tinyML® Summit

Enabling Ultra-low Power Machine Learning at the Edge

Products and applications enabled by tinyML

March 28 – 29, 2023

TINY ML

www.tinyML.org

Why TinyML Applications Fail

An examination of common challenges and issues encountered in real-world projects

Chris Knorowski

CTO SensiML

chris.knorowski@sensiml.com

Qualifying if **TinyML** is the *right tool* for an application

Does machine learning make this solution scalable

Security/Privacy

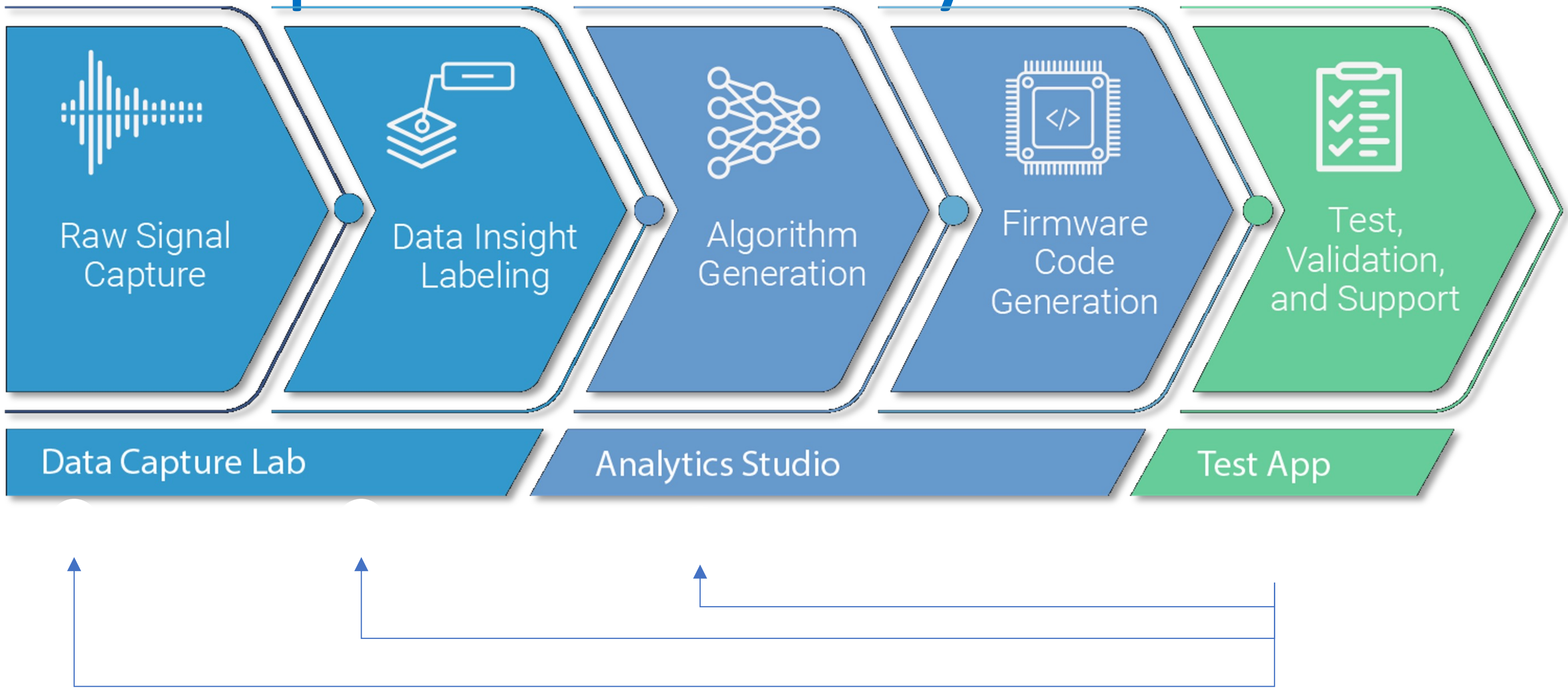
Latency

Remote Devices or Limited Connectivity

Power

Economical

Steps to build a TinyML Model



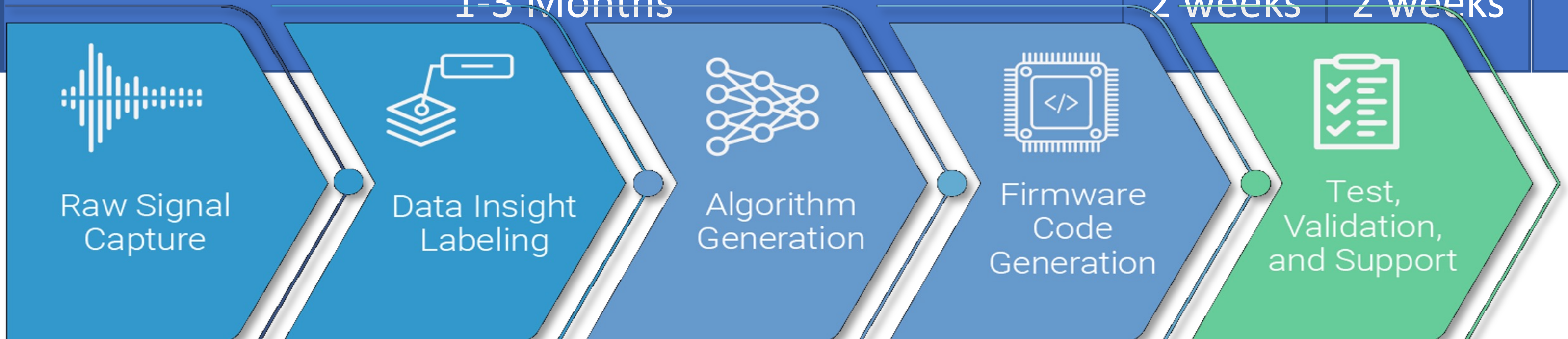
microcontrollers sensors accelerators data curation model training connectivity

deployment model monitoring updating models dashboard model compression/quantization

Steps to build an application that uses TinyML

1. Customer wants feature X
2. Do initial demo of tools/model with internal PoC similar to their use case convince yourselves this can be done and convince them externally that the feature is possible.
3. Come up with an SoW to work on a PoC for their specific application
4. Come up with data collection protocol/plan for PoC
5. Carry out data collection plan with customer device
6. Build model
7. Integrate model into PoC for test and validation
8. Customer happy with PoC, but now wants it in the product

2 weeks	2 weeks	2 weeks	2 weeks	1-3 Months	2 weeks	2 weeks	….



Take a holistic to application development to build a robust model that can make it to production

T I N Y

tinyML Deployment Working Group White Paper #1

February 20, 2023

There is far more than "fit & predict" development required to deliver Tiny ML based products.

