

# ROS 2 EMBEDDED WORKING GROUP

## Pet Your Own Bot!

Learn to build your pet robots with micro-ROS



Embedded Working Group: 27th of February at 17:00 CET

**NEXT WEEK**

# Thank you!

A thank-you to the micro-ROS team

- including Pablo Garrido

A thank-you to the many ROS2 developers!

# Micro-ROS Robot

100% ROS2, 100% open source

- Resembles Turtlebot3 Burger
  - LiDAR, 2-wheel differential drive
  - ROS2 mapping, navigation
- Simple, affordable
  - Runs on Arduino ESP32 (not Raspberry Pi)
  - 3D printed
- More information:
  - makerspet.com (diy hardware) + kaia.ai (software)
  - remake.ai (business)



200mm model



300mm model



makerspet.com

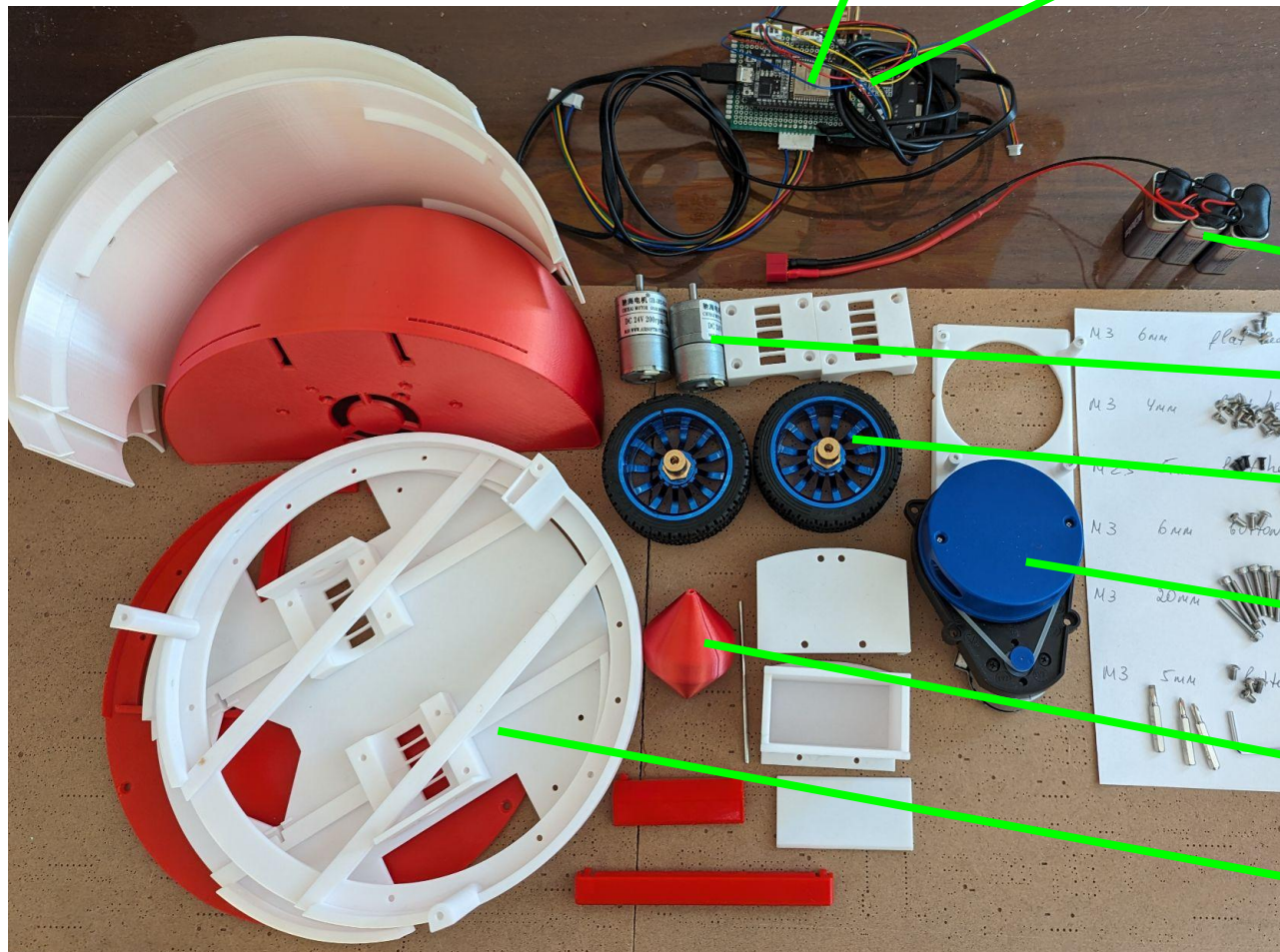


kaia.ai

# 3D-printed DIY Kit

ESP32 MCU

Breakout Board



Alkaline batteries

2x BLDC motors

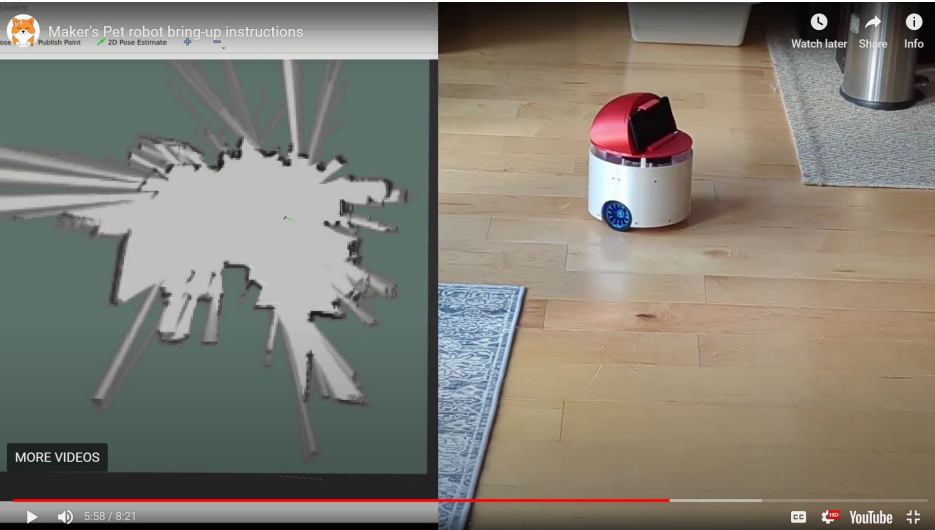
65mm wheels

Low-cost  
LDS/LiDAR

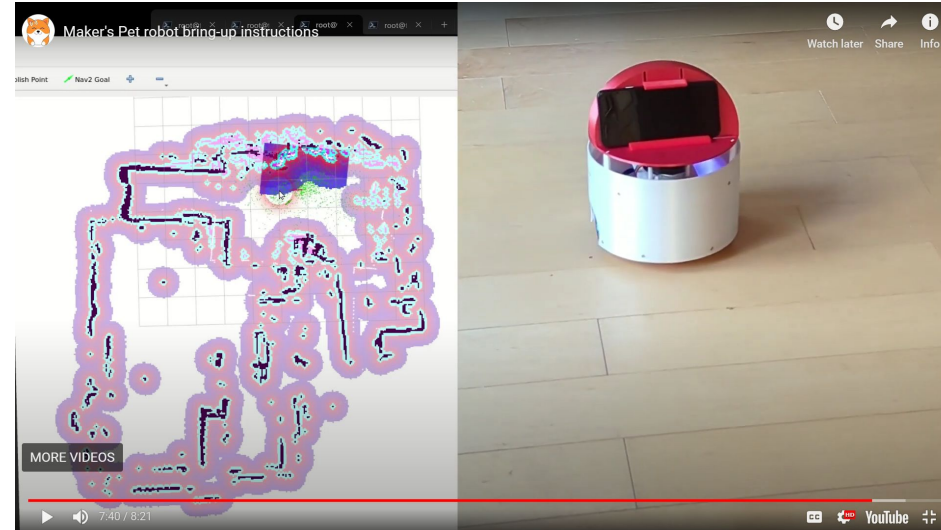
Caster wheel

3D-printed body

# ROS2 Mapping, Navigation



Mapping (Nav2, Cartographer)



