Machine Learning on Microcontrollers

Arduino Days 2024 @ Bitraf, Oslo

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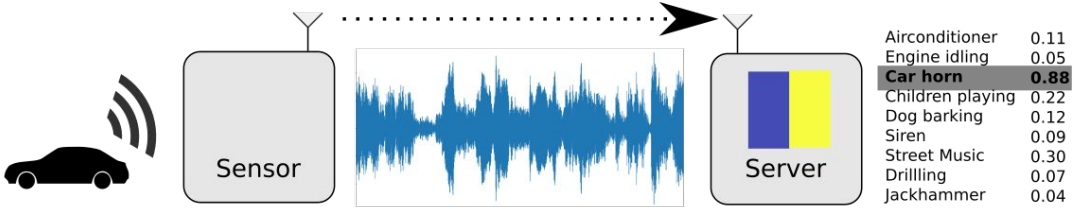
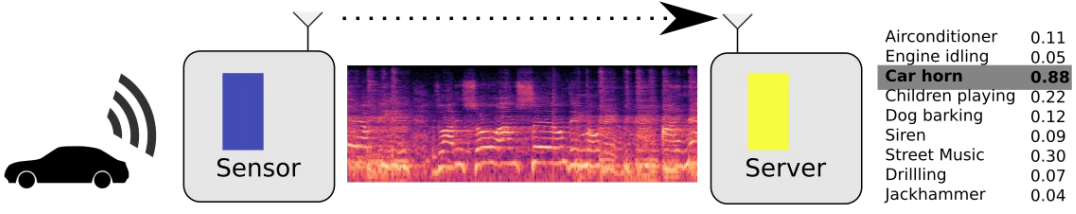
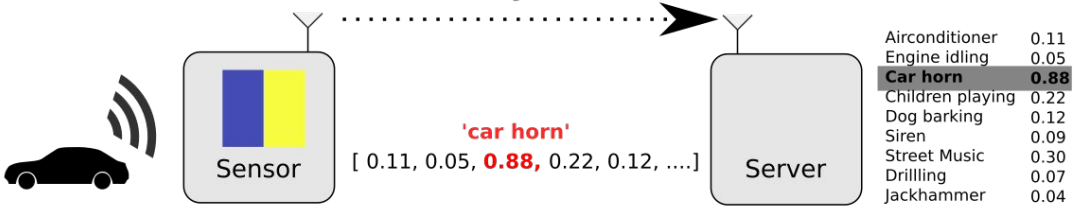
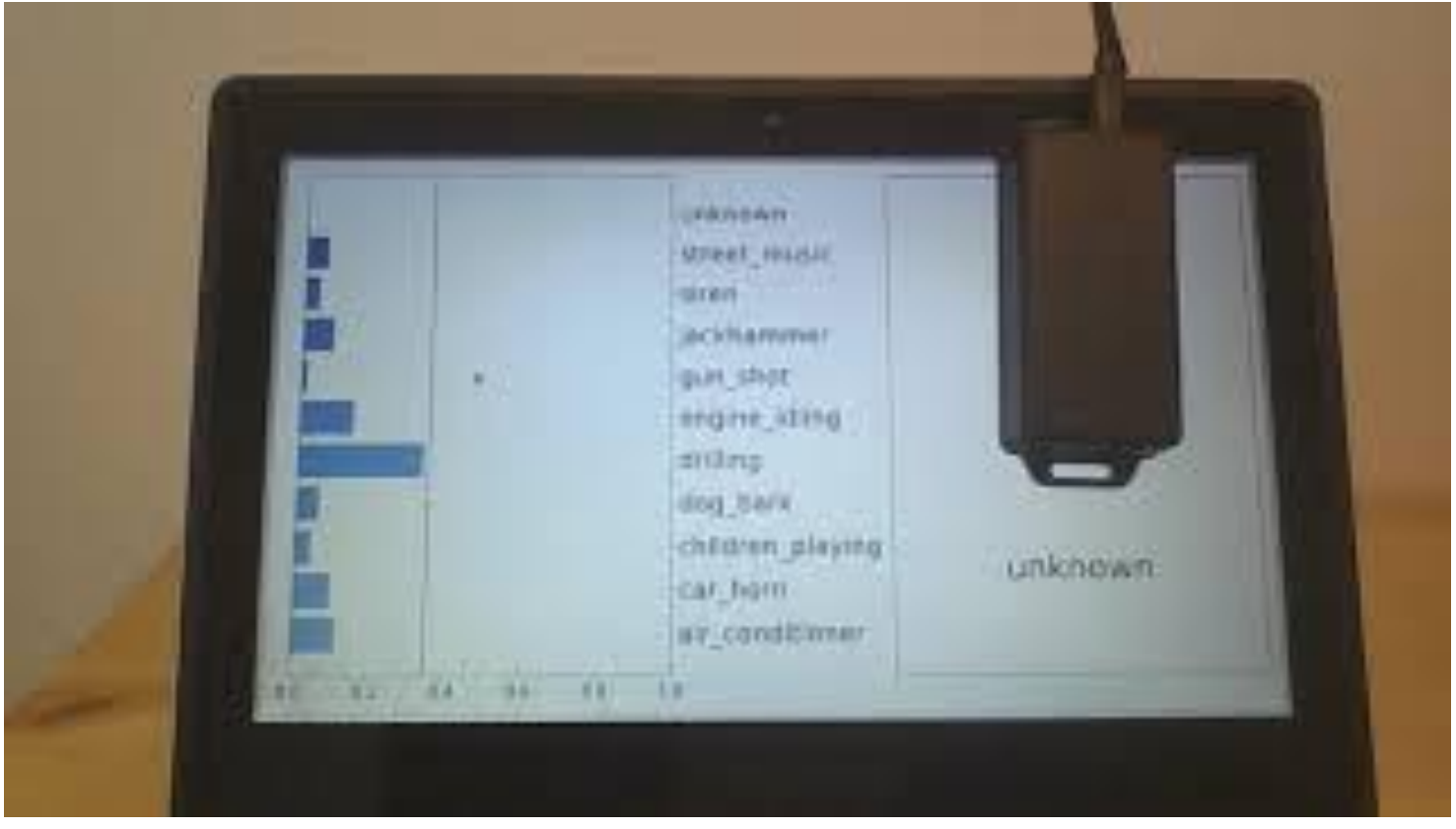
Motivation