This is the first white paper in a series exploring challenges and solutions for deploying ultra-low power machine learning (ML) at the edge of the cloud. The authors are members of the tinyML® Foundation Deployment Working Group. The opinions expressed are not necessarily representative of the tinyML Foundation, its sponsors, or the authors' employers.

https://www.tinyml.org/static/98111ec2e44e63079e10872b485777a0/tinyML_Deployment_WG_White_Paper_1.pdf

What are they keys to the success of a TinyML application?

Machine Learning
Data Science
Analytics

Embedded Firmware
Hardware
Connectivity

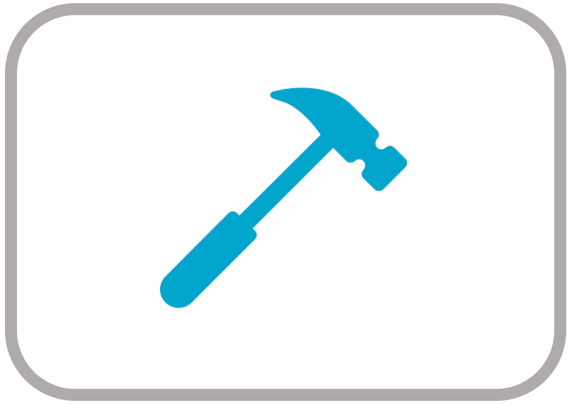
Domain and Business
Expertise

Setting priorities: Horizontal vs Vertical Scaling

"I need this feature **in my** application. Can **you build it**?"

"I need this feature **in your** application. Can **you add** it?"