Navigation/SLAM (Nav2)

Bring-up instructions video  
[https://youtu.be/L\\_XbkA4pwRc](https://youtu.be/L_XbkA4pwRc)

# Open Source Links

3D printed body

[https://github.com/makerspet/3d\\_models](https://github.com/makerspet/3d_models)

Firmware

<https://github.com/kaiaai/firmware>

PC Docker image

`docker pull kaiaai/kaiaai-ros-dev:humble (or :iron)`

Instructions

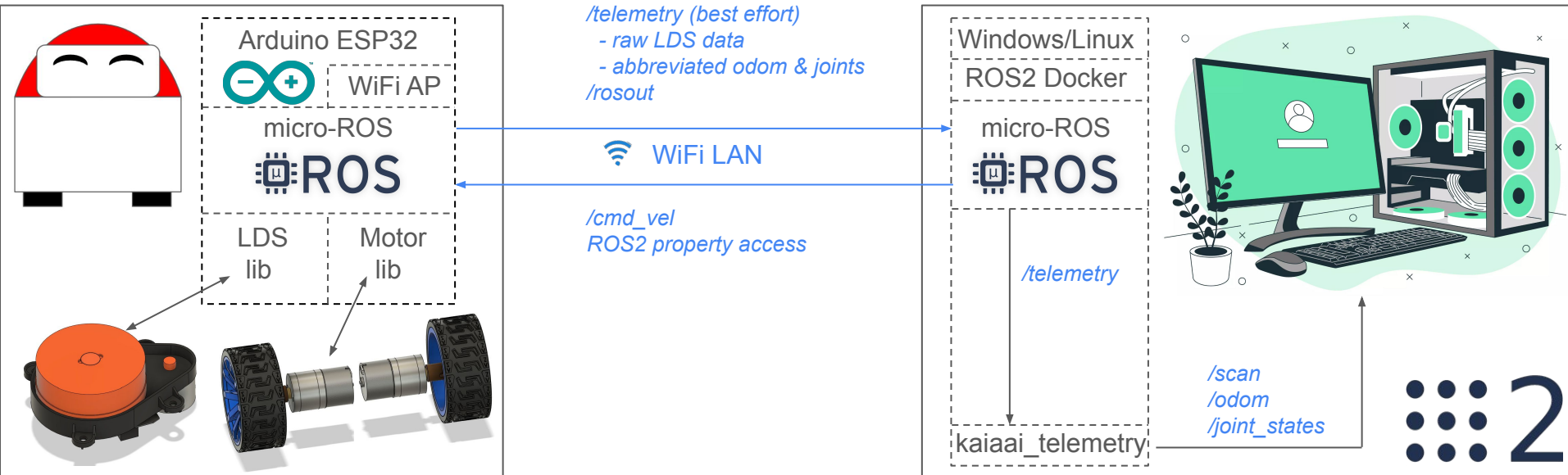
Build, bring-up videos

<https://bit.ly/3UTeLbc>

Command reference

<https://github.com/kaiaai/kaiaai>

# System Architecture as of 2/2024



# Hardware Overview

ESP32 micro-controller module (\$3..\$5)

- 2.4GHz WiFi, Bluetooth/LE
- 2 cores 240MHz Xtensa 32-bit
- Single-precision float multiplier, no divider
- 520KB SRAM; TSMC 40nm

2x 24V BLDC motors w/encoder

- PWM speed, CW/CCW; PID control

24V Power Connector

- Alkaline; 6S1P LiPo optional

LiDAR/LDS connects to MCU serial

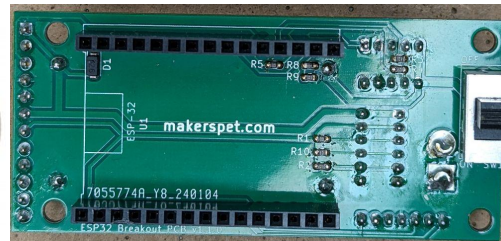
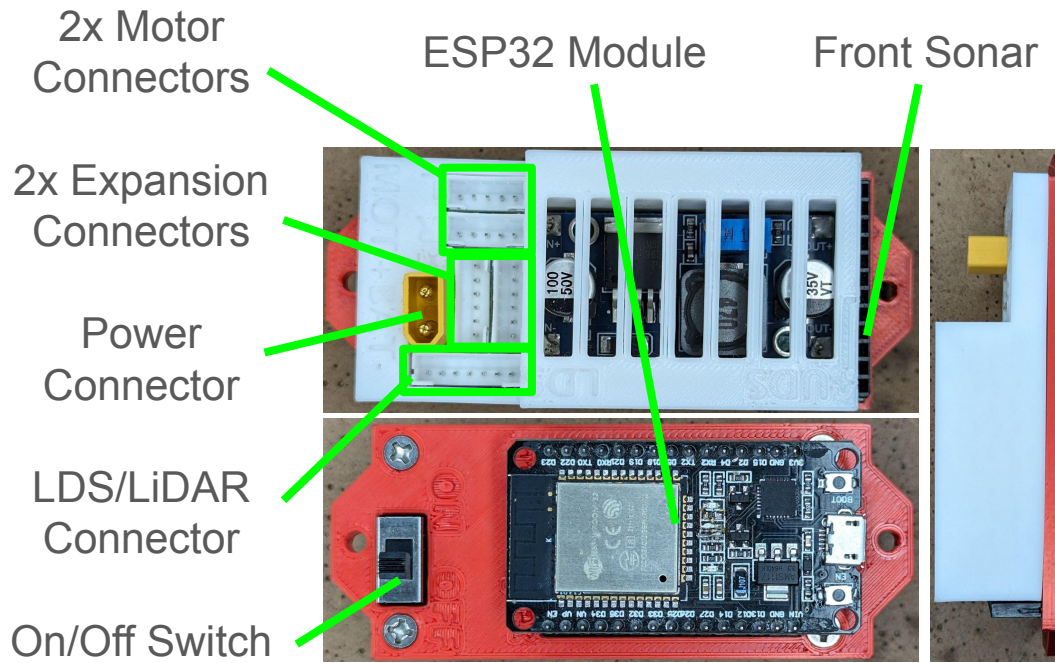
- There is no Raspberry Pi

