tinyML® EMEA

Enabling Ultra-low Power Machine Learning at the Edge

tinyML EMEA Technical Forum 2021 Proceedings

June 7 – 10, 2021

Virtual Event

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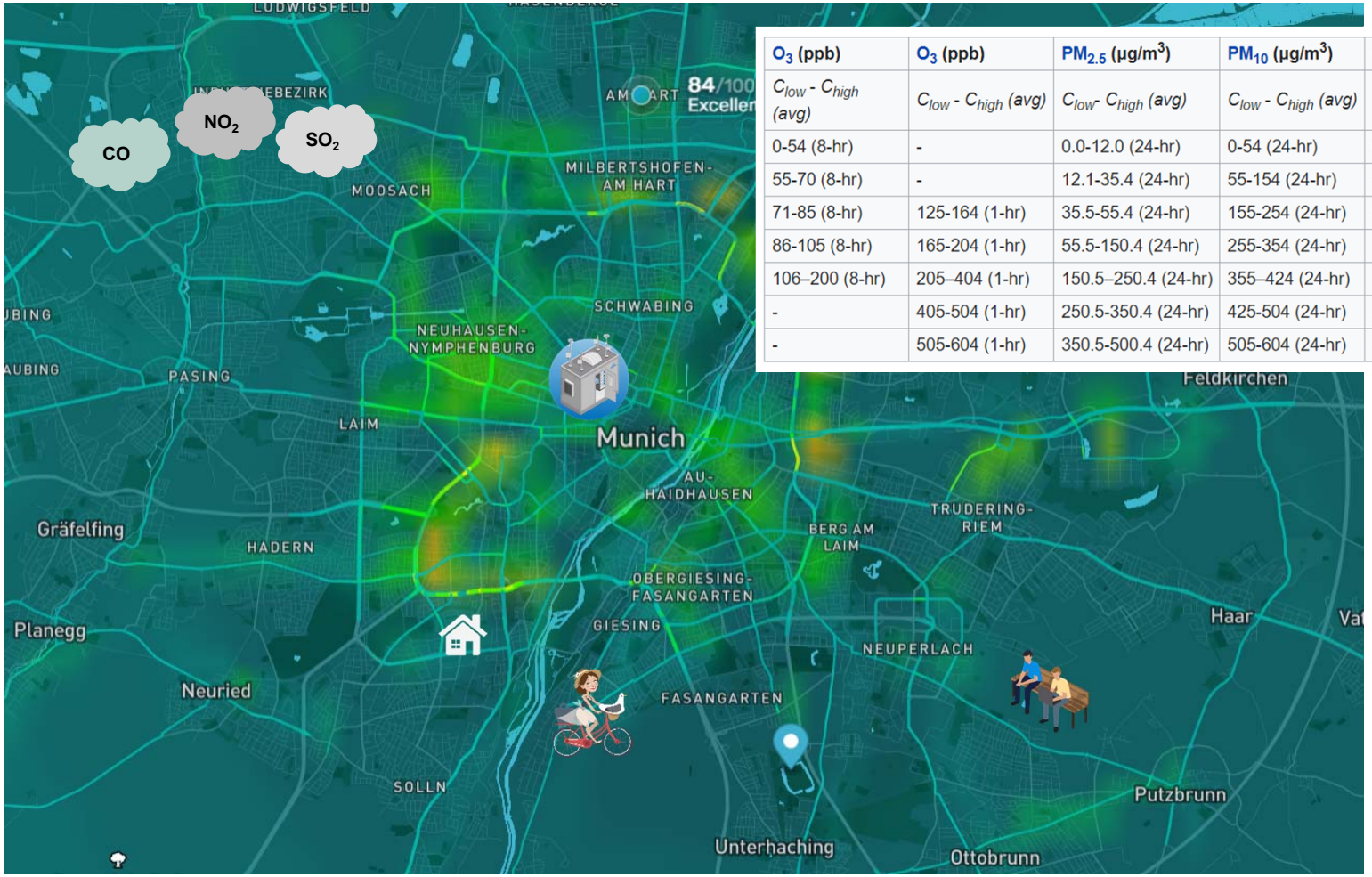
tinyML Design for Environmental Sensing Applications