Key Partner Platforms

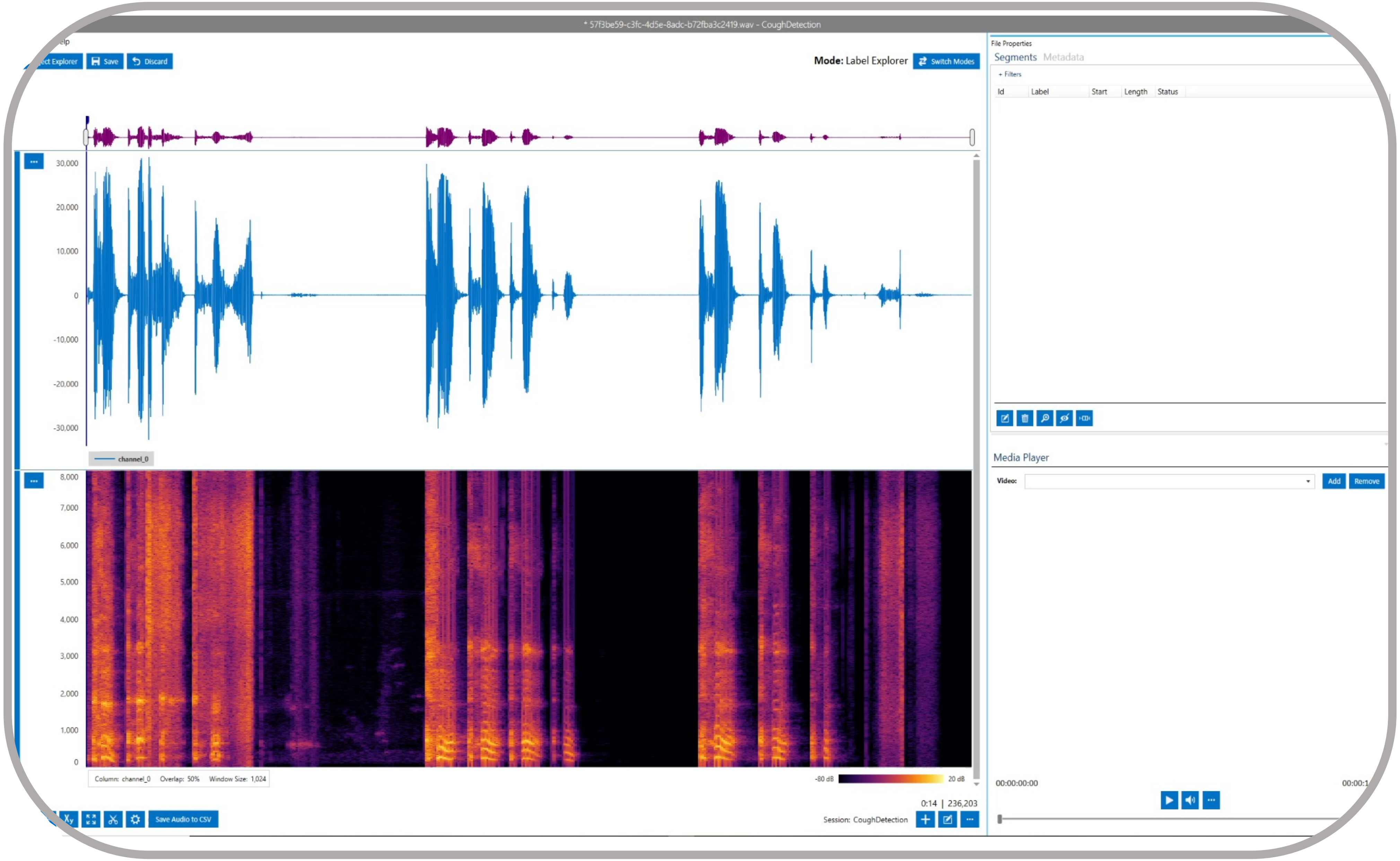


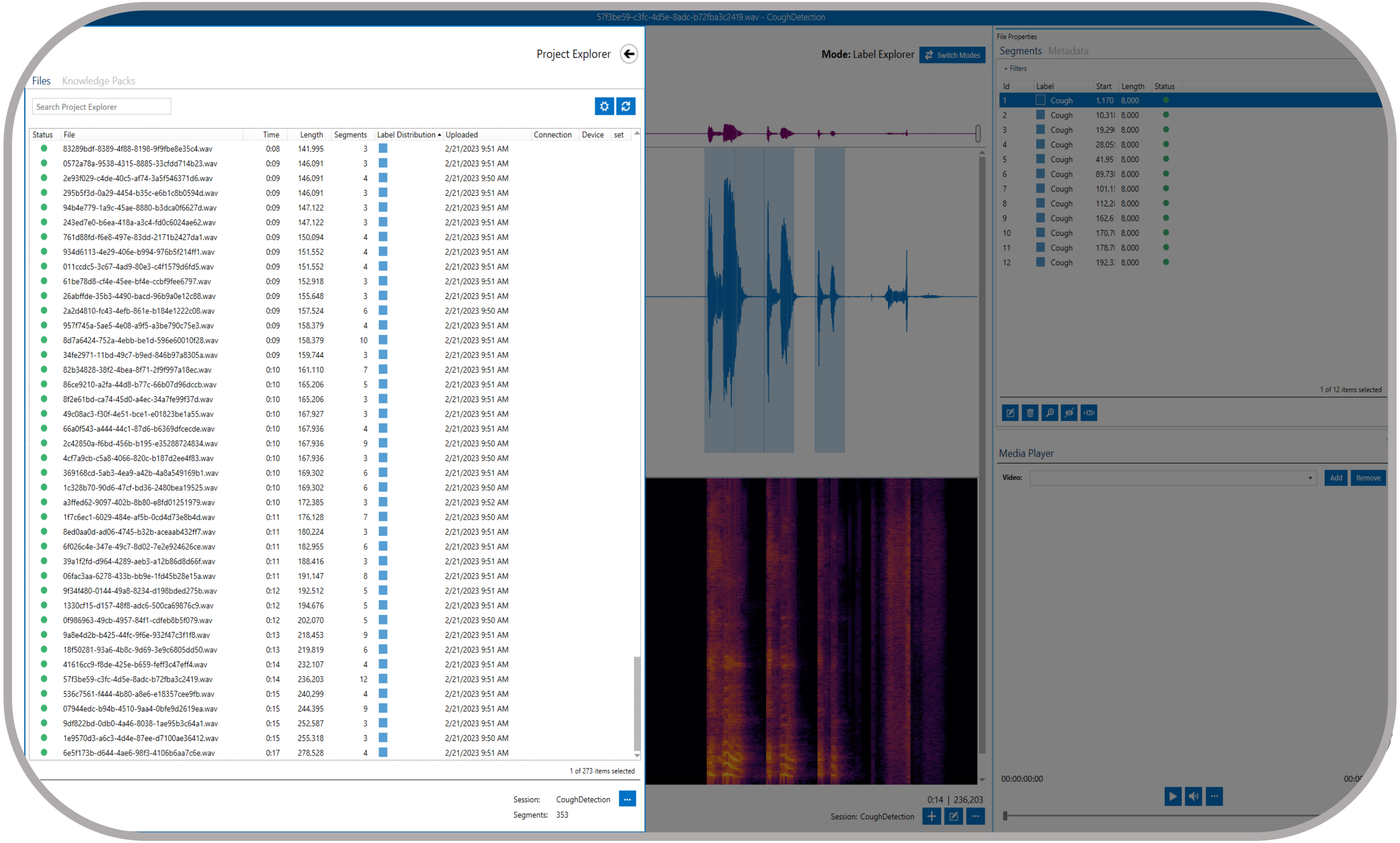
Simplifying Model APIs

Easy to Integrate Data API

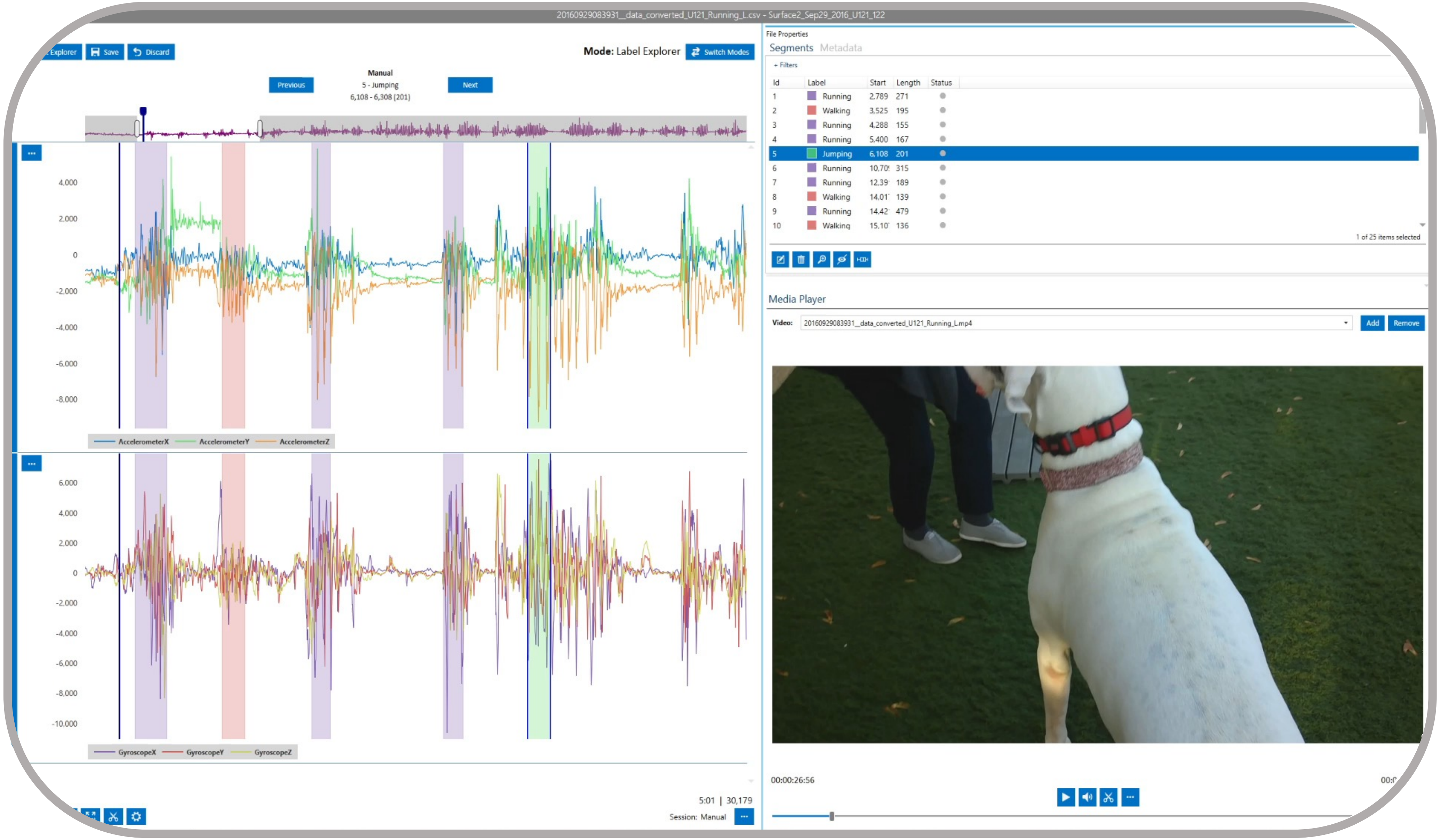
Documentation and PoCs

Data collection and annotation effort


* 57f3be59-c3fc-4d5e-8adc-b72fba3c2419.wav - CoughDetection
Save
Discard
Mode: Label Explorer
Switch Modes
File Properties
Segments
Metadata
+ Filters
Id
Label
Start
Length
Status
channel_0
Column: channel_0 Overlap: 50% Window Size: 1,024
-80 dB
20 dB
0:14 | 236,203
Save Audio to CSV
Session: CoughDetection
Media Player
Video:
Add
Remove
00:00:00:00