2x Expansion Slots

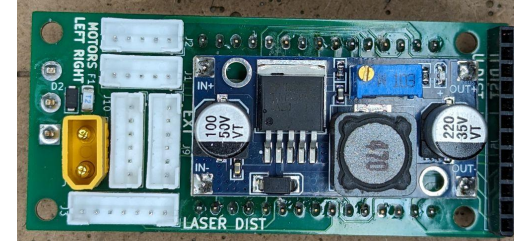
- 1x for the robot's Head
- 1x for the robot's Body

Front Sonar (optional)

- Detect obstacles "invisible" to LDS



ESP32 Breakout Board - Top



ESP32 Breakout Board - Top

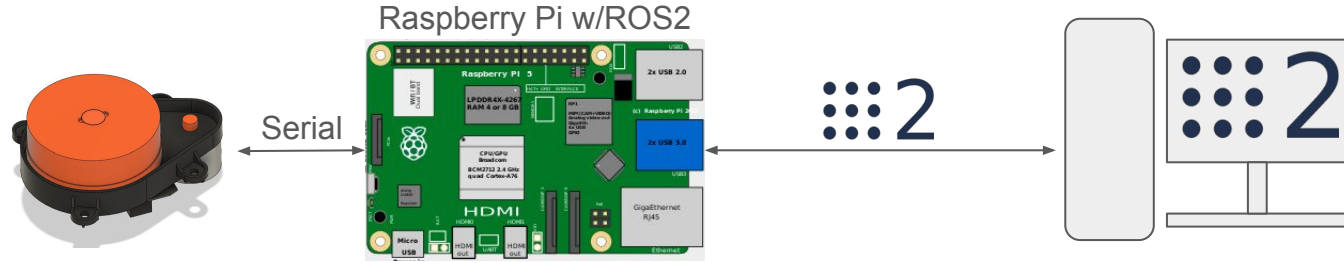


# LiDAR/LDS Use Case

Problem: Low-cost LDS OEM SDK/ROS2 nodes require PC (or Raspberry Pi) serial 😞

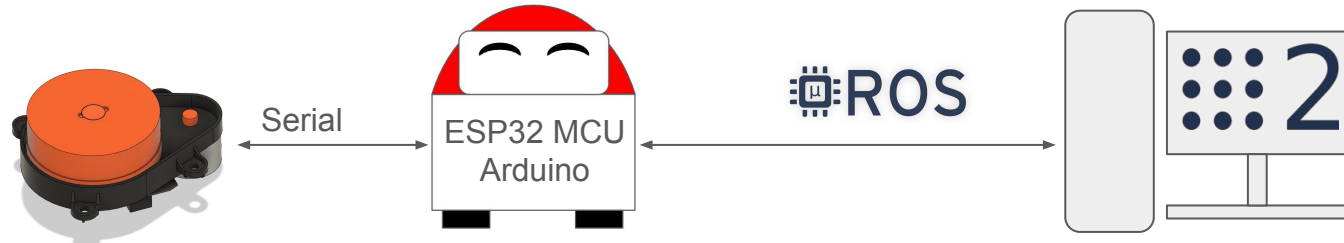
- A low-end LDS generates approx. ~6..16KB/sec for low-cost LDS
- Amount of data per sec  $\approx$  (LDS sampling freq) \* (3 bytes) \* Overhead

Standard  
(e.g. Turtlebot3)



vs.

Desired



# LiDAR/LDS Solution Considerations

Some low-end LDS

- are optimized for vacuum cleaner use
- lack motor control
- have TX only (no RX)
- require expensive calculations (tan, sin)
- lack SDK



\* Lack built-in motor control

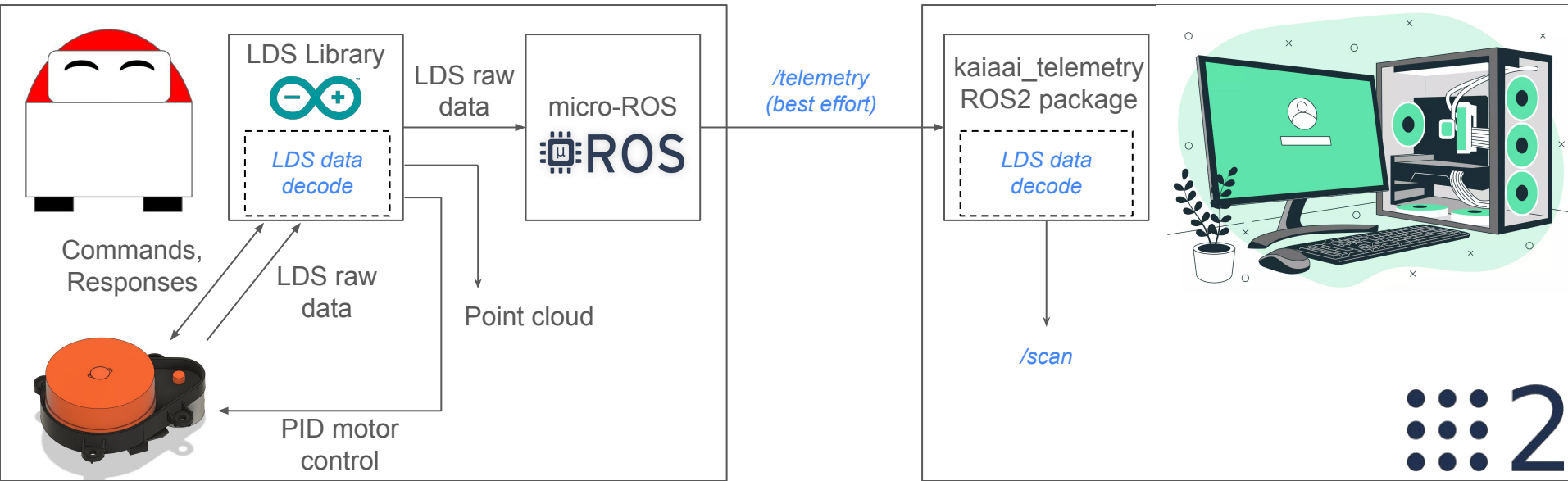
# LiDAR/LDS Solution Considerations - contd.

- Serial “extender” solutions available
  - No “Serial over micro-ROS”
- Two types of LiDAR/LDS communications via same serial port
  - Configuration commands and responses - two-way over a reliable transport; lag-insensitive
  - Data - one-way, lag-sensitive stream; lossy transport OK
- Adding another transport in addition to micro-ROS not desirable
  - Websockets, socket.io, MQTT, vanilla UDP, etc.
- Virtual “loss-on/off” bi-directional serial port over micro-ROS? 🤔
  - Complicated
  - Non-lossy when SDK probes/configures/starts LDS; lossy when data streams one way
  - Allows reusing OEM ROS2 SDK 😊
  - Motor control should still run on Arduino (PID lag-sensitive loop)
- Are we are “stressing out” micro-ROS?
  - Is micro-ROS not meant to stream “larger” data like LDS?

