

SCUTTLE Assembly Guide

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Last Revised: 2022.12.28





In This Guide:

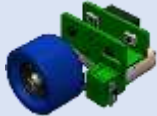
Resources



Resources for Building

- 3D Model
- Build Videos
- Tips to begin Assembly

Graphics



Assembly Views

- Views of completed sub-assemblies
- Callouts of key components in assembly

Mistakes



Mistakes

- Coming soon – the most common errors in building

Parts

Off-the-shelf (OTS) Components

- Features of main robot components
- Key performance parameters
- Alternate options for OTS parts
- A selection of extra components that are popular and easy to integrate

Assembly Resource: 3D Model



1

Find the latest SCUTTLE (v2.4)

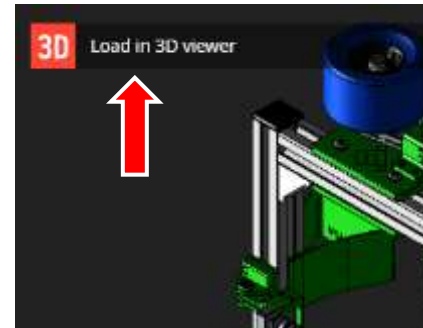
Jump to
GrabCAD Model



Always check for a newer version.

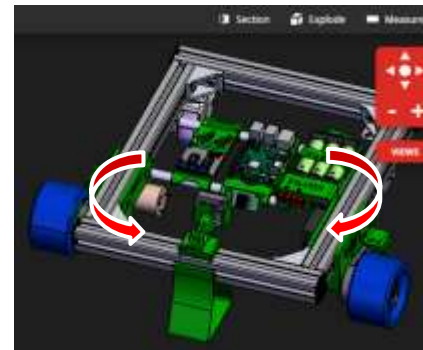
2

Navigate to the STEP assembly



3

Explore in your web browser!



Use Rotate, Section, and Explode to explore the model



Assembly Resource: Videos



Assembly Resource: First-Build Videos



The best videos to get started.



1) Wheels Prep [\[VIDEO\]](#)



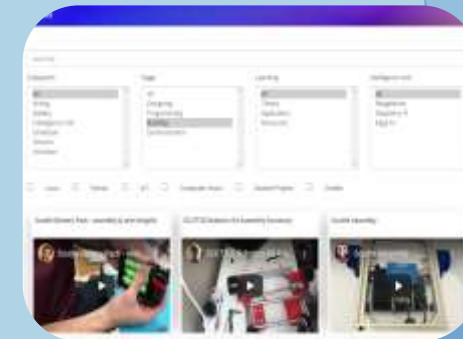
2) All Fasteners Explained [\[VIDEO\]](#)



3) Chassis Animation [\[VIDEO\]](#)



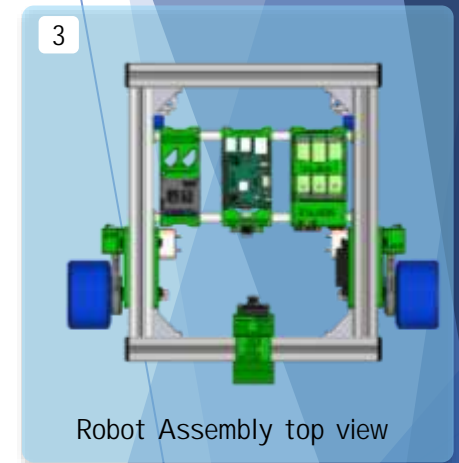
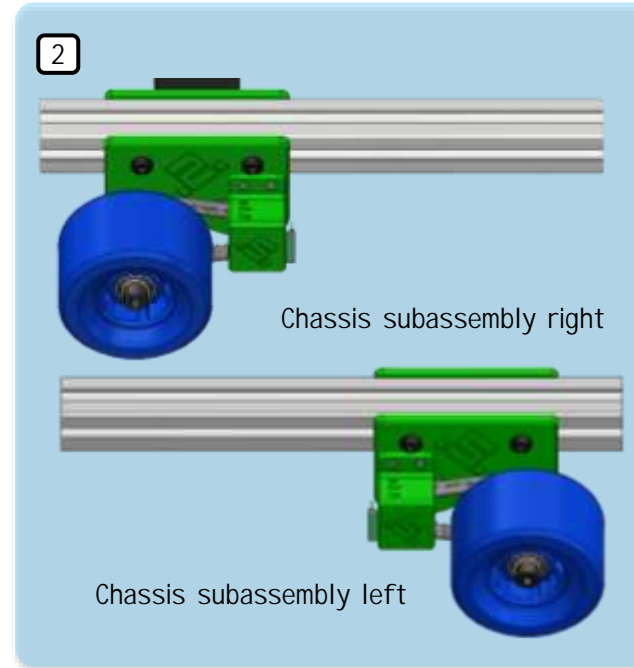
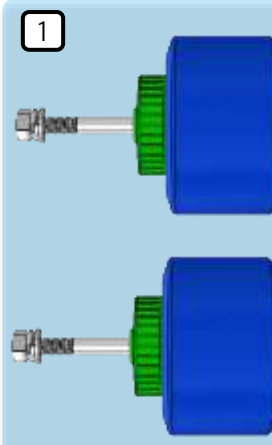
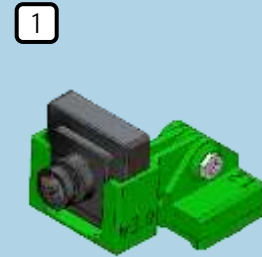
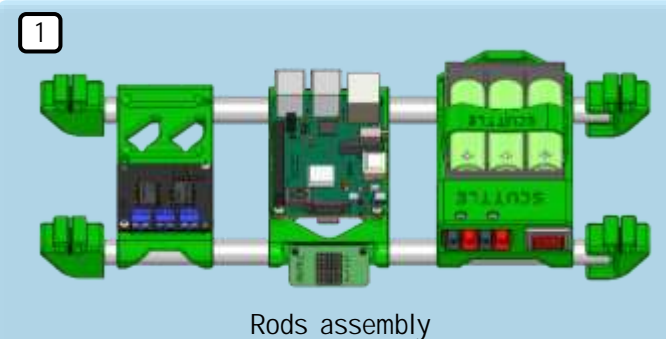
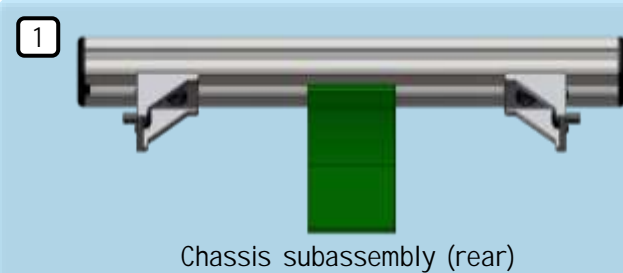
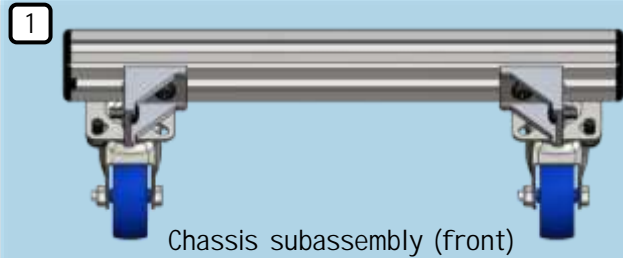
4) Build Timelapse [\[VIDEO\]](#)



5) First Time Build [\[TAGGED LIST\]](#)

