Carnegie Mellon University

Mind Drive: EEG-Controlled Arduino Car

Members:

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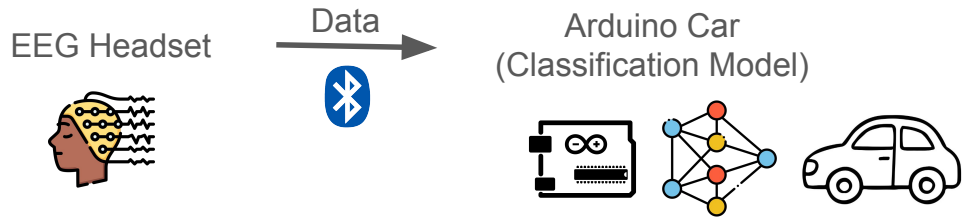
Mind Drive



Motivation & Objective

- **Electroencephalogram (EEG)**, also known as “brain wave”, is a promising brain computer interface technology that is **low-cost** and **non-invasive**.
- **Goal: Build a prototype device that can read EEG, decode the user intent, and use that to control an Arduino Car**.

Target users

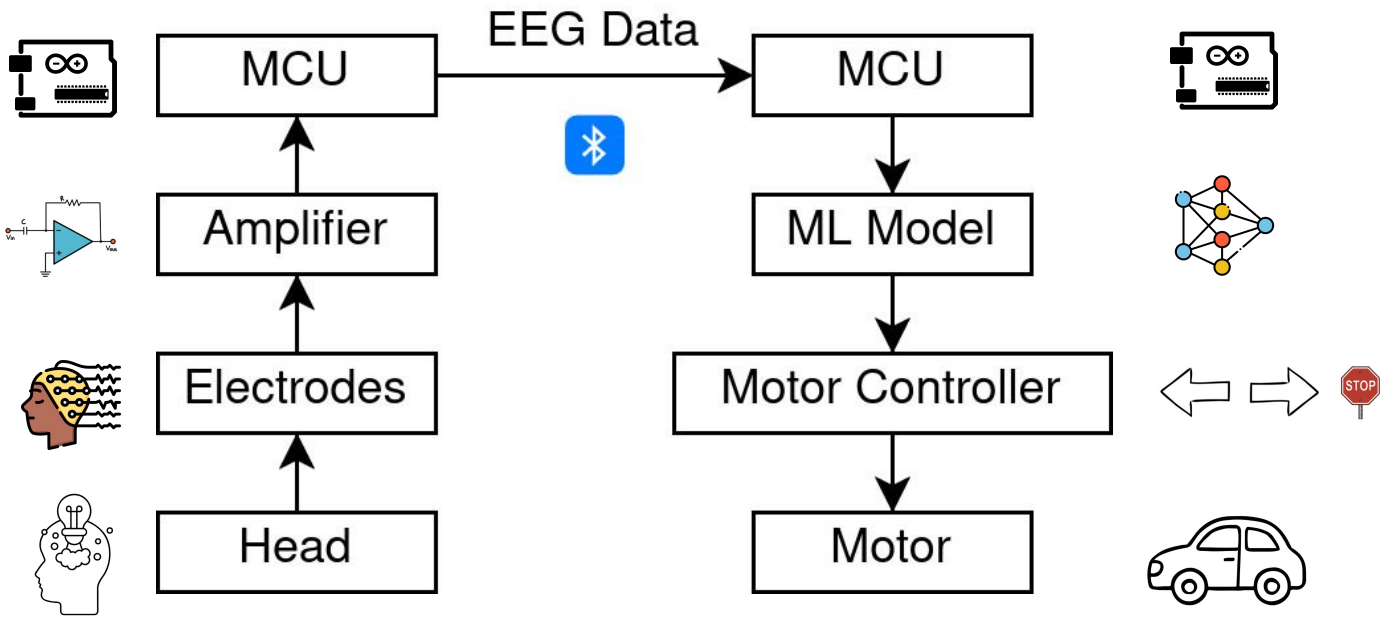
- Disabled people who need a different way to control things
- Hobbists wanting to try out BCI technologies
- Researchers working on EEG related projects

