

SciTinyML – ICTP Workshop

Scientific Use of Machine Learning on Low Power Devices

Machine Learning Sensors

Acknowledgements: Z. Asgar, C. Banbury, B. Brown, E. Chen, J. MacArthur, B. Plancher, S. Prakash, S. Katti, V. J. Reddi, P. Warden & the Useful Sensors Team



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John A. Paulson School of Engineering and Applied Sciences | Harvard University |
Web: <https://mpstewart.io>



Applications of Machine Learning



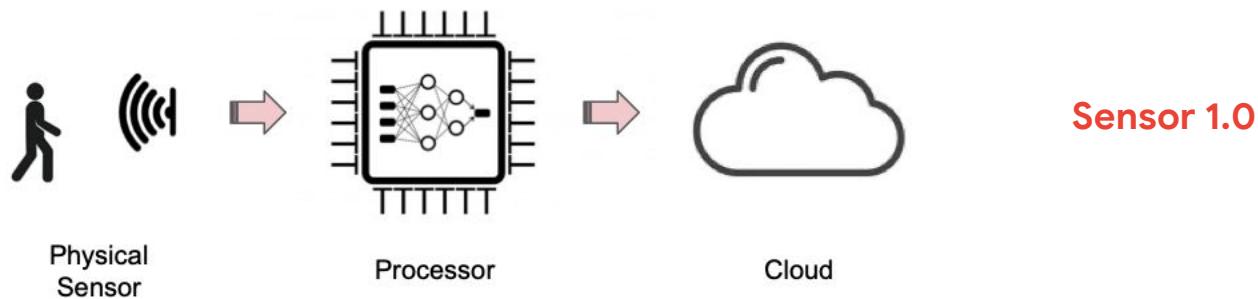


No Good Data Left Behind

5 Quintillion
bytes of data produced
every day by IoT

<1%
of unstructured data is
analyzed or used at all

The “Classic” TinyML Paradigm



Is Your TV Watching You? How +
avast.com/c-smart-tv-spying-on-you

TinyML Harvard MLC Seed Meta \$\$\$ TimeBuddy Geo Chart Example CS249r Other Bookmarks

Academy

Avast Academy > Security > Internet of Things > How to Stop Your Smart TV From Spying on You

INTERNET OF THINGS

How to Stop Your Smart TV From Spying on You

A voice command starts your TV's recognition, and viewing data from interconnectivity has privacy implications. Here's how to stop smart TV spying and how the best

FBI warns about snoopy smart TVs spying on you +
zdnet.com/article/fbi-warns-about-snoopy-smart-t...

TinyML Harvard MLC Seed Meta \$\$\$ TimeBuddy Geo Chart Example CS249r Other Bookmarks

ZDNET tomorrow belongs to those who embrace it today

Home / Innovation / Security

/ innovation

FBI warns about snoopy smart TVs spying on you

An FBI branch office warns smart TV users that they can be gateways for hackers to come into your home. Meanwhile, the smart TV OEMs are already spying on you.

Written by Steven Vaughan-Nichols, Senior Contributing Editor on Dec. 3, 2019

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The 17 best Cyber Monday tech deals still

Google Calls Hidden Microphone in Its Nest Home Security Devices an 'Error'

New Technology > Security

Google Calls Hidden Microphone in Its Nest Home Security Devices an 'Error'

The company says its was an oversight, but it does little to stem paranoia.

BY SAM BLUM PUBLISHED: FEB 21, 2019

2021 Editors' choice

tech radar



How to stop your smart home +
theguardian.com/technology/2020/mar/08/how-to...
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The Observer Smart homes

How to stop your smart home spying on you

Everything in your smart home, from the lightbulbs to the thermostat, could be recording you or collecting data about you. What can you do to protect your privacy?

Most viewed

Bryan Adams: 'My doc says men need sex 27 times a month, but who gets that?' Attacks on Pacific northwest power stations raise

*How do we architect future Tiny Machine Learning (tinyML) sensors
efficiently, effectively and robustly into the embedded ecosystem?*

Machine Learning Sensors

“

An ML sensor is a **self-contained system** that utilizes **on-device machine learning** to extract **useful information** by observing some complex set of phenomena in the **physical world** and reports it through a **simple interface** to a wider system.

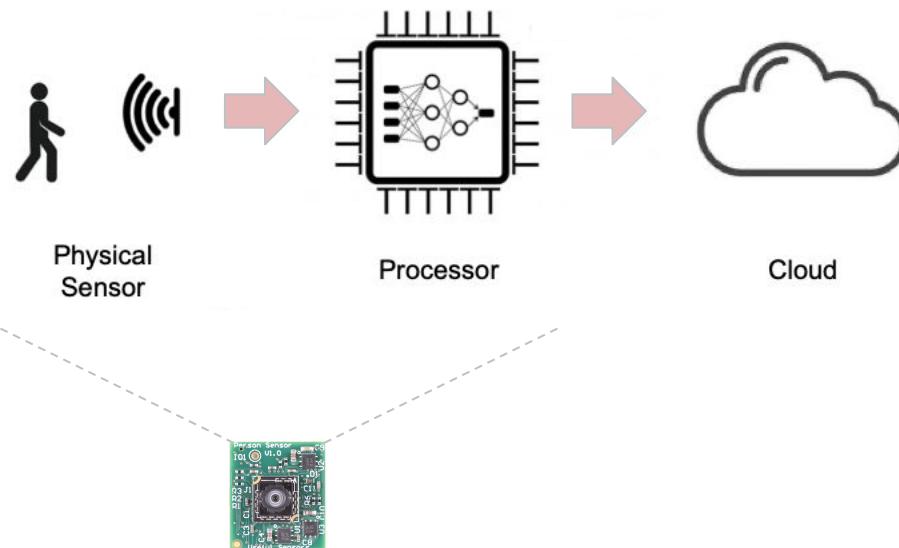
”

