

tinyML[®] Talks

Enabling Ultra-low Power Machine Learning at the Edge

“Practical TinyML for industrial safety and personnel performance monitoring”

Oleg Puzanov - Leantegra

December 20, 2021



www.tinyML.org

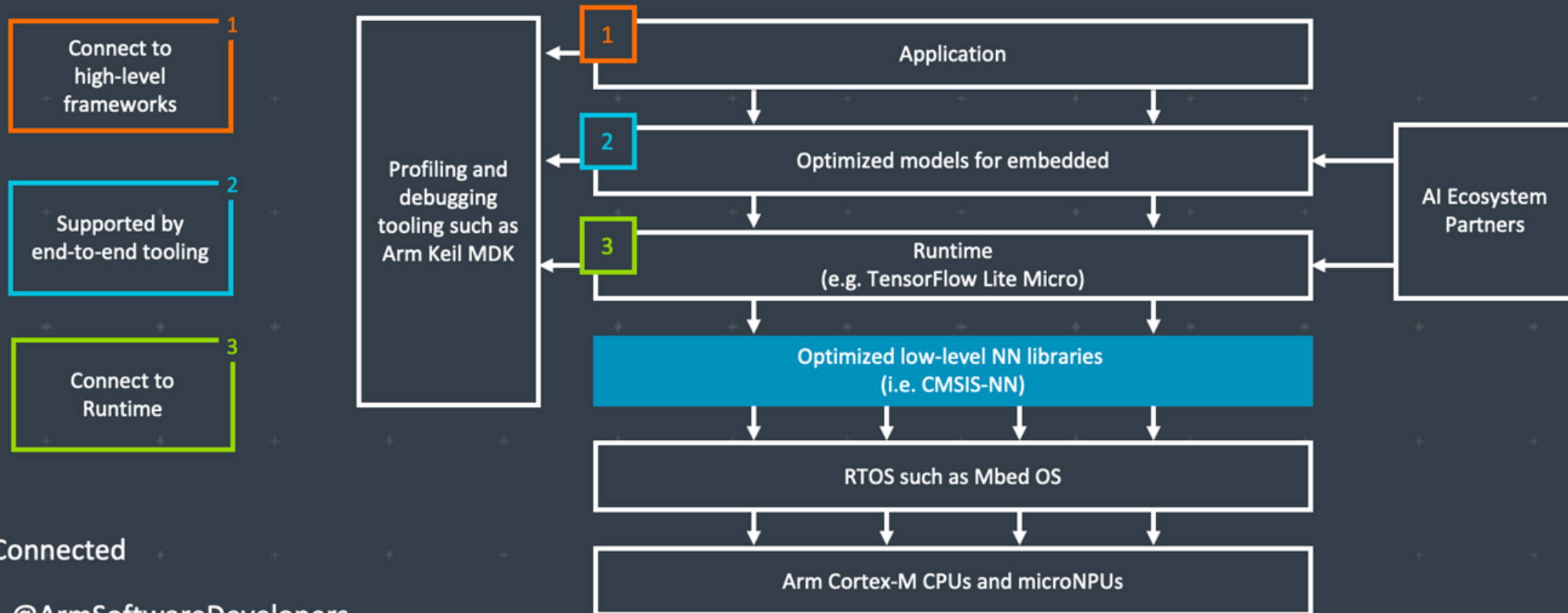


tinyML Talks Strategic Partners



Additional Sponsorships available – contact Olga@tinyML.org for info

Arm: The Software and Hardware Foundation for tinyML



Stay Connected

 @ArmSoftwareDevelopers

 @ArmSoftwareDev

Resources: developer.arm.com/solutions/machine-learning-on-arm



WE USE AI TO MAKE OTHER AI FASTER, SMALLER AND MORE POWER EFFICIENT



Automatically compress SOTA models like MobileNet to <200KB with **little to no drop in accuracy** for inference on resource-limited MCUs



Reduce model optimization trial & error from weeks to days using Deeplite's **design space exploration**



Deploy more models to your device without sacrificing performance or battery life with our **easy-to-use software**

BECOME BETA USER bit.ly/testdeeplite

mobilityXlab

arm



TinyML for all developers



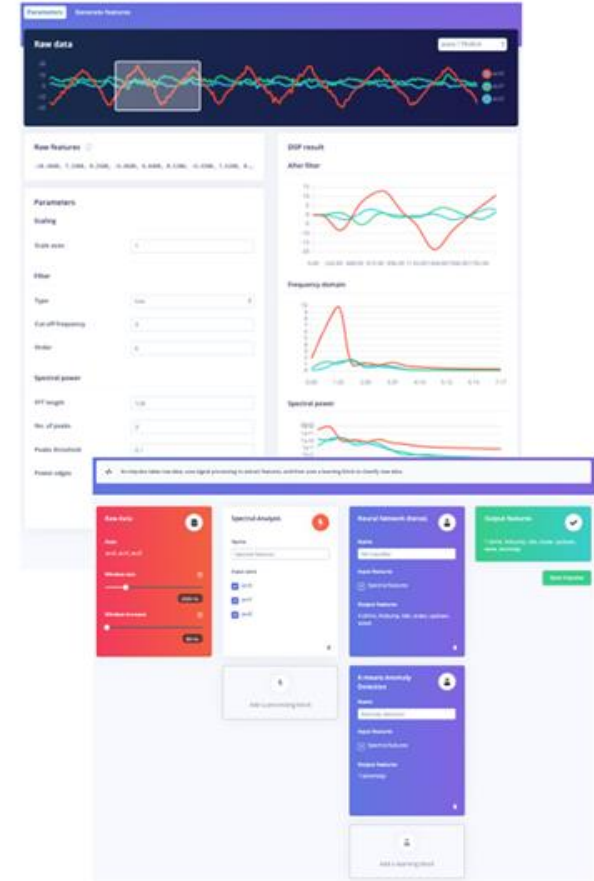
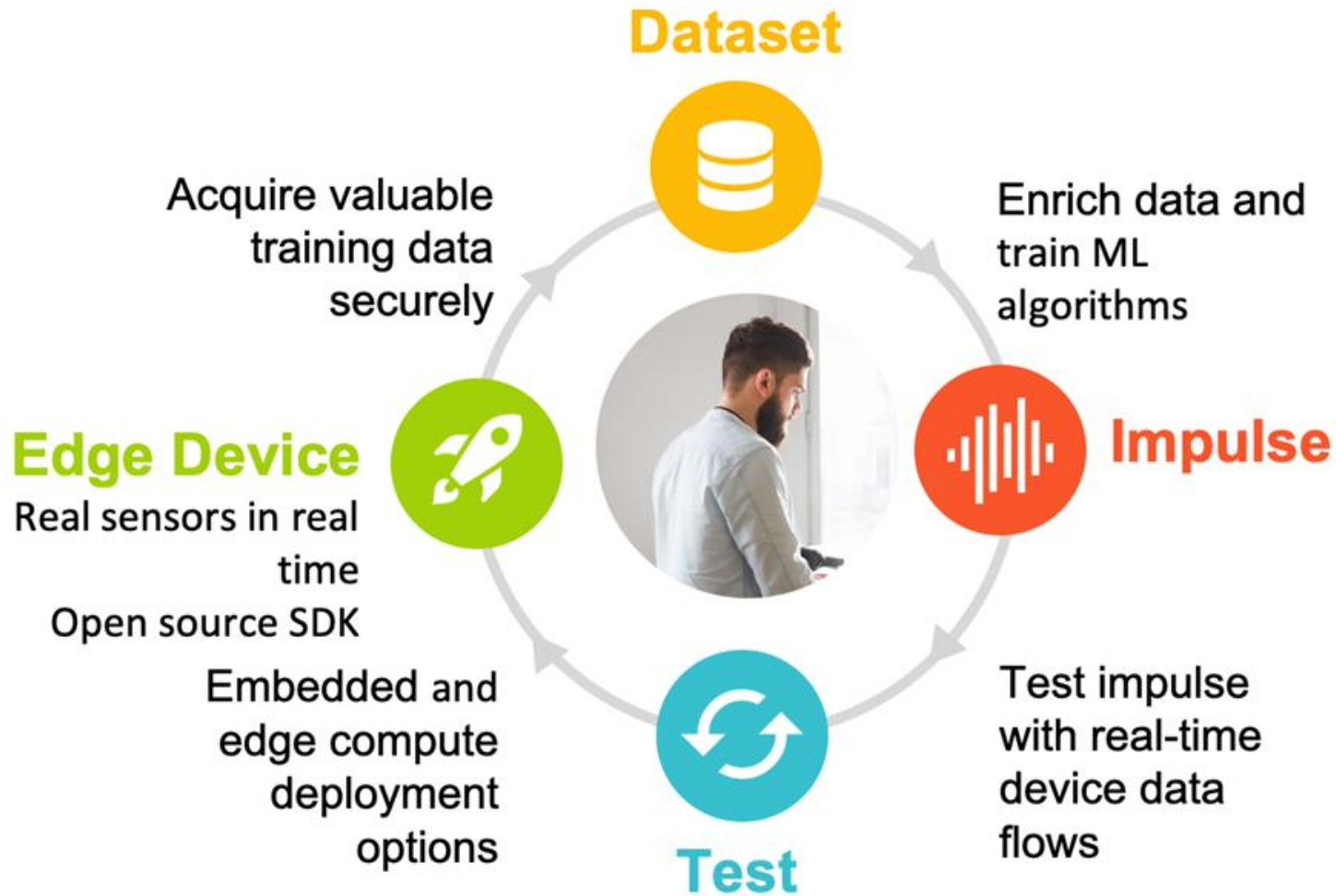
C++ library