# LiDAR/LDS Current Solution

Send LDS data *raw, one-way, best effort* over *micro-ROS* WiFi UDP

- I.e. “one-way lossy serial”, encapsulated in micro-ROS messages
- LDS control (commands, motor control PID) runs on MCU only
- Not ideal, requires “porting” SDK 😞



# kaiaai\_telemetry Package

## Receives

- raw LDS data
- abbreviated odom
- abbreviated joint\_pos/vel

## Calculates & Converts

- raw LDS to /scan
- abbreviated odom to /odom
- abbreviated joint\_pos/vel to /joint\_states

[https://github.com/kaiaai/kaiaai\\_msgs/msg/KaiaaiTelemetry.msg](https://github.com/kaiaai/kaiaai_msgs/msg/KaiaaiTelemetry.msg)

builtin\_interfaces/Time stamp

uint32 seq

float32 odom\_pos\_x

float32 odom\_pos\_y

float32 odom\_pos\_yaw

float32 odom\_vel\_x

float32 odom\_vel\_yaw

float32[] joint\_pos

float32[] joint\_vel

uint8[] lds

KaiaaiTelemetry message

# Arduino ESP32 Firmware

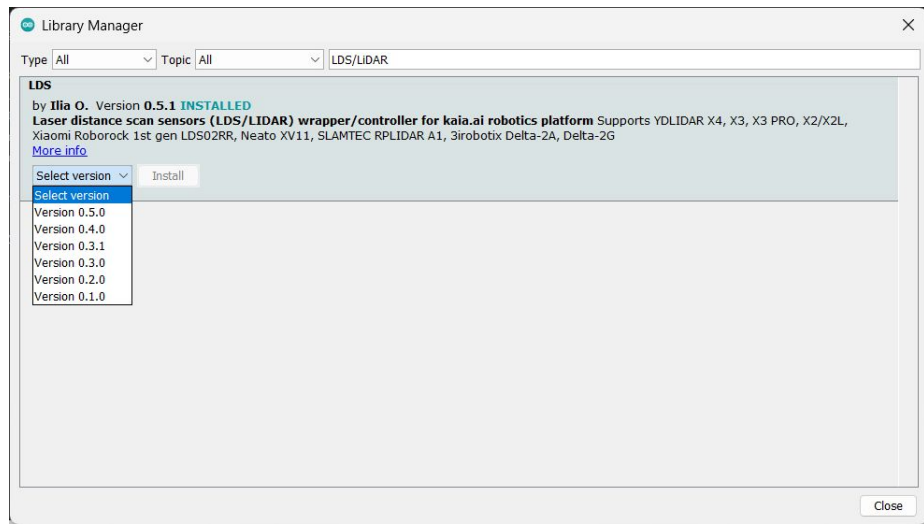
<https://github.com/kaiaai/firmware>

## Required libraries

- micro-ROS
- LDS library (kaia.ai)
- Motor control library (kaia.ai)
  - PWM, PID control
  - Encoder tracking
- Web server for configuration, WiFi access

## Miscellaneous Notes

- micro-ROS message size affect transport speed, reliability
  - Currently ~412 bytes (data fields total)
- Firmware parses /cmd\_vel
  - calculates speed ramp



## LDS Library (kaia.ai)

- Parse packets
  - Read scan frequency
  - Detect scan complete
  - Make raw packets available (to micro-ROS)
  - Signal (to micro-ROS) end-of-rotation, e.g. to flush LDS data to reduce lag
  - (Optional) Compute point cloud, e.g. for obstacle avoidance
- PID control of LDS motor

# micro-ROS for Arduino - Customized

[https://github.com/kaiaai/micro\\_ros\\_arduino\\_kaiaai/](https://github.com/kaiaai/micro_ros_arduino_kaiaai/)

A micro-ROS/micro\_ros\_arduino fork

- Apache 2.0 license (same as original repo)
- Published, maintained as Arduino library

Configuration & tweaks

- Added kaiaai\_messages to build
- git-clone, build works on Windows
- +5 max services for param server
  - Robot node has ROS parameters
- Took WiFi.begin() out of set\_microros\_wifi\_transports()
- Miscellaneous tweaks

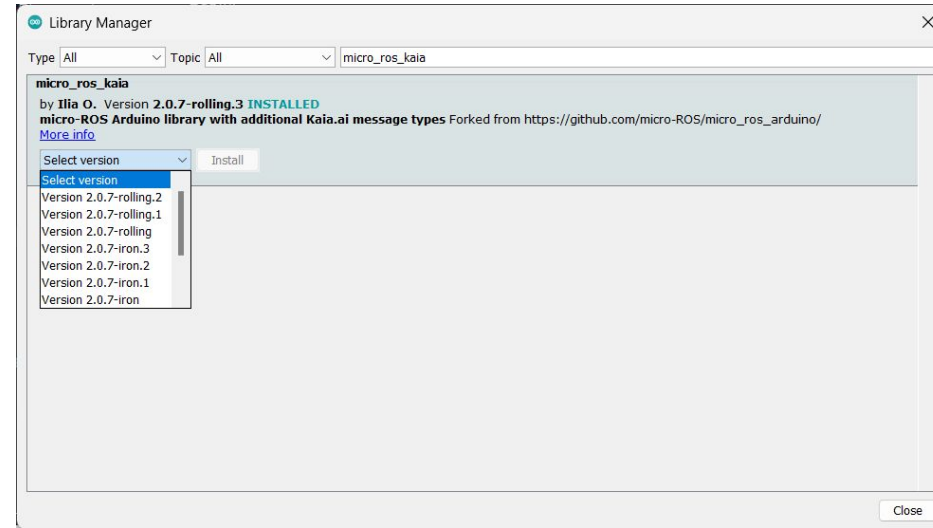


Fig. Arduino Library Manager window showing micro\_ros\_kaia library

# Robot Configuration as of 2/2024

When robot is *unable to connect to WiFi*, robot enters the *configuration mode*.