Machine Learning Sensors

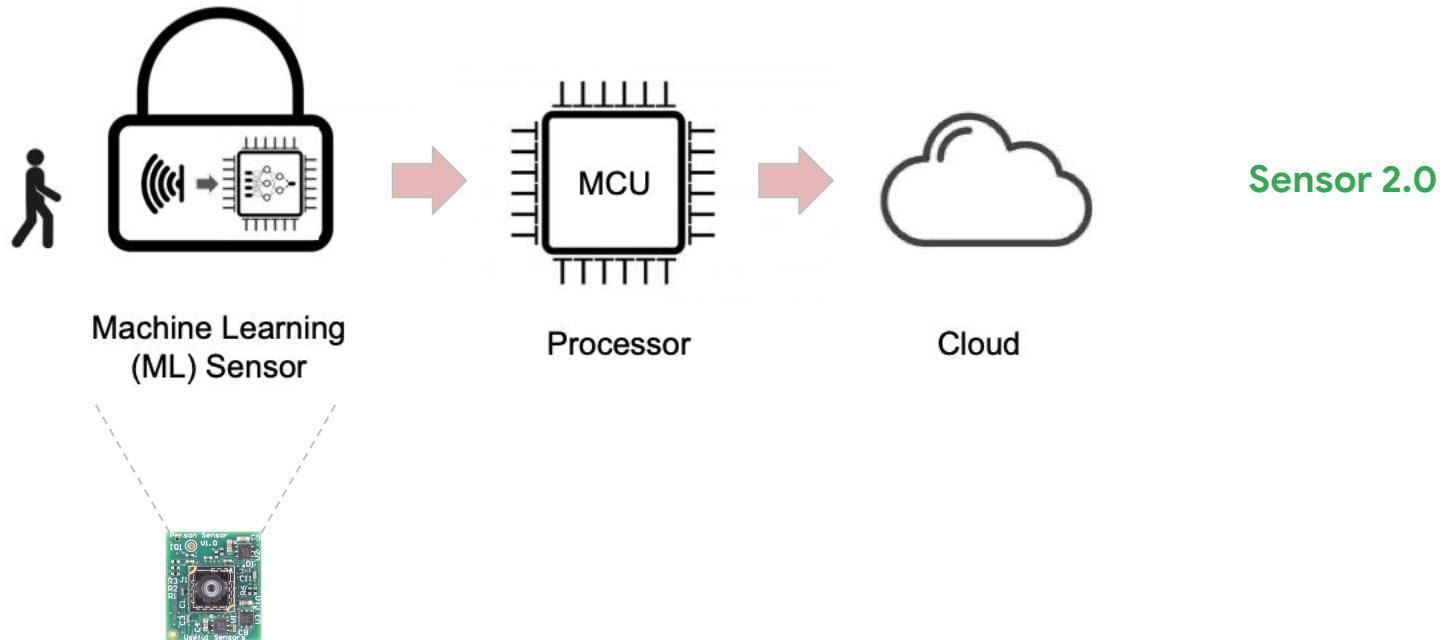


by Useful Sensors

Machine Learning Sensors



Machine Learning Sensors



ML Sensors - Guiding Set of Principles

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The screenshot shows the Digi-Key website interface for searching temperature sensors. The search bar at the top contains the query "temperature sensor". Below the search bar, there are several filter categories on the left: Manufacturer (Search Filter), Series (Search Filter), Packaging (Bag, Box, Bulk, Cut Tape (CT), Digi-Reel®, Strip, Tape & Box (TB), Tape & Reel (TR), Tray, Tube), Product Status (Active, Discontinued at Digi-Key, Last Time Buy, Not For New Designs, Obsolete), Sensor Type (Analog, Analog, Digital, Analog, Infrared (IR), Analog, Local, Analog, Local/Remote, Analog, Remote, Analog/Digital, Local/Remote, Digital, Digital, Infrared (IR), Digital, Local), Sensing Temperature - Local (Search Filter, -55°C ~ 100°C, -55°C ~ 120°C, -55°C ~ 125°C, -55°C ~ 130°C, -55°C ~ 150°C, -55°C ~ 175°C, -55°C ~ 200°C, -55°C ~ 250°C, -70°C ~ 380°C (IR), -70°C ~ 380°C, -64°C ~ 125°C, -64°C ~ 150°C, -64°C ~ 191°C, -50°F ~ 300°F, -40°F ~ 100°C), Sensing Temperature - Remote (Search Filter, -250°C ~ 2500°C, -200°C ~ 850°C, -70°C ~ 380°C (IR), -70°C ~ 380°C, -64°C ~ 125°C, -64°C ~ 150°C, -64°C ~ 191°C, -55°C ~ 125°C, -55°C ~ 127°C), Output Type (Search Filter, 1-Wire®, 2-Wire Serial, 2-Wire Serial, I²C, 2-Wire Serial, PC/SMBUS, 3-Wire (CLK, DQ, RST), 3-Wire Serial, Analog Current and Voltage, Analog Current), Voltage - Supply (Search Filter, 1.08V ~ 1.98V, 1.08V ~ 3.6V, 1.4V ~ 2.75V, 1.4V ~ 3.6V, 1.4V ~ 5.5V, 1.5V ~ 3.6V, 1.5V ~ 5.5V, 1.6V ~ 3.6V, 1.6V ~ 5.5V), and Resolution (Search Filter, -11.7mV/°C, 10µs/°C, 4mV/°C, 5.194mV/°C, 5.5mV/°C, 5.5mV/°C, 8.2mV/°C, 6.2mV/°C, 6.25mV/°C, 6.45mV/°C). At the bottom, there are additional filters for Stocking Options (In Stock, Normally Stocking, New Product), Environmental Options (RoHS Compliant, Non-RoHS Compliant), Media (Datasheet, Photo, EDA/CAD Models), Marketplace Product (Exclude), and a search bar for "temperature sensor". The total result count is 3,131.