57f3be59-c3fc-4d5e-8adc-b72fba3c2419.wav - CoughDetection
Project Explorer
Files
Knowledge Packs
Search Project Explorer
Status File Time Length Segments Label Distribution Uploaded Connection Device set
83289bdf-8389-4f88-8198-9f9fbe8e35c4.wav 0:08 141,995 3 2/21/2023 9:51 AM
0572a78a-9538-4315-8885-33cfdd714b23.wav 0:09 146,091 3 2/21/2023 9:51 AM
2e93f029-c4de-40c5-af74-3a5f546371d6.wav 0:09 146,091 4 2/21/2023 9:50 AM
295b5f3d-0a29-4454-b35c-e6b1c8b0594d.wav 0:09 146,091 3 2/21/2023 9:51 AM
94b4e779-1a9c-45ae-8880-b3dca0f6627d.wav 0:09 147,122 3 2/21/2023 9:51 AM
243ed7e0-b6ea-418a-a3c4-fd0c6024ae62.wav 0:09 147,122 3 2/21/2023 9:51 AM
761d88fd-f6e8-497e-83dd-2171b2427da1.wav 0:09 150,094 4 2/21/2023 9:51 AM
934d6113-4e29-406e-b994-976b5f214ff1.wav 0:09 151,552 4 2/21/2023 9:51 AM
011ccdc5-3c67-4ad9-80e3-c4f1579d6fd5.wav 0:09 151,552 4 2/21/2023 9:51 AM
61be78d8-cf4e-45ee-bf4e-ccbf9fee6797.wav 0:09 152,918 3 2/21/2023 9:51 AM
26abffde-35b3-4490-bacd-96b9a0e12c88.wav 0:09 155,648 3 2/21/2023 9:51 AM
2a2d4810-fc43-4efb-861e-b184e1222c08.wav 0:09 157,524 6 2/21/2023 9:50 AM
957f745a-5ae5-4e08-a9f5-a3be790c75e3.wav 0:09 158,379 4 2/21/2023 9:51 AM
8d7a6424-752a-4ebb-be1d-596e60010f28.wav 0:09 158,379 10 2/21/2023 9:51 AM
34fe2971-11bd-49c7-b9ed-846b97a8305a.wav 0:09 159,744 3 2/21/2023 9:51 AM
82b34828-38f2-4bea-8f71-2f9f997a18ec.wav 0:10 161,110 7 2/21/2023 9:51 AM
86ce9210-a2fa-44d8-b77c-66b07d96dccb.wav 0:10 165,206 5 2/21/2023 9:51 AM
8f2e61bd-ca74-45d0-a4ec-34a7fe99f37d.wav 0:10 165,206 3 2/21/2023 9:51 AM
49c08ac3-f30f-4e51-bce1-e01823be1a55.wav 0:10 167,927 3 2/21/2023 9:51 AM
66a0f543-a444-44c1-87d6-b6369dfcecde.wav 0:10 167,936 4 2/21/2023 9:51 AM
2c42850a-f6bd-456b-b195-e35288724834.wav 0:10 167,936 9 2/21/2023 9:50 AM
4cf7a9cb-c5a8-4066-820c-b187d2ee4f83.wav 0:10 167,936 3 2/21/2023 9:50 AM
369168cd-5ab3-4ea9-a42b-4a8a549169b1.wav 0:10 169,302 6 2/21/2023 9:51 AM
1c328b70-90d6-47cf-bd36-2480bea19525.wav 0:10 169,302 6 2/21/2023 9:50 AM
a3ffed62-9097-402b-8b80-e8fd01251979.wav 0:10 172,385 3 2/21/2023 9:52 AM
1f7c6ec1-6029-484e-af5b-0cd4d73e8b4d.wav 0:11 176,128 7 2/21/2023 9:50 AM
8ed0aa0d-ad06-4745-b32b-aceaab432ff7.wav 0:11 180,224 3 2/21/2023 9:51 AM
6f026c4e-347e-49c7-8d02-7e2e924626ce.wav 0:11 182,955 6 2/21/2023 9:51 AM
39a1f2fd-d964-4289-aeb3-a12b86d8d66f.wav 0:11 188,416 3 2/21/2023 9:51 AM
06fac3aa-6278-433b-bb9e-1fd45b28e15a.wav 0:11 191,147 8 2/21/2023 9:51 AM
9f34f480-0144-49a8-8234-d198bded275b.wav 0:12 192,512 5 2/21/2023 9:51 AM
1330cf15-d157-48f8-adc6-500ca69876c9.wav 0:12 194,676 5 2/21/2023 9:51 AM
0f986963-49cb-4957-84f1-cdfeb8b5f079.wav 0:12 202,070 5 2/21/2023 9:50 AM
9a8e4d2b-b425-44fc-9f6e-932f47c3f1f8.wav 0:13 218,453 9 2/21/2023 9:51 AM
18f50281-93a6-4b8c-9d69-3e9c6805dd50.wav 0:13 219,819 6 2/21/2023 9:51 AM
41616cc9-f8de-425e-b659-feff3c47eff4.wav 0:14 232,107 4 2/21/2023 9:51 AM
57f3be59-c3fc-4d5e-8adc-b72fba3c2419.wav 0:14 236,203 12 2/21/2023 9:51 AM
536c7561-f444-4b80-a8e6-e18357cee9fb.wav 0:15 240,299 4 2/21/2023 9:51 AM
07944edc-b94b-4510-9aa4-0bfe9d2619ea.wav 0:15 244,395 9 2/21/2023 9:51 AM
9df822bd-0db0-4a46-8038-1ae95b3c64a1.wav 0:15 252,587 3 2/21/2023 9:51 AM
1e9570d3-a6c3-4d4e-87ee-d7100ae36412.wav 0:15 255,318 3 2/21/2023 9:50 AM
6e5f173b-d644-4ae6-98f3-4106b6aa7c6e.wav 0:17 278,528 4 2/21/2023 9:51 AM
1 of 273 items selected
Session: CoughDetection
Segments: 353
Mode: Label Explorer
Switch Modes
0:14 | 236,203
Session: CoughDetection
File Properties
Segments
Metadata
+ Filters
Id Label Start Length Status
1 Cough 1,170 8,000
2 Cough 10,31 8,000
3 Cough 19,29 8,000
4 Cough 28,05 8,000
5 Cough 41,95 8,000
6 Cough 89,73 8,000
7 Cough 101,1 8,000
8 Cough 112,2 8,000
9 Cough 162,6 8,000
10 Cough 170,7 8,000
11 Cough 178,7 8,000
12 Cough 192,3 8,000
1 of 12 items selected
Media Player
Video:
Add
Remove
00:00:00:00

