Assignment 2-A
TurtleBot3 Burger Teardown

GROUP 1

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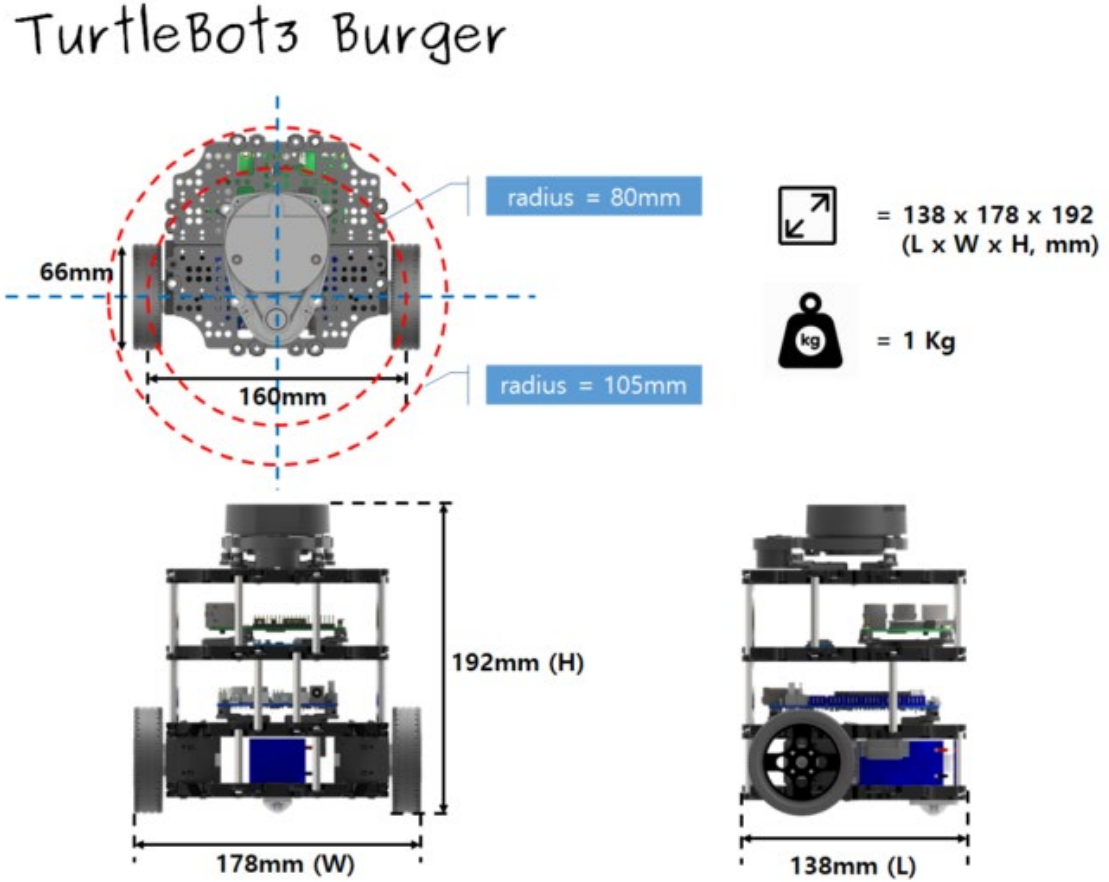
GitHub Repository

Feature Overview

- Differential drive mechanism
- Small form factor
- Multi-mode actuators
- Multi-sensor lineups
- Affordable cost
- Open hardware
- Open firmware
- Open software
- ROS enabled

TURTLEBOT3



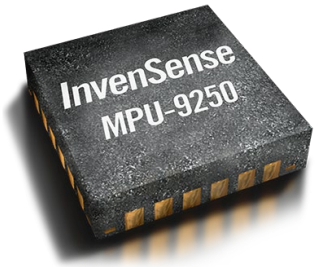
Source: ROBOTIS Inc.