Arduino library



WebAssembly

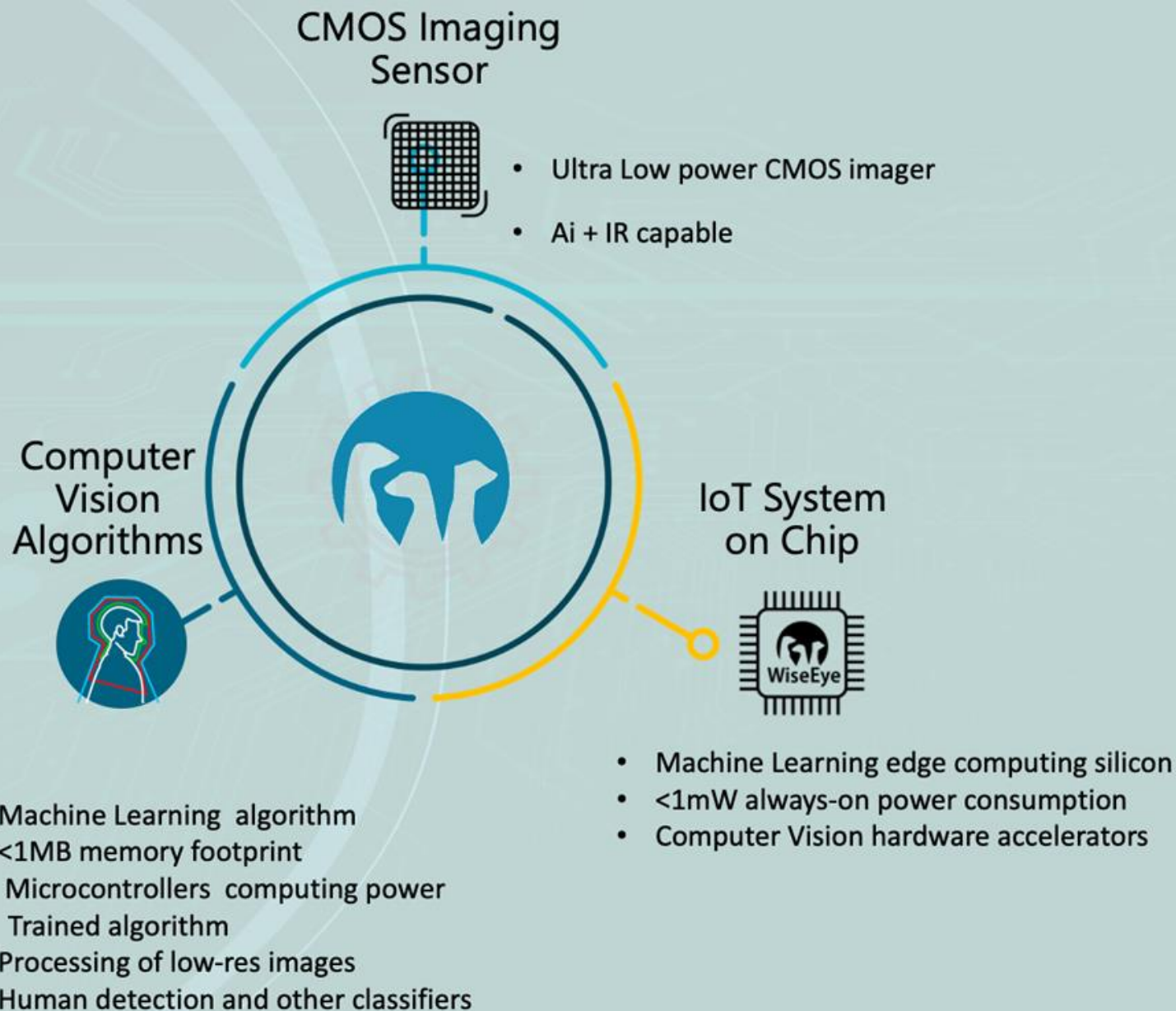


www.edgeimpulse.com



The Eye in IoT

Edge AI Visual Sensors



info@emza-vs.com



Enabling the next generation of **Sensor and Hearable products** to process rich data with energy efficiency