Jianyu Zhao, Cecilia Carbonelli, Torsten Hinz, Wolfgang Furtner
June 7th 2021

Motivation: Environmental Sensing



O_3 (ppb)	O_3 (ppb)	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)	CO (ppm)	SO_2 (ppb)	NO_2 (ppb)	AQI	AQI
C_{low} - C_{high} (avg)	C_{low} - C_{high} (avg)	C_{low}- C_{high} (avg)	C_{low} - C_{high} (avg)	C_{low} - C_{high} (avg)	C_{low} - C_{high} (avg)	C_{low} - C_{high} (avg)	I_{low} - I_{high}	Category
0-54 (8-hr)	-	0.0-12.0 (24-hr)	0-54 (24-hr)	0.0-4.4 (8-hr)	0-35 (1-hr)	0-53 (1-hr)	0-50	Good
55-70 (8-hr)	-	12.1-35.4 (24-hr)	55-154 (24-hr)	4.5-9.4 (8-hr)	36-75 (1-hr)	54-100 (1-hr)	51-100	Moderate
71-85 (8-hr)	125-164 (1-hr)	35.5-55.4 (24-hr)	155-254 (24-hr)	9.5-12.4 (8-hr)	76-185 (1-hr)	101-360 (1-hr)	101-150	Unhealthy for Sensitive Groups
86-105 (8-hr)	165-204 (1-hr)	55.5-150.4 (24-hr)	255-354 (24-hr)	12.5-15.4 (8-hr)	186-304 (1-hr)	361-649 (1-hr)	151-200	Unhealthy
106–200 (8-hr)	205–404 (1-hr)	150.5–250.4 (24-hr)	355–424 (24-hr)	15.5–30.4 (8-hr)	305–604 (24-hr)	650–1249 (1-hr)	201–300	Very Unhealthy
-	405-504 (1-hr)	250.5-350.4 (24-hr)	425-504 (24-hr)	30.5-40.4 (8-hr)	605-804 (24-hr)	1250-1649 (1-hr)	301-400	Hazardous
-	505-604 (1-hr)	350.5-500.4 (24-hr)	505-604 (24-hr)	40.5-50.4 (8-hr)	805-1004 (24-hr)	1650-2049 (1-hr)	401-500	

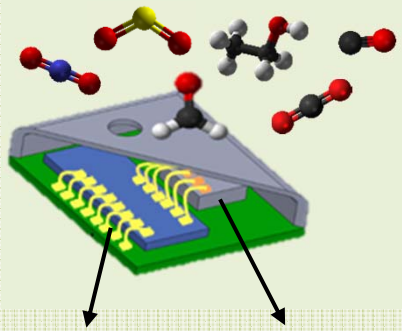
- Typical sensing targets
  - Temperatures
  - Humidity
  - Gases
  - Particles

Fig 1. Air quality monitoring in everyday life [1] and the EPA (United States Environmental Protection Agency) definition of Air Quality Index(AQI) categories [2].

Low-cost Environmental Sensing Applications

Sensor System

On-sensor signal processing and data analysis on battery-powered devices



PSoC® Analog Coprocessor (Arm® Cortex®-M0+)