Why ML on microcontrollers?

Extracting useful **information** from sensor *data*

Architecture	Privacy	Data Traffic	Compute constraints
A) Cloud model 	Bad	Bad	None
B) Sensor preprocess, classify in cloud 	Medium	Medium	Medium
C) Sensor classification (TinyML) 	Great	Great	Challenge!

Automatic classification of noise for Noise Monitoring



Tracking coffee bean roasting

Feasibility

What can be done & not
(on generic microcontroller)

Machine Learning requires compute

Microcontrollers have limited
RAM, FLASH, CPU

Task feasibility versus microcontroller type

	RAM (kB)	**FLASH** (kB)	**CPU** (CoreMark)		**IMU** 100 hz 5 s	**Sound** 16 kHz 1 s	**Image** 64x64 px 1 fps
Arduino Uno ATMega 328 @ 16 Mhz	2	32	4.0		✓	❌	❌
Arduino Nano BLE 33 NRF52840 ARM Cortex M4F @ 64 Mhz	256	1 000	215		✓	✓	❌
Arduino Nano ESP32 ESP32-S3 @ 240 Mhz	8 000	16 000	613 (per core)		✓	✓	✓
Teensy 4.0 ARM Cortex M7 @ 600 Mhz	1 000	2 000	2313 (per core)		✓	✓	✓