I.e. robot sets up:

1. A temporary Access Point
2. HTTP server at 192.168.4.1

**Kaia.ai Robot Configurator**

SSID 2.4GHz:

WiFi Password:

Local PC IPv4:

Local PC Port:

Robot model:

Laser sensor:

Motor model:

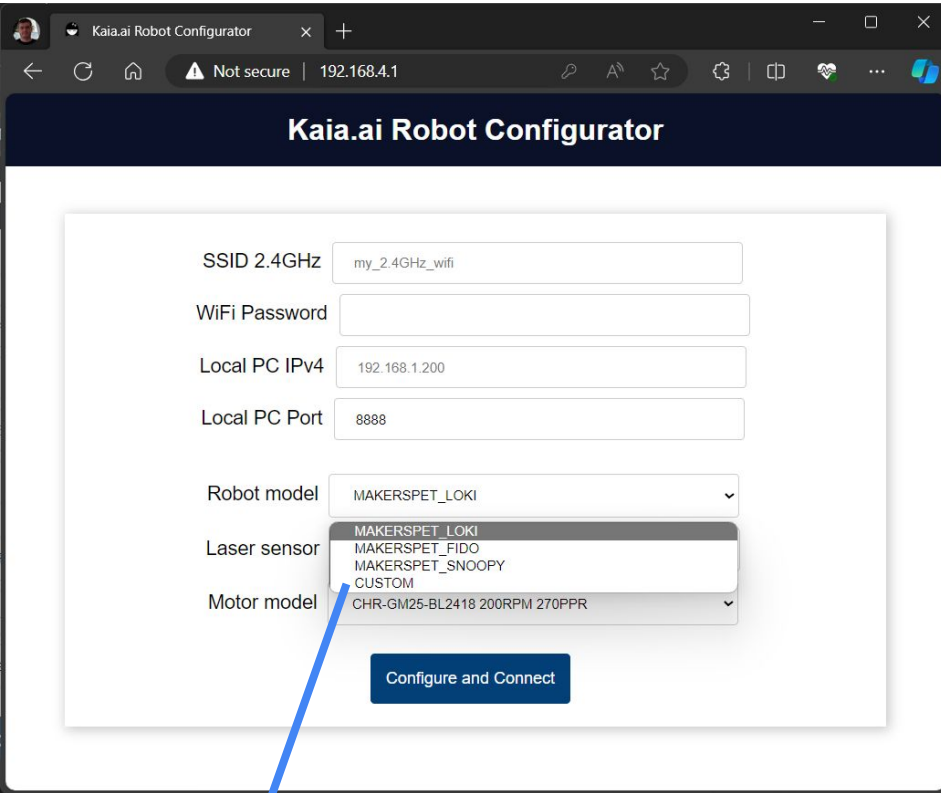
WiFi LAN access

micro-ROS agent

Robot hardware options



# Robot Configuration - cont.

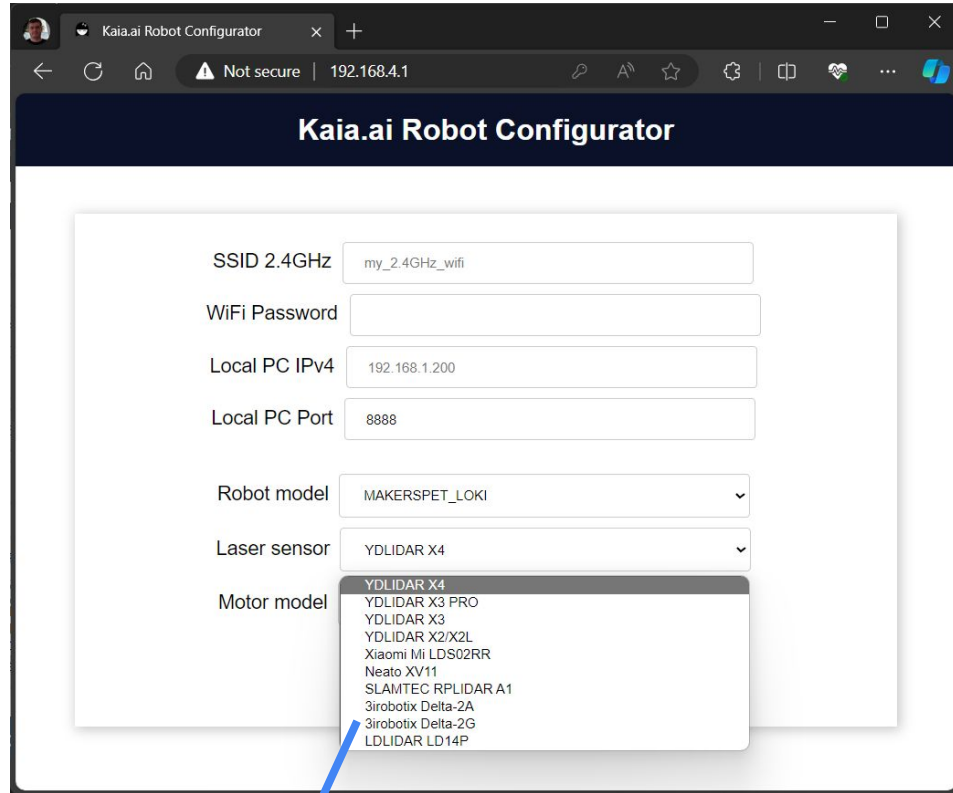


The screenshot shows the Kaia.ai Robot Configurator interface. The fields are filled with the following values:

- SSID 2.4GHz: my\_2.4GHz\_wifi
- WiFi Password: (empty)
- Local PC IPv4: 192.168.1.200
- Local PC Port: 8888
- Robot model: MAKERSPET\_LOKI
- Laser sensor: MAKERSPET\_LOKI (dropdown menu is open showing options: MAKERSPET\_LOKI, MAKERSPET\_FIDO, MAKERSPET\_SNOOPY, CUSTOM)
- Motor model: CHR-GM25-BL2418 200RPM 270PPR (dropdown menu is open showing options: CHR-GM25-BL2418 200RPM 270PPR)

A blue arrow points from the caption below to the Motor model dropdown menu. A blue button labeled "Configure and Connect" is located at the bottom of the form.