Sensor MEMS

Air quality monitoring
Gas Analysis

Indoor / Outdoor Applications

Air Quality monitoring at the city level

Fine-granular sensing is required for various applications

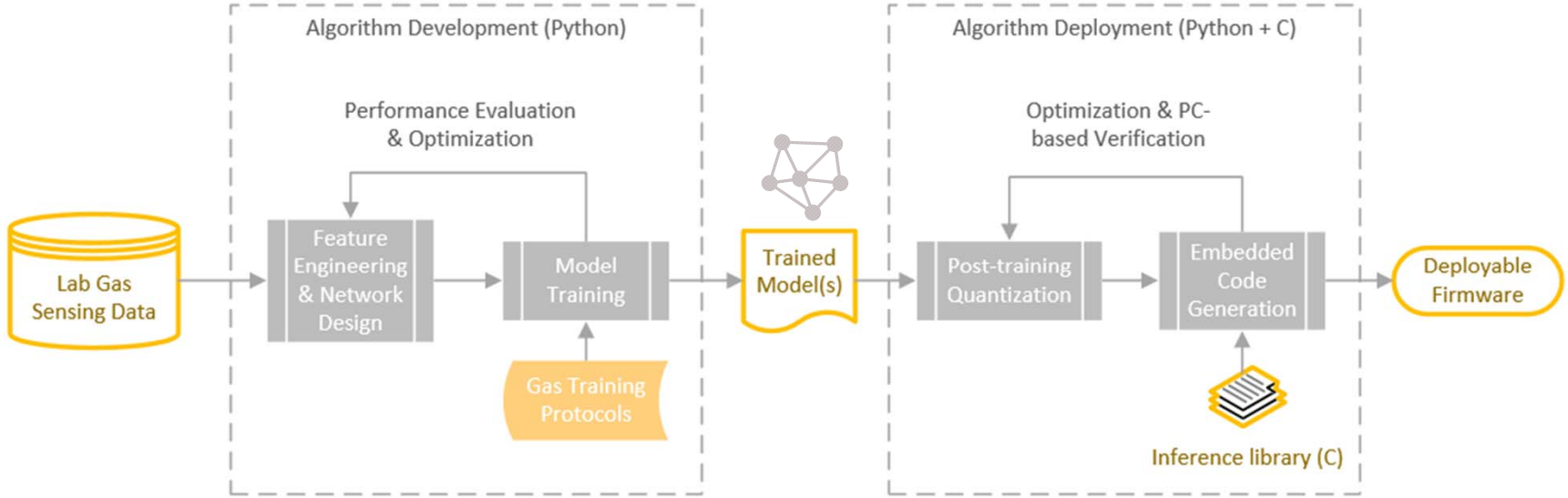
Re-route

Pollution heat maps

City management

Fig 2. Low-cost sensor system does both data collection and on-sensor concentration estimation, and it can be used in various indoor and outdoor applications.

Development and Deployment of Gas Sensing Algorithms



Hardware platforms:

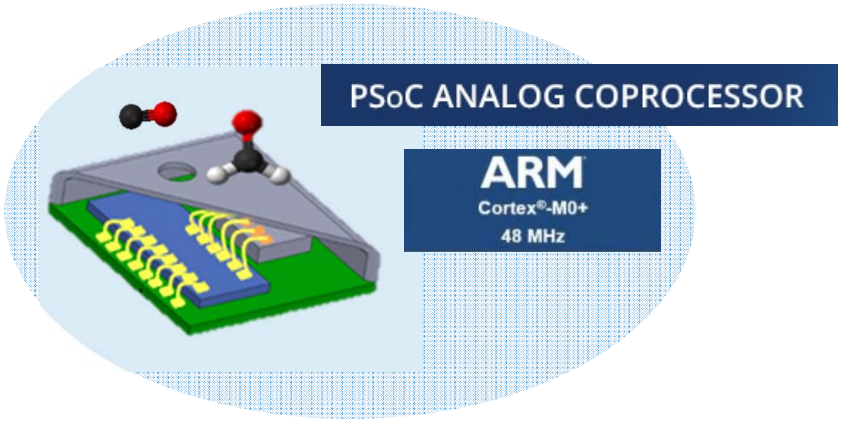
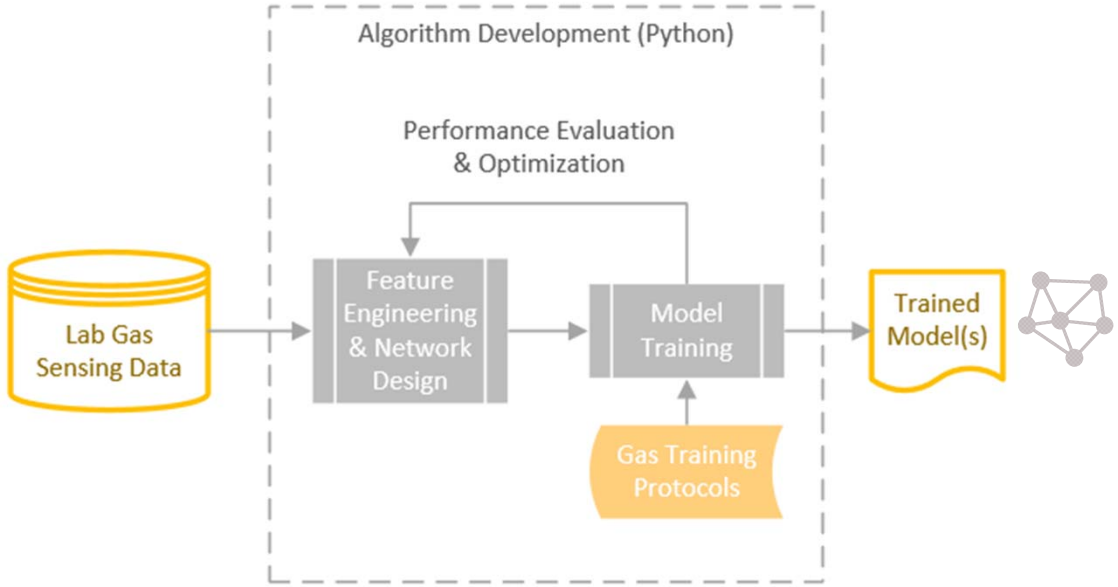


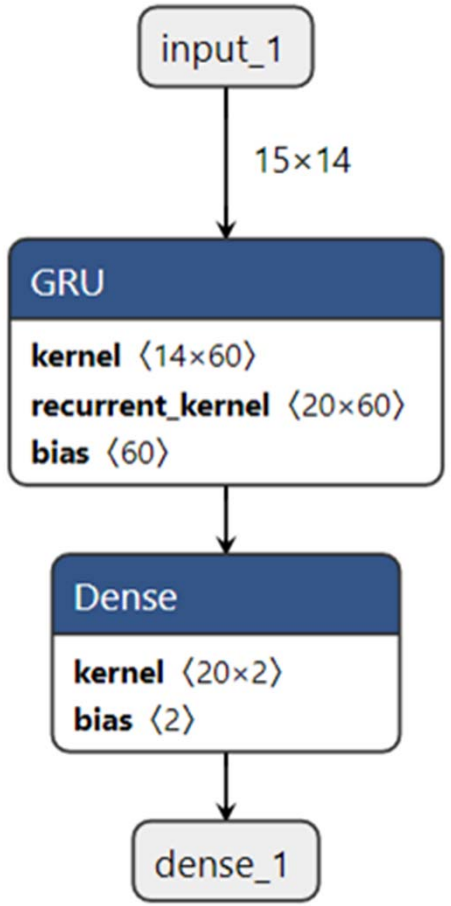
Fig 3. Development and deployment workflow of gas sensing algorithms and the corresponding hardware platforms.