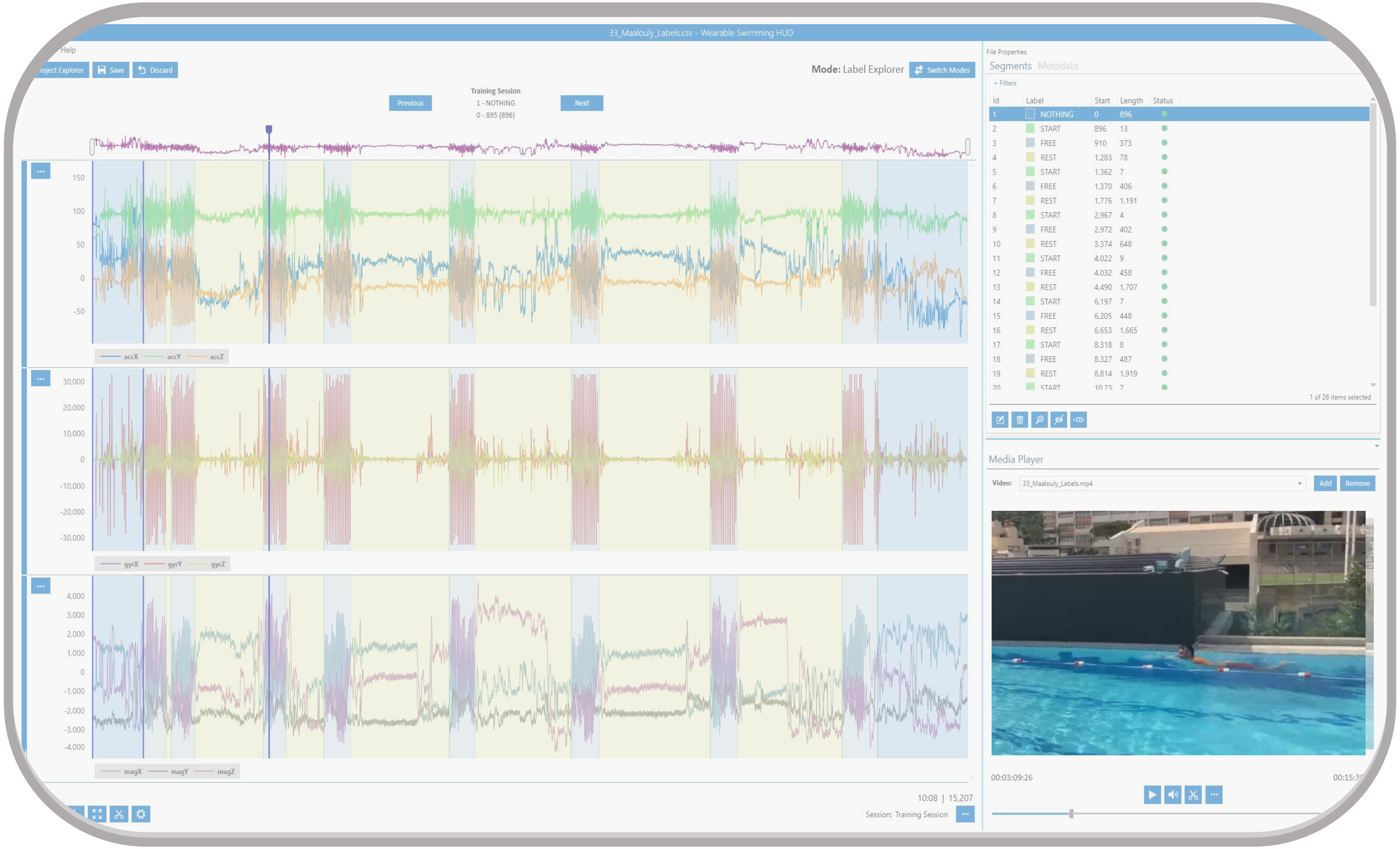
Models and Datasets as IP



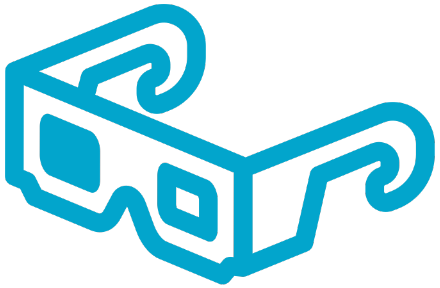
20160929083931__data_converted_U121_Running_L.csv - Surface2_Sep29_2016_U121_122
Explorer
Save
Discard
Mode: Label Explorer
Switch Modes
Manual
Previous
5 - Jumping
6,108 - 6,308 (201)
Next
4,000
2,000
0
-2,000
-4,000
-6,000
-8,000
AccelerometerX
AccelerometerY
AccelerometerZ
6,000
4,000
2,000
0
-2,000
-4,000
-6,000
-8,000
-10,000
GyroscopeX
GyroscopeY
GyroscopeZ
5:01 | 30,179
Session: Manual
File Properties
Segments
Metadata
+ Filters
Id Label Start Length Status
1 Running 2,789 271
2 Walking 3,525 195
3 Running 4,288 155
4 Running 5,400 167
5 Jumping 6,108 201
6 Running 10,70 315
7 Running 12,39 189
8 Walking 14,01 139
9 Running 14,42 479
10 Walking 15,10 136
1 of 25 items selected
Media Player
Video:
20160929083931__data_converted_U121_Running_L.mp4
Add
Remove
00:00:26:56