| Compare | Mfr Part # | Quantity Available | Price | Series | Package | Product Status | Sensor Type | Sensing Temperature - Local | Sensing Temperature - Remote | Output Type | Voltage - Supply | Resolution | Features | Accuracy - Highest (Lowest) | Test Condition |
|--------------------------|---|--|--|----------------------|---|----------------|-----------------------|-----------------------------|------------------------------|----------------------|------------------|---------------|--|-----------------------------|--|
| <input type="checkbox"/> |  TMP236A2DBZT SENSOR TEMPERATURE Texas Instruments | 1,053 In Stock | 1 : \$1.49000 250 : \$0.71800 Tape & Reel (TR) | - | Tape & Reel (TR)   Cut Tape (CT)  Digi-Reels  | Active | Analog, Local | -10°C ~ 125°C | - | Ratiometric, Voltage | 3.1V ~ 5.5V | 19.5mV/ °C | - | ±2°C | -10°C ~ 125°C |
| <input type="checkbox"/> |  TMP236A4DCKT SENSOR TEMPERATURE Texas Instruments | 1,678 In Stock | 1 : \$1.24000 250 : \$0.59800 Tape & Reel (TR) | - | Tape & Reel (TR)   Cut Tape (CT)  Digi-Reels  | Active | Analog, Local | -10°C ~ 125°C | - | Ratiometric, Voltage | 3.1V ~ 5.5V | 19.5mV/ °C | - | ±4°C | -10°C ~ 125°C |
| <input type="checkbox"/> |  TMP236A2DKCT SENSOR TEMPERATURE Texas Instruments | 2,307 In Stock | 1 : \$1.10000 250 : \$0.67800 Tape & Reel (TR) | - | Tape & Reel (TR)   Cut Tape (CT)  Digi-Reels  | Active | Analog, Local | -10°C ~ 125°C | - | Ratiometric, Voltage | 3.1V ~ 5.5V | 19.5mV/ °C | - | ±2°C | -10°C ~ 125°C |
| <input type="checkbox"/> |  TMP451HQDQFTQ1 SENSOR TEMPERATURE Texas Instruments | 340 In Stock | 1 : \$2.65000 250 : \$1.02860 Tape & Reel (TR) | Automotive, AEC-Q100 | Tape & Reel (TR)   Cut Tape (CT)  Digi-Reels  | Active | Digital, Local/Remote | -40°C ~ 125°C | -64°C ~ 191°C | PC/SMBus | 1.7V ~ 3.6V | 12 b | One-Shot, Output Switch, Programmable Limit, Shutdown Mode | ±1°C (±2°C) | 0°C ~ 70°C (-40°C ~ 125°C) |
| <input type="checkbox"/> |  TMP236A4DBZT SENSOR TEMPERATURE Texas Instruments | 596 In Stock | 1 : \$1.32000 250 : \$0.63800 Tape & Reel (TR) | - | Tape & Reel (TR)   Cut Tape (CT)  Digi-Reels  | Active | Analog, Local | -10°C ~ 125°C | - | Ratiometric, Voltage | 3.1V ~ 5.5V | 19.5mV/ °C | - | ±4°C | -10°C ~ 125°C |
| <input type="checkbox"/> |  TMP451HQDQFTQ1 SENSOR TEMPERATURE Texas Instruments | 227 In Stock 3,250 Factory  | 1 : \$2.65000 250 : \$1.02860 Tape & Reel (TR) | Automotive, AEC-Q100 | Tape & Reel (TR)   Cut Tape (CT)  Digi-Reels  | Active | Digital, Local/Remote | -40°C ~ 125°C | -64°C ~ 191°C | PC/SMBus | 1.7V ~ 3.6V | 12 b | One-Shot, Output Switch, Programmable Limit, Shutdown Mode | ±1°C (±2°C) | 0°C ~ 70°C (-40°C ~ 125°C) |
| <input type="checkbox"/> |  TMP461AIRUNT-S TEMPERATURE SENSOR Texas Instruments | 9,073 In Stock 10,000 Factory  | 1 : \$2.56000 250 : \$1.28020 Tape & Reel (TR) | - | Tape & Reel (TR)   Cut Tape (CT)  Digi-Reels  | Active | Digital, Local/Remote | -40°C ~ 125°C | -64°C ~ 191°C | SMBus | 1.7V ~ 3.6V | 11 b | One-Shot, Output Switch, Programmable Limit, Shutdown Mode, Standby Mode | ±1°C (±1.25°C) | -10°C ~ 100°C (-40° ~ 125°C) |
| <input type="checkbox"/> |  TMP12FP ANALOG TEMPERATURE SENSOR Analog Devices Inc. | 1,253 Marketplace | 108 : \$2.79000 Bulk | - | Bulk  | Active | Digital, Local | -40°C ~ 125°C | - | SPI | 2.7V ~ 5.5V | 12 b | One-Shot, Shutdown Mode | ±2°C (±2.5°C) | -25°C ~ 85°C (-40°C ~ 125°C) |
| <input type="checkbox"/> |  MAX6630MUT-T DIGITAL TEMPERATURE SENSOR Analog Devices Inc./Maxim Integrated | 3,396 Marketplace | 110 : \$2.75000 Bulk | - | Bulk  | Active | Digital, Local | -55°C ~ 125°C | - | SPI | 3V ~ 5.5V | 12 b | Shutdown Mode | ±0.8°C (-5°C, 6.5°C) | 25°C (150°C)  |
| <input type="checkbox"/> |  TMP35FT9 ANALOG TEMPERATURE SENSOR Analog Devices Inc. | 20,365 Marketplace | 298 : \$1.01000 Bulk | Automotive | Bulk  | Active | Analog, Local | 10°C ~ 125°C | - | Analog Voltage | 2.7V ~ 5.5V | 10mV/°C | Shutdown Mode | ±2°C (±3°C) | 25°C (10°C ~ 125°C) |
| <input type="checkbox"/> |  MAX6629MUT-T DIGITAL TEMPERATURE SENSOR Analog Devices Inc./Maxim Integrated | 9,848 Marketplace | 139 : \$2.17000 Bulk | - | Bulk  | Active | Digital, Local | -55°C ~ 125°C | - | SPI | 3V ~ 5.5V | 12 b | Shutdown Mode | ±0.8°C (-5°C, 6.5°C) | 25°C (150°C) |
| <input type="checkbox"/> |  AD22103KR-REEL ALL ANALOG TEMPERATURE SENSORS | 2,350 Marketplace | 289 : \$1.04000 Bulk | AD22103 | Bulk  | Active | Analog, Local | 0°C ~ 100°C | - | Analog | 2.7V ~ 3.6V | 28mV/°C | - | ±2°C (±2.5°C) | 25°C (0°C ~ 100°C) |

Feedback Need Help? 

ML Sensors - Guiding Set of Principles

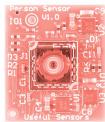
1. We need to **raise the level of abstraction** to enable ease of use for scalable deployment of ML sensors; not everyone should be required to be a developer or an engineer to leverage ML sensors into their ecosystem.



Person
detector



Gaze
sensor



Voice
command



Text
recognizer



...



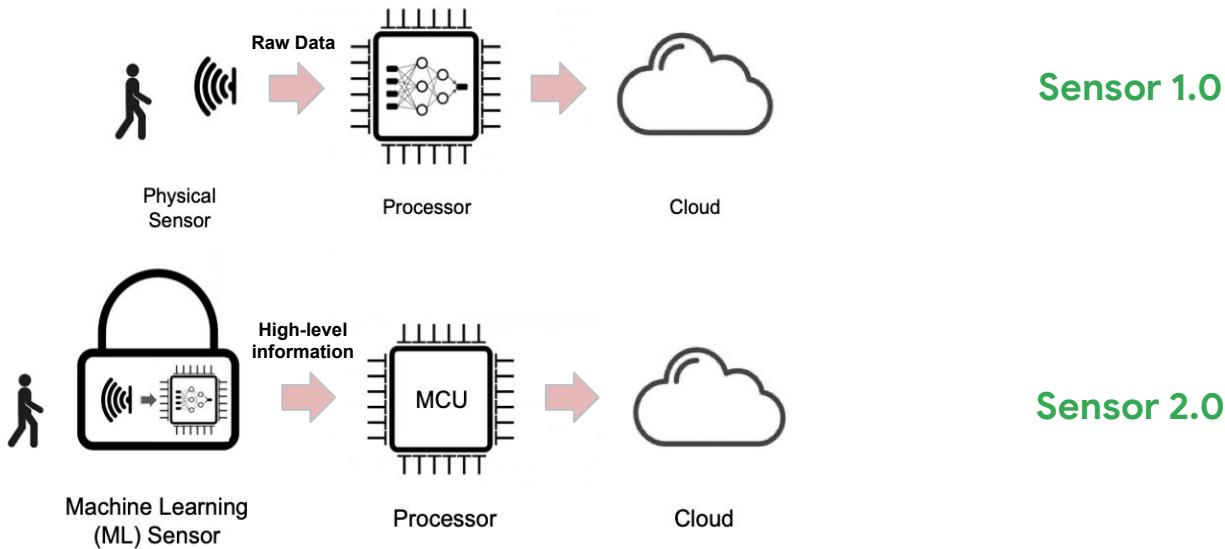
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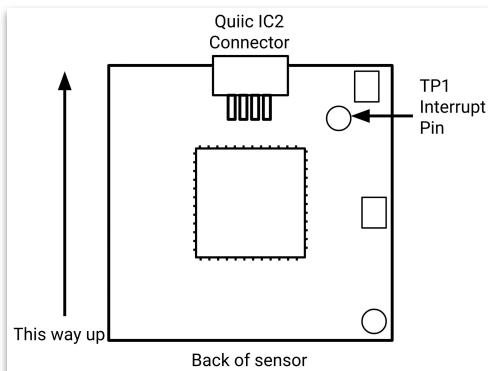