Algorithm Development



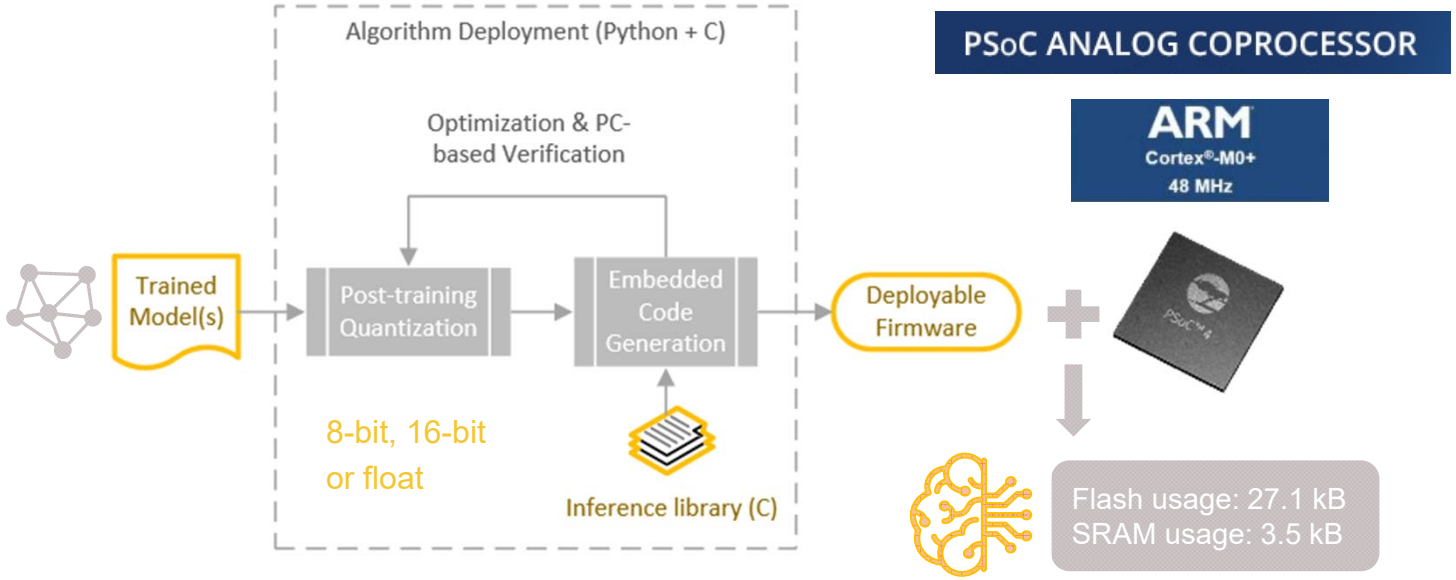
- Data collection in the lab
  - Reason: lack of reliable reference devices in the field
  - Challenge: measurement protocol design
- Network selection: Gated Recurrent Unit (GRU)
  - Exploits time properties while keeping the memory footprint within the budget

Example network architecture:

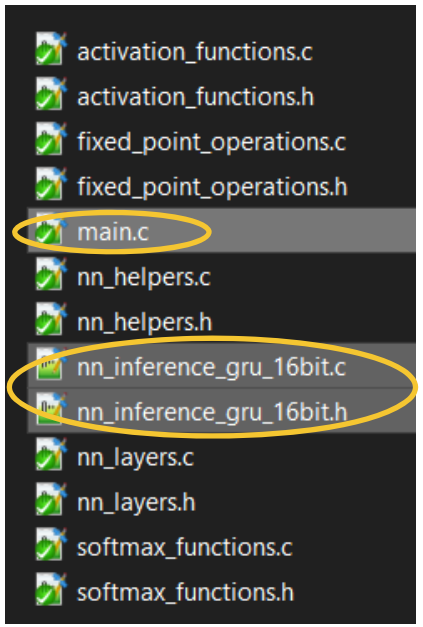


- 14 extracted features
- 15 time steps (5-min time series)
- 20 hidden units
- 2 output concentration values

Algorithm Deployment



Example Deployable Firmware:



The other files come from the inference library

Generated Files

- Deployment on an embedded device
  - Cypress PSoC® analog coprocessor (ARM® Cortex®-M0+, 4 kB RAM, 32 kB flash)
    - Sensor control, signal measurement, real-time concentration estimation and communication
  - Challenges
    - Extremely limited computational resource and memory footprint
    - No operation system, so the C code needs to run on bare metal