Assembly Sequence

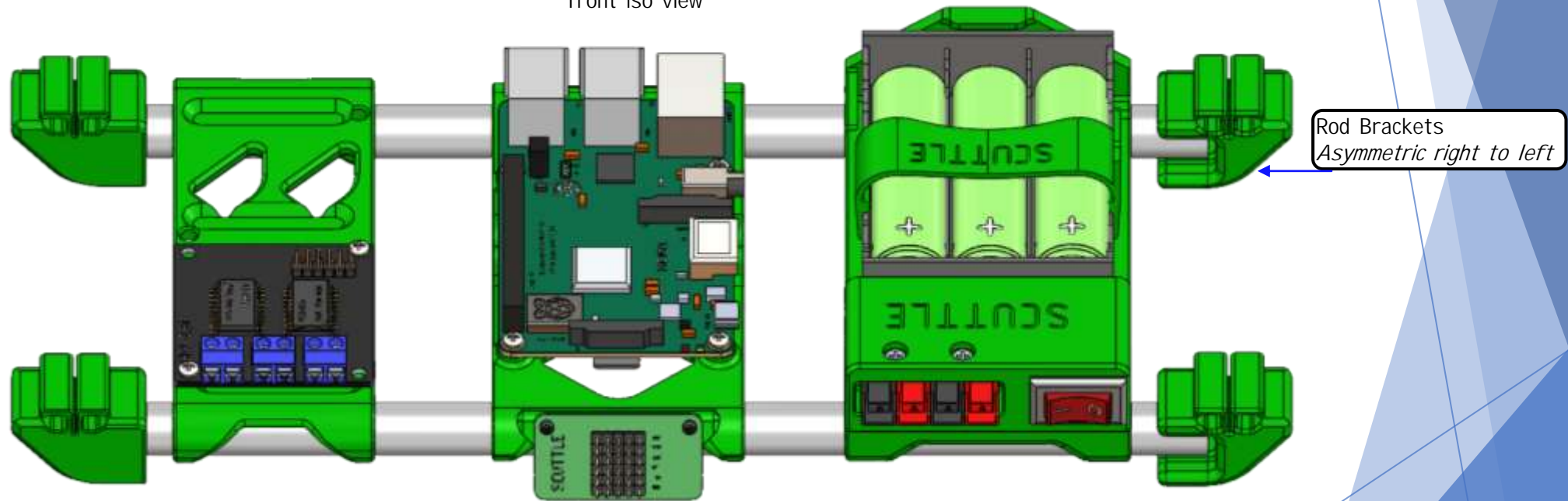
- 1 Build Subassemblies
- 2 Build Subassemblies
- 3 Combine to make