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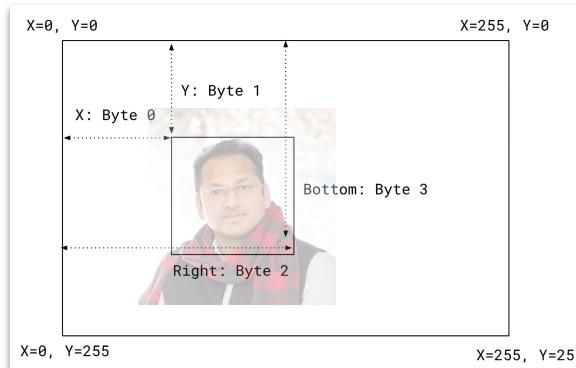
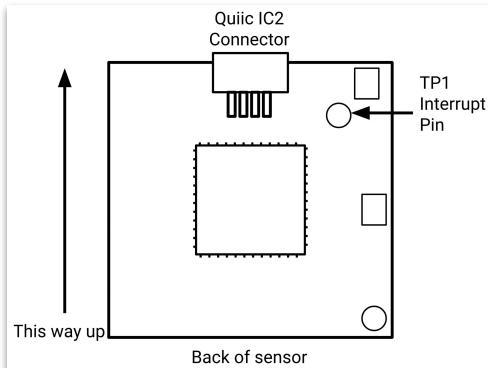
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We need to define or rely on standard interfaces and mechanisms for communication with sensors.

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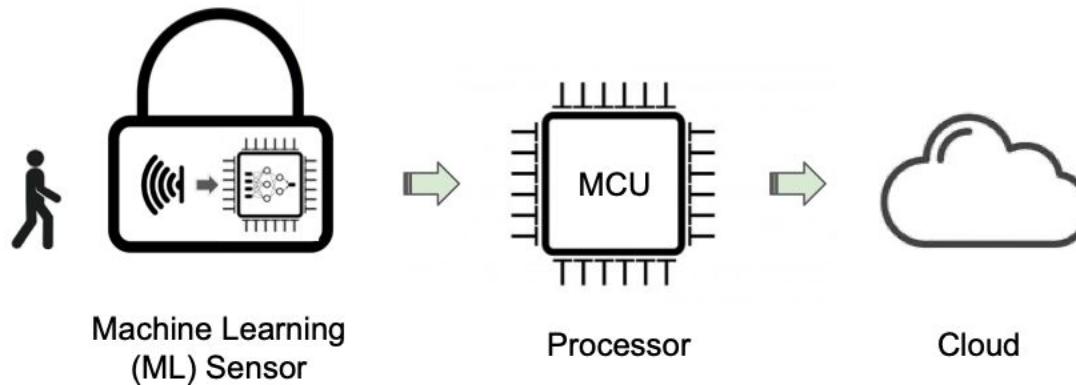


We need to define data formats to enable interoperability and exchange of ML sensors across manufacturers

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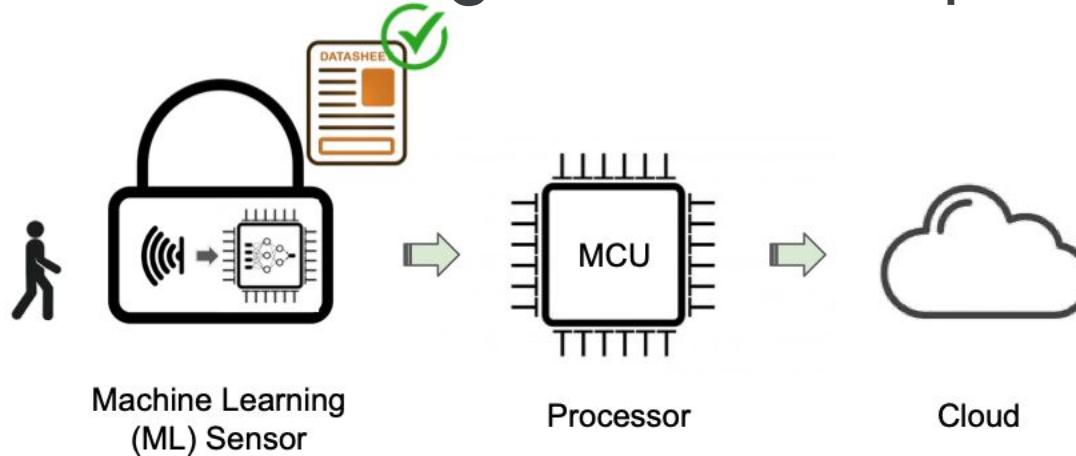
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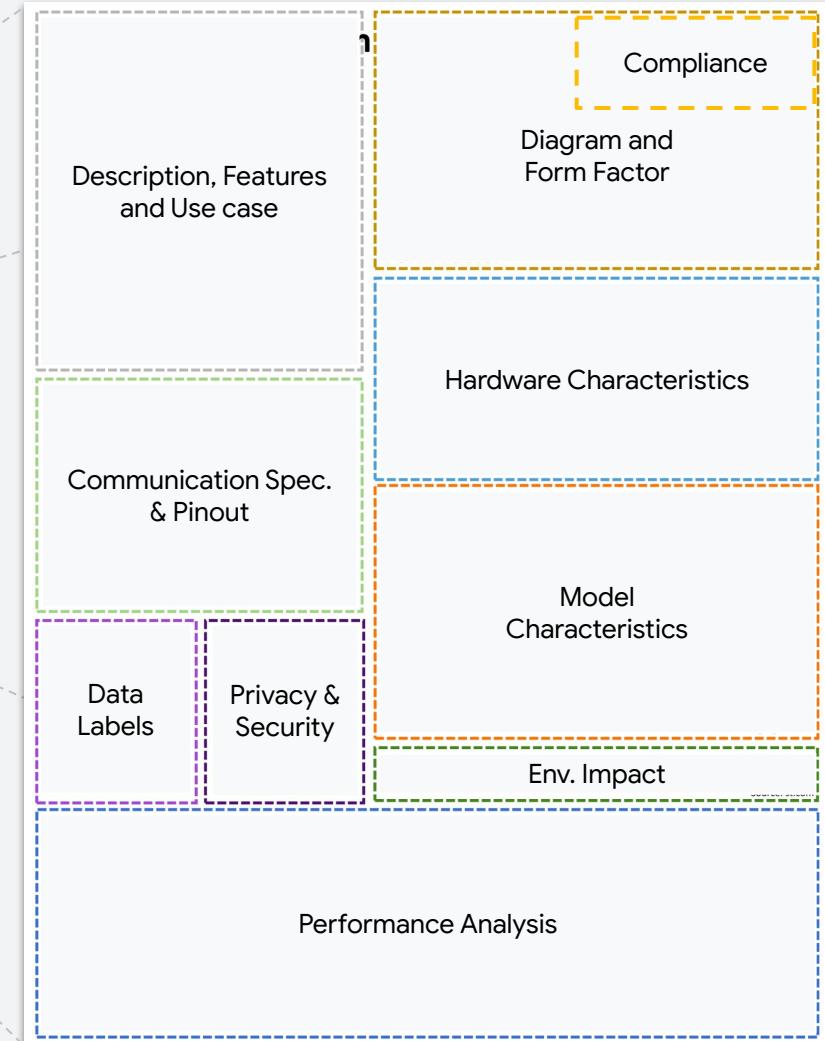
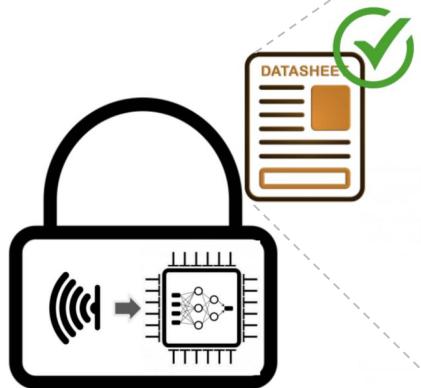
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E.g. ML Sensors Datasheets