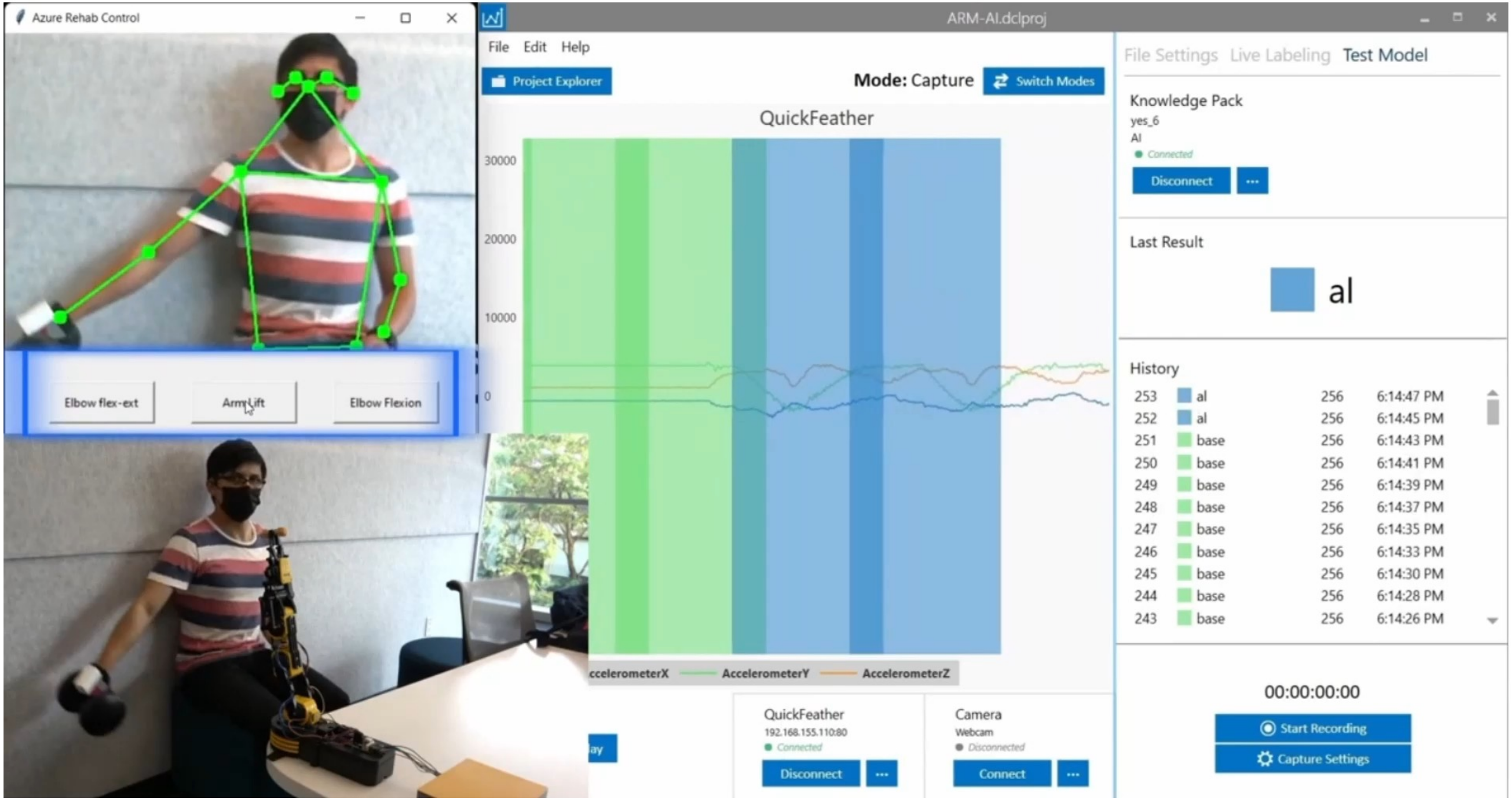
Defining the Model Scope

Save
Discard
Mode: Label Explorer
Switch Modes
Training Session
20 - BREAST
3,311 - 3,656 (346)
Previous
Next
accX
accY
accZ
gyrX
gyrY
gyrZ
magX
magY
magZ
3:14 | 4,854
Session: Training Session
File Properties
Segments
Metadata
+ Filters
Id Label Start Length Status
2 START 1,107 2
3 UNDERWATER 1,109 93
4 FLY 1,203 241
5 OPEN 1,444 57
6 UNDERWATER 1,502 84
7 FLY 1,587 245
8 OPEN 1,832 50
9 UNDERWATER 1,883 35
10 BACK 1,919 339
11 FLIP 2,258 34
12 UNDERWATER 2,293 30
13 BACK 2,324 365
14 REST 2,689 89
15 START 2,779 17
16 UNDERWATER 2,797 86
17 BREAST 2,884 326
18 OPEN 3,210 50
19 UNDERWATER 3,261 49
20 BREAST 3,311 346
1 of 28 items selected
Media Player
Video:
1002_Hind_Labels.mp4
Add
Remove
00:02:31:88

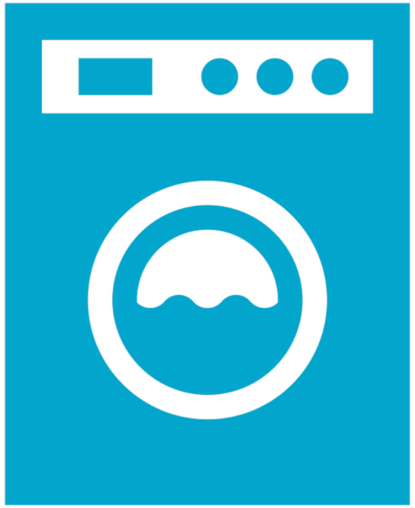

33_Maalouly_Labels.csv - Wearable Swimming HUD
Help
Save
Discard
Mode: Label Explorer
Switch Modes
Training Session
1 - NOTHING
0 - 895 (896)
Previous
Next
accX accY accZ
gyrX gyrY gyrZ
magX magY magZ
10:08 | 15,207
Session: Training Session
File Properties
Segments Metadata
+ Filters
Id Label Start Length Status
1 NOTHING 0 896
2 START 896 13
3 FREE 910 373
4 REST 1,283 78
5 START 1,362 7
6 FREE 1,370 406
7 REST 1,776 1,191
8 START 2,967 4
9 FREE 2,972 402
10 REST 3,374 648
11 START 4,022 9
12 FREE 4,032 458
13 REST 4,490 1,707
14 START 6,197 7
15 FREE 6,205 448
16 REST 6,653 1,665
17 START 8,318 8
18 FREE 8,327 487
19 REST 8,814 1,919
1 of 26 items selected
Media Player
Video: 33_Maalouly_Labels.mp4
Add
Remove
00:03:09:26