Visible Image



Sound



IR Image



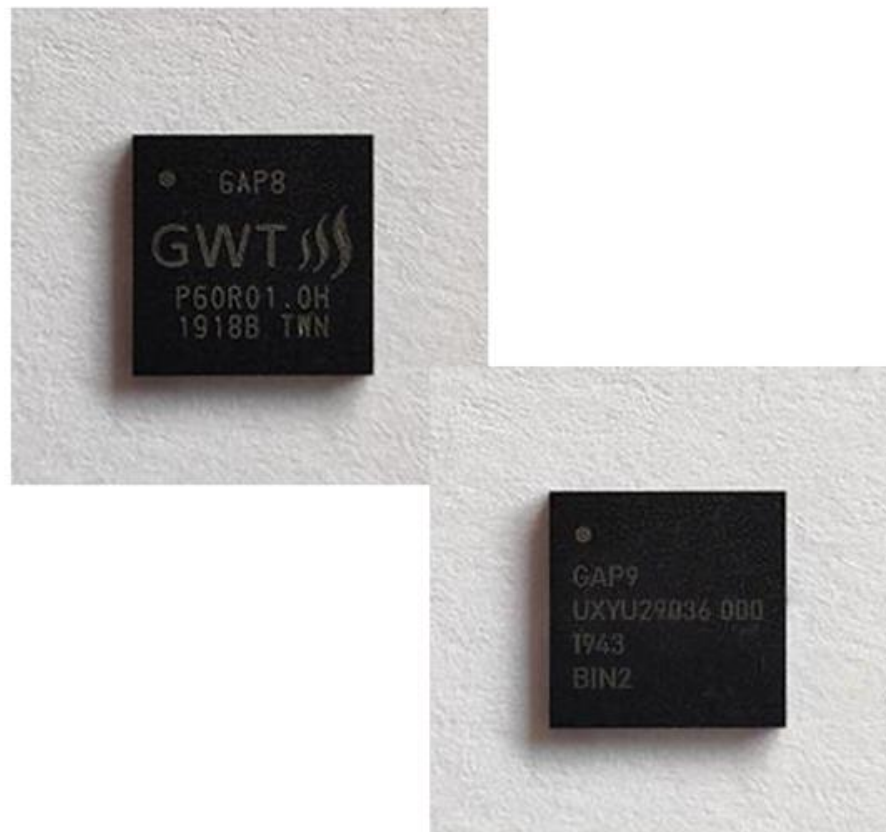
Radar



Bio-sensor



Gyro/Accel



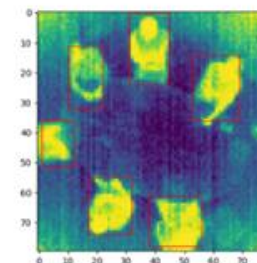
Wearables / Hearables



Battery-powered consumer electronics



IoT Sensors



⚡ Grovety Inc.

SOFTWARE DEVELOPMENT SERVICES FOR TINYML SOLUTIONS

1

Development tools

SDK, IDE, compilers, leveraging on TVM, uTVM & LLVM

2

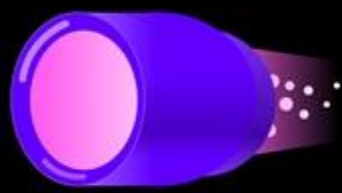
Firmware

Drivers, BSP, protocols, etc.

arm

AI PARTNER

Distributed infrastructure for TinyML apps



Develop at warp speed



Automate deployments



Device orchestration

HOTG is building the distributed infrastructure to pave the way for AI enabled edge applications



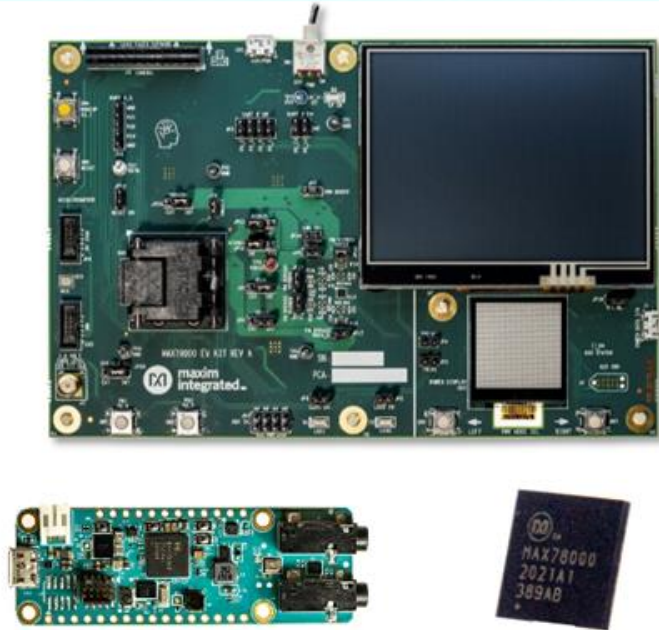
Latent AI

Adaptive AI for the Intelligent Edge

[Latentai.com](https://latent.ai)

Maxim Integrated: Enabling Edge Intelligence

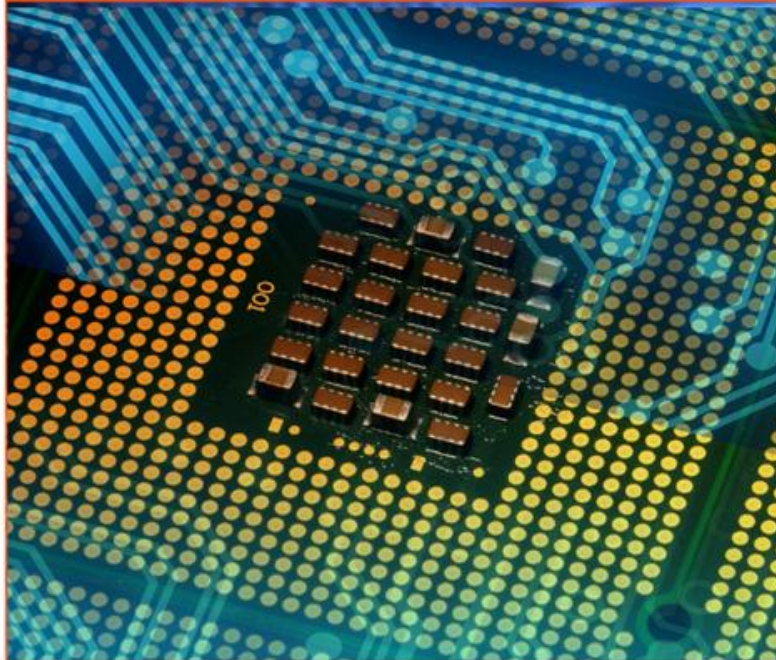
Advanced AI Acceleration IC



The new MAX78000 implements AI inferences at low energy levels, enabling complex audio and video inferencing to run on small batteries. Now the edge can see and hear like never before.

www.maximintegrated.com/MAX78000

Low Power Cortex M4 Micros



Large (3MB flash + 1MB SRAM) and small (256KB flash + 96KB SRAM, 1.6mm x 1.6mm) Cortex M4 microcontrollers enable algorithms and neural networks to run at wearable power levels.

www.maximintegrated.com/microcontrollers

Sensors and Signal Conditioning



Health sensors measure PPG and ECG signals critical to understanding vital signs. Signal chain products enable measuring even the most sensitive signals.

www.maximintegrated.com/sensors

Qeexo AutoML

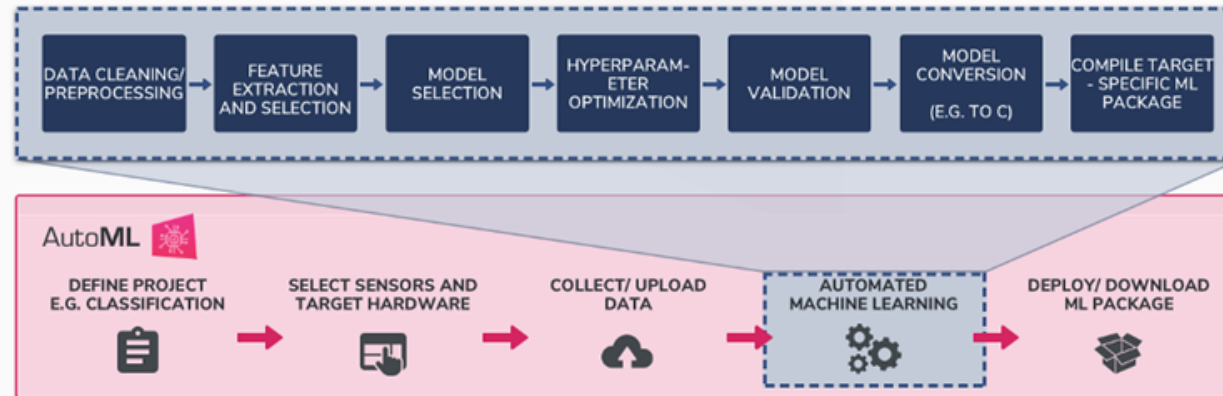


Automated Machine Learning Platform that builds tinyML solutions for the Edge using sensor data