Embedded ML solution

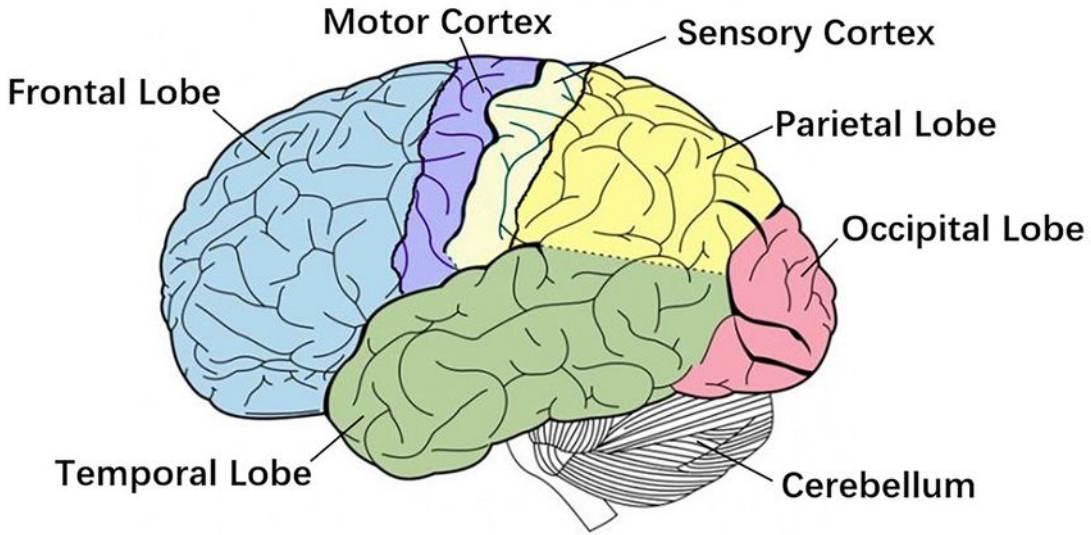
- Latency: real time control
- Economics: no data transmission and cloud processing costs
- Reliability: no need for internet connection
- Privacy: users’ EEG signals are sensitive data

