 -sSf \
    https://sh.rustup.rs | sh
source ~/.cargo/env
```

CAN Bus Setup

Configure CAN interface 10 min

1. Load CAN Modules:

```
# Add to /etc/modules-load.d/can.conf
echo "can" | sudo tee /etc/modules-load.d/can.conf
echo "can_raw" | sudo tee -a /etc/modules-load.d/can.conf
echo "slcan" | sudo tee -a /etc/modules-load.d/can.conf
```

2. Create Startup Service:

Create /etc/systemd/system/can.service:

```
[Unit]
Description=CAN Bus Interface
After=network.target

[Service]
Type=oneshot
RemainAfterExit=yes
ExecStart=/sbin/ip link set can0 type can bitrate 500000
ExecStart=/sbin/ip link set can0 up
ExecStop=/sbin/ip link set can0 down

[Install]
WantedBy=multi-user.target
```

```
sudo systemctl enable can.service
sudo systemctl start can.service
```

3. Verify CAN:

```
# Should show can0 interface
ip link show can0

# Monitor CAN traffic (VESCs should send status)
candump can0
```

LiDAR Setup

Configure LiDAR network 15 min

1. Network Configuration:

The Mid-360 uses a static IP. Configure the Jetson Ethernet:

```
# Add to /etc/netplan/01-lidar.yaml
network:
  version: 2
  ethernets:
    eth0:
      addresses:
        - 192.168.1.50/24
      routes:
        - to: 192.168.1.0/24
          via: 192.168.1.1
```

```
sudo netplan apply
```

2. LiDAR Default Settings:

Parameter	Value
LiDAR IP	192.168.1.1xx (xx = last 2 of serial)
Host IP	192.168.1.50
Data Port	56000
Command Port	56001

3. Test Connection:

```
# Ping LiDAR (replace with your unit's IP)
ping 192.168.1.100

# Install Livox SDK2 for testing
git clone https://github.com/Livox-SDK/Livox-SDK2
cd Livox-SDK2 && mkdir build && cd build
cmake .. && make -j4
```

bvrd Installation

Install rover daemon 15 min

1. Clone Repository:

```
cd /opt
sudo mkdir muni && sudo chown muni:muni muni
git clone https://github.com/muni-works/bvr.git
cd bvr/firmware
```

2. Build:

```
cargo build --release
sudo cp target/release/bvrd /opt/muni/bin/
```

3. Install Service:

```
sudo cp config/bvrd.service /etc/systemd/system/
sudo systemctl daemon-reload
sudo systemctl enable bvrd
sudo systemctl start bvrd
```

4. Verify:

```
sudo systemctl status bvrd
journalctl -u bvrd -f
```

Firmware Overview

The rover uses two main firmware components.

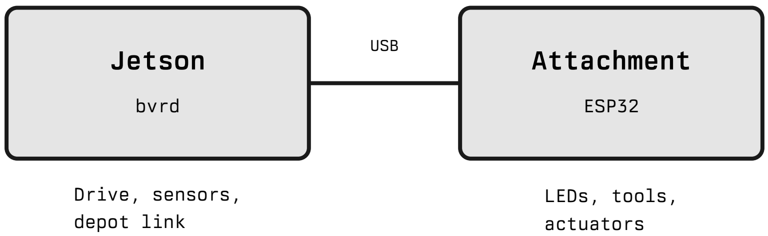


Figure 50: Firmware architecture: Jetson runs bvrd, attachments run on ESP32.

bvrd (Jetson)

- Main rover daemon
- Motor control via CAN
- Sensor fusion
- Depot communication
- Attachment discovery

Attachment (ESP32)

- Tool-specific firmware
- LED control
- Local sensors
- SLCAN protocol
- Status heartbeat

Updating bvrd

Deploy firmware updates 5 min

Prerequisites:

- SSH access to Jetson
- Rust toolchain with aarch64 target

Build and Deploy:

```
# On development machine
cd bvr/firmware
cargo build --release --target aarch64-unknown-linux-gnu