E.g. ML Sensors Datasheets



PA1 Person Detection Module

Description: The PA1 Person Detection Module enables you to quickly and easily add smarts to your IoT deployment to monitor and detect for humans. You can use this module indoors and outdoors to understand where and when humans arrive at your deployment site.

Features:

- Real-time Person Detection with On-Device ML
- Indoor and Outdoor Detection
- Finds a person within a distance of 10 meters to a minimum distance of 1m
- Operates in low and high light environments (1-20000 Lux) across a wide temperature range (0 to 50 °C)
- Features Color and Black-and-White Detection Modules

Use Cases:

- Smart business and home security systems
- Multi-modal key word spotting for virtual assistants
- Occupancy sensors and other infrastructure sensors

Description, Features, and Use case

Source: docs.luxonis.com

Diagram and Form Factor

| Symbol | Rating | Min | Max | Unit |
|--------------------|-----------------------|------|------|------|
| V _{DD} | Recommended | 4.75 | 5.25 | V |
| I _{DD} | Maximum | 3.5 | 5.5 | V |
| I _{IN} | Maximum | 0 | 1.5 | A |
| I _{OUT} | Maximum | 8 | W | |
| I _{Power} | Idle Power Draw | 2.4 | 2.6 | W |
| T _{case} | Operating Temperature | 45 | 85 | °C |

Communication Spec. & Pinout

Sources: fabacademy.org, electroschematics.com, and exp.com/docs

| Pin | Name | Function |
|-----|--------------|---------------------------------|
| 1 | VCC | 14 GND (-) |
| 2 | Pin 10 | 13 Pin 0 (Analog Input 0, AREF) |
| 3 | Pin 9 | 12 Pin 1 (Analog Input 1) |
| 4 | Pin 8 | 11 Pin 2 (Analog Input 2) |
| 5 | (PWMA) Pin 8 | 10 Pin 3 (Analog Input 3) |
| 6 | (PWMB) Pin 7 | 9 Pin 4 (Analog Input 4, SCK) |

Hardware Characteristics

Hardware Characteristics

Source: docs.luxonis.com

Model Characteristics

Model performance: Measured with Precision-Recall (PR) and Area Under the PR Curve (PR-AUC). Download raw performance results data [here](#). Disaggregated performance measured with Recall, which captures specific characteristics. Equal recall across all conditions leads to the "Equality of Recall" criterion

Performance evaluated on:

- A subset of [Open Images](#)
- [Face Detection Data Set and Benchmark](#)
- [Labeled Faces in the Wild](#)

Source: modelcards.witsonai.com

Env. Impact

Environmental Impact: Full life cycle analysis can be found [here](#). 390g CO₂ eq 23L Water

Source: steam

Performance Analysis

False Positive Rate vs Distance from Nearest Static Object

Performance Analysis

False Positives per Hour

Distance from Sensor (cm)

Indoor (blue), Outdoor (orange), Low light (green)

Detection Accuracy

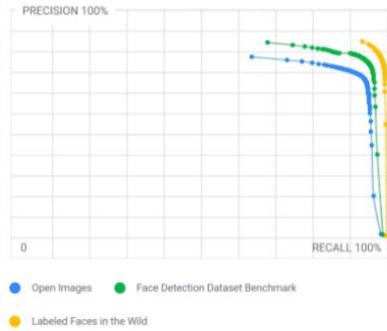
Distance to Nearest Dynamic Object

Distance from Sensor (cm)

27

Model Characteristics

"Model cards aim to provide a **concise, holistic picture of a machine learning model**. To start, a model card explains **what a model does**, its **intended audience**, and who **maintains it**. A model card also provides insight into the construction of the model, including **its architecture** and the **training data used**." – Google Cloud



Model performance:

Measured with [Precision-Recall \(PR\)](#) and [Area Under the PR Curve \(PR-AUC\)](#). Download raw performance results data [here](#). Disaggregated performance measured with [Recall](#), which captures how often the model misses faces with specific characteristics. Equal recall across subgroups corresponds to the "[Equality of Opportunity](#)" fairness criterion.

Performance evaluated on:

- A subset of [Open Images](#)
- [Face Detection Data Set and Benchmark](#)
- [Labeled Faces in the Wild](#)

Source: [modelcards.withgoogle.com](#)

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- Finds a person's location and tracks them across a minimum of 10m distance
- Operates in an ambient light range of 100-20000 Lux
- Features Color and Black-and-White Detection Modules

Use Cases:

- Smart business and home security systems
- Multi-modal key word spotting for virtual assistants
- Occupancy sensors and other infrastructure sensors

Description, Features, and Use Cases

Sources: [fabacademy.org](#), [electromechanics.com](#), and [esp.com/sites](#)



Communication Spec. & Pinout

Communication Specification and Pinout



Privacy & Security

IoT Security & Privacy Label



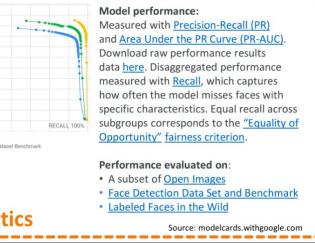
Compliance

Diagram and Form Factor

Source: [docs.amazonaws.com](#)

Hardware Characteristics

Hardware Characteristics



Source: [modelcards.withgoogle.com](#)