Robot base size options



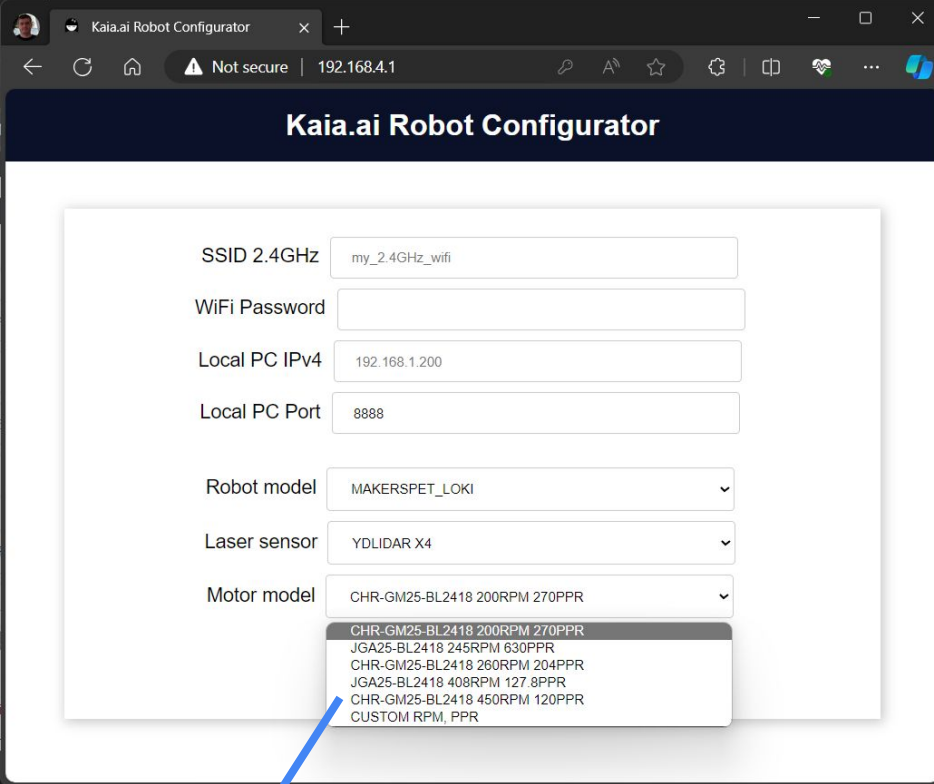
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- SSID 2.4GHz: my\_2.4GHz\_wifi
- WiFi Password: (empty)
- Local PC IPv4: 192.168.1.200
- Local PC Port: 8888
- Robot model: MAKERSPET\_LOKI
- Laser sensor: YDLIDAR X4 (dropdown menu is open showing options: YDLIDAR X4)
- Motor model: YDLIDAR X4 (dropdown menu is open showing options: YDLIDAR X4, YDLIDAR X3 PRO, YDLIDAR X3, YDLIDAR X2/X2L, Xiaomi Mi LDS02RR, Neato XV11, SLAMTEC RPLIDAR A1, 3irobotix Delta-2A, 3irobotix Delta-2G, LDIDAR LD14P)

A blue arrow points from the caption below to the Motor model dropdown menu.

Robot LiDAR/LDS model options

# Robot Configuration - cont.



The screenshot shows the Kaia.ai Robot Configurator web interface. The form includes the following fields:

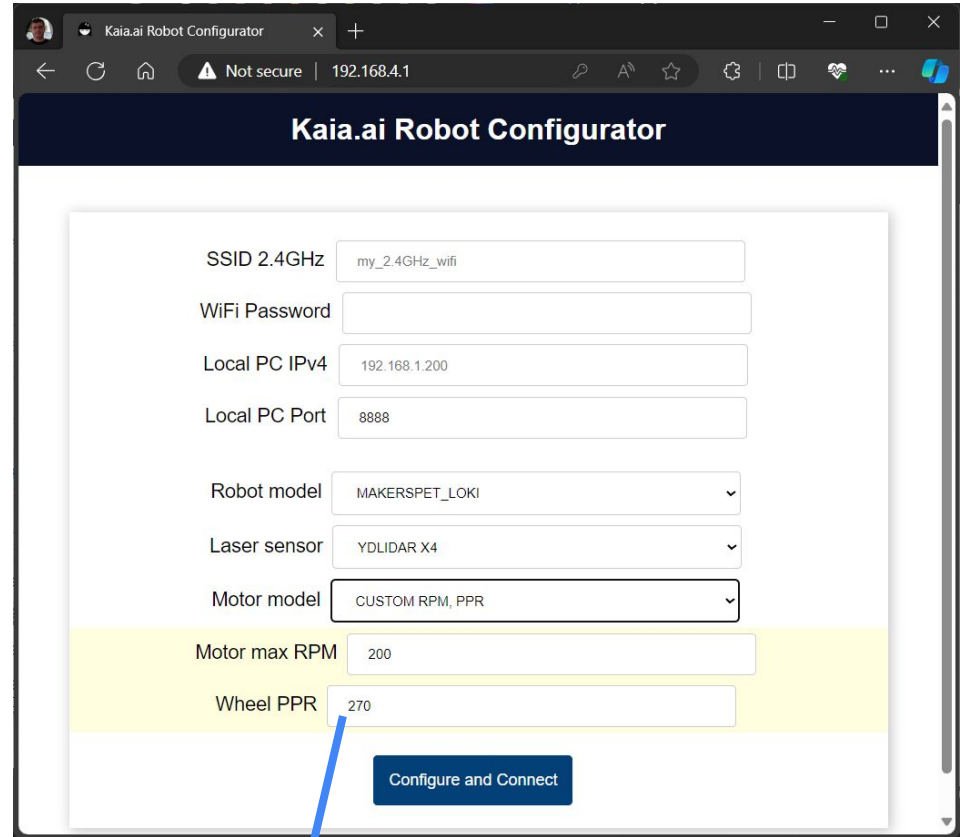
- SSID 2.4GHz:
- WiFi Password:
- Local PC IPv4:
- Local PC Port:
- Robot model:
- Laser sensor:
- Motor model:

The Motor model dropdown menu is open, showing the following options:

- CHR-GM25-BL2418 200RPM 270PPR
- JGA25-BL2418 245RPM 630PPR
- CHR-GM25-BL2418 260RPM 204PPR
- JGA25-BL2418 408RPM 127.8PPR
- CHR-GM25-BL2418 450RPM 120PPR
- CUSTOM RPM, PPR

A blue arrow points from the caption below to the Motor model dropdown menu.

Robot motor model options



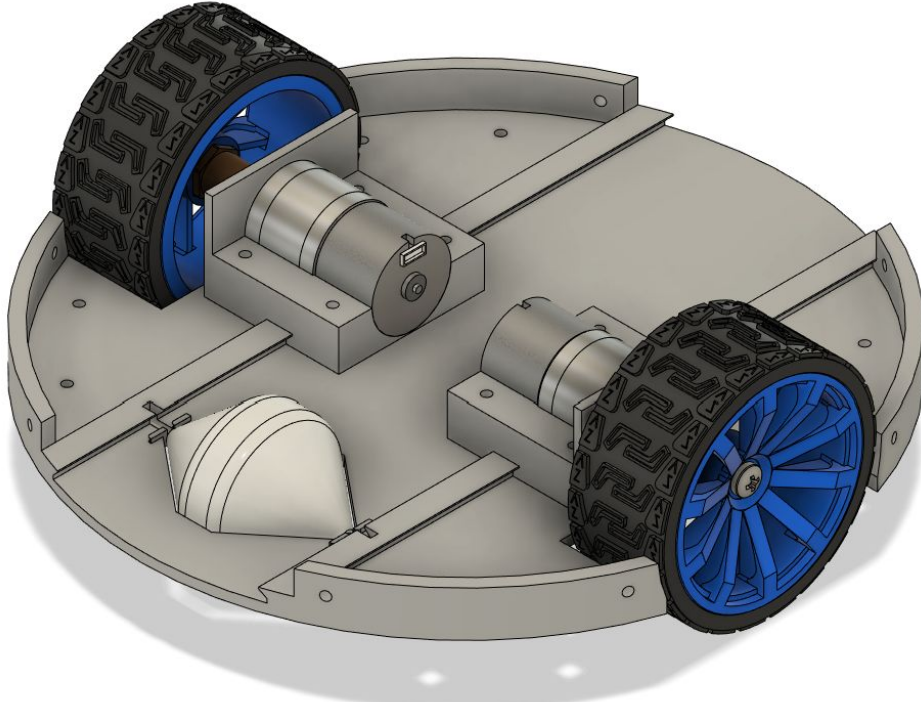
The screenshot shows the Kaia.ai Robot Configurator web interface. The form includes the following fields:

- SSID 2.4GHz:
- WiFi Password:
- Local PC IPv4:
- Local PC Port:
- Robot model:
- Laser sensor:
- Motor model:
- Motor max RPM:
- Wheel PPR:

The Motor max RPM and Wheel PPR fields are highlighted in yellow. A blue arrow points from the caption below to the Wheel PPR field.