# Copy to Jetson
scp target/aarch64-unknown-linux-gnu/release/bvrd \
    muni@<jetson-ip>:/opt/muni/bin/

# On Jetson - restart service
ssh muni@<jetson-ip>
sudo systemctl restart bvrd
```

Verify:

```
# Check service status
sudo systemctl status bvrd

# View logs
journalctl -u bvrd -f
```

Updating Attachment Firmware

Flash ESP32 attachments 10 min

Prerequisites:

- ESP32 Rust toolchain (espup install)
- espflash tool installed
- Attachment connected via USB

Build:

```
cd mcu/bins/esp32s3
source ~/export-esp.sh
cargo build --release
```

Flash:

```
espflash flash \
    --ignore-app-descriptor \
    --partition-table partitions.csv \
    --bootloader bootloader.bin \
    --min-chip-rev 0.0 \
    target/xtensa-esp32s3-none-elf/release/mcu-esp32s3
```

Monitor Serial Output:

```
espflash monitor
# Or: screen /dev/cu.usbserial-0001 115200
```

If flash fails:

1. Unplug USB
2. Hold BOOT button
3. Plug in USB (keep holding)
4. Release after 2 seconds
5. Retry flash command

Attachment Protocol

Attachments communicate via SLCAN (CAN-over-serial).

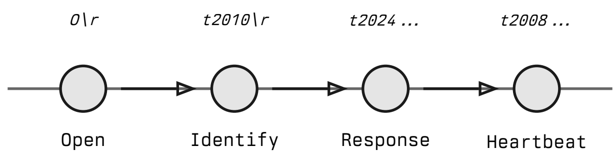


Figure 51: Discovery flow: open channel, identify, then heartbeat begins.

CAN Message IDs (Attachment Slot 0):

ID	Direction
Purpose	0x200
Attach → Host	Heartbeat (1Hz)
0x201	Host → Attach
Identify request	0x202
Attach → Host	Identity response
0x203	Host → Attach
Command	0x204
Attach → Host	Acknowledgment

Text Commands (for debugging):

```
led 255,0,0    # Set LED red
cycle          # Rainbow cycle mode
state running  # Set state
help           # Show commands
```

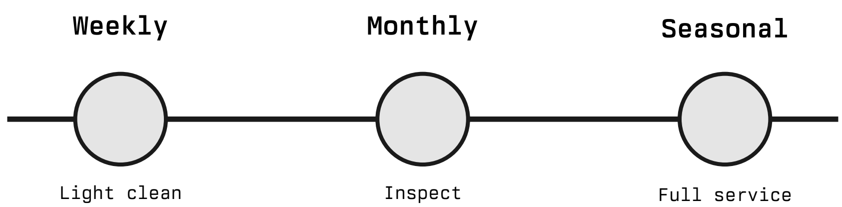
Maintenance

A well-maintained rover is a reliable rover. The maintenance tasks are simple: clean it, inspect it, keep the bolts tight and the battery healthy.

The schedule below is based on real-world operation in Cleveland conditions (salt, snow, mud, temperature swings). If you operate in a milder environment, you can extend the intervals. If you're running daily in harsh conditions, shorten them.

Maintenance Schedule

Preventive maintenance overview varies



Weekly
- Clean wheels and chassis
- Wipe camera lens
- Wipe LiDAR lens
- Check connector seating
- Verify wheel spin
- Test E-Stop function

Monthly
- Inspect all wiring
- Check bolt torque
- Clean electrical contacts
- Check battery health
- Update firmware
- Review error logs

Seasonal
- Full electrical inspection
- Check wheel bearings
- Replace worn tires
- Deep clean chassis
- Calibrate sensors
- Battery capacity test

Troubleshooting

Diagnose common issues

varies

Symptom	Likely Cause
Solution	Won’t power on
Battery disconnect	Check XT90 connection, verify fuse
No video feed	Camera USB
Reconnect camera, check USB hub power	Motor not responding
CAN wiring	Check CAN connections, verify VESC ID
Erratic movement	VESC ID mismatch
Verify IDs match wheel positions	E-Stop won’t release
Button stuck	Check relay wiring, verify mechanism
Overheating	Ventilation blocked
Clean vents, reduce load	Poor LTE signal
Antenna position	Reposition antenna, check SIM
Battery dies quickly	Battery age
Check cell balance, replace if needed	Jerky motion
Motor calibration	Re-run VESC motor detection
Drift to one side	Wheel alignment
Re-align motor brackets	

Diagnostic Commands:

```
# Check system status
bvr status

# List CAN devices
bvr can scan

# Test individual motor
bvr motor test <id>

# View recent logs
journalctl -u bvrd -n 100
```

▸ Troubleshooting Walkthrough

Storage

Store rover properly 5 min

50-60%	Disconnect	15-25°C
Battery charge	Unplug battery	Temperature

Short-Term Storage (< 1 week):

- [ ] Press E-Stop
- [ ] Disconnect battery
- [ ] Cover if stored outdoors

Long-Term Storage (> 1 week):

- [ ] Charge battery to 50-60%
- [ ] Disconnect battery completely
- [ ] Clean chassis and wheels
- [ ] Cover camera and LiDAR lenses
- [ ] Store in dry location (15-25°C)
- [ ] Check battery monthly (recharge if < 40%)

Returning from Storage:

1. Inspect for moisture, corrosion, pest damage
2. Charge battery fully
3. Run pre-flight checklist
4. Test all functions before field use

Bill of Materials

This is everything you need to build one BVR0 from scratch. Prices are approximate as of late 2025 and vary by region and vendor.

A few notes on sourcing: the expensive items (Jetson, LiDAR, camera) are worth buying from authorized distributors for warranty support. The commodity items (extrusions, fasteners, wire) can come from anywhere. The hub motors are sourced from AliExpress because that's where they're cheapest; allow 2-3 weeks for shipping.

The total cost ($4,200) is roughly split: one-third mechanical, one-third power/drive, one-third compute/sensors. If you're building multiple units, the mechanical and power costs drop significantly with bulk ordering.

Structural

Part	Qty	Unit	Total	Source
2020 Aluminum Extrusion, 1m	6	$8	$48	Amazon / 8020.net
90° Corner Bracket	16	$1.50	$24	Amazon
M5×10 Button Head Bolt	64	$0.15	$10	McMaster
M5 T-Nut (drop-in)	64	$0.20	$13	Amazon
M5 T-Nut (pre-load)	32	$0.15	$5	Amazon
25mm Aluminum Tube (mast)	1	$15	$15	Local metal supplier

Drivetrain

Part	Qty	Unit	Total	Source
Hub Motor 350W 48V	4	$85	$340	AliExpress / ODrive
VESC 6.7 (Flipsky)	4	$120	$480	Flipsky
M5×12 Button Head Bolt	8	$0.15	$2	McMaster
4mm Bullet Connectors	24	$0.50	$12	Amazon

Power

Part	Qty	Unit	Total	Source
48V 20Ah Downtube Battery	1	$400	$400	Unit Pack Power / Luna
XT90 Connector Pair	2	$4	$8	Amazon
XT60 Connector Pair	6	$2	$12	Amazon
100A ANL Fuse + Holder	1	$15	$15	Amazon
DC-DC 48V→12V 10A	1	$35	$35	Amazon
10 AWG Silicone Wire (red)	3m	$2/m	$6	Amazon

10 AWG Silicone Wire (black)	3m	$2/m	$6	Amazon
E-Stop Mushroom Button	1	$12	$12	Amazon
40A Relay (E-Stop)	1	$8	$8	Amazon

Electronics

Part	Qty	Unit	Total	Source
Jetson Orin NX 16GB	1	$600	$600	Seeed / Arrow
Carrier Board w/ CAN	1	$130	$130	Seeed / Waveshare
USB 3.0 Hub (powered)	1	$25	$25	Amazon
LTE Modem (USB)	1	$50	$50	Amazon
22 AWG Wire (CAN, assorted)	10m	$0.50/m	$5	Amazon
JST-XH 4-pin Connector	10	$0.50	$5	Amazon
Electrical Tape	2 rolls	$3	$6	Amazon
Velcro Strips	1 pack	$8	$8	Amazon

Sensors

Part	Qty	Unit	Total	Source
Livox Mid-360 LiDAR	1	$1,000	$1,000	Livox
Insta360 X4 Camera	1	$500	$500	Insta360