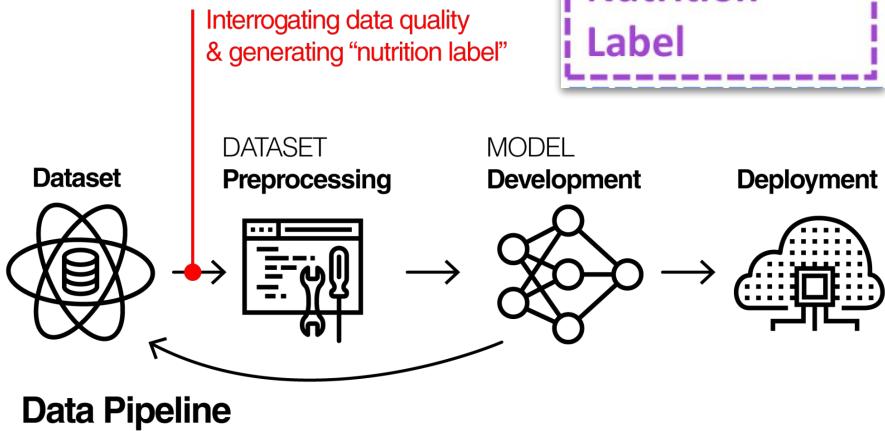
Env. Impact

Environmental Impact: Full Product Lifecycle

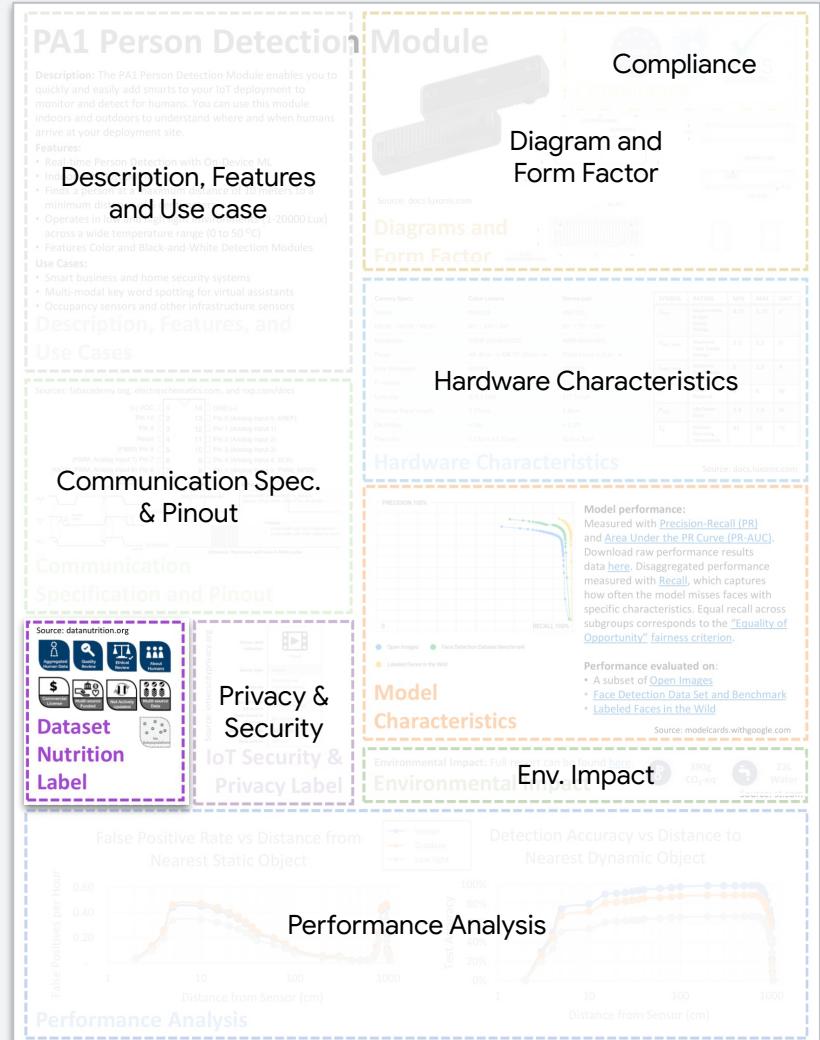
286g CO₂ eq

23L Water

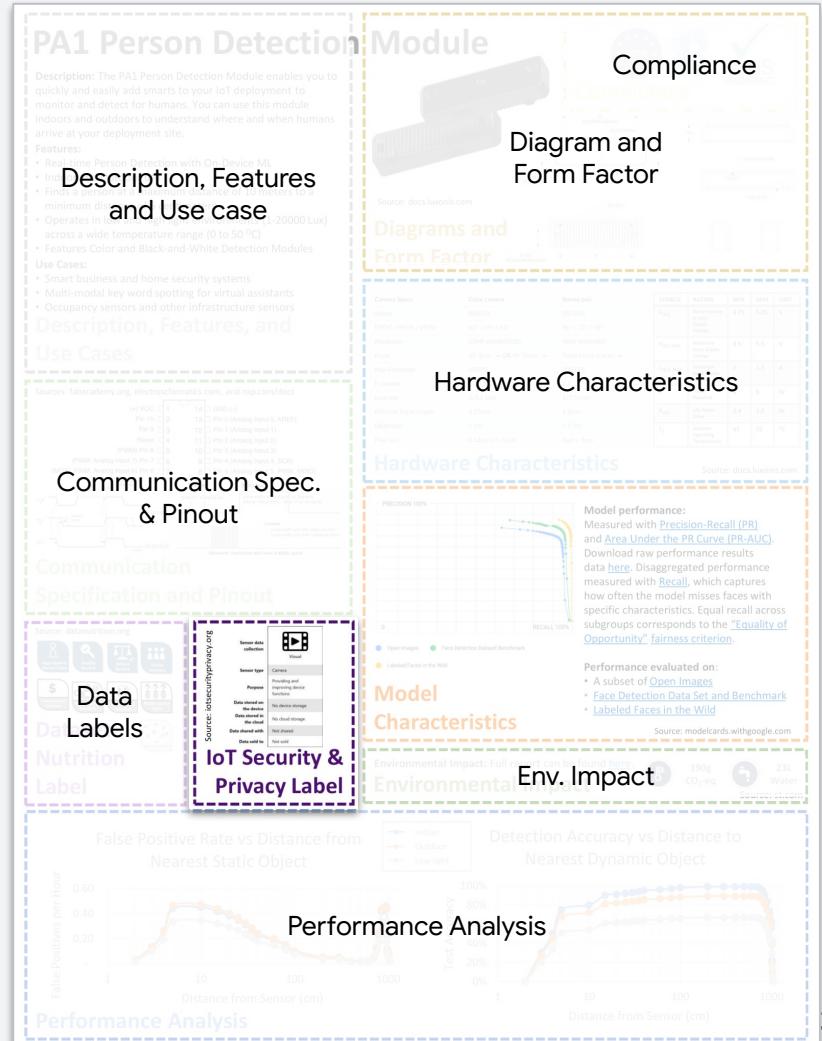
Source: [modelcards.withgoogle.com](#)

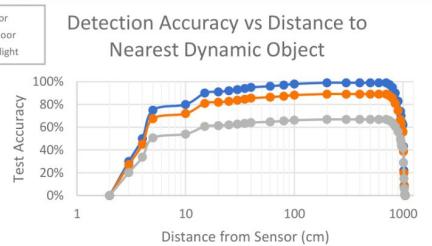
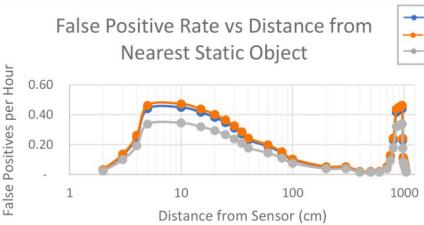


“There’s a missing step in the AI development pipeline: assessing datasets based on standard quality measures that are both qualitative and quantitative. We are working on packaging up these measures into an easy to use Dataset Nutrition Label.” - Dataset Nutrition Project



*“... designing a **usable security and privacy label** for smart devices to **help consumers** make informed choices about Internet of Things device purchases and encourage manufacturers to **disclose their privacy and security practices.**” – IoT Security & Privacy*





Performance Analysis

We require **systematic methodologies** to evaluate how an **end-to-end system** performs under **real-world conditions**

PA1 Person Detection Module

Description: The PA1 Person Detection Module enables you to quickly and easily add smarts to your IoT deployment to monitor and detect for humans. You can use this module indoors and outdoors to understand where and when humans arrive at your deployment site.