Examples

For Getting Started

“Magic Wand” using Accelerometer

“Magic Wand” using Accelerometer

TensorFlow Lite Micro Arduino library
https://github.com/tensorflow/tflite-micro-arduino-examples#how-to-install

Create custom gestures. Online gesture recorder

https://tinyml.seas.harvard.edu/magic_wand/

tinyML Summit 2021 Tutorial: Building a Magic Wand (Pete Warden)

https://www.youtube.com/watch?v=vKRdQHO7tIY

Speech Command Recognition using Microphone

Speech Command Recognition using Microphone

Build Your Own Voice-Controlled Robot with ESP32 & TensorFlow Lite
https://www.youtube.com/watch?v=cp2qRrhaZRA

Official example
https://github.com/tensorflow/tflite-micro/tree/main/tensorflow/lite/micro/examples/micro_speech

Can train custom models

Can be adapted to detecting Sound Events that are not speech

Object Detection / Object tracking using camera

Object Detection / Object tracking using camera

OpenMV Tensorflow Lite micro
https://docs.openmv.io/library/omv.tf.html

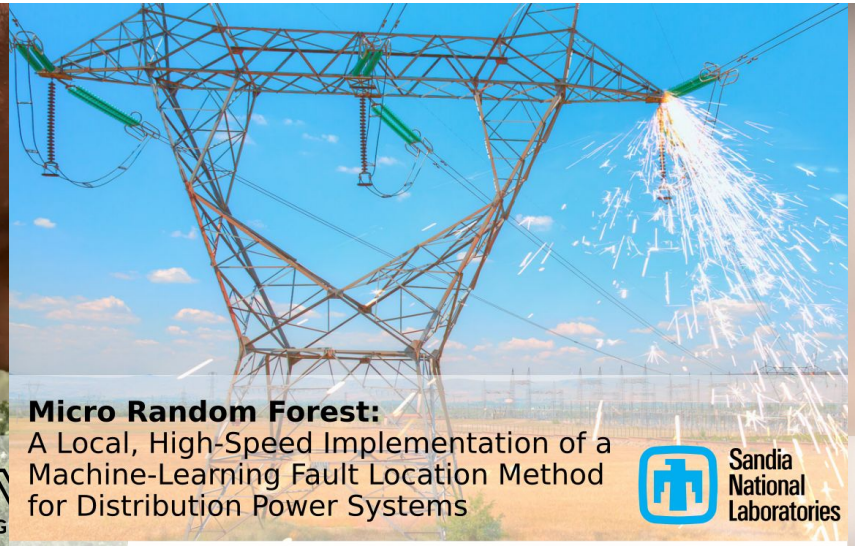
Cup detection
OpenMV Convolutional Neural Network
https://github.com/ARM-software/EndpointAI/tree/60b2a782194d74662eaf57051c71b799f5076f60/ProofOfConcepts/Vision/OpenMvCupDetect

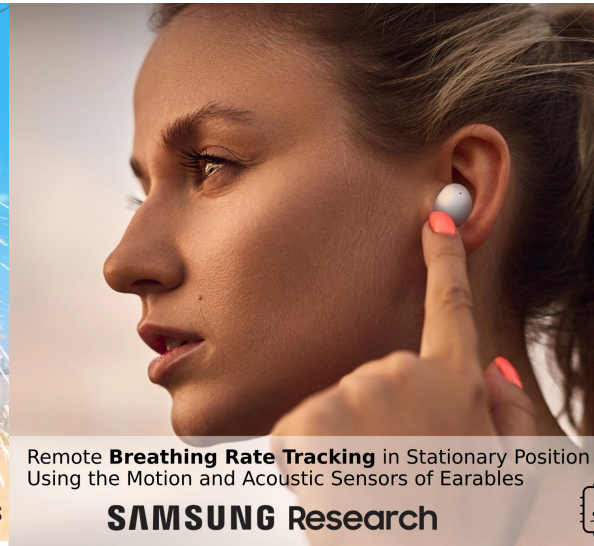
OpenMV Arduino tutorial face detection Haar
https://docs.arduino.cc/tutorials/portenta-vision-shield/creating-basic-face-filter/