Key Features

- Supports 17 ML methods:
 - Multi-class algorithms: GBM, XGBoost, Random Forest, Logistic Regression, Gaussian Naive Bayes, Decision Tree, Polynomial SVM, RBF SVM, SVM, CNN, RNN, CRNN, ANN
 - Single-class algorithms: Local Outlier Factor, One Class SVM, One Class Random Forest, Isolation Forest
- Labels, records, validates, and visualizes time-series sensor data
- On-device inference optimized for low latency, low power consumption, and small memory footprint applications
- Supports Arm® Cortex™ - M0 to M4 class MCUs

End-to-End Machine Learning Platform



For more information, visit: www.qeexo.com

Target Markets/Applications

- Industrial Predictive Maintenance
- Smart Home
- Wearables
- Automotive
- Mobile
- IoT

Qualcomm
AI research

Advancing AI research to make efficient AI ubiquitous

Power efficiency

Model design, compression, quantization, algorithms, efficient hardware, software tool

Personalization

Continuous learning, contextual, always-on, privacy-preserved, distributed learning

Efficient learning

Robust learning through minimal data, unsupervised learning, on-device learning

A platform to scale AI across the industry



Perception

Object detection, speech recognition, contextual fusion



Reasoning

Scene understanding, language understanding, behavior prediction



Action

Reinforcement learning for decision making



Edge cloud



Cloud



IoT/IIoT



Automotive



Mobile



Reality AI[®]

Add Advanced Sensing to your Product with Edge AI / TinyML

<https://reality.ai>



info@reality.ai



[@SensorAI](https://twitter.com/SensorAI)



[Reality AI](https://www.linkedin.com/company/reality-ai)

**Pre-built Edge AI sensing modules,
plus tools to build your own**

Reality AI solutions

Prebuilt sound recognition models for
indoor and outdoor use cases

Solution for industrial anomaly detection

Pre-built automotive solution that lets cars
“see with sound”

Reality AI Tools[®] software

Build prototypes, then turn them into
real products

Explain ML models and relate the function
to the physics

Optimize the hardware, including
sensor selection and placement

BROAD AND SCALABLE EDGE COMPUTING PORTFOLIO

Microcontrollers & Microprocessors

Arm® Core



Arm® Cortex®-M 32-bit MCUs
Arm ecosystem, Advanced security, Intelligent IoT



Arm®-based High-end 32 & 64-bit MPUs
High-resolution HMI, Industrial network & real-time control



Arm® Cortex®-M0+ Ultra-low Power 32-bit MCUs
Innovative process tech (SOTB), Energy harvesting

Renesas Synergy™ Arm®-based 32-bit MCUs for Qualified Platform
Qualified software and tools

Renesas Core



Ultra-low Energy 8 & 16-bit MCUs
Bluetooth® Low Energy, SubGHz, LoRa®-based Solutions



High Power Efficiently 32-bit MCUs
Motor control, Capacitive touch, Functional safety, GUI



40nm/28nm process Automotive 32-bit MCUs
Rich functional safety and embedded security features

Core technologies

AI

A broad set of high-power and energy-efficient embedded processors

Security & Safety

Comprehensive technology and support that meet the industry's stringent standards



Digital & Analog & Power Solution

Winning Combinations that combine our complementary product portfolios

Cloud Native

Cross-platforms working with partners in different verticals and organizations



seeed studio

The IoT Hardware Enabler



Build Smart IoT Sensor Devices From Data

SensiML pioneered TinyML software tools that auto generate AI code for the intelligent edge.

- End-to-end AI workflow
- Multi-user auto-labeling of time-series data
- Code transparency and customization at each step in the pipeline

We enable the creation of production-grade smart sensor devices.



sensiml.com



SynSense

SynSense builds **sensing and inference** hardware for **ultra-low-power** (sub-mW) **embedded, mobile and edge** devices. We design systems for **real-time always-on smart sensing**, for audio, vision, IMUs, bio-signals and more.

<https://SynSense.ai>



SYNTIANT

End-to-End
Deep Learning
Solutions
for
TinyML & Edge AI



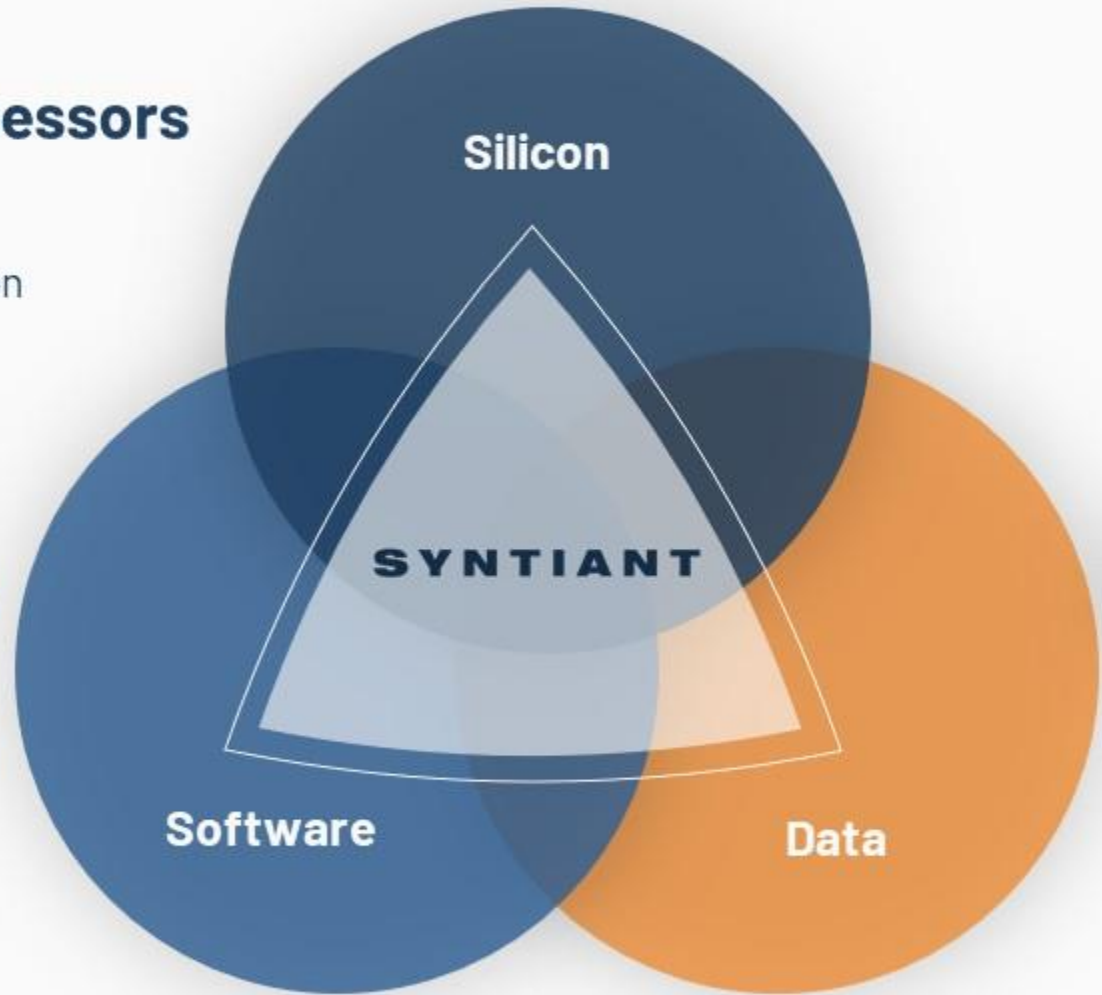
Neural Decision Processors

- At-Memory Compute
- Sustained High MAC Utilization
- Native Neural Network Processing



ML Training Pipeline

- Enables Production Quality Deep Learning Deployments



Data Platform

- Reduces Data Collection Time and Cost
- Increases Model Performance



tinyML Summit 2022

Miniature dreams can come true...