Custom motor parameters

# Robot Configuration - cont.



Currently, a compatible robot must have

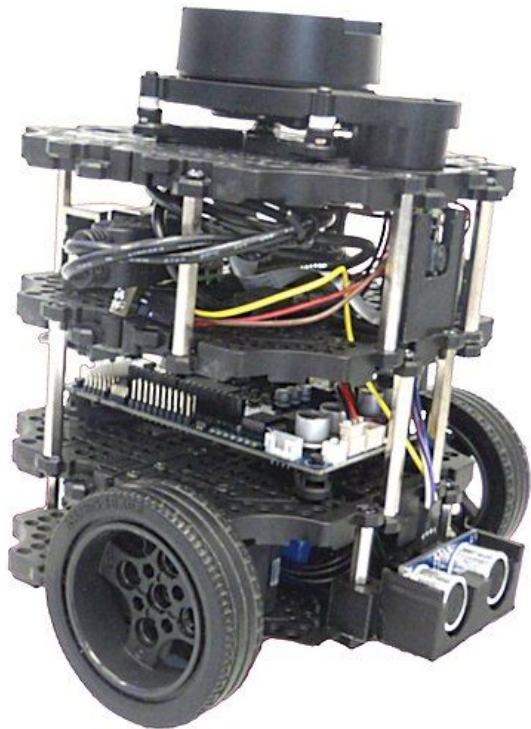
- a round base
- two-wheel differential drive
- LDS/LiDAR center above base centerpoint

A screenshot of the Kaia.ai Robot Configurator web interface. The page title is "Kaia.ai Robot Configurator". The interface contains several input fields and dropdown menus for configuring a robot. A blue arrow points from the "Max acceleration" field to the text "Custom base parameters" below the screenshot.

|                  |  |
|------------------|--|
| SSID 2.4GHz      | <input type="text" value="my_2.4GHz_wifi"/>                |
| WiFi Password    | <input type="password"/>                                   |
| Local PC IPv4    | <input type="text" value="192.168.1.200"/>                 |
| Local PC Port    | <input type="text" value="8888"/>                          |
| Robot model      | <input type="text" value="CUSTOM"/>                        |
| Robot model name | <input type="text" value="MAKERSPET_LOKI"/>                |
| Base dia., mm    | <input type="text" value="202"/>                           |
| Wheel base, mm   | <input type="text" value="159.063"/>                       |
| Wheel dia., mm   | <input type="text" value="67"/>                            |
| Max acceleration | <input type="text" value="2.0"/>                           |
| Laser sensor     | <input type="text" value="YDLIDAR X4"/>                    |
| Motor model      | <input type="text" value="CHR-GM25-BL2418 200RPM 270PPR"/> |

Custom base parameters

# Robot Economics and micro-ROS



Turtlebot3 Burger

Maker's Pet

Raspberry Pi 4

->

ESP32

OpenCR 1.0 board

->

Breakout board

Dynamixel XL430-W250  
smart actuators

->

~7x cheaper  
BLDC motors

2x 65mm wheels

->

No change

LiPo battery

->

Alkaline battery  
ESP32 is low-power

Battery charger

->

None

LDS HLS-LFCD2/3

->

<\$20 LDS

Color camera

->

No cost

Robotis US \$659.30

Total <\$100

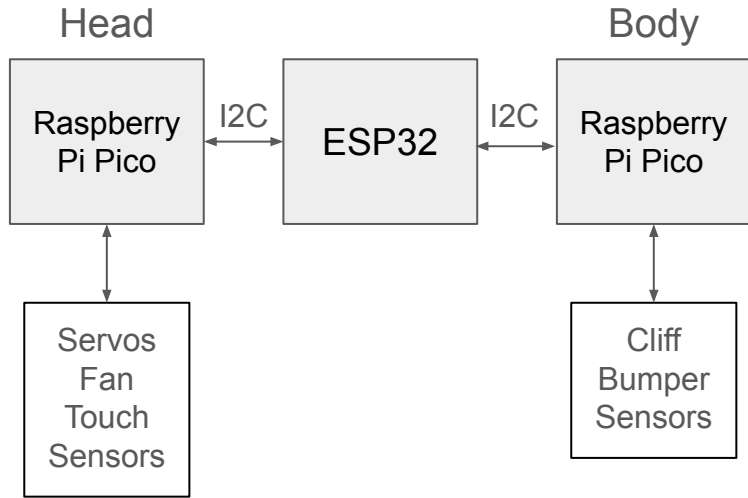


- micro-ROS slashes parts cost for certain robot types
- Proliferation of robotic vacuum cleaners helps slash LDS costs
- Replacing Raspberry Pi with MCU simplifies system (no RPi setup, SSH/VNC, display, etc.)

# Hardware Extensions

2x ESP32 I2C extensions slots

- Head
- Body

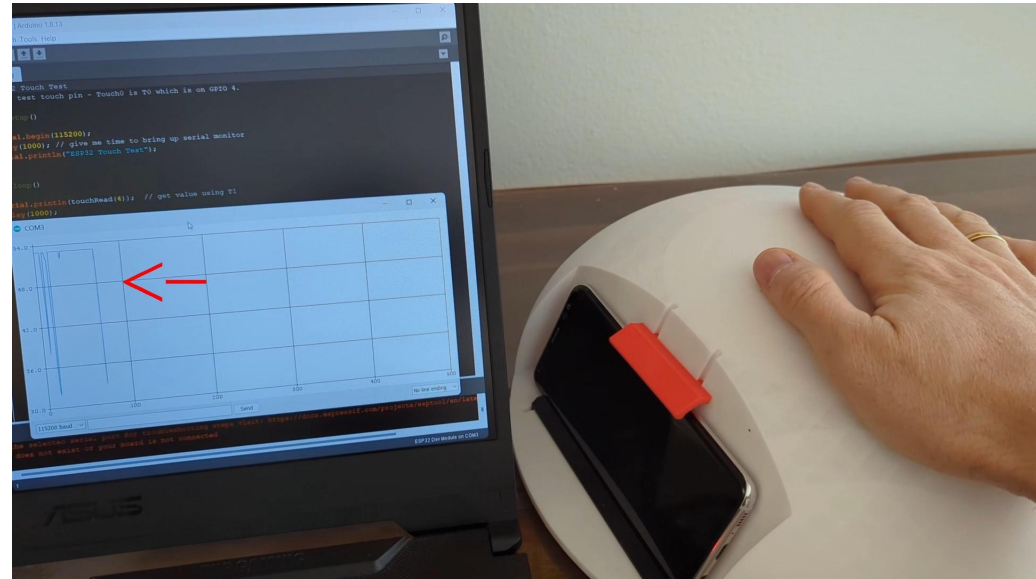


# Adding Sense of Touch



- Place sticky copper tape from the inside
- Connect to MCU GPIO
- Place your hand, tape capacitance increases
- MCU ADC measures capacitance (charge/discharge time)