VIEW: Rods Assembly

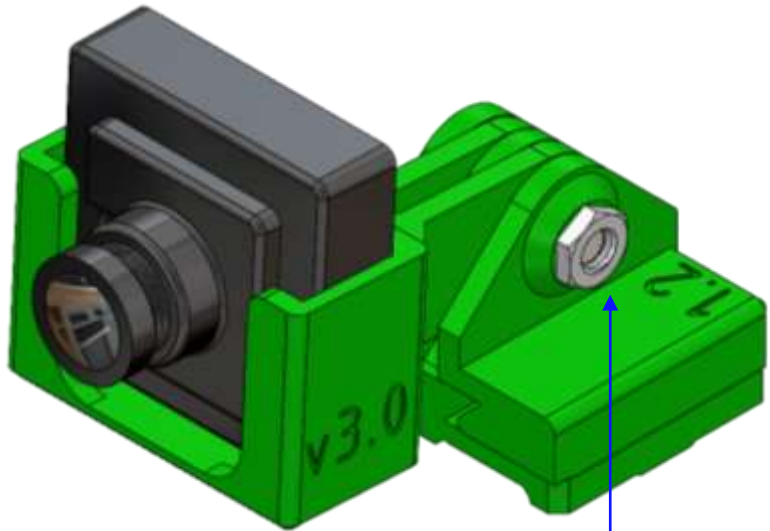


SCUTTLE™ v2.4 Rods Assembly
front iso view



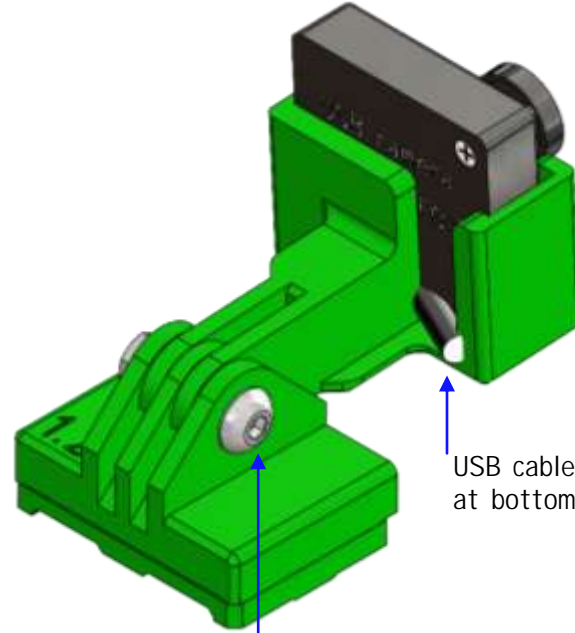
VIEW: Camera Assembly

Isometric view 1



M5 Nut nests into plastic

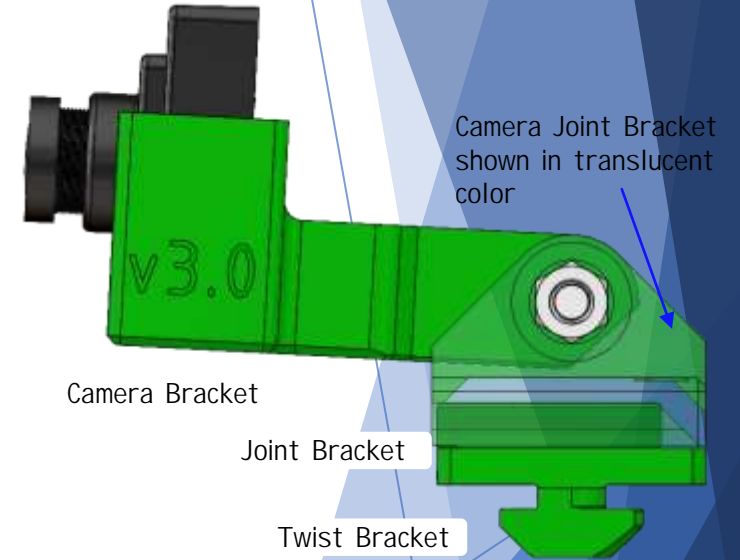
Isometric view 2



Screw, M5x20mm

USB cable exits at bottom

Side view



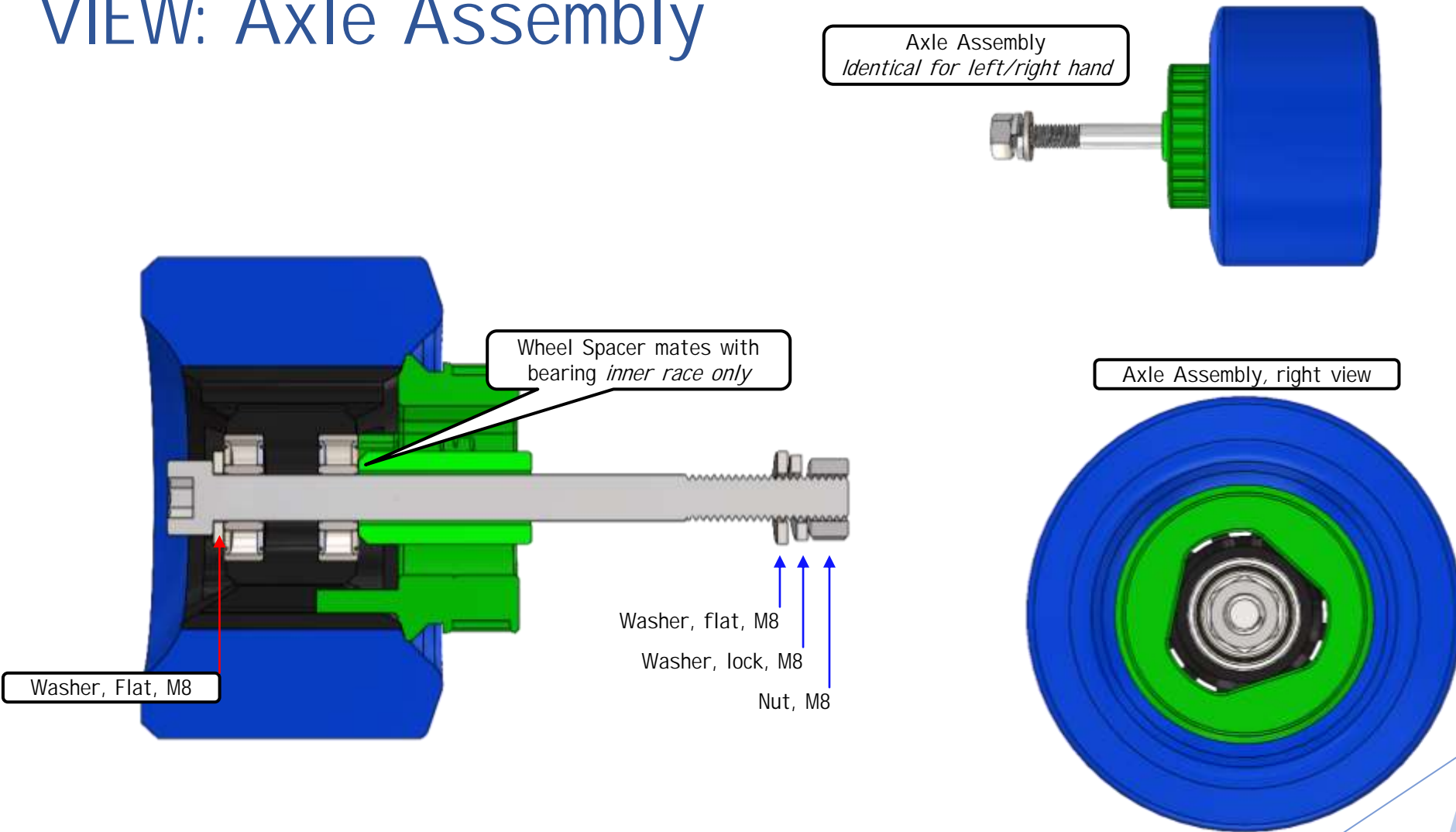
Camera Joint Bracket shown in translucent color

Camera Bracket

Joint Bracket

Twist Bracket

VIEW: Axle Assembly



VIEW: Right-hand Wheel Assembly

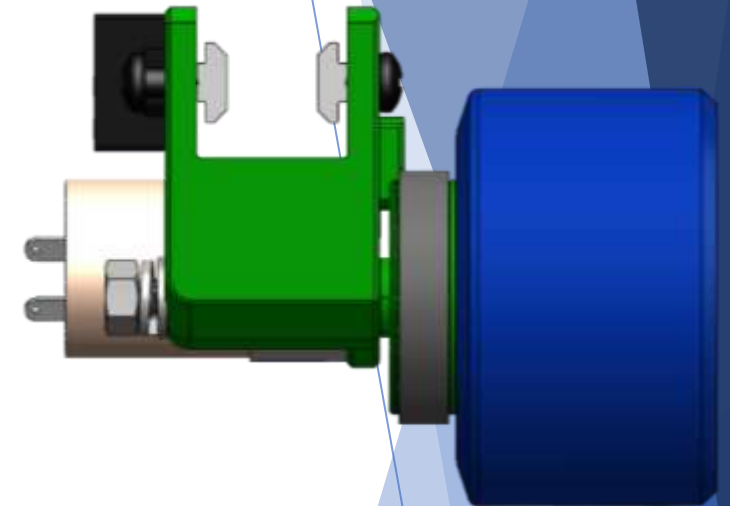
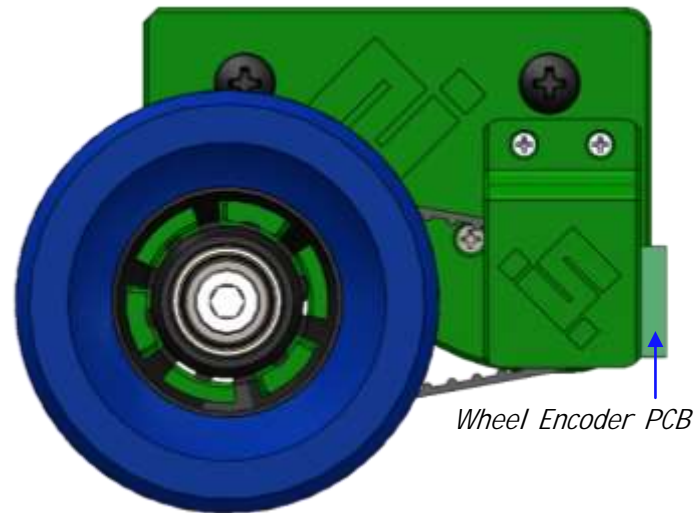
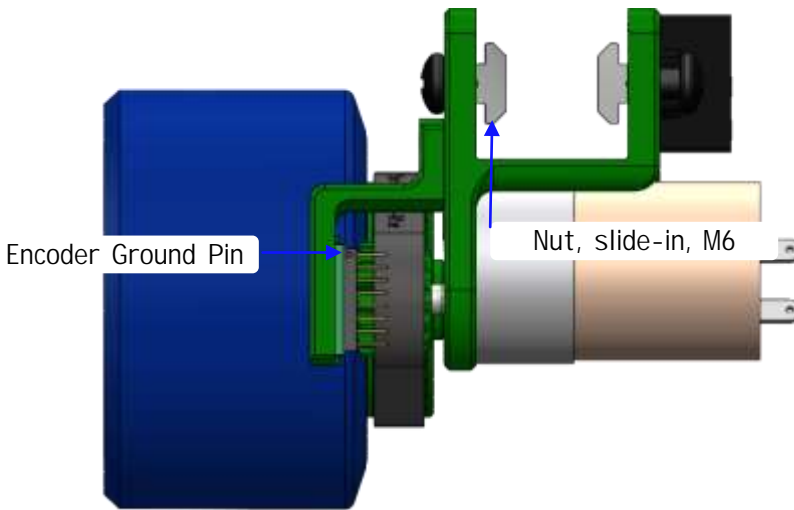
Wheel Assembly (right wheel)
Symmetric for left/right hand



front view

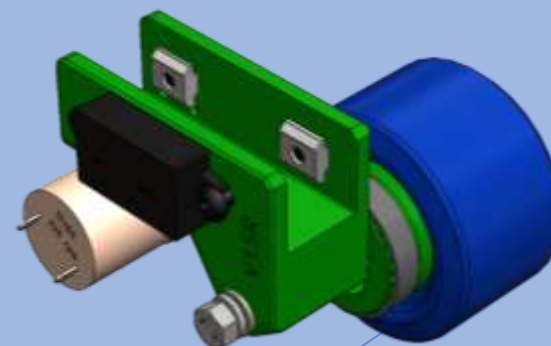
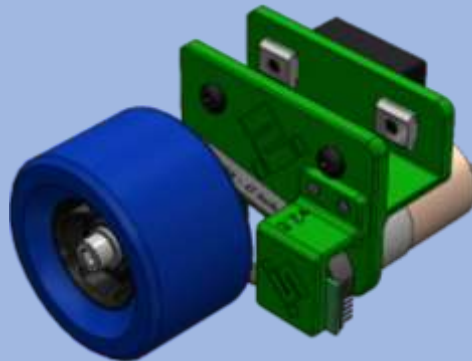
side view