Features:

- Real-time Person Detection with Cloud Service API
- Indoor and Outdoor Detection
- Fine-grained Detection (e.g., Face, Head)
- Operates in Low Light Conditions (0.5 Lux - 20000 Lux) across a wide temperature range (0 to 50°C)
- Features Color and Black-and-White Detection Modules

User Cases:

- Smart business and home security systems
- Multi-modal key word spotting for virtual assistants
- Occupancy sensors and other infrastructure sensors

Description, Features, and Use cases

Source: docs.luxonis.com

Diagrams and Form Factor

Source: docs.luxonis.com

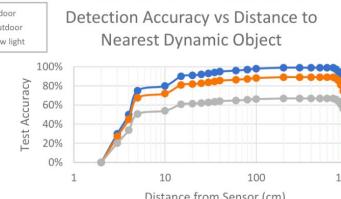
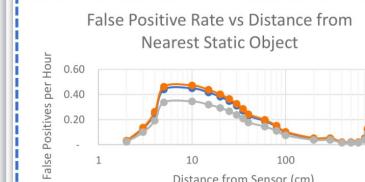
Hardware Characteristics

Source: docs.luxonis.com

Communication Spec. & Pinout

Source: fablabnyc.org, electronica-test.com, and naga.com/docs

| Pin No. | Name | Function |
|---------|-------------|--------------|
| 1 | GND | Ground |
| 2 | VDD | Power supply |
| 3 | PIR IN | PIR Input |
| 4 | PIR GND | PIR Ground |
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Performance Analysis

E.g.



Compliance

ML sensors ought to be **tested by 3rd party certification agencies or bodies that specialize in AI/ML technologies.**

PA1 Person Detection Module

Description: The PA1 Person Detection Module enables you to quickly and easily add smarts to your IoT deployment to monitor and detect for humans. You can use this module indoors and outdoors to understand where and when humans arrive at your deployment site.

Features

- Real-time Person Detection with On-Device ML
- Includes a color camera and a black-and-white camera with a minimum resolution of 1280x720 pixels
- Operates in an ambient light range of 100-20000 Lux across a wide temperature range (0 to 50 °C)
- Features Color and Black-and-White Detection Modules

Use Cases:

- Smart business and home security systems
- Multi-modal key word spotting for virtual assistants
- Occupancy sensors and other infrastructure sensors

Description, Features, and Use Cases

Sources: fabacademy.org, electronica-mag.com, and esp.com/sites

| Pin | Name | Function |
|-----|-----------|------------|
| 1 | VDD | Power |
| 2 | PIR | PIR Sensor |
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IoT ≈ The Internet of Trash?

Environmental Impact: Full report can be found [here](#).

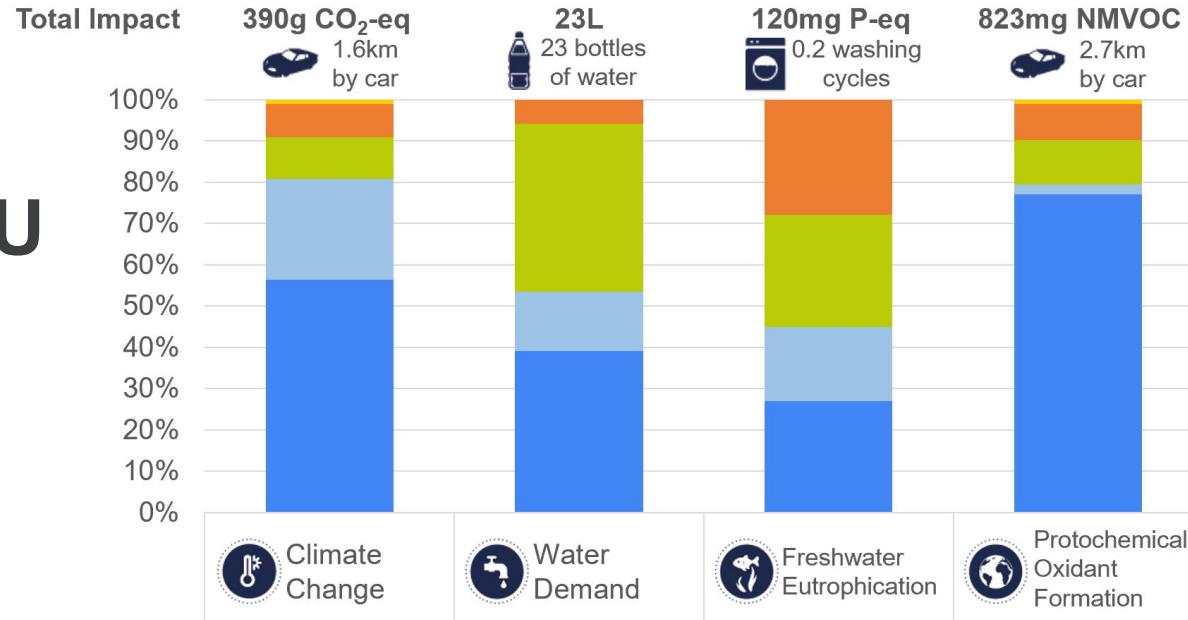
390g
CO₂-eq

source: st.com

Environmental Impact

We must quantify the effects of ML sensors in terms of carbon emissions. Carbon emissions have two sources: (1) **operational energy consumption**, and (2) **hardware manufacturing and infrastructure**. The former has been decreasing thanks to software and hardware innovations but the **total footprint is growing**.

Assessing the Environmental Impact of an MCU



Source:

https://www.st.com/content/st_com/en/about/st_approach_to_sustainability/sustainability-priorities/sustainable-technology/eco-design/footprint-of-a-microcontroller.html