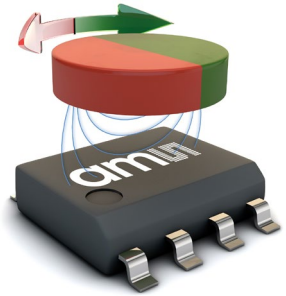
Existing Hardware

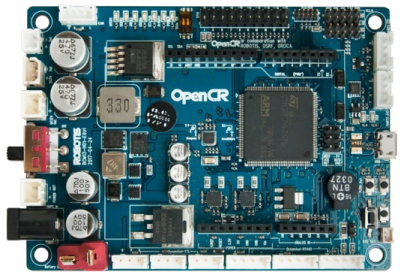
Note 1: Complete list of specifications available here

Note 2: The TurtleBot3 Burger provided in class has add-on Pi Camera v2

- **Battery:** 11.1 V 1800 mAh LiPo
- **Sensors:**
  - LDS-01 360° planar LiDAR*
  - MPU-9250 9-axis IMU**
  - AS5601 magnetic absolute encoders
- **Computers:**
  - Raspberry Pi 3B+ single board computer (SBC)***
  - OpenCR1.0 auxiliary low-level controller board
- **Actuators:** DYNAMIXEL XL430-W250-T continuous rotation s







*LDS-02 is applied since 2022.

**9-axis MPU-9250 IMU has been replaced with 6-axis ICM-20648 IMU since 2020.

***Raspberry Pi 3 Model B+ is applied since 2019. Earlier model is equipped with Raspberry Pi 3 Model B. Raspberry Pi 4 Model B is applied since 2021 September.

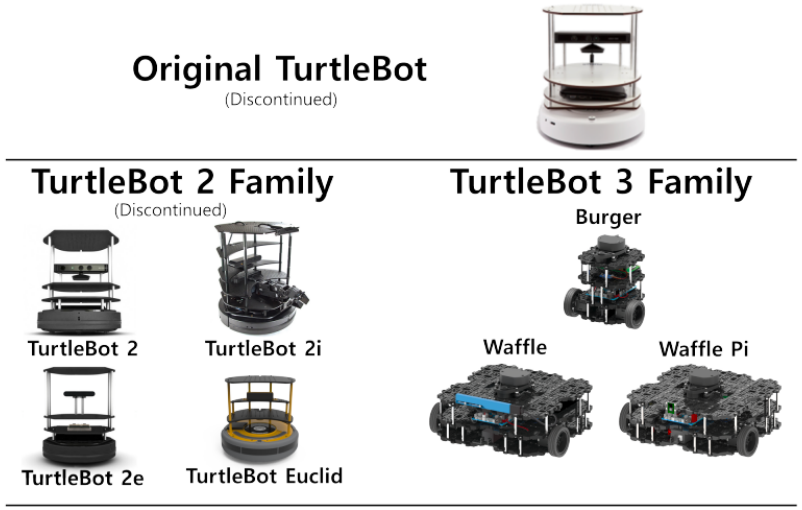
TurtleBot Version Comparison

TurtleBot Version	Mobile Base	Battery Pack	Computer(s)	Sensor(s)	Actuator(s)	Developer(s)	Release Date
TurtleBot1	iRobot Create	3000 mAh	Asus 1215N Laptop	Gyro, MS Kinect (RGBD-Cam), Encoders	iRobot Create Robot Base Motors	Willow Garage	Nov 2010
TurtleBot2	Yujin Kobuki	2200 mAh	Asus 1215N Laptop	Gyro, MS Kinect (RGBD-Cam), Encoders	iClebo Kobuki Robot Base Motors	Yujin Robot	Oct 2012
TurtleBot3	Burger, Waffle, Waffle Pi	1800 mAh	Raspberry Pi (or Intel Joule 570x), OpenCR1.0	2D LiDAR, 9-Axis IMU, Encoders, Pi Camera (Mono-Cam), Intel RealSense RGBD-Cam	DYNAMIXEL Servo Motors	ROBOTIS, OSRF	May 2017

- **TurtleBot1:** Costs $1400, large, less flexibility, deprecated
- **TurtleBot2:** Costs $1500, huge, less modular, deprecated
- **TurtleBot3:** Costs $650, small, modular, continued support

Robotis and OSRF Announce TurtleBot 3 Smaller, Cheaper, and Modular (IEEE Spectrum, By Evan Ackerman, 12 Oct 2016)