Summary

- Low-cost and fine-granular environmental sensing devices are emerging with the rising environmental concerns worldwide
- ML techniques allow for more accurate analysis of complex sensor behaviors
  - Specifically, a GRU can be used to analyze time series data for gas concentration estimation
- After network quantization and code generation, we managed to deploy a gas sensing algorithm on an ARM® Cortex®-M0+ processor
- The deployment toolchain can be reused for similar sensor applications

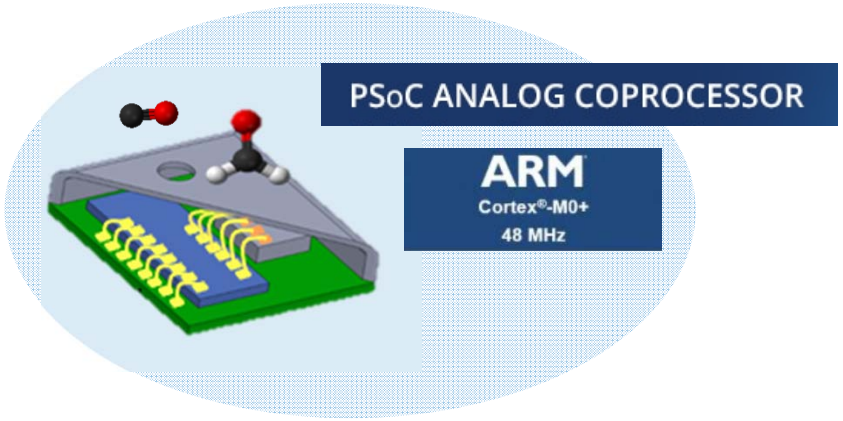


Fig 4. Example of a gas sensing system with PSoC® analog coprocessor .

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Reference

[1] The air quality heat map is taken as a screenshot from BreezoMeter website (https://www.breezometer.com/air-quality-map/)

[2] https://en.wikipedia.org/wiki/Air_quality_index

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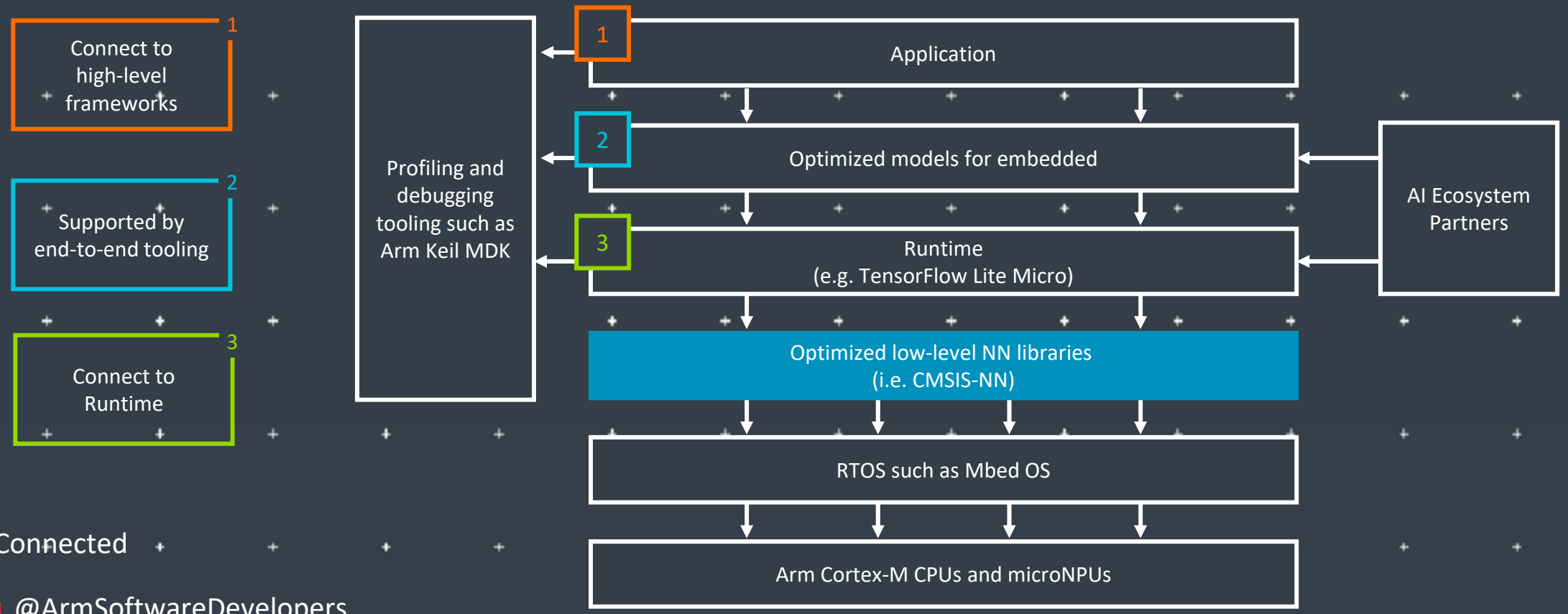