rear view

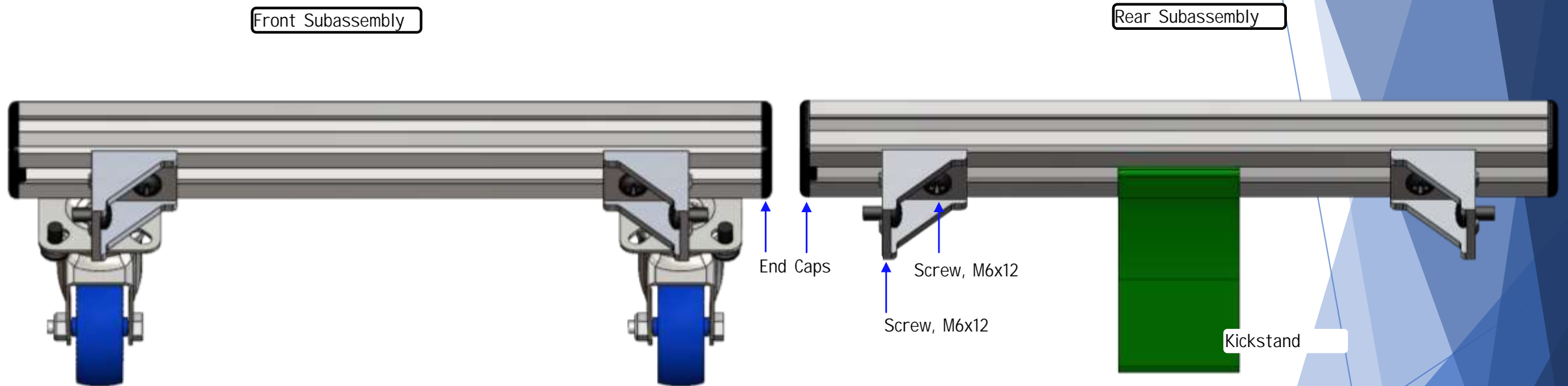


iso view 1

iso view 2



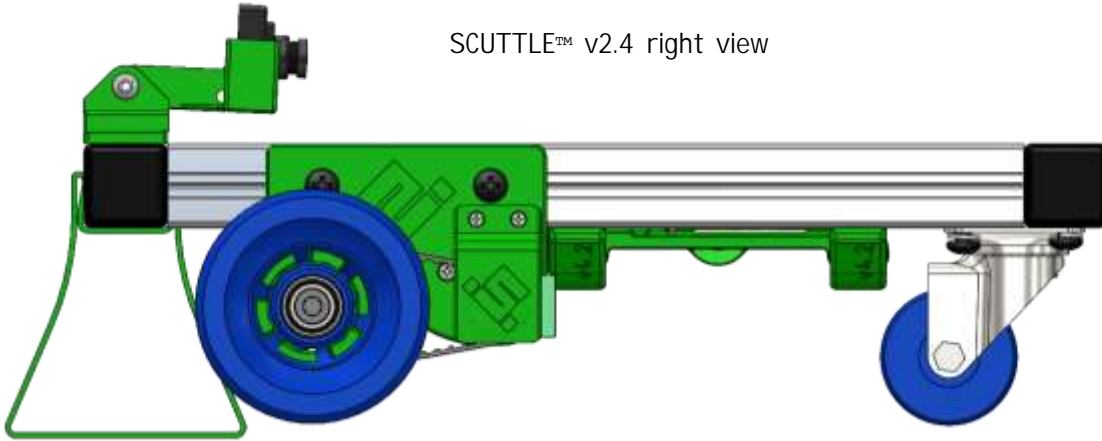
VIEW: Chassis Subassemblies



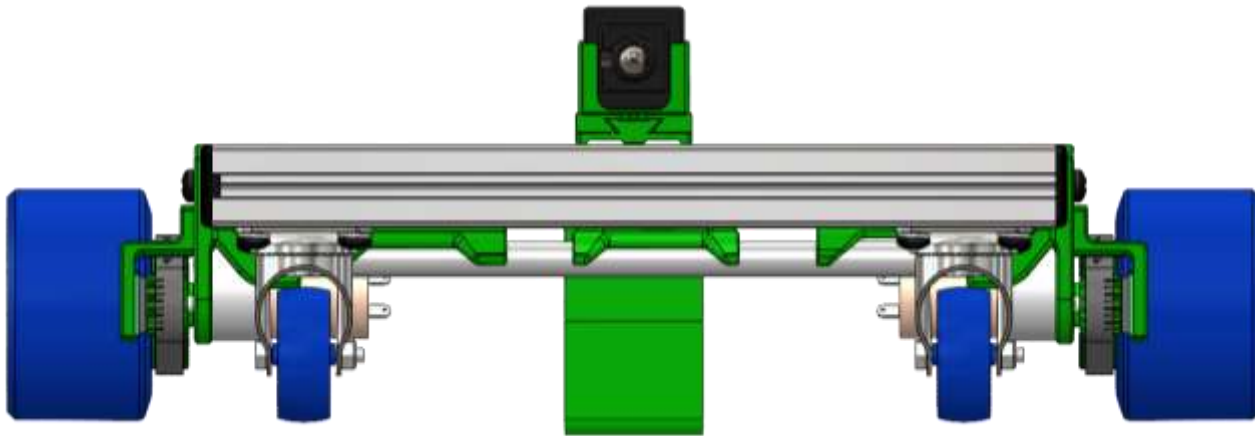
VIEW: Full Robot



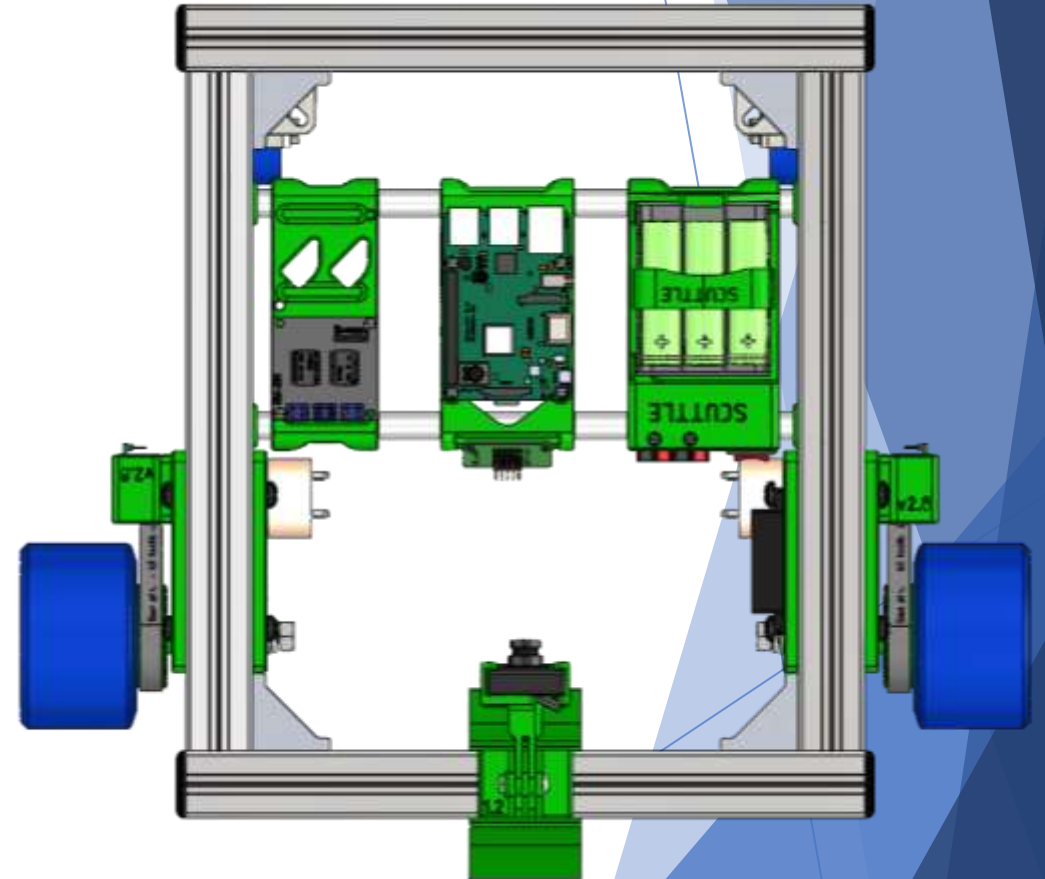
SCUTTLE™ v2.4 right view



SCUTTLE™ v2.4 front view



SCUTTLE™ v2.4 top view











Assembly Check List

- ▶ Front Caster has clearance to rotate 360 degrees
- ▶ Camera bracket seats on camera pivot without sliding off
- ▶ Electronics
 - ▶ Sequenced by Battery, CPU, Motor Driver (right to left)
- ▶ Chassis
 - ▶ End-caps (4) fit snugly or have hot glue to remain fixed
 - ▶ Chassis flatness is achieved (extrusions lie on same plane)
 - ▶ Extrusion faces touch their perpendicular mating extrusions (no gap)