Source: IEEE Spectrum



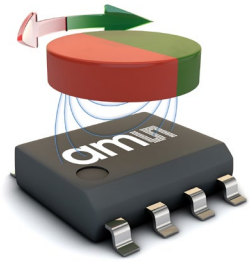
Source: TurtleBot.com

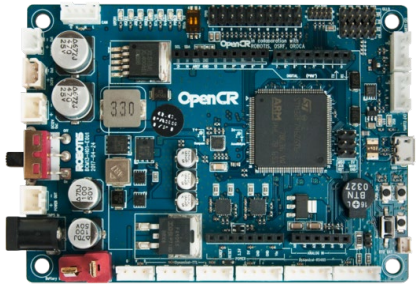
Replacement Hardware

Note 1: Actuators and low-level compute need not be replaced

Note 2: These replacements do not consider cost constraint

- **Battery:** 11.1 V 3000 mAh 3S 50C LiPo
- **Sensors:**
  - LiDAR: RPLIDAR-A3 360° planar LiDAR
  - IMU: VN-110 9-axis IMU
  - Encoders: AS5601 magnetic absolute encoders
  - Camera: ZED X Mini RGBD camera
- **Computers:**
  - High level: Jetson Nano B01 developer kit
  - Low level: OpenCR1.0 auxiliary low-level controller board
- **Actuators:**
  - DYNAMIXEL XL430-W250-T continuous rotation servos (CRS)





Hardware for Educational Deployment - Battery

Candidates	Voltage Rating	Current Capacity	Discharge	Form Factor	Weight	Cost
✓ OVONIC 3S Li-Po	11.1 V	3000 mAh	50 C	105x32x28 mm	193 g	$22.81
Traxxas 3S Li-Po	11.1 V	5000 mAh	25 C	135x44x28 mm	354 g	$69.95
OVONIC 2S Li-Po	7.4 V	6200 mAh	50 C	137x46x24 mm	280 g	$19.5
AES 3 Cell Li-Ion	11.1 V	2600 mAh	1.6 C	69x57x18 mm	156 g	$36.00
AES 6 Cell Li-Ion	11.1 V	5200 mAh	1.6 C	69x57x39 mm	283 g	$59.00

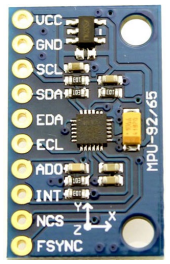
Hardware for Educational Deployment - LIDAR

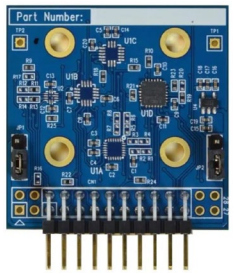
Candidates	Range	FOV	Resolution	Sampling Rate	Scan Rate	Cost
ROBOTIS LDS-01	0.12 – 3.5 m	360°	1°	1.8 kHz	5.0 Hz	$196.10
ROBOTIS LDS-02	0.16 – 8.0 m	360°	1°	2.3 kHz	5.0 Hz	$211.38*
✓ Slamtec RPLIDAR A1	0.15 – 12.0 m	360°	1°	8.0 kHz	10.0 Hz	$99.00
Slamtec RPLIDAR A3	0.20 – 25.0 m	360°	0.225°	16.0 kHz	15.0 Hz	$599.00
YDLIDAR X4	0.12 – 10.0 m	360°	0.645°	5.0 kHz	10.0 Hz	$79.99
Hokuyo UST-10LX	0.06 – 30.0 m	270°	0.125°	N/A	40.0 Hz	$1,595.00
Sick TIM310	0.05 – 25.0 m	270°	0.33°	N/A	15.0 Hz	$1,503.00

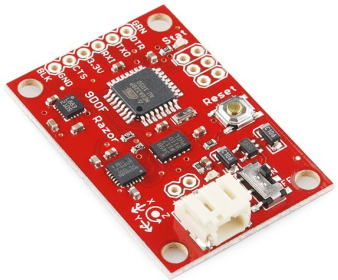
*Exact cost data for LDS-02 is not available, value approximated by adding 25% markup to LDS-01 cost.

Hardware for Educational Deployment - IMU

Candidates	DOF	Range	Noise Sensitivity	Form Factor	Weight	Cost
✓ InvenSense MPU-9250	9	±2000°/s | ±16 g | ±4800 μT	0.01°/s/√Hz | 300 μg/√Hz	15x25x3 mm	3.78 g	$14.99
InvenSense ICM-20648	6	±2000°/s | ±16 g	0.015°/s/√Hz | 230 μg/√Hz	38.1x 38.1x1.6 mm	4.45 g	$40.00
SparkFun Razor IMU	9	±2000°/s | ±16 g | ±8 G	0.03°/s/√Hz | 300 μg/√Hz	28x41x6 mm	5 g	$124.95
VectorNav VN-110	9	±490°/s | ±15 g | ±2.5 G	0.001°/s/√Hz | 40 μg/√Hz	56x56x23 mm	125 g	N/A