Components

System Design



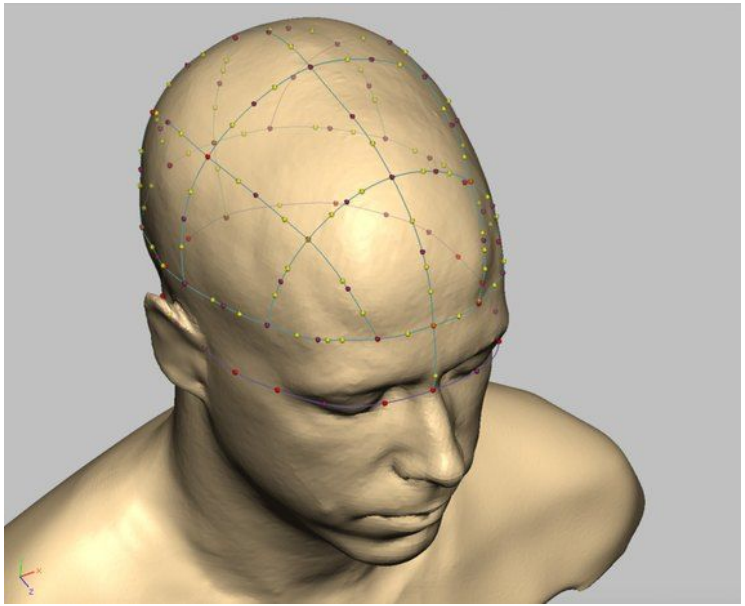
The Motor Cortex

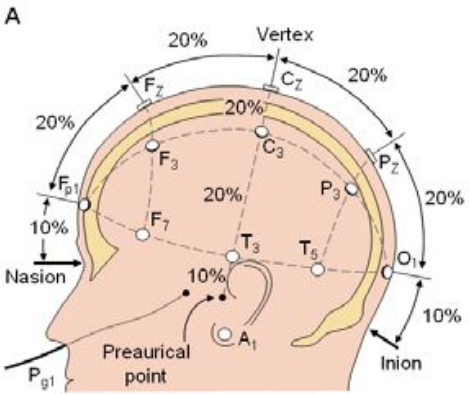


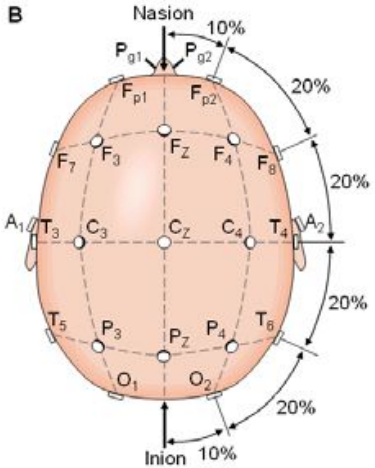
Images:

https://www.researchgate.net/publication/331905251_Corticomuscular_Coherence_and_Its_Applications_A_Review

The EEG 10-20 System







Images:

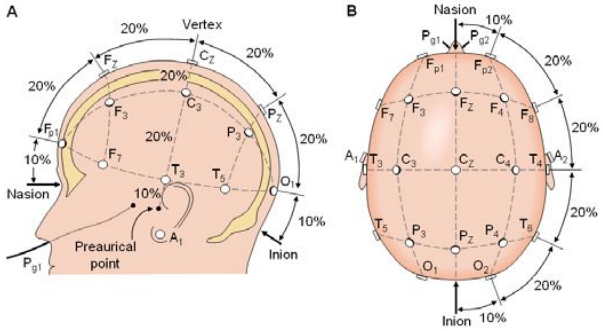
https://threeformfashion.com/?p=299

https://www.researchgate.net/publication/303836379_SoundPacman_Audio_Augmented_Reality_in_Location-based_Games

Hardware

EEG Headset

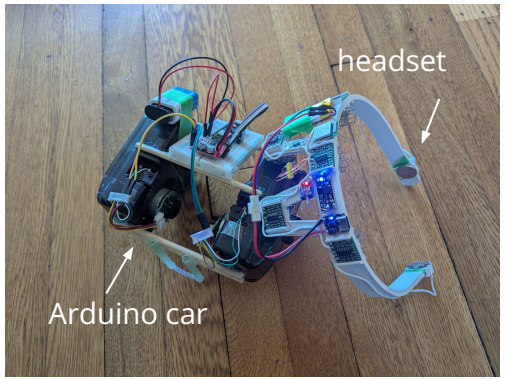
- 5 channels over the motor cortex:
  C3, Cz, C4, FC1, FC2



- Instrumentation Amplifier
  (3000 times, 1-60Hz bandpass filter)

Arduino Car

- ESP32
- Motor driver IC



Hardware

EEG Headset

5 channels over the motor cortex
(C3 Cz C4 FC1 FC2)

Instrumentation Amplifier
(3000 times, 1-60Hz bandpass filter)

Arduino Car

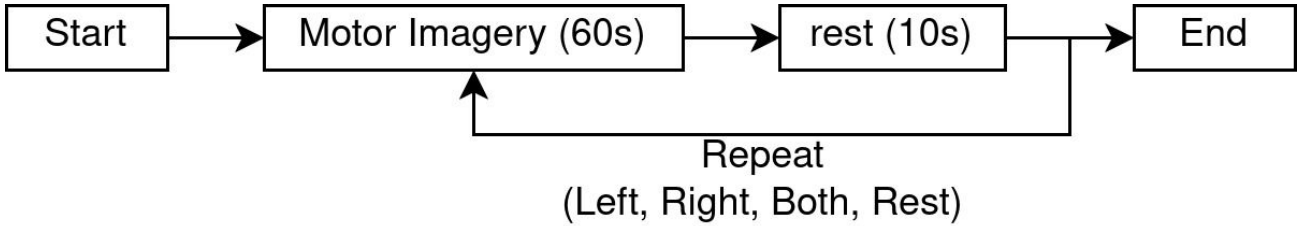
ESP32

Motor driver IC

Dataset Collection

- Collected 10 Sessions (~40 mins) on one person
- 4 classes: Left, Right, Both, Rest
- For each class, make visual imagination
- 5 EEG Channels, 180Hz using the custom made EEG headset