- ▶ Wheel Assemblies
 - ▶ Belt is aligned parallel to outside face of wheel bracket
 - ▶ M8 hex nut is only tight enough to flatten the lock-washer (no further)
 - ▶ Both wheels can be rotated by hand with equal torque (both wheels, both directions)
- ▶ Battery
- ▶ Fasteners
 - ▶ For M6 fasteners: slide-in nuts are used in wheel brackets while drop-in nuts are used elsewhere.



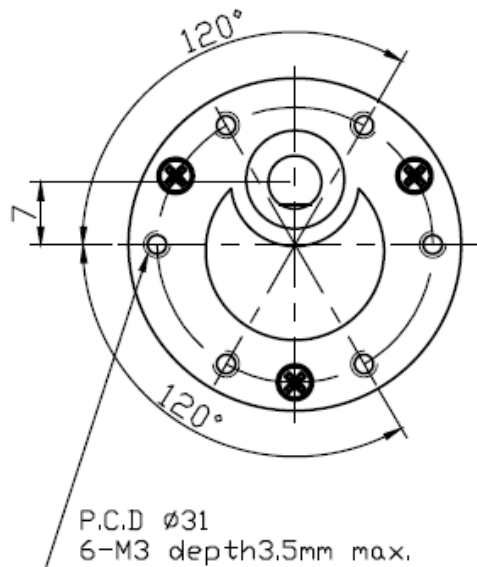
SCUTTLE Revision Numbers

Item	Naming	Compatible with previous?	Where to find	Frequency of updates	Format	Example of this kind of revision
Robot assembly, major	vX.x	✗	grabCAD		SLDASM, STEP	Changed robot construction. To use wheel brackets instead of assembly of plates.
Robot assembly, minor	vX.x	✓	grabCAD		SLDASM, STEP	Many minor improvements on the modeling but not the design function
3D printed part, major	vX.x	✗	gitHub		STL	Changed a bracket design to a new shape. Does not fit in place of the old part.
3D printed part, minor	vX.x	✓	gitHub		STL	Improved a bracket for printability or clearances. Still fits in old part assembly.
OTS part	None	✓	by request		SLDPRT, STEP	Designed a new CAD model to reflect hardware measurements
Subassembly, major	vX.x	✗	grabCAD			Tested a new kind of camera and sharing the model of a new camera & custom bracket. Not changing standard components.

Motor: DC gearmotor, 200rpm



12v dc motor
with gearbox



Front face
drawing

Scuttle has two motors for driving the rear wheels. Each is a 12v DC motor with a gearbox that reduces the output speed to 200 RPM. The 6mm shaft is offset by 7mm from the centerline of the motor, which helps raise the clearance of the motor housing from the ground in the robot chassis. Three M3x10 screws fasten the motor to the motor plate.

The motor leads must be soldered to wires of 18 AWG or larger.

Alternates: you can find other versions of this motor with different speeds. The 250RPM version, has higher speed and lower torque.

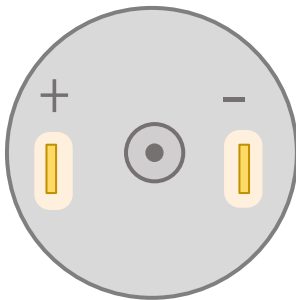
Converting to brushless is an exciting option but it requires both hardware and software adaptations, and higher cost.

Motor Specs:

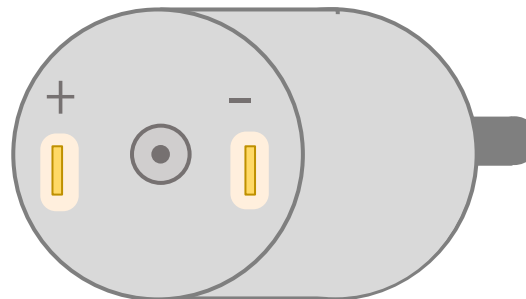


12v dc motor
with gearbox

	Value	Unit		
Speed, no-load	267	RPM		
Speed, rated	202	RPM		
Current, no-load	0.07	A		
Current, rated	0.48	A		
Current, at stall	1.60	A		
Torque, rated	0.96	Kg-cm	0.094	N-m
Torque, at stall	3.9	Kg-cm	0.38	N-m



Back side
of motor



Belt & Pulleys: HTD5 and T5



HTD Profile, 9mm wide,
Readily sourced in Asia

T5 Profile, 10mm wide
Readily sourced in USA

15 tooth T5
motor pulley



13 tooth HTD
motor pulley

The drivetrain design has 5mm tooth pitch so users can easily 3D print pulleys with sufficient tolerance for a nice mesh. The belts have breaking strength over 500 kg force! However, the motor pulley would fail much sooner.

There are two variants of the assembly (as of 2021.10) but you can customize pulleys any way you want. **Increasing the wheel pulley size increases torque and reduces speed.** Go crazy and build a 200kg-ready “[Muscle SCUTTLE](#)” by combining [metal gears](#), bigger motor, and [custom ratios](#).

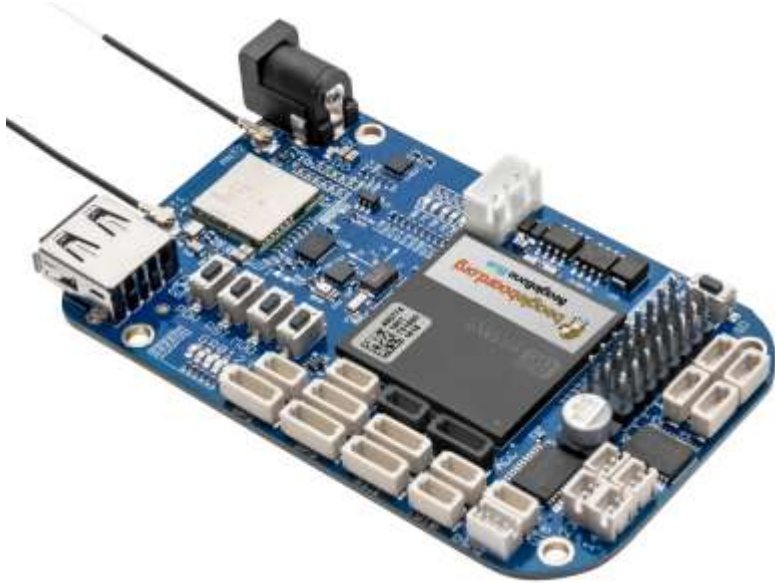
Alternates: Belt types and pulley pairs.

Belt Design	Common mfr	Reinforcement	Material	Tooth Shape
HTD-5	Continental	Fiberglass	Rubber	Round
T5	Continental	Steel	Urethane	Trapezoid

Motor Pulley	Wheel Pulley	Ratio	Belt Length (mm)	Width (mm)
15	30	0.500	245	9
13	25	0.520	225	10



Embedded Computer – Beaglebone Blue



Beaglebone Blue

The beaglebone Blue is an embedded Linux computer with extra robotics features such as built in motor drivers and dual WiFi modules, power management and servo ports.