March 28-30, 2022

Hyatt Regency San Francisco Airport

<https://www.tinymml.org/event/summit-2022/>

Registration will be open on **December 15, 2021**.

Deadline for poster submission is **December 17**.

*The Best Product of the Year and the Best Innovation of the Year awards are open for nominations between **November 15 and February 28**.*

tinyML Research Symposium 2022

March 28, 2022

<https://www.tinymml.org/event/research-symposium-2022>

Call for papers – Submission deadline is **December 17, 2021**.

More sponsorships are available: sponsorships@tinymml.org



Next tinyML Talks

Date	Presenter	Topic / Title
Tuesday, January 4	Cedric Nugteren, software engineer, Plumerai	Demoing the world's fastest inference engine for Arm Cortex-M

Webcast start time is 8:00 am Pacific time

Please contact talks@tinymml.org if you are interested in presenting

tinyML Ukraine Org Committee



**Oleg
Boguslavskyi**

Co-owner @ Data Science UA
<https://data-science-ua.com>

<https://www.linkedin.com/in/schummi/>

20+ years of experience in IT. Worked in world-famous companies Motorola/Freescale, AMD, LG Electronics, Ring/Amazon etc. He has experience in building IT delivery organizations from scratch to several hundred people.

In 2016-2017 he worked on a solution unique to the automotive industry with 3D Augmented Navigation, which includes components used for Autonomous Driving, which is available in Audi cars starting 2021.

In 2017-2019 he worked as General Manager at Ring Ukraine, which was sold to Amazon for over 1 billion USD, where together with the company's COO he was able to scale the company from a few dozen to 1000+ highly skilled specialists in 3 years, as well as helped to deliver a large number of new flagship products.



**Sergii
Kaschenko**

COO @ Yellow
<https://yellow.com>

<https://www.linkedin.com/in/kashchenko/>

In his recent roles of COO and R&D director, he executed strategic startup transformations and implemented processes for rapid growth of technology business.

Before that, he had a 16 years track record of engineering leadership, working on embedded software for Sequans, AMD, LG Electronics, Nordic Semiconductor and others.

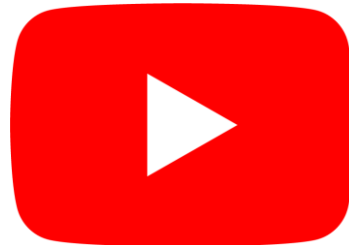
Sergii holds an MBA degree from London Business School and MSc degree in Computer Science from National Aerospace University.



Reminders

Slides & Videos will be posted tomorrow

Please use the Q&A window for your questions



tinyml.org/forums

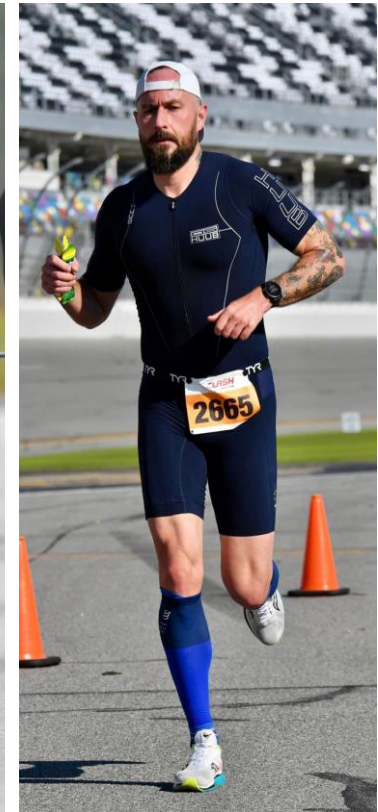
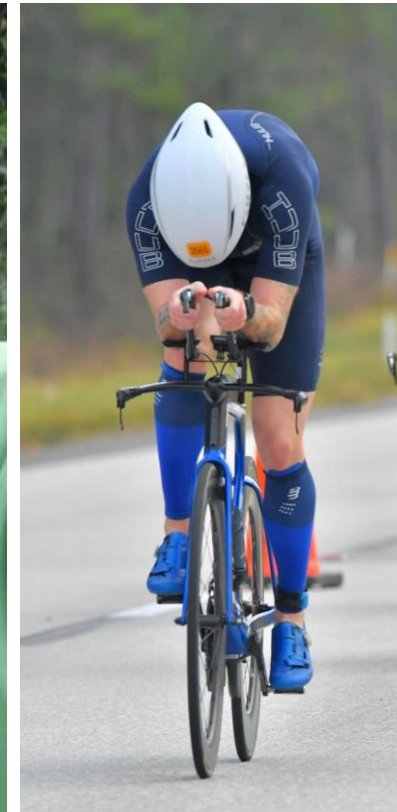
youtube.com/tinyml





Speaker: Oleg Puzanov

- ★ CEO and Co-Founder at Leantegra:
www.legantegra.com
- ★ Since 2003 in commercial IT projects and companies
- ★ Embedded systems and IoT projects from year 2004
- ★ Serious about sports: 6 x Ironman, 10 x Half Ironman, multiple ultra marathons





Leantegra: Our Focus

Industrial RTLS and safety



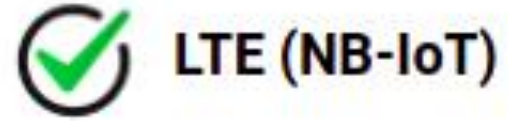
BLE



UWB



Wi-Fi



LTE (NB-IoT)



TETRA



5G - development in progress



MINES



FACTORIES



WAREHOUSES



OIL&GAS





Case Study: DTEK Underground Mine



Successfully launched and completed the project for DTEK - the largest energy company in Ukraine.

2,100 BLE beacons and 1700 Smart Lamp devices deployed in Yubileynaya mine, together with a customized Leantegra CVO Portal.

Reverse BLE RTLS as the main technology for positioning and industrial Wi-Fi as the backhaul network.

Main features: BLE RTLS, messaging, methane-CO telemetry, alarms, rich multi-layered mapping, advanced data reporting.

T I N Y



Customers and Partners

IT.Integrator





Leantegra Hardware



UWB-BLE RTLS tags



IP67 RTLS anchors



Mining BLE-LTE Locators



ATEX BLE Beacons



IP67 BLE Beacons



Mining BLE-WiFi Locators



Example #1: Smart Cap Lamp

Reverse LTE-BLE locator based on Cat-M1 and NB-IoT protocols, embedded into cap lamps.
Developed for [Dundee Precious Metals](#) mine in Bulgaria.



Example #2: Smart Cap Lamp

BLE-WiFi locator and Smart Lamps for [DTEK](#) underground mine in Ukraine.
Supports the reverse RTLS and telemetry for methane, CO and temperature.



Developed in partnership with InPromtex company.



Leantegra Software

DASHBOARD Broadcast Message Search by MAC

Total inside the mine: 89 (42 | 46) On this map: 87 (41 | 45)

Search by name,...

Horizon-180

Holmes John

Personnel ID: 12508736

Position: Electrician L2

Department: Dep.infrastructure A1

SN: TU1442

Charge: 9

Methane: 0.00

message (up to 69 symbols)

Send Message

Show Track

DASHBOARD Broadcast Message Search by MAC

Total inside the mine: 89 (46 | 42) On this map: 87 (46 | 40)

Search by name,...