Scheme:



Embedded Machine Learning Model

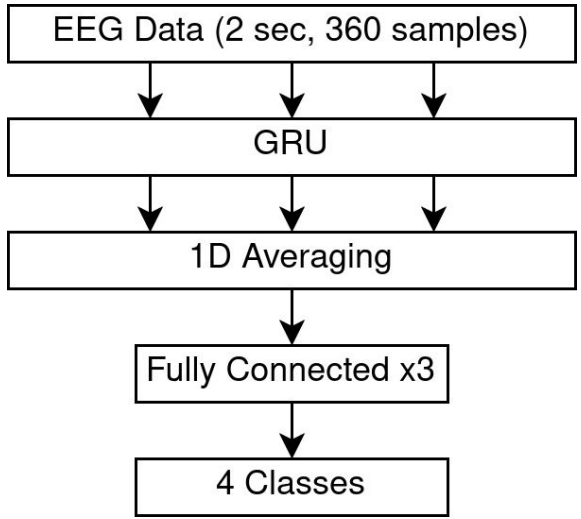
Data preprocessing

- 1-60Hz bandpass filter (remove noisy, uninformative information from the input data)

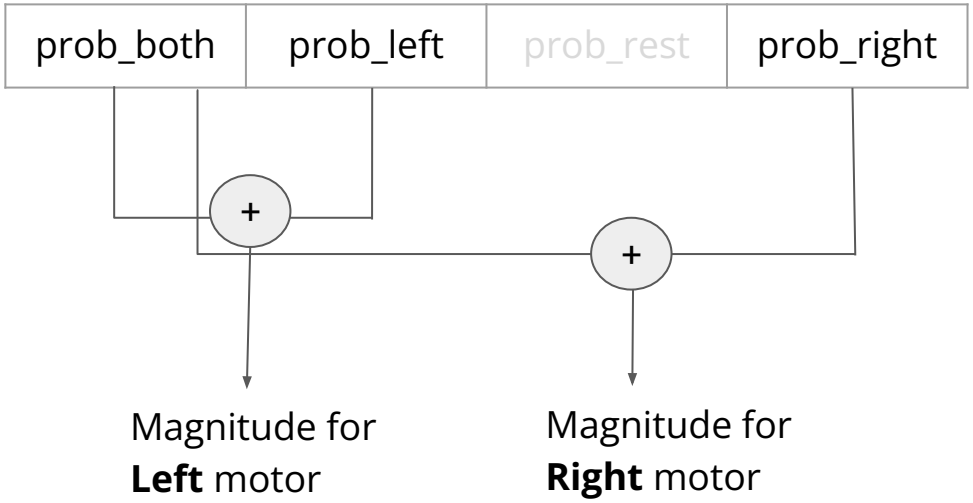
Model selection

- Experimented with various model architectures including CNN, RNN, LSTM, GRU based models
- Sequence models have much better performance than CNN even with less number of parameters
- However, RNN and LSTM are much slower and more difficult to deploy on the microcontroller