More resources:

Beaglebone Blue [Wiki](#)

Beaglebone Blue [Specification Sheet](#)

Beaglebone Blue [Schematic](#)

Summary [Video](#) in 1 Minute

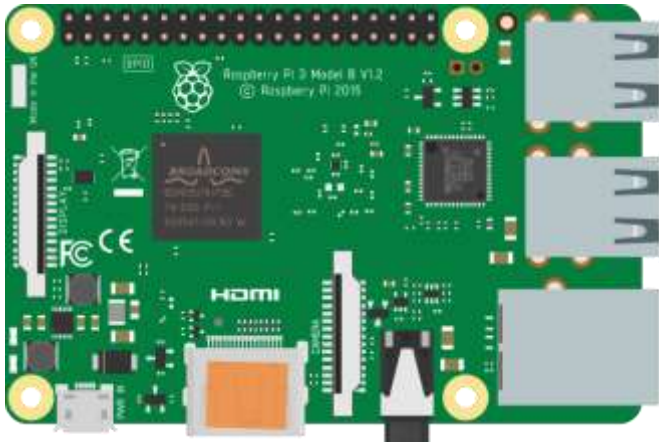
Alternates: you can also use Raspberry Pi or other single board computer (SBC).

Other modules will require separate purchase of:

- Power regulator
- 2nd Wifi Dongle
- Servo driver (if used)



Embedded Computer – Raspberry Pi 4



Raspberry Pi (model 3 shown)

Raspberry Pi is the top-selling embedded Linux computer, with higher computing performance but it lacks onboard modules compared with the Beagle (LiPo charger, PWM generators, secondary WiFi module) and it requires a regulated power input. Pi is the standard as of SCUTTLE v2.3 for the kit offering. SCUTTLE software is tested on Pi v3B and forward.

More resources:

Raspberry Pi [website](#)

Raspberry Pi pin diagram at pinout.xyz

Raspberry Pi 4 v1.2 sold at mouser.com

Raspberry Pi 4 [datasheet](#)

Key Features:

- ARM Processor**—quad-core @1.5Ghz for model 4
- Connectivity**— onboard WiFi transceiver
- Memory**— LPDDR4 (2 gigabytes selection)
- Hard disc**—uses the user-selected SD card for hard drive, (32gb Samsung Evo Select is standard)
- Input Power**--5v DC, minimum 3A



Embedded Computer – TI TDA4VM Board



TDA4VM-based Edge AI SK Board

The Edge AI Starter Kit (SK) board with TDA4VM Processor leaps into deep learning territory with 8 Tera Operations Per Second (TOPS) and is specialized for realtime processing of up to 8 camera inputs and multiple.

More resources:

SCUTTLERobot.org [Partner Page](#)

Edge AI [Robotics Academy](#)

Edge AI Starter Kit [Product Page](#) (\$249 USD)

Unboxing and Starting [Video](#)

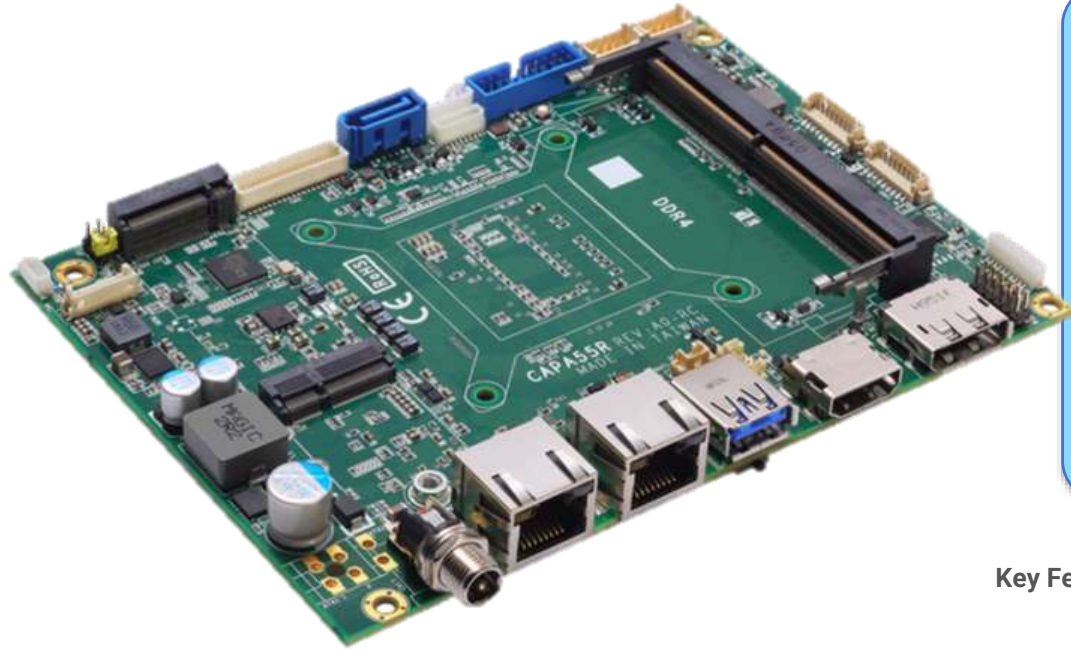
TI/Robotics software [Quick Start](#)

Key Features:

- Camera interfaces**—two CSI-2 ports compatible with Raspberry Pi and a high-speed 40-pin Semtec camera connector connecting up to eight cameras (requires TIDA-01413 sensor fusion add-on card)
- Connectivity**—three USB 3.0 Type A ports, one USB 3.0 Type C ports, one ethernet port, one M.2 Key E connector and one M.2 Key M connector, four CAN-FD interfaces, four UART terminals over one USB bridge
- Memory**—DRAM, LPDDR4-4266, 4 gigabytes total memory, support for inline ECC
- Display**—DisplayPort with up to 4K resolution with MST support and 1080 HDMI



Embedded Computer – Axiomtek / Intel CAPA55R



Axiomtek Industrial SBC with Intel i7, Gen11

The Intel flavor of SCUTTLE runs the Axiomtek CAPA55R, an industrial embedded computer. Users aiming for the strongest processing power (and power consumption) for industrial applications will find professional levels of documentation, engineering, and services accompanying this board with a higher price range.

More resources:

Axiomtek [Product Page](#)

CAPA55R [Brochure](#)

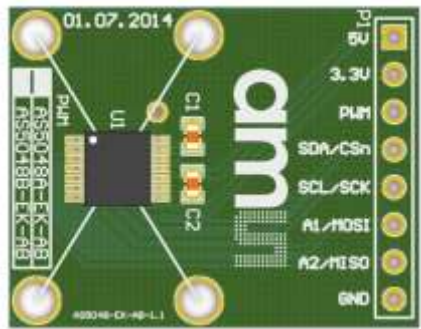
Example Industrial Warehousing Robot: [Alphabot](#)

USB-i2C Adapter (not included) [On AliExpress](#)

Key Features:

- Expandable memory & HDD** —with 3 slots for M.2 cards
- Active Cooling**—the bare board comes with processor heat-sink and fan, tested and characterized by Axiomtek.
- Full Desktop Feature array**—offers ports found on modern laptops and desktops, plus expansion headers for customization, common on full ATX sized motherboards.
- High Power** —Performance-tested with 12 to 24v supply, with onboard power regulation. 5v can be sourced from this board's USB hub to support peripherals.

Encoders



ASM AS5048B
Encoder PCB

Two AMS AS5048B encoders are required for SCUTTLE, with one at each motor pulley.

Some details:

- It's actually an angular position sensor. It returns degrees, from 0 to 360.
- It communicates over I2C. The left-hand encoder is addressed as 0x40 and the Right-hand encoder is addressed as 0x41, assigned by address pins.
- They measure the rotation of the motor pulley, and the software adjusts for (approx 1:2) wheel:motor turn ratio
- The sensor is paired with a diametrically opposed magnet, mounted at the end of the motor shaft.