Slow test and validation iterations




Azure Rehab Control
Elbow flex-ext
Arm Lift
Elbow Flexion
ARM-AI.dclproj
File Edit Help
Project Explorer
Mode: Capture
Switch Modes
QuickFeather
30000
20000
10000
0
AccelerometerX
AccelerometerY
AccelerometerZ
QuickFeather
192.168.155.110:80
Connected
Disconnect
Camera
Webcam
Disconnected
Connect
File Settings
Live Labeling
Test Model
Knowledge Pack
yes_6
AI
Connected
Disconnect
Last Result
al
History
253 al 256 6:14:47 PM
252 al 256 6:14:45 PM
251 base 256 6:14:43 PM
250 base 256 6:14:41 PM
249 base 256 6:14:39 PM
248 base 256 6:14:37 PM
247 base 256 6:14:35 PM
246 base 256 6:14:33 PM
245 base 256 6:14:30 PM
244 base 256 6:14:28 PM
243 base 256 6:14:26 PM
00:00:00:00
Start Recording
Capture Settings

Condemn technology based on a misunderstanding of limits



Where does TinyML fit into Predictive maintenance

Rotating Machinery Faults

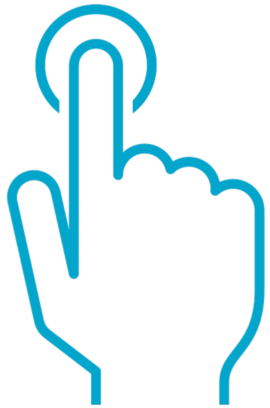
- Vibration data sometimes temperature
- Compute FFT – send up sample once every X hours (probably not going to beat a historical FFT data set analyzed in the cloud)
- Set threshold - set alert above threshold (can we improve over a threshold method?)

Anomaly detection in repeated gestures of industrial machines

- Need to know context of the machine motion. This can involve being in the control path. Which means TinyML may not be necessary.

High bandwidth sensors in difficult to reach places(audio, image) are good fits for TinyML applications

Sensor calibration vs. real-world deployment



Optimized modules targeting specific applications

- IMU + Mic + Wifi + LCD Module + Enclosure
- IMU mounted enclosure for picking up vibration signatures
- Dual Mic + Enclosure with different dampening characteristics

Why TinyML Applications Fail

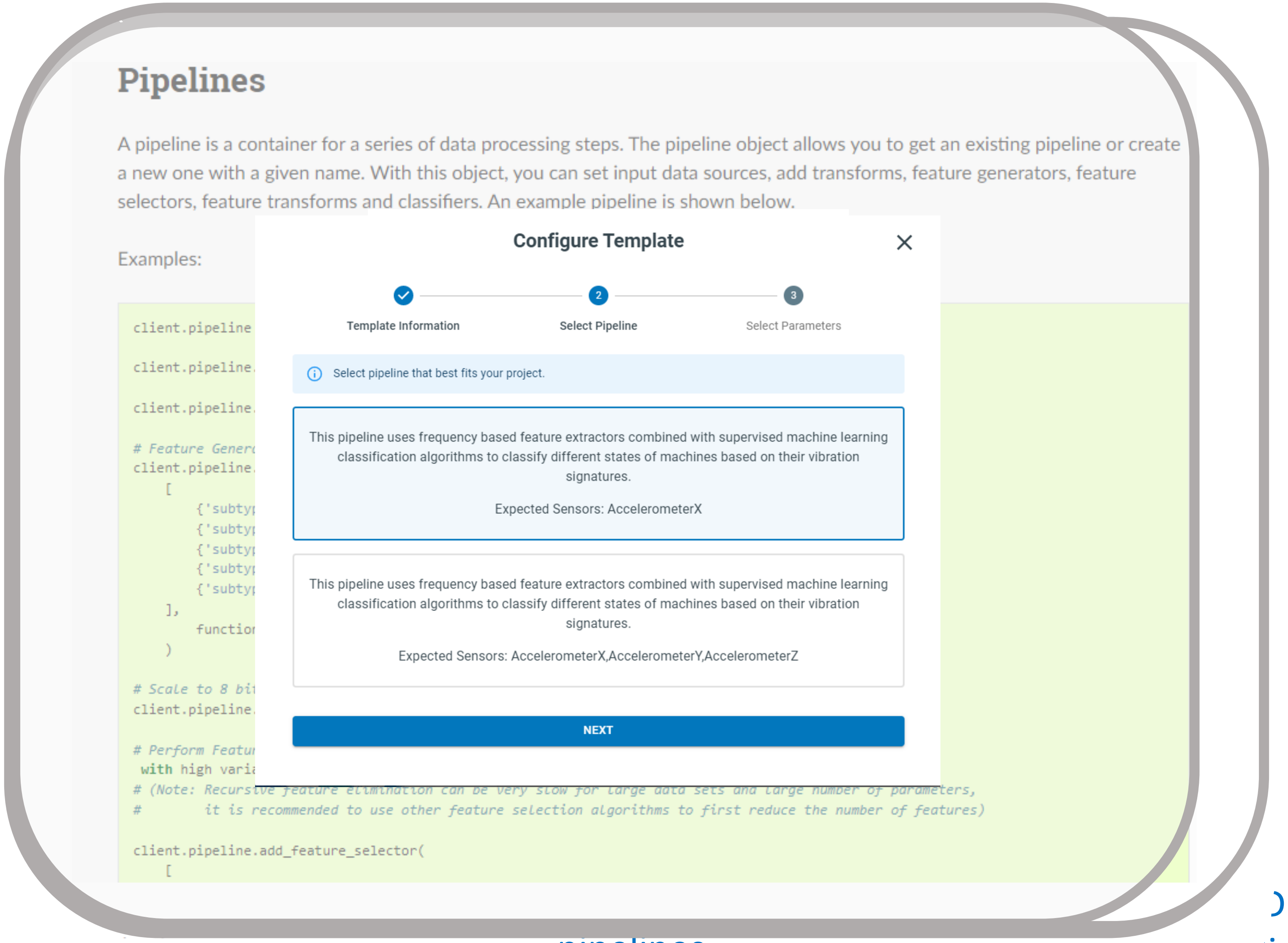
An examination of common challenges and issues encountered in real-world projects

Chris Knorowski

CTO SensiML

chris.knorowski@sensiml.com

SensiML™



Templates for commo

pipelines

)K for programmatic
line creation

SUPPORTED DEVICES

- Arduino Nano 33 BLE Sense
- Arduino Nicla Sense ME
- Infineon PSoC™ 6
- M5Stack M5StickC PLUS ESP32-PICO Mini IoT Dev Kit
- Microchip Technology AVR128DA48 Curiosity Nano Evaluation Kit
- Microchip Technology PIC-IoT WG Development Board
- Microchip Technology SAMD21 ML Eval Kit (SAM-IoT WG)
- Nordic Thingy
- onsemi RSL10 Sense
- QuickLogic Chilkat
- QuickLogic QuickAI
- QuickLogic QuickFeather
- Raspberry Pi
- Silicon Labs Thunderboard Sense 2
- Silicon Labs xG24 Dev Kit
- SparkFun QuickLogic Thing Plus - EOS S3
- ST SensorTile
- ST SensorTile.box