Model Architecture

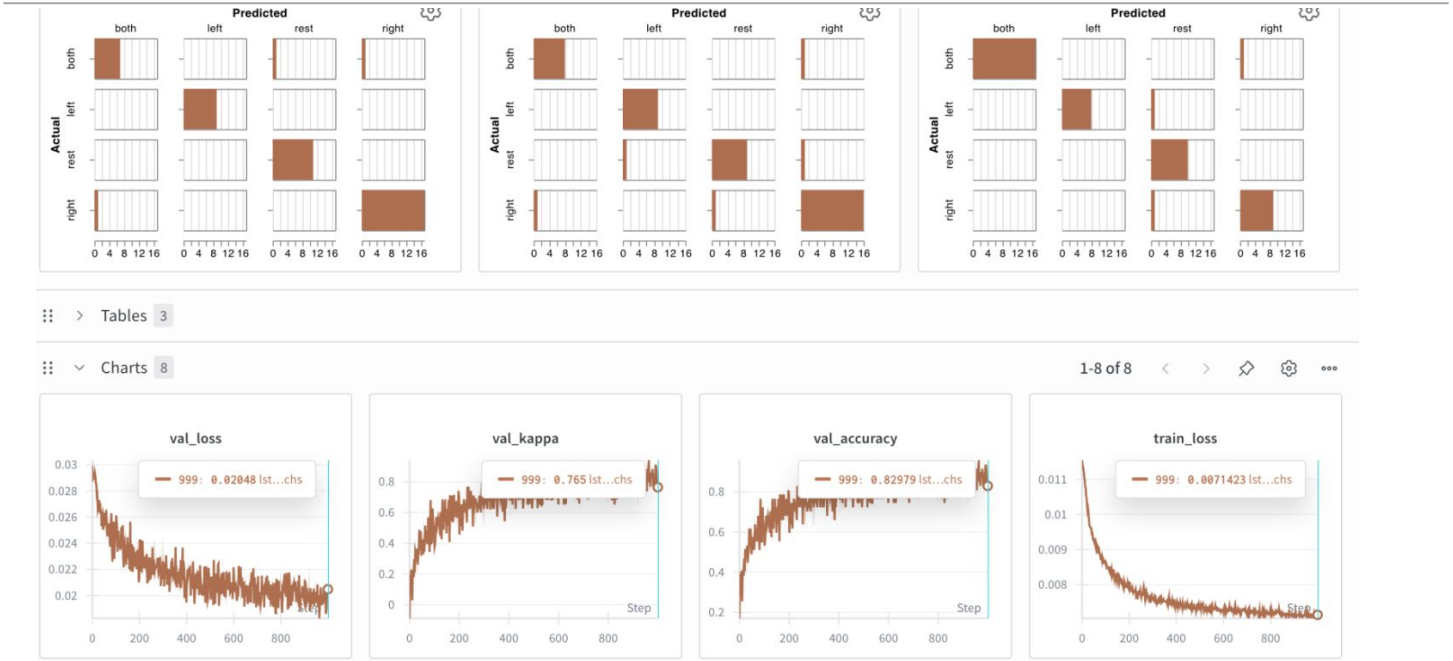


Model Classification to Car Control

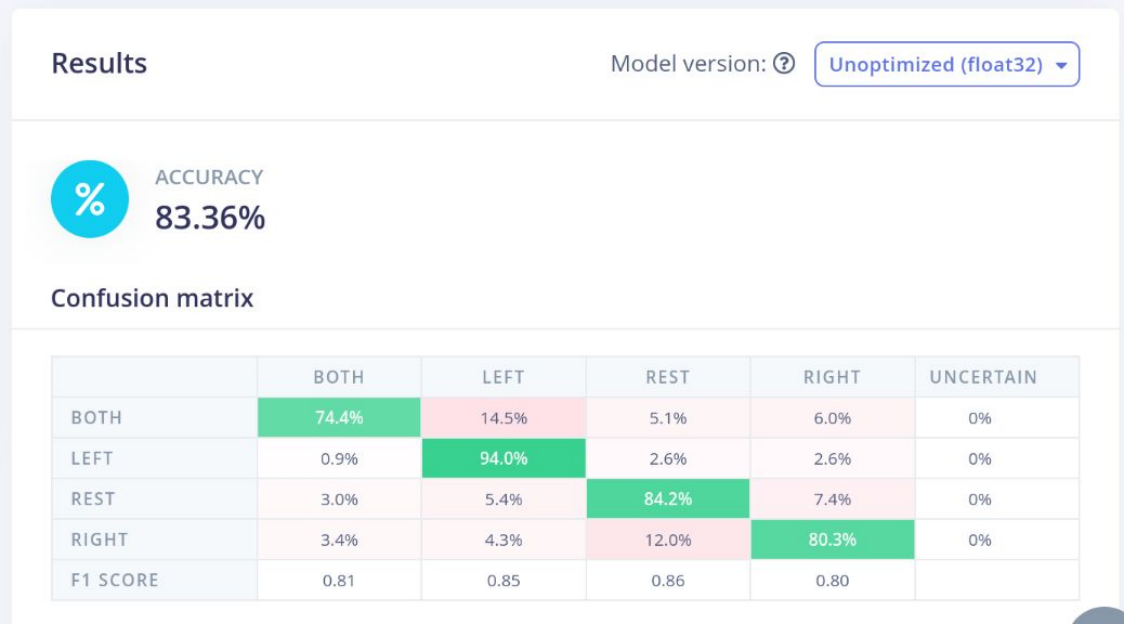


Results

Validation Accuracy



Test Accuracy



Results

Model version: Unoptimized (float32)

ACCURACY
83.36%

Confusion matrix

	BOTH	LEFT	REST	RIGHT	UNCERTAIN
BOTH	74.4%	14.5%	5.1%	6.0%	0%
LEFT	0.9%	94.0%	2.6%	2.6%	0%
REST	3.0%	5.4%	84.2%	7.4%	0%
RIGHT	3.4%	4.3%	12.0%	80.3%	0%
F1 SCORE	0.81	0.85	0.86	0.80	