My Projects

emlearn

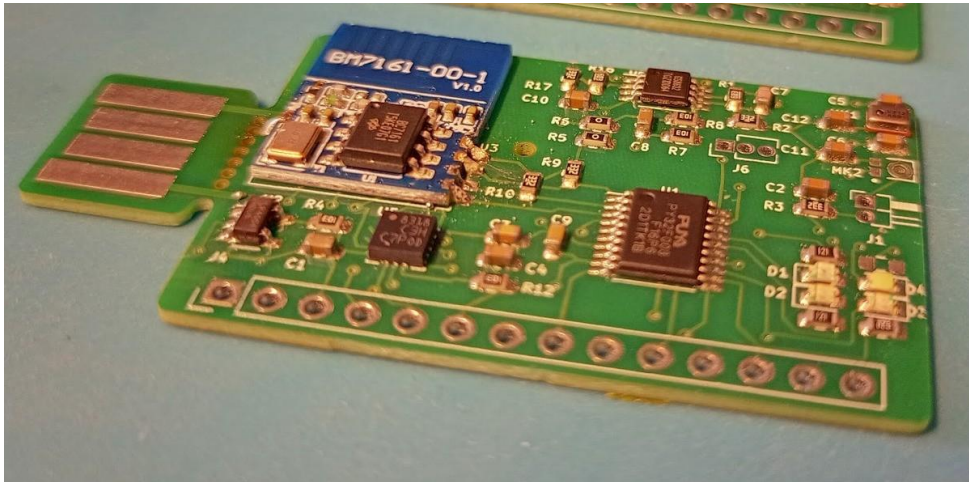
Project for “classical” ML models (pre neural-networks)
Running on the smallest microcontrollers < 16 kB RAM
Used in 30+ RnD projects worldwide
http://github.com/emlearn/emlearn

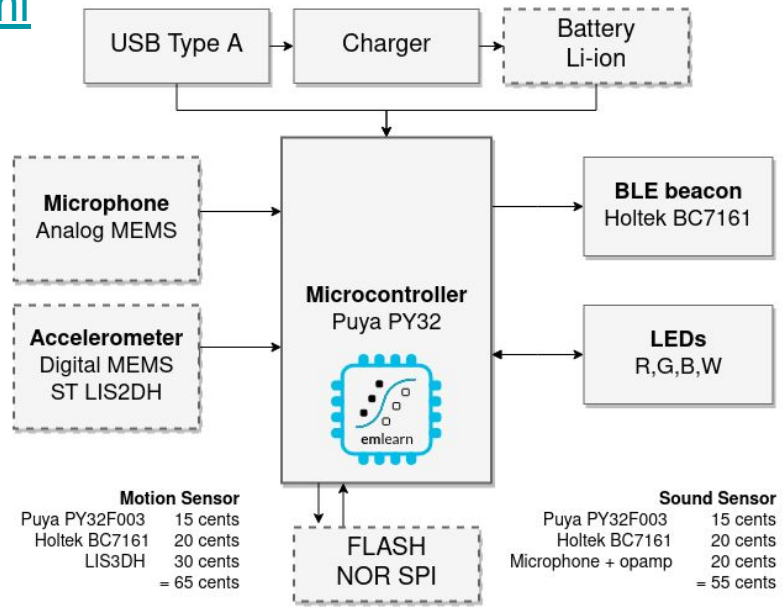




1 dollar TinyML system

Goal: Sound and accelerometer sensing using ML for under 1 USD in total component cost (BOM)
https://hackaday.io/project/194511-1-dollar-tinyml
Challenge: 3 kB RAM / 32 kB FLASH





Summary

Machine Learning is used in sensor-systems to extract useful information

Current microcontrollers can handle many tasks: motion data, sound and image analysis

Open source software libraries available