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C++ library

Arduino library

WebAssembly

Dataset

Acquire valuable training data securely

Enrich data and train ML algorithms

Edge Device

Real sensors in real time

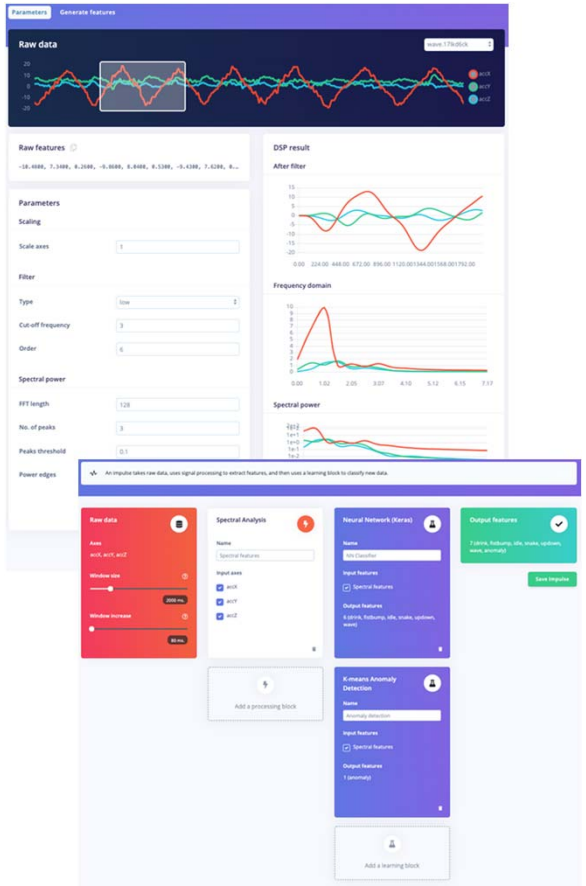
Open source SDK

Impulse

Embedded and edge compute deployment options

Test impulse with real-time device data flows

Test



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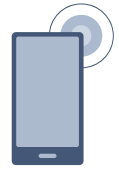