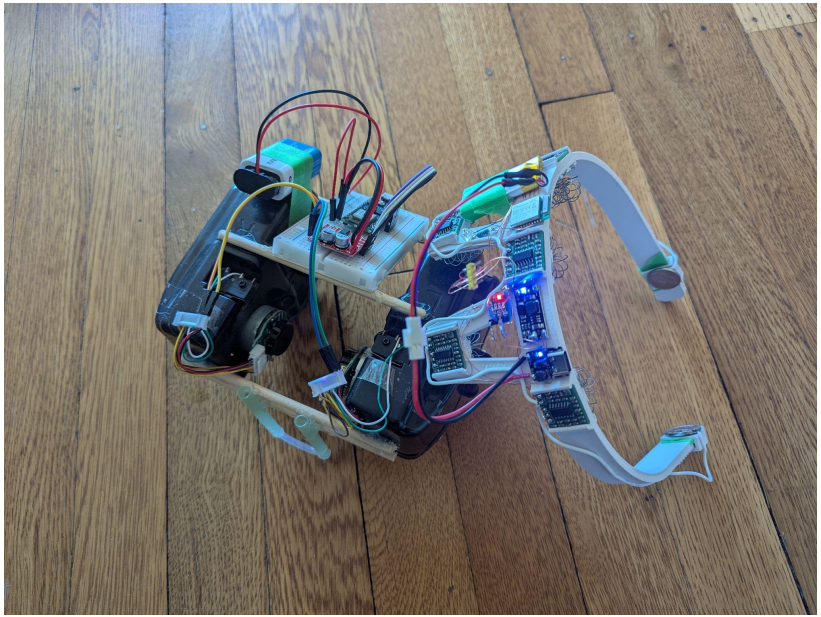
Embedded Performance

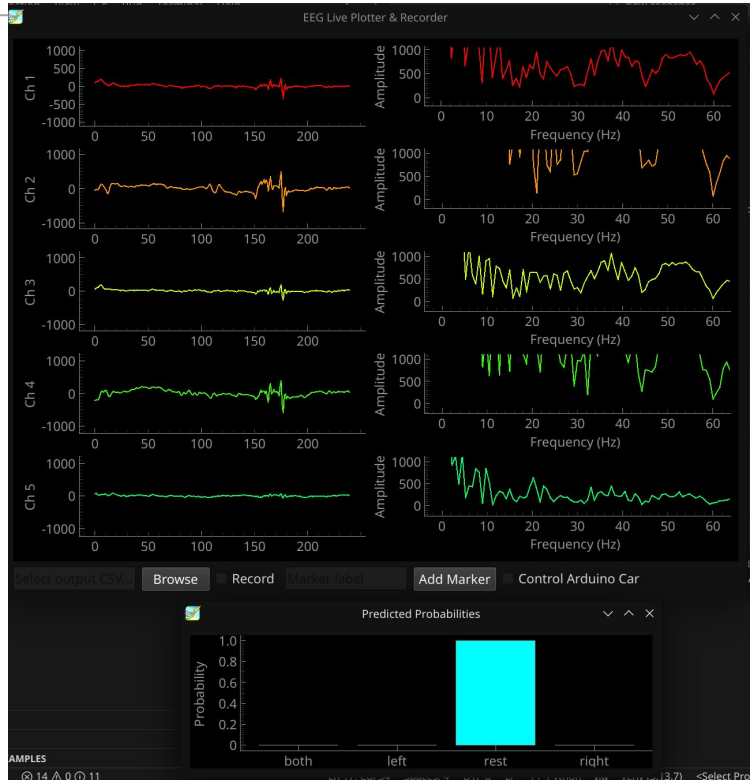
	GRU	Fully Connected
Flash Size	16.4KiB	9.7KiB