Resources for the encoder:
AMS AS5048B [Datasheet](#)

The encoder addresses are set by soldering and wiring according to our wiring diagrams.

	Pin A0	Pin A1	Resulting i2c address
Left Encoder	LOW	HIGH	0x41
Right Encoder	LOW	LOW	0x40

Dual Motor Driver



Motor Driver
with dual MC33886

A number of motor driver options are available. The standard choice is HW-231 motor driver which uses the NXP MC3386 H-Bridge. The ground is connected directly to the battery pack and it accepts two input pin pairs as PWM channels.

Resources for the motor driver are here:

- MC3386 [Datasheet](#)

Alternate: the ever-common L298N will also work for driving the motors, but it will not drive enough current for full output of our motors. It's an option if you're just learning and want to save money.

Important Features:

- Board is available from array of unbranded distributors with genuine FETs.
- Drives up to 5A per channel, continuously.
- Up to 10KHz PWM frequency
- 5.0 to 40.0v operation

Battery Pack



Version 2 Battery Pack with
Cover Removed

The battery pack is a 3-cell lithium ion pack with a nominal voltage of 11.1v (3.7v per cell) combined with a few off-the-shelf parts and a 3D printed case. The capacity is 3400 mAh (we verified!) And they have enough capacity to drive SCUTTLE for several hours.

With additional actuators, a significant payload, or demanding sensors such as the SICK LIDAR, it is advised to add more capacity to the robot. The cells must not be drained below 2.8 volts each to prevent damage.

Resources for the battery pack are here:

- Panasonic NCR18650B [datasheet](#)
- Battery Cell handling and protection [youtube video](#)
- Instructions: [Battery Cell supplemental info](#)
 - shows more on assembly.

Alternate: our next favorite cell is undergoing testing and it's the LG HE4. We discovered it by this [comparison](#) video. It has a lower cost and nearly-equal performance.

LIDAR (optional)



SICK TiM561 LIDAR

SCUTTLE has been enhanced with a lidar manufactured by SICK sensor company. This lidar performs laser-based ranging in 270 degree plane at 0.33 degree resolution, 15 times per second! The USB interface is used to communicate to the microprocessor and the power is directly provided by the 11.1v battery pack.

Resources for the LIDAR unit are here:

- [Pysicktim](#) python library on Github
- [Operating instructions](#) from SICK
- [Technical information](#) from SICK

Important links:

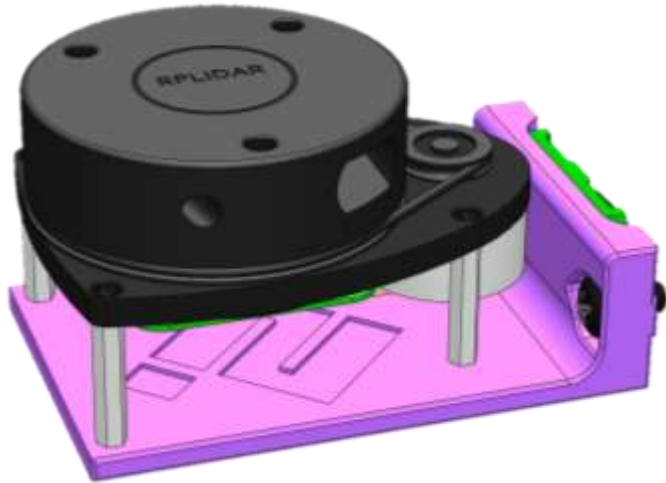
[Datasheet](#) from SICK

[User Manual](#) from SICK

[Software](#) maintained by SICK on GitHub

[Software](#) library applying TiM561 to Python (pysicktim)

LIDAR (Preferred Model)

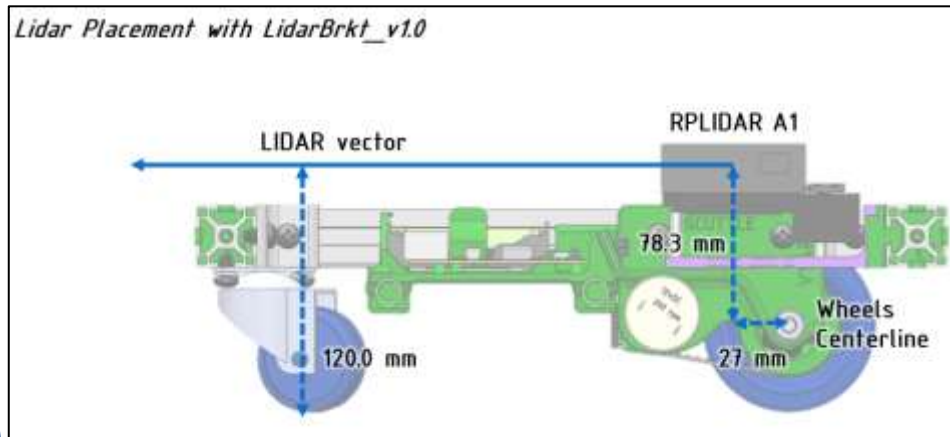


RPLIDAR A1 with Bracket

This selection of LIDAR is economical and tested using Python and ROS. Slamtec offers a free desktop GUI for testing the lidar off the robot. As of 2021 this unit sells for around \$99 on amazon.

Resources for the LIDAR unit are here:

- [Printable bracket](#) CAD design
- [2D Drawing](#) from Slamtec
- [ROS Package](#) from SLAMTEC on Github



Key Parameters:

Power Consumption: 1.5 watts (tested by us)