[https://github.com/kaiaai/pico\\_touch\\_pio](https://github.com/kaiaai/pico_touch_pio)  
YouTube <https://youtu.be/oTpgZuBU10Q>



# Smartphone/Tablet

Bring-your-own (old) smartphone (or 8" tablet) \$0

- Connects to ROS2 PC
  - display
  - color camera feed
  - mic, speakers audio
  - IMU

Display interface runs in a browser

- Websockets transport using RobotWebTools  
rosbridge\_suite

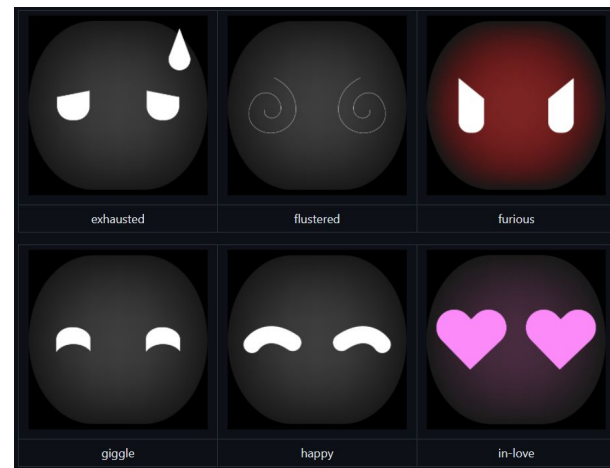
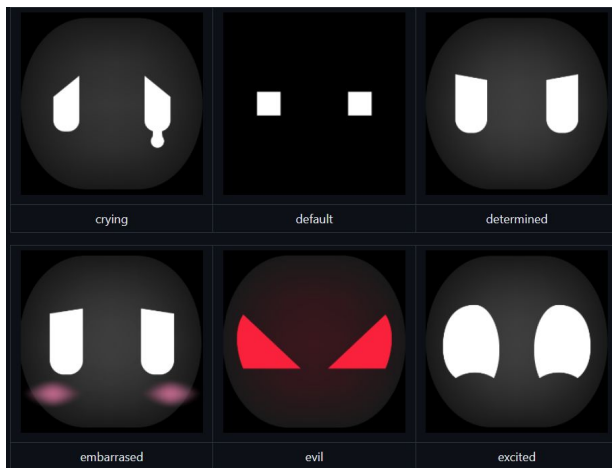
TBD moving ROS2 from PC to smartphone in the long-term

- We've built ROS2 on Android smartphone using Termux (no root)



# Facial Expressions

<https://github.com/kaiaai/kaia-face.js>





# Development Environment

## Docker

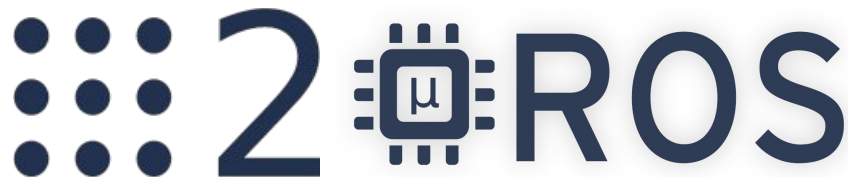
- ROS2 desktop (RViz, Gazebo, etc.)
- micro-ROS
- Windows (Linux OK)

<https://hub.docker.com/r/kaiaai/kaiaai-ros-dev>

- `docker pull kaiaai/kaiaai-ros-dev:humble`
- `docker pull kaiaai/kaiaai-ros-dev:iron`

Dockerfile <https://github.com/kaiaai/docker>

- FROM osrf/ros:\$distro\_tag-desktop
- Installs micro-ROS base, agent
- Kaia.ai-specific packages



PC setup requires

- Docker
- XLaunch (for Windows)
- Arduino IDE

# Kaia.ai Robot Software Platform

A software platform for multi-skilled home robots.

- Goal: wide consumer acceptance of multi-skilled home robots

Teaser video <https://youtu.be/5xbXqkkQknk>

- On top of ROS, ML/AI
- First pre-release around end of 2024
- In stealth mode until then 🕒



# YouTube

@makerspet DIY hardware

@kaiaai software

@remakeai startup

The screenshot shows the YouTube channel page for 'Maker's Pet'. The browser address bar displays 'https://www.youtube.com/@MakersPet'. The channel's profile picture is a cartoon orange cat. The channel name is 'Maker's Pet' with 376 subscribers and 21 videos. The bio reads: 'Learn, build, code pet robots - Arduino, ROS, ESP32, 3D printing!'. There are buttons for 'Customize channel' and 'Manage videos'. The navigation menu includes Home, Videos, Shorts, Playlists, and Community. The 'For You' section features four video thumbnails: 'Maker's Pet robot bring-up instructions' (8:21, 6.3K views), 'Maker's Pet robot Arduino ESP32 breakout board setup instructions' (4:01, 3.2K views), 'Maker's Pet robot assembly instructions' (12:29, 805 views), and 'Maker's Pet robot 3D printing instructions' (12:29, 1.7K views). The 'Videos' section shows a 'Play all' button and a row of video thumbnails, including 'Loki robot's laser sensor wobble fix' (0:42, 206 views), 'Maker's Pet robot 3D printing instructions' (4:43, 1.7K views), 'Maker's Pet robot bring-up instructions' (8:21, 6.3K views), 'Robot Arduino firmware, ROS2/Docker PC setup...' (10:21, 1K views), and 'Maker's Pet robot assembly instructions' (12:29, 805 views).

# Look us up

## GitHub

- <https://github.com/makerspet>
- <https://github.com/kaiaai>

## Web/Blog

- <https://makerspet.com> DIY hardware
- <https://kaia.ai> Software
- <https://remake.ai> Startup

## Facebook

- Group  
<https://www.facebook.com/groups/243730868651472/>
- Makerspet  
<https://www.facebook.com/profile.php?id=61550661555594>
- Kaia.ai <https://www.facebook.com/kaiaai/>

## Launch Mailing List

- <http://eepurl.com/gBV7tb>

## Twitter

- <https://twitter.com/makerspet/>
- <https://twitter.com/RemakeAi>
- [https://www.instagram.com/remake\\_ai](https://www.instagram.com/remake_ai)

## Instagram

- [https://www.instagram.com/makerspet\\_com/](https://www.instagram.com/makerspet_com/)
- [https://www.instagram.com/kaia\\_\\_ai](https://www.instagram.com/kaia__ai)

## Reddit

- <https://www.reddit.com/r/3dPrintedHomeRobots/>