RAM Usage	4096 Bytes	1024 Bytes
Inference Time	1ms	1ms

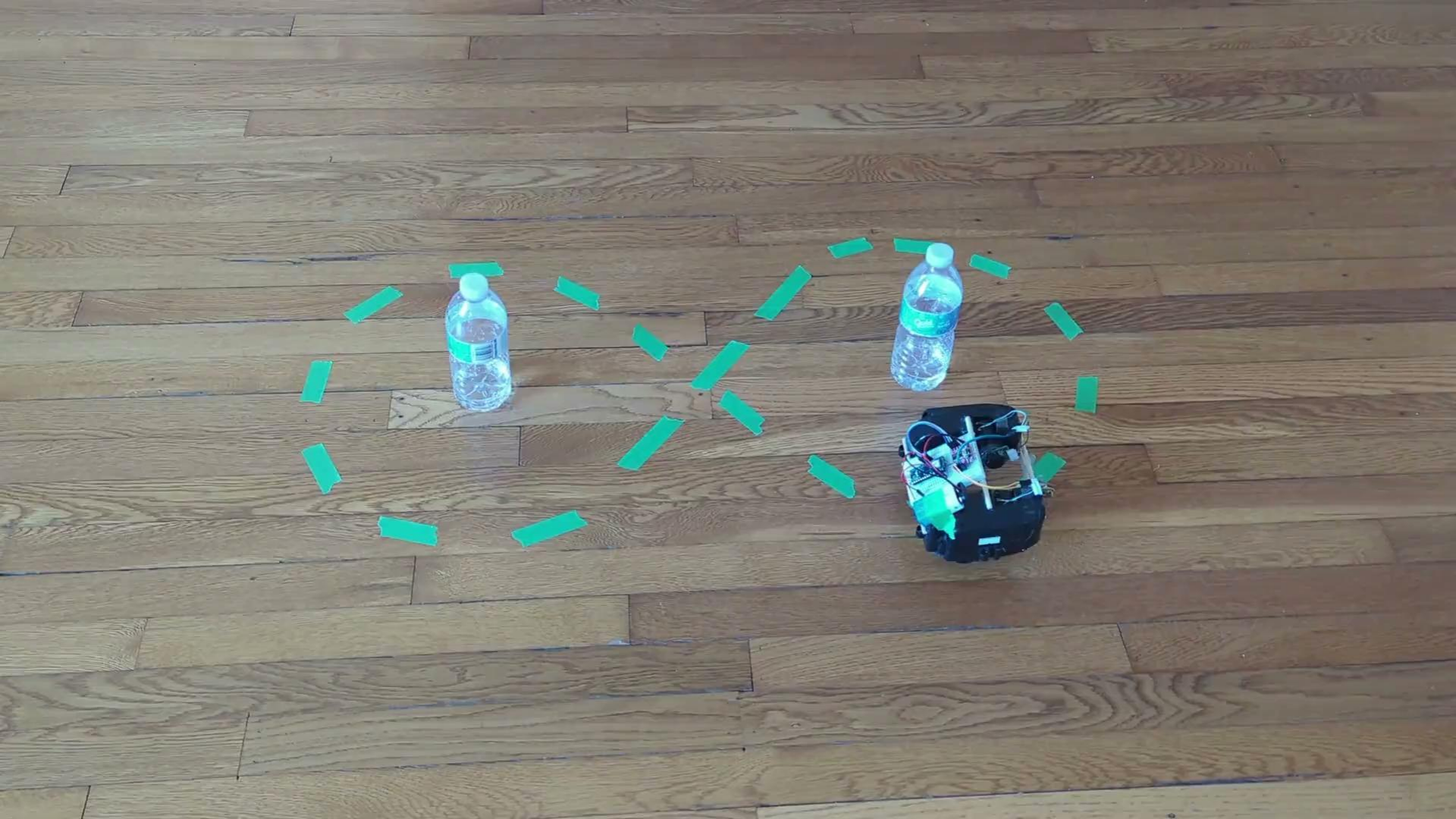
180 samples per second + 10 full inference per second:

180ms + 10ms = 190ms = 19% CPU load

Hardware & Software







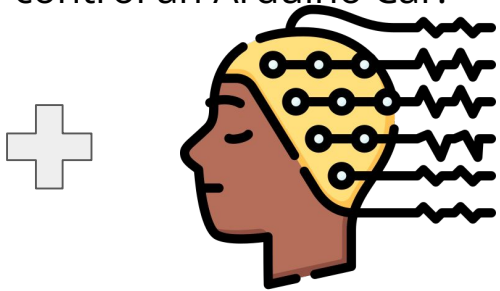
Challenges

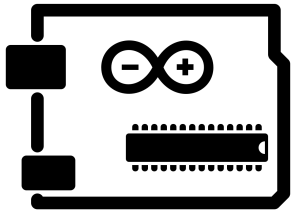
- Data Collection
  - Data is noisy, hard to do data cleaning manually
  - Domain shifting issue across session
  - Hard to reuse public datasets
- Model Training
  - Small dataset -> prone to overfitting
  - Model accuracy ≠ user experience (different class have different implication on car controlling)
- Deployment
  - Bad framework support for recursive neural networks
  - Limited computation & memory on MCU
  - Bluetooth debugging

Q&A

Overview

- **Electroencephalogram (EEG)**, also known as “brain wave”, is a promising brain computer interface technology that is **low-cost** and **non-invasive**.
- EEG has potential for various applications, such as health monitoring, accessibility tools, or simply input device for entertainment.
- Goal: Build a prototype device that can read EEG, decode the user intent, and use that to control an Arduino Car.





Target Users

This project can be beneficial for:

- Disabled people who need a different way to control things
- Hobbists wanting to try out BCI technologies
- Researchers working on EEG related projects

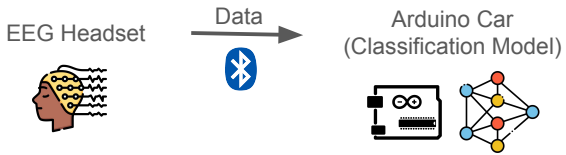
Why using Embedded Machine Learning

Latency
- Low latency is required for most applications

Economics
- No data transmission and cloud processing costs

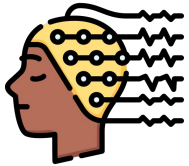
Reliability
- No need for internet connection

Privacy
- The users EEG signals are sensitive data



System Design

EEG Headset



Data

Arduino Car
(Classification Model)