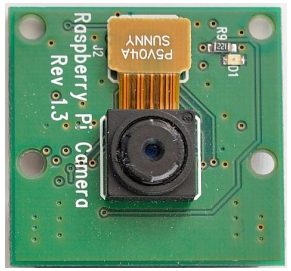




Hardware for Educational Deployment - Camera

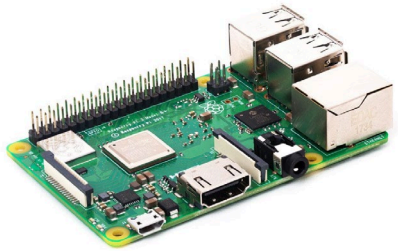
Candidates	Depth	Resolution	FOV	Frame Rate	Form Factor	Weight	Cost
PiCamera v1	No	5 MP (2592×1944 px)	53.5°	1080p30	25x24x9 mm	3 g	$25.00
PiCamera v2	No	8 MP (3280 × 2464 px)	62.2°	1080p47	25x24x9 mm	3 g	$25.00
✓ PiCamera v3	No	11.9 MP (4608 x 2592 px)	66°	1296p56	25x24x11.5 mm	4 g	$25.00
Intel RealSense D435	Yes	2 MP	69° |87°	1080p30 |720p90	90x25x25 mm	72 g	$333.75
ZED X Mini	Yes	2.3 MP	110° |120°	1200p60 |1200p120	94x30x37 mm	150 g	$549.00

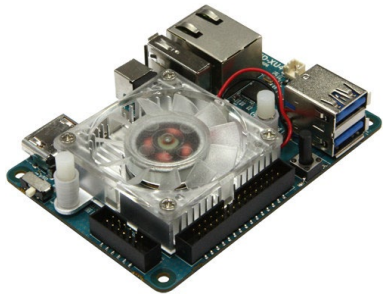
Note: Detailed comparison of Pi camera versions is available here



Hardware for Educational Deployment - Computer

Candidates	CPU	GPU	Memory	Form Factor	Weight	Cost
Raspberry Pi 3B+	Cortex-A53, 1.4 GHz	Videocore-IV	1GB LPDDR2	82x56x19.5 mm	50 g	$35.00
Raspberry Pi 4B	Cortex-A72, 1.5 GHz	VideoCore VI	1-8 GB LPDDR4	88x58x19.5 mm	46 g	$75.00
Odroid XU4	Cortex-A15, 2.0 GHz/ Cortex-A7, 1.3 GHz	Mali-T628 MP6	2 GB LPDDR3	83x58x20 mm	38 g	$59.00
✓ NVIDIA Jetson Nano b01	Cortex-A57, 1.43 GHz	128-core Maxwell	4 GB LPDDR4	100x80x29 mm	141 g	$149.00
NVIDIA Jetson Xavier NX	NVIDIA Carmel, 1.9 GHz	384-core Volta	8-16 GB LPDDR4x	103x90.5x31 mm	172 g	$1999.00

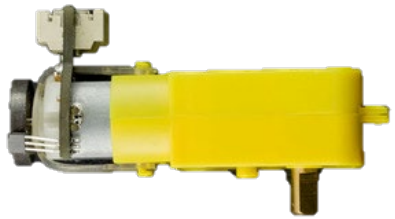




Hardware for Educational Deployment - Actuators

Candidates	Power Rating	Range	Speed	Torque	Encoder	Form Factor	Weight	Cost
DYNAMIXEL XL430-W250*	11.1 V | 1.3 A	360°	57 RPM	1.4 Nm	2048 CPR	28.5x46.5x34 mm	57.2 g	$49.90
All Metal TT Motor	6.0 V | 1.0 A	360°	120 RPM	0.18 Nm	N/A	69.5x22x20.7 mm	39.4 g	$5.95
✓ TT Motor with Encoder	6.0 V | 2.8 A	360°	160 RPM	0.08 Nm	1920 CPR	79.5x22x20.7 mm	50.0 g	$7.40
NEMA 17 Stepper Motor	12.0 V | 350 mA	360°	50 RPM	0.28 Nm	N/A	58x42.3x42.3 mm	240 g	$14.00
Tower-Pro MG-995	6.0 V | 2.8 A	170°	62.5 RPM	0.98 Nm	Internal feedback	40.7x19.7x42.9 mm	62.41 g	$19.95

*ROBOTIS recommends that new and existing AX series users transition to XL430-W250.

Thank You!