RTK GPS Module (optional)	1	$200	$200	SparkFun

Miscellaneous

Part	Qty	Unit	Total	Source
Zip Ties (assorted)	1 pack	$8	$8	Amazon
Heat Shrink Tubing	1 kit	$12	$12	Amazon
Loctite 243 (blue)	1	$8	$8	Amazon
Dielectric Grease	1	$6	$6	Amazon
Cable Sleeve (split loom)	5m	$1/m	$5	Amazon

Subtotals

Structural	$115
Drivetrain	$834
Power	$502
Electronics	$829
Sensors	$1,700
Misc	$39

Total: $4,019

Excludes tools, shipping, and taxes.
Prices vary by region and vendor.

Hardware Reference

1:1 SCALE — Print at 100%

Print this page at 100% scale. Use to verify hardware sizes.

Bolt Sizes (Socket Head Cap Screw)

M3 × 8 | M4 × 10 | M5 × 12 | M5 × 16

Electronics | Motors | Frame | Standoffs

Washer and Nut Sizes

M3 washer | M4 washer | M5 washer | M5 nut

Wire Gauges (Cross-Section)

10 AWG — 48V Power
18 AWG — 12V
22 AWG — CAN/Signal

Connector Sizes

i **NOTE** If hardware doesn’t match these silhouettes at 100% print scale, verify your print settings. Some PDF viewers default to “Fit to Page” which scales incorrectly.

Glossary

This manual uses a lot of acronyms and technical terms. If you encounter an unfamiliar term, check here first.

AWG American Wire Gauge. Lower numbers = thicker wire. 10 AWG for power, 22 AWG for signals.

BLDC Brushless DC motor. Uses electronic commutation instead of brushes.

BVR Base Vectoring Rover. Muni's first rover morphology.

CAN Controller Area Network. Industrial communication bus used for motor control.

CAN_H / CAN_L CAN High and CAN Low. Differential pair signals.

CCW / CW Counter-clockwise / Clockwise. Motor rotation direction.

DC-DC DC-DC converter. Steps voltage down (48V → 12V).

DT Connector Deutsch DT connector. Weatherproof automotive connector.

E-Stop Emergency Stop. Cuts power to motors immediately.

FOC Field-Oriented Control. Advanced motor control algorithm for smooth, efficient operation.

GPIO General Purpose Input/Output. Digital pins on the Jetson.

Hub Motor Motor integrated into the wheel hub. No external gears or chains.

Jetson NVIDIA Jetson. Embedded AI computer. BVR0 uses Orin NX.

LiDAR Light Detection and Ranging. Laser-based 3D sensor.

LiPo Lithium Polymer battery. High energy density, requires careful handling.

LTE Long-Term Evolution. Cellular data connection.

Nm Newton-meter. Unit of torque.

RTK Real-Time Kinematic. GPS correction for centimeter accuracy.

Skid-Steer Steering method where left and right sides drive at different speeds.

T-Nut Threaded nut that slides into aluminum extrusion T-slots.

Teleop Teleoperation. Remote control of the rover by a human operator.

Termination 120Ω resistor at CAN bus endpoints to prevent signal reflection.

VESC Vedder Electronic Speed Controller. Open-source motor controller.

XT Connector Amass XT series. Yellow power connectors (XT90, XT60, XT30).

Index

Page numbers reference the first significant mention of each topic. See the Table of Contents for section-level navigation.

Municipal Robotics
Cleveland, Ohio
muni.works