Horizon-180

- Show Track
- Methane Map
- Green
- Yellow
- Orange
- Red
- Temperature Map
- Map for Wi-Fi RSSI
- Personnel
- Active
- Inactive
- Charging
- Beacons
- Active
- Inactive
- Planned
- Device Names
- Base Map

ARCHIVE: ALARMS / RTLS / SMS / GEOFENCING 14.06.2021 Date Search

Total: 41

Type	Last Name	Personnel ID	Device	Data	Matchpoint	Time	Status	Details
	Black	12502895	TU0996	Methane: 2.48	AB-PK3	14.06.2021, 12:29:56	New	Details
	Smith	12501570	TU1242	--	AB-PK2	14.06.2021, 12:29:25	New	Details
	Williams	12502419	TU0361	Methane: 3.12	AB-PK1	14.06.2021, 12:02:03	New	Details
	Holmes	12511357	TU1466	--	BA-PK1	14.06.2021, 11:36:38	New	Details
	Jackson	12502317	TU0165	Methane: 2.77	AB-PK3	14.06.2021, 11:32:58	New	Details
	Green	12503193	TU1074	--	AB-PK3	14.06.2021, 11:07:44	New	Details

DASHBOARD Broadcast Message Search by MAC

Total inside the mine: 89 (38 | 50) On this map: 87 (38 | 45)

Search by name,...

Horizon-180

From: 14-06-2021

June 2021

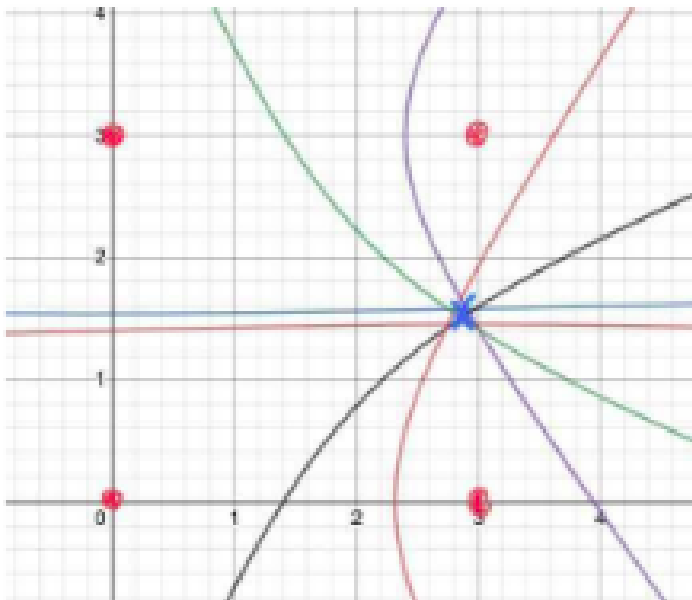
	Sun	Mon	Tue	Wed	Thu	Fri	Sat
22	30	31	01	02	03	04	05
23	06	07	08	09	10	11	12
24	13	14	15	16	17	18	19
25	20	21	22	23	24	25	26
26	27	28	29	30	01	02	03
27	04	05	06	07	08	09	10

Today Clear Close

Our Algorithms: Wireless UWB TDoA

Fully wireless and asynchronous TDoA algorithm, which doesn't require clock synchronizations among RTLS anchors.

The algorithm had been researched and developed by Leantegra - patent pending.



- ▶ Up to 100x times less power consumption than UWB TWR.
- ▶ Up to 500 trackables in one zone (one room) - good scalability.
- ▶ Normally TDoA systems require clock syncing over Ethernet cables, which limits choices for the network equipment. No such limitation here.

Some Theory: IMU

Accelerometer

- Linear acceleration measured in m/s^2 or g
- Includes the gravity component, which must be subtracted
- Zero-G offset - deviation at rest from $[0;0;1]$ gravity vector

Gyroscope

- Angular velocity in deg/sec or rad/sec
- Bias affected by temperature
- Orientation = integration of angular velocity

Magnetometer

- Magnetic field strength on each axis, measure in Gauss

Barometer

- Barometric pressure sensor, used for altitude measurement

3DOF
 accel

6DOF
 accel, gyro

7DOF
 accel, gyro,
 barom

9DOF
 accel, gyro,
 magn

10DOF
 accel, gyro,
 magn, barom



IMU: What We Use



STMicroelectronics LIS2DH12

3-axis
accelerometer,
used in older
WiBeat BLE
beacons and
UT-100 UWB
tags.



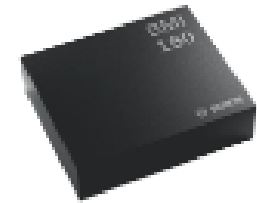
Bosch BMP390

High precision
barometer,
used in all
newer UWB
anchors and
tags.



Bosch BMI270

IMU with 3-axis
accelerometer
and 3-axis
gyroscope, used
in all newer
UWB tags.



Bosch BMI160

IMU with 3-axis
accelerometer and
3-axis gyroscope,
used in some
customer devices.



Our Usage Scenarios for IMU

Adaptive Transmission



Power saving mode with dynamic adjustments of TX rate for RTLS tags, based on active-inactive state.

Kalman Filtering for RTLS



Accelerometer is used as a second data source for Kalman filter in the RTLS engine. Smoother trajectories on a map.

Motion Recognition



Previously custom code for ML and now TensorFlow Lite with Edge Impulse SaaS for on-device ML scenarios.



On-device ML Advantages

Power savings - for the case of UWB RTLS devices up to 5-10 times (!!):

- Smaller UWB frames
- Smaller TX rate

Latency - enabling sub-10ms scenarios for feedbacks:

- Haptic feedback
- Emergency braking for collision avoidance

Offline mode - devices keep working without network coverage:

- Important for life-critical systems
- Partial network coverage is possible = less IT infrastructure expenses

Motion Recognition v0.1: Custom Code

Back in early 2019 implemented the custom code for ML algorithms running on Leantegra
WiBeat 2.0 BLE beacons: Nordic nRF52832, LIS2DH12 accelerometer



- No gyroscope - no rotation matrix and no linear acceleration vector in the formula.
- Scalar formula instead of vectors:
ACC = SQRT(AX*AX + AY*AY + AZ*AZ) - GS
- Comments:
 - ◆ ACC - resulting acceleration
 - ◆ AX, AY, AZ - raw acceleration data
 - ◆ GS - gravity scalar with zero-G offset
- Must be trained and later used in one specific position - for example: mounted on hard hats.
- Not flexible to other mounting options - as wearable or carried inside pockets.