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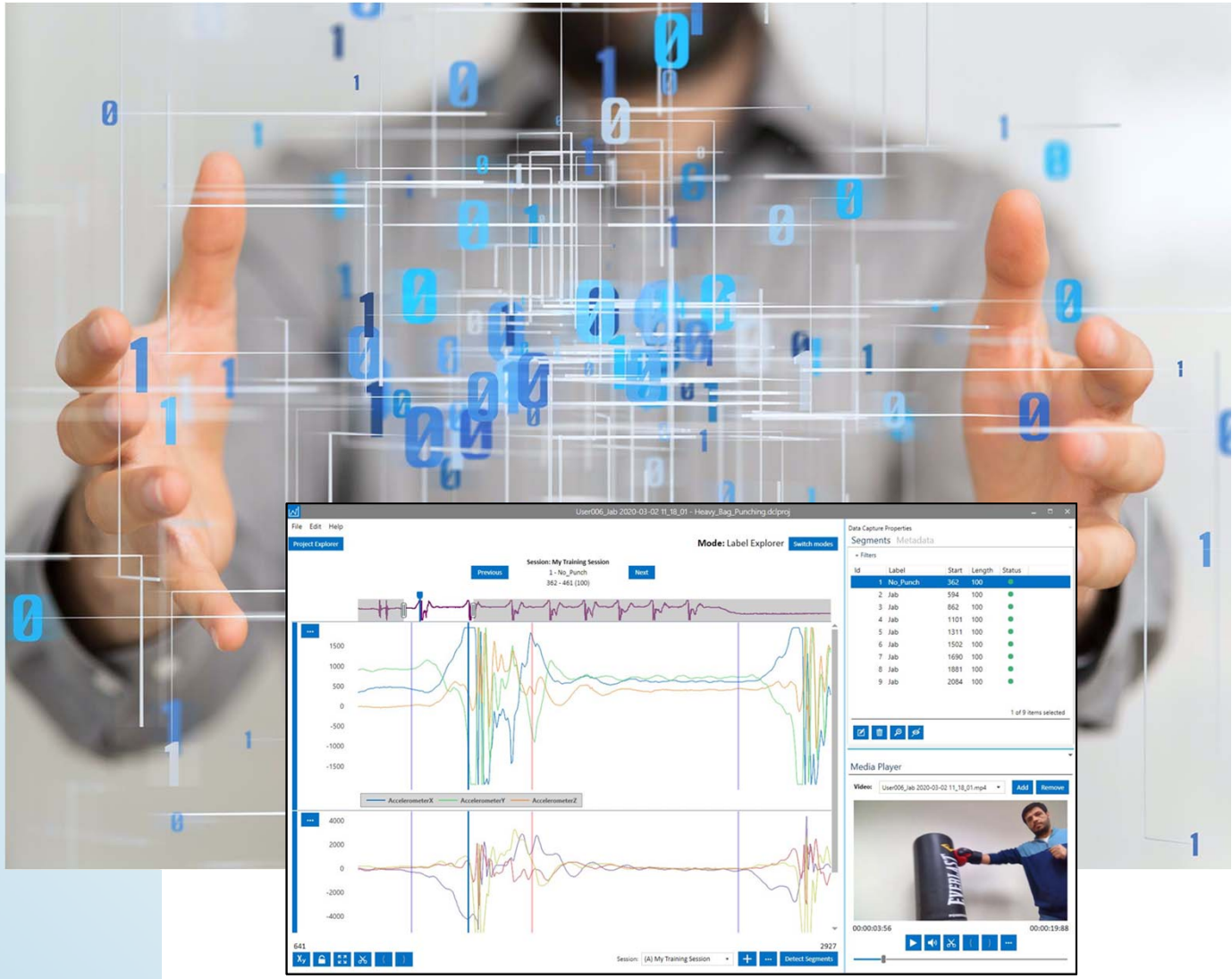

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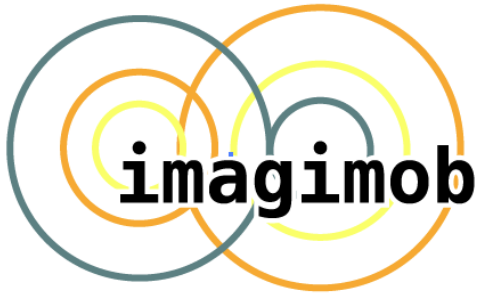

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