Select a Target

Compilers

arm ARM GCC Generic SELECT	android Android NDK	ESPRESSIF Espressif ESP-IDF	Microchip MPLAB XC16
Microchip MPLAB XC32	Microchip MPLAB XC8	Windows Windows x86_64	intel x86 GCC Generic

Development Platforms

ARDUINO Arduino Nano33 BLE Sense	ARDUINO Arduino Nicla Sense ME	Infineon Infineon CY8CKIT-062S2-43012	M5STACK M5StickC PLUS ESP32-PICO Development Kit
Microchip Microchip AVR128DA48 Curiosity Nano Evaluation Kit	Microchip Microchip PIC-IoT WG Development Board	Microchip Microchip SAMD21 ML Evaluation Kit	NORDIC Nordic NRF52 SDK 13
NORDIC Nordic Thingy52	NXP NXP i.MX RT10XX	onsemi onsemi RSL10 Sense	QuickLogic QuickLogic QuickFeather
QuickLogic	QuickLogic	Raspberry Pi	SILICON LABS

SUPPORTED COMPILERS

- Android Native Development Kit
- Arm GCC Cortex M4/M7/A53
- Espressif ESP-IDF ESP32
- Microchip XC8/XC16/XC32
- x86_64 (GCC 9.2/mingw-64 9.3)

APPLICATION EXAMPLES

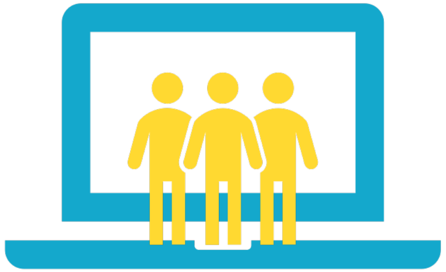
- Keyword Spotting
- Boxing Punch Gesture Recognition
- Robot Arm Gesture Recognition
- Fan State Condition Monitoring
- Audio Anomaly Detection
- Vibration Anomaly Detection
- Audio Cough Detection
- Guitar Note Audio Recognition
- Smart Lock Audio Recognition
- Wizard Magic Wand Gesture Game

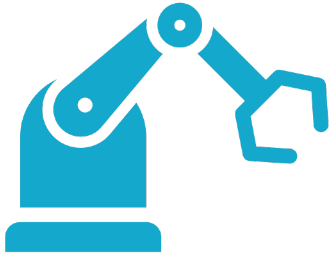
Meet the customer where they are at

We Sell: TinyML toolkit for Smart Sensors

To: Application developers and system integrators

To enable: rapid development of novel applications for edge devices





SensiML Analytics Toolkit - Market Leading AutoML Technology for IoT Endpoint Algorithms

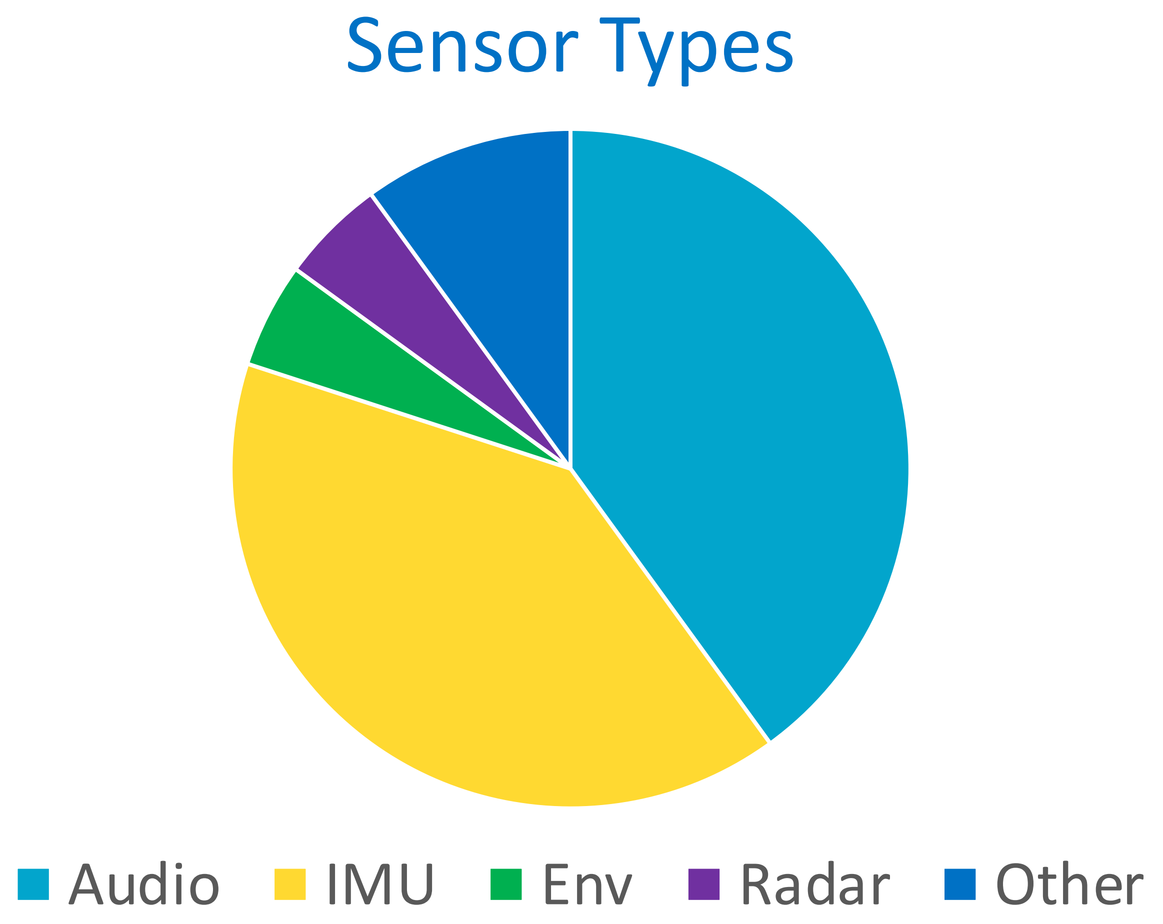
Customer Profile: Hotbeds of Activity

Consumer

Health and Wellness

Agricultural

Industrial


Sensor Types
Audio
IMU
Env
Radar
Other

- DSCNN is not the write solution for audio, baggage

- Adam NXP
- Matheiu STM

- Does it scale to a real product – Person detect endless amount of data conditions
- Play the audio backwards

Copyright Notice

www.tinyml.org