T I N Y



Motion Recognition v0.1: Result





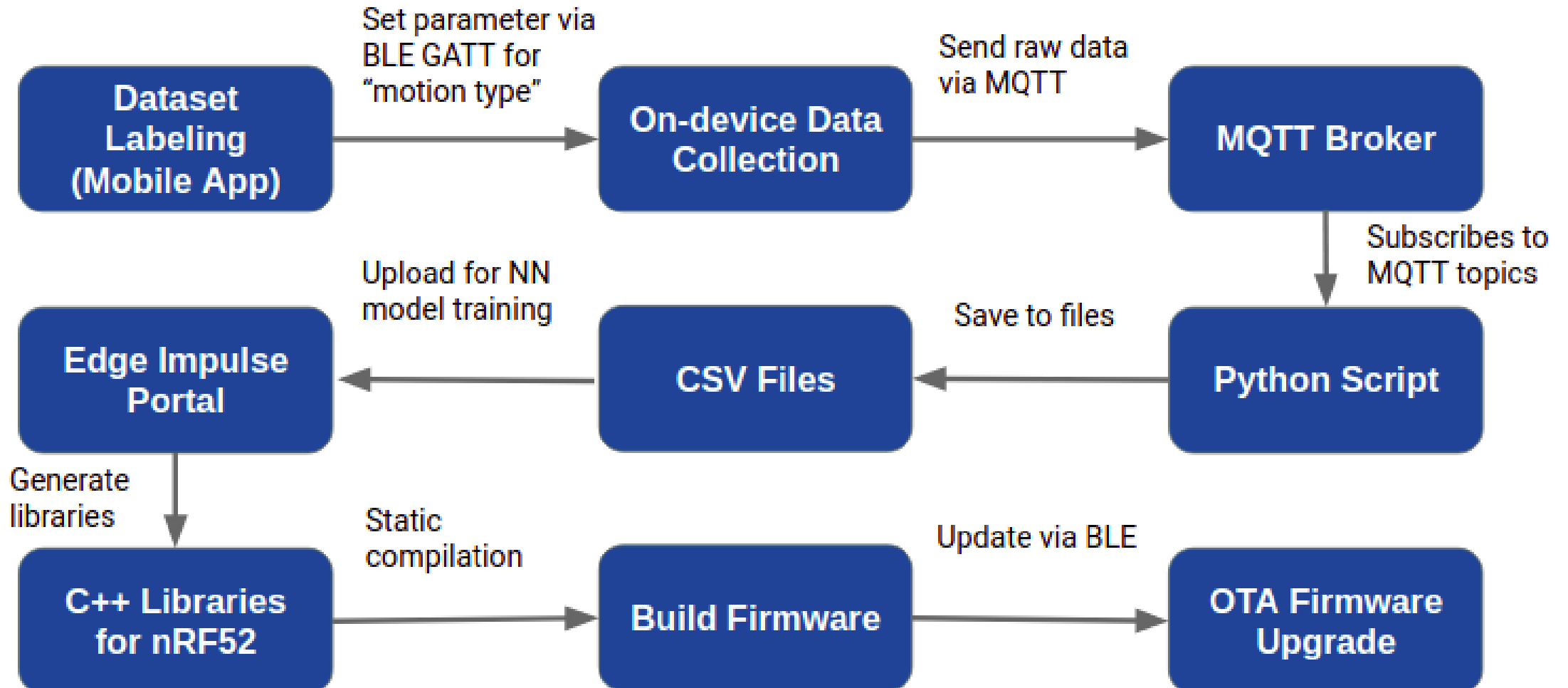
New Framework: TagML

Time-critical detection and machine learning scenarios, which run entirely on Leantegra UWB-BLE devices or industrial PPE appliance.

Integrated and customized **TensorFlow Lite** libraries and **Edge Impulse SaaS** for Leantegra UWB-BLE devices to enable on-device machine learning scenarios.