Range: 12 m radially, 2D plane

Rotation: 5.5 rpm

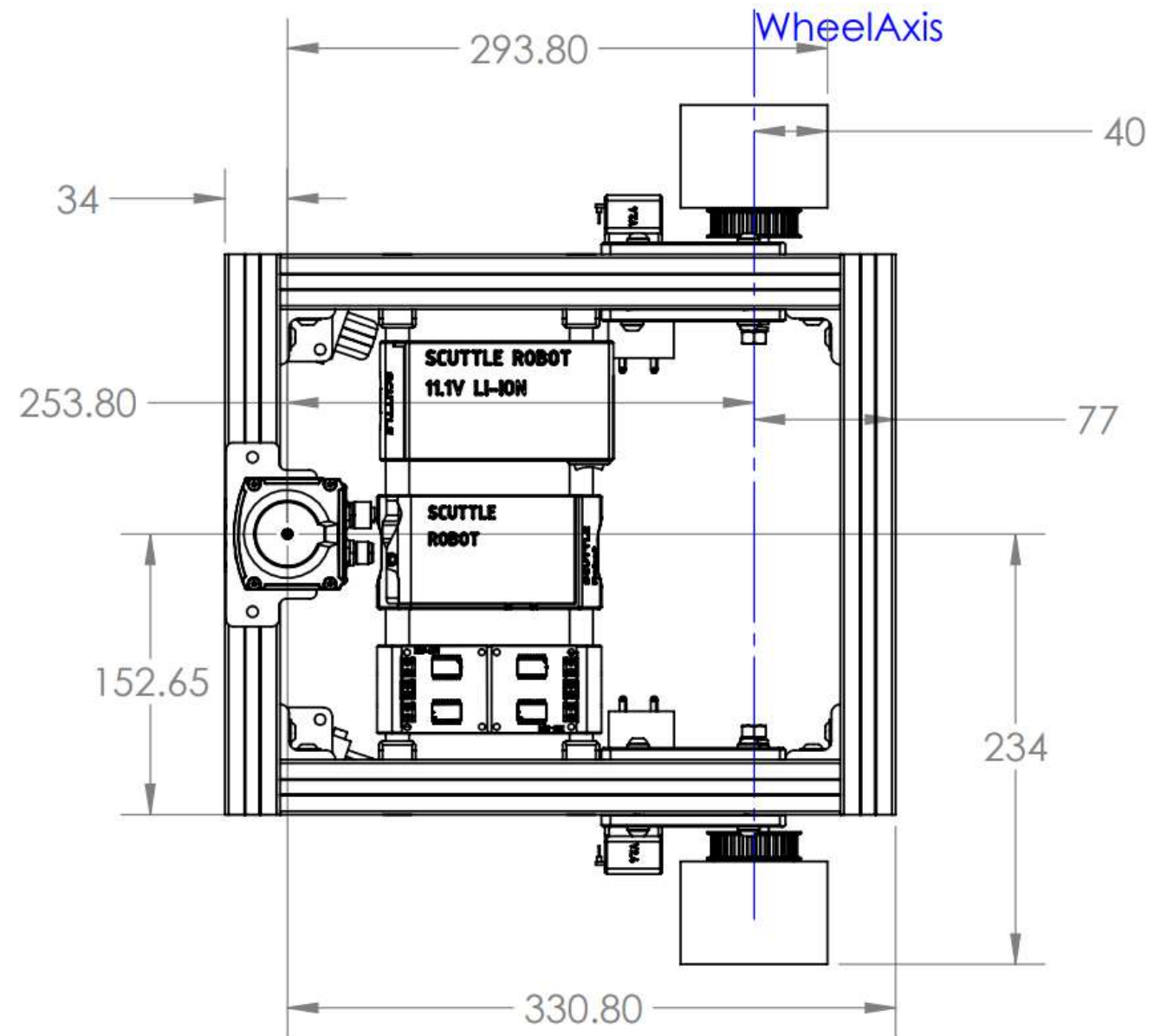
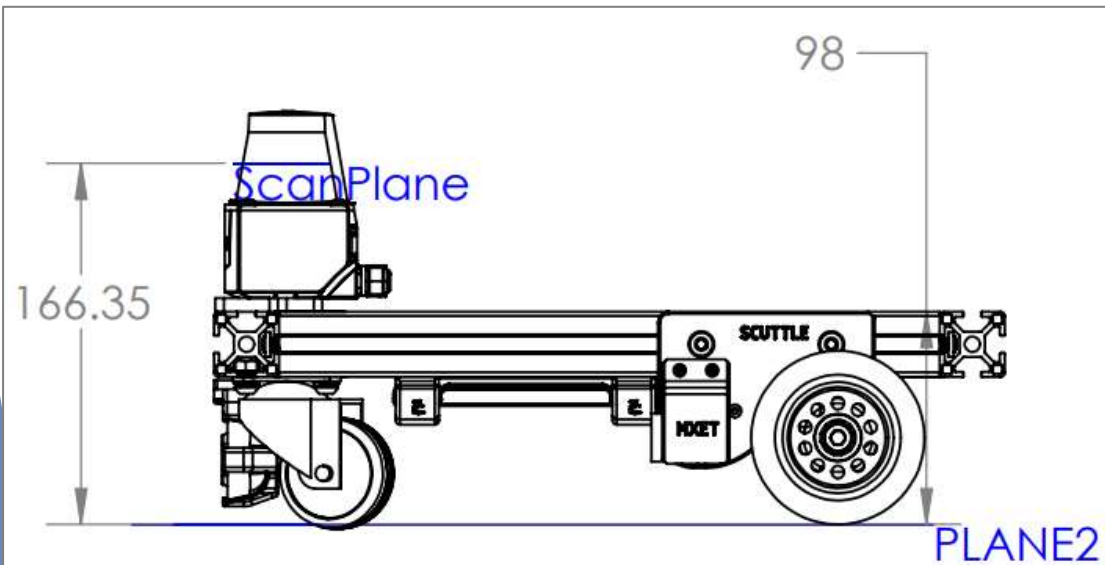
Resolution: 1 degree

LIDAR (continued)



SICK TIM561 LIDAR

Dimensions and basic mounting configuration shown.





USB Camera (v2.3 forward)



M720 model USB Camera

As of 2020, the camera is an industrial wide-angle USB unit. The steel square housing makes it easy to design custom adaptations for Computer Vision tasks. The specs:

Resolution: 720P

Field of view: 150 degrees

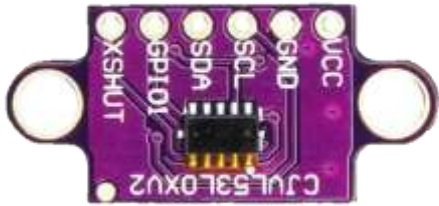
Microphone: built-in

Model designation for this camera:

M720 or HF867_720P_2.1MM

Alternate options have been successfully tested including Logitech C270 & WyzeCam with webcam firmware. Some will work with no changes to software, and some will require minor changes.

Time-of-Flight (ToF) Sensor



VL53L0X ToF Sensor

The ToF sensor uses a light beam to measure distances to the nearest surface.

This sensor is ultra-low power, highly repeatable, and low cost. It uses i2c protocol, a big advantage over the ultrasonic option.

The key functional difference between this sensor and the ultrasonic sensor is the directionality of the beam.

Resources for the HC-SR04 are here:

VL53L0X on [Amazon](#) (\$12.99 for 2pcs)

VL53L0X on [Adafruit](#) (with tutorials)

Fantastic details in the [Datasheet](#)

Specs:

- Operates on 3.3 or 5.0v
- typical sensing range [50mm to 1200mm]
- typical accuracy of 7% of measurement
- typical sensing time, 30ms (33 per second!)
- repeatability around 5% of measurement



Detection range pattern

Ultrasonic Sensor



HC-SR04 Ultrasonic
Ranging Sensor

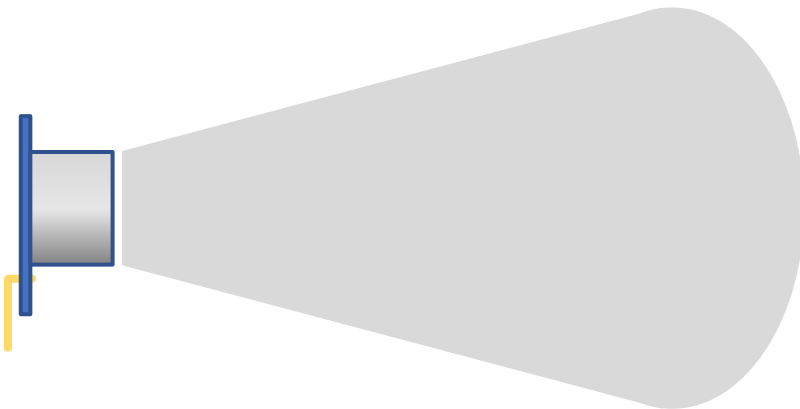
The ultrasonic sensor is for range-finding. It's an optional item to support autonomous driving and obstacle avoidance.

There are versions of this board which require 5v (more common) or only 3.3v (less common). If your board requires 5.0v then power will need to be drawn directly from the power port on the beaglebone.

Resources for the HC-SR04 are here:

HC-SR04 [Datasheet](#)

Alternate options include ToF sensors, IR rangefinders, or full-on LIDAR. Both have been successfully tested.



Detection range pattern

Power Connector



Anderson Powerpole
Connector Housings

Our Anderson Powerpole (APP) power connector is rapidly gaining popularity. It's carefully chosen with these metrics in mind:

- Easy for students to crimp, no soldering
- High Current (15, 30, and 45A)
- Modular, for expansion
- Affordable

Many power electronics, such as radio-controlled cars are using gold-plated barrel connectors. You can use any connector that supports sufficient current but this is our favorite.

See the [tools guide](#) for the matching crimping tool.

Spade “Quick Connect” Connector



Spade Quick Connect
Terminal

This spade connector may be the most common of all connectors inside in appliances and automotive circuits. These are best suited for connections that are not frequently plugged and unplugged.

- Low cost
- High Current (for AC or DC)
- Tin plated brass resists corrosion
- Nylon insulation for safety