TagML: E2E Deployment Process



TagML: E2E Deployment Process

MQTT data collection and saving into CSV files

```

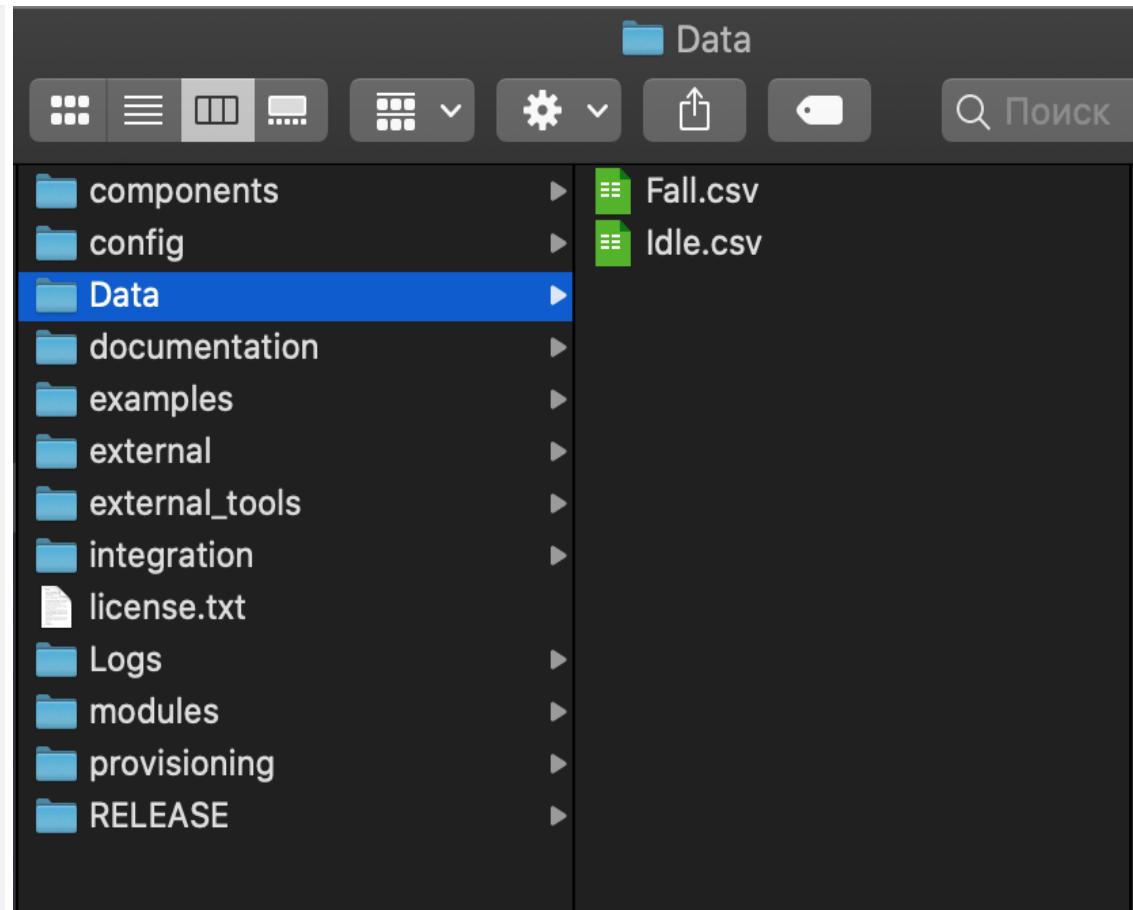
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2021-12-18 19:33:11 Topic: Yubileinaya/RTLS/Locators/Y... Qos: 2
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```





TagML: E2E Deployment Process

The pipeline in Edge Impulse

The screenshot displays the Edge Impulse web interface for configuring a pipeline. On the left is a navigation sidebar with the following items: Dashboard, Devices, Data acquisition, Impulse design, Create impulse, Raw data, Spectral features, NN Classifier, EON Tuner, Retrain model, Live classification, Model testing, Versioning, Deployment, GETTING STARTED, Documentation, and Forums. The main workspace contains several configuration panels:

- Time series data** (red panel):
 - Axes: accX, accY, accZ
 - Window size: 2000 ms
 - Window increase: 80 ms
 - Frequency (Hz): 12,5
 - Zero-pad data:
- Raw Data** (white panel):
 - Name: Raw data
 - Input axes: accX, accY, accZ
- Neural Network (Keras)** (purple panel):
 - Name: NN Classifier
 - Input features: Raw data, Spectral features
 - Output features: 2 (Fall, Idle)
- Output features** (green panel):
 - 2 (Fall, Idle)
 - Save Impulse button
- Spectral Analysis** (white panel):
 - Name: Spectral features
 - Input axes: accX, accY, accZ
- Add a learning block** (dashed box):
 - Placeholder for a new learning block.



TagML: E2E Deployment Process

Generating features and testing the NN model in Edge Impulse

#1 Click to set a description for this version

Parameters **Generate features**

Training set

Data in training set	2m 30s
Classes	2 (Fall, Idle)
Window length	2000 ms.
Window increase	80 ms.
Training windows	1,824

Generate features

Feature explorer (1 824 samples)

X Axis: accX RMS, Y Axis: accY RMS, Z Axis: accZ RMS

Legend: ● Fall (blue), ● Idle (orange)

accZ RMS (0-4000), accY RMS (0-1500), accX RMS (0-6000)

Fall.csv.2n3vfr93
Window: 53600 - 55600 ms.
Label: Fall
[View sample](#)
[View features](#)

Legend: ● accX (red), ● accY (green), ● accZ (blue)

0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000 11000 12000 13000 14000 15000 16000 17000 18000 19000 20000

Model

Model version: Quantized (int8)

Last training performance (validation set)

ACCURACY	98.9%	LOSS	0,38
----------	-------	------	------

Confusion matrix (validation set)

	FALL	IDLE
FALL	97.6%	2.4%
IDLE	0%	100%
F1 SCORE	0.99	0.99

Feature explorer (full training set)

- Fall - correct
- Idle - correct
- Fall - incorrect
- Idle - incorrect

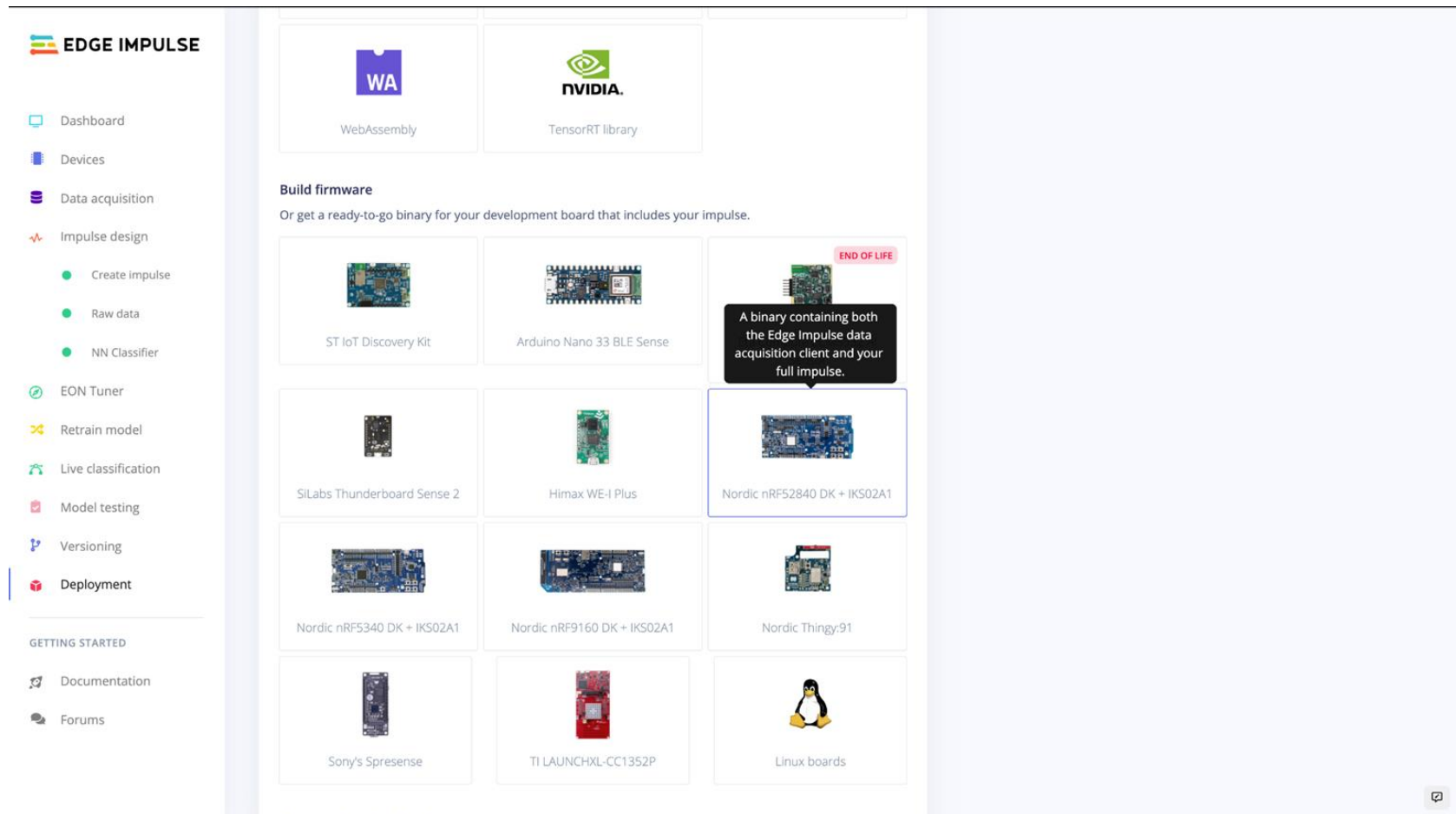
Visualization layer 3, Visualization layer 2, Visualization layer 1

On-device performance

INFERRING TIME	1 ms.	PEAK RAM USAGE	1,8K	FLASH USAGE	19,8K
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TagML: E2E Deployment Process

Generating C++ library for Nordic nRF52840, compiling the device firmware



The screenshot shows the Edge Impulse web interface. On the left is a navigation sidebar with the following items: Dashboard, Devices, Data acquisition, Impulse design (with sub-items: Create impulse, Raw data, NN Classifier), EON Tuner, Retrain model, Live classification, Model testing, Versioning, and Deployment. Below the sidebar are sections for 'GETTING STARTED' (Documentation, Forums) and 'EDGE IMPULSE' (WebAssembly, TensorRT library).

The main content area is titled 'Build firmware' and includes the text: 'Or get a ready-to-go binary for your development board that includes your impulse.' Below this is a grid of 12 development board options:

- ST IoT Discovery Kit
- Arduino Nano 33 BLE Sense
- SiLabs Thunderboard Sense 2
- Himax WE-I Plus
- Nordic nRF52840 DK + IKS02A1 (highlighted with a blue border and a tooltip that reads: 'A binary containing both the Edge Impulse data acquisition client and your full impulse.') (marked with a red 'END OF LIFE' tag)
- Nordic nRF5340 DK + IKS02A1
- Nordic nRF9160 DK + IKS02A1
- Nordic Thingy:91
- Sony's Spresense
- TI LAUNCHXL-CC1352P
- Linux boards



TagML: Result

MQTT data from the RTLS devices is delivered to Leantegra RTLS server and CVO Portal for visualizations

The screenshot displays the Leantegra RTLS dashboard interface. On the left is a navigation menu with options: Dashboard, Archive, Geofencing, Personnel, Campaigns, Content, Groups, Locations, Devices, and Users. The main area is titled 'DASHBOARD' and shows a map of a mine with personnel locations represented by red and green dots. A search bar at the top left of the map area is labeled 'Search by name, SN or personnel ID'. A dropdown menu at the top right of the map area is labeled 'Horizon-180'. A pop-up window for 'Holmes John' is open, displaying the following information:

- Holmes John** (with a close button)
- Data: 6 hours ago
- Personnel ID: 12510115
- Position: Electrician L2
- Department: Dep.infrastructureA1
- SN: TU0622
- Activity: **Walking**
- Heart Rate: 98
- message (up to 69 symbols)
- Send Message
- Show Track

Buttons for 'Broadcast Message' and 'Search by MAC' are visible at the top right of the dashboard.



Thank You

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