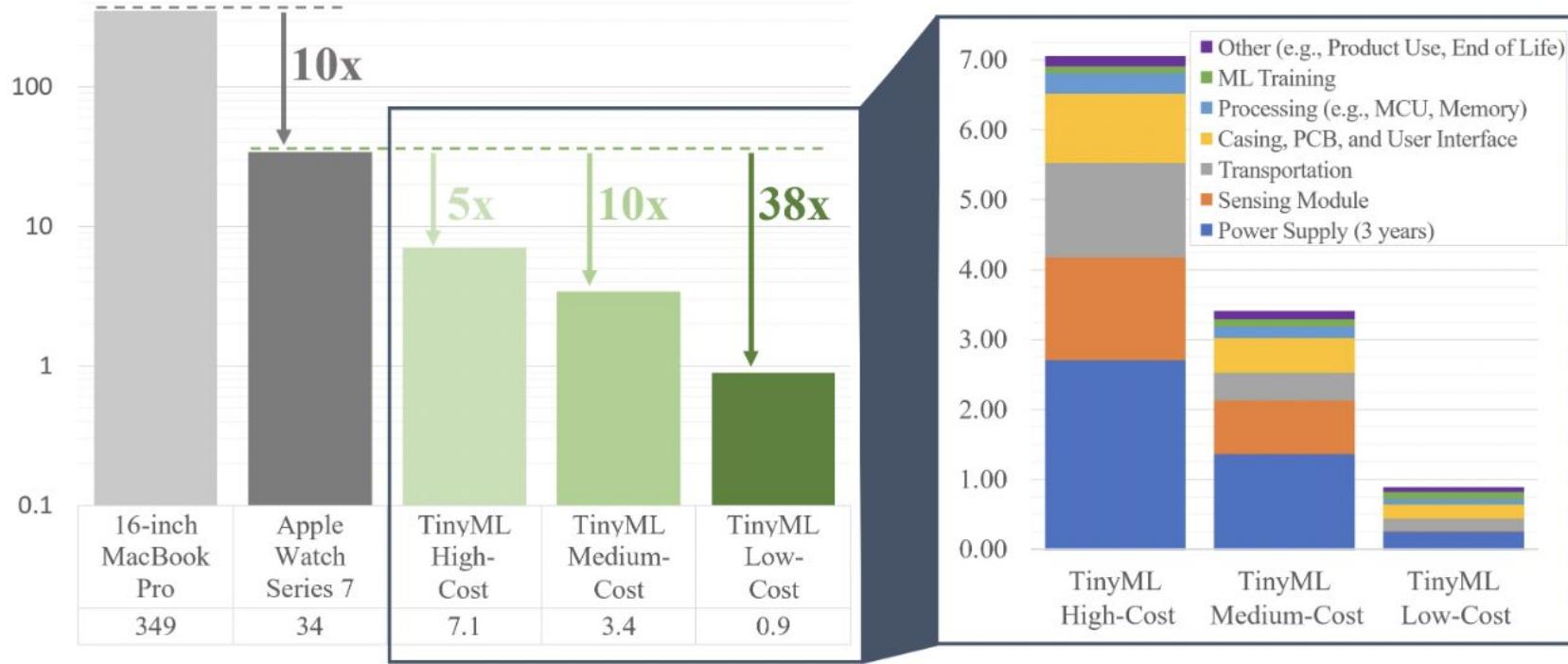
Total Life Cycle Emissions (kg CO₂-eq)

Figure 4. A breakdown of different TinyML system footprints highlights that the footprint is largely attributable to the embodied footprint of the power supply, onboard sensors, and transportation. Note that actuator and connectivity blocks from Pirson and Bol [21] are encapsulated in “Other” and “Processing”, respectively, while “Product Use” captures the operational footprint. The carbon footprint of TinyML Systems was also compared with Apple’s Series 7 Watch [12] and 16-inch MacBook Pro [11] as baseline references. For more details and to compute the footprint of your own TinyML system see github.com/harvard-edge/TinyML-Footprint.

ML Sensors - Guiding Set of Principles

1. We need to **raise the level of abstraction** to enable ease of use for scalable deployment of ML sensors; not everyone should be required to be a developer or an engineer to leverage ML sensors into their ecosystem.
2. The ML sensor's **design should be inherently data-centric** and defined by its input-output behavior instead of exposing the underlying hardware and software mechanisms that support ML model execution.
3. An ML sensor's **implementation must be clean and complexity-free**. Features such as reusability, software updates, and networking must be thought through to ensure data privacy and secure execution.
4. ML sensors **must be transparent**, indicating in a publicly and freely accessible ML sensor datasheet all the relevant information to supplement the traditional information available for hardware sensors.
5. We as a community should aim to **foster an open ML sensors ecosystem by maximizing data, model, and hardware transparency** where possible, without necessarily relinquishing any claim to intellectual property.

[TinyML](#)[Harvard](#)[MLC](#)[Research](#)[Seeed](#)[CS141](#)[TimeBuddy](#)[VJs Funding](#)[Enterprise - Suppl...](#)[Geo Chart Exampl...](#)[Other Bookmarks](#)

MLSensors

Machine Learning Sensors

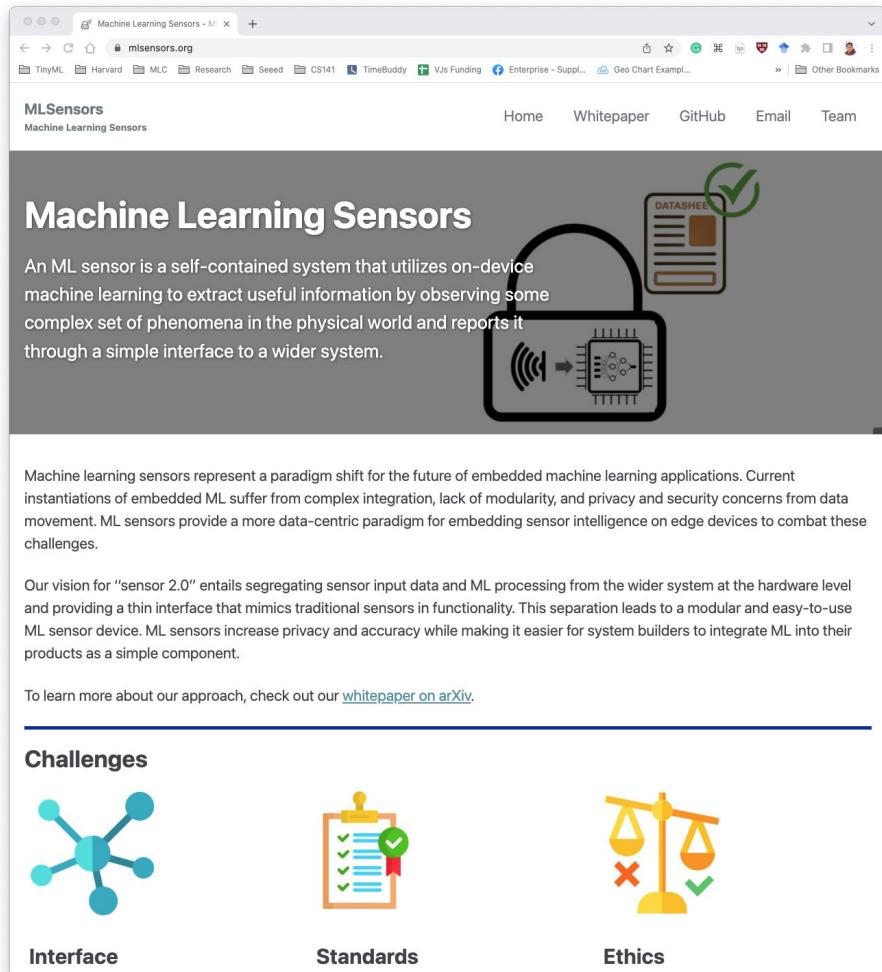
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Machine Learning Sensors

An ML sensor is a self-contained system that utilizes on-device machine learning to extract useful information by observing some complex set of phenomena in the physical world and reports it through a simple interface to a wider system.



Machine learning sensors represent a paradigm shift for the future of embedded machine learning applications. Current instantiations of embedded ML suffer from complex integration, lack of modularity, and privacy and security concerns from data

Machine Learning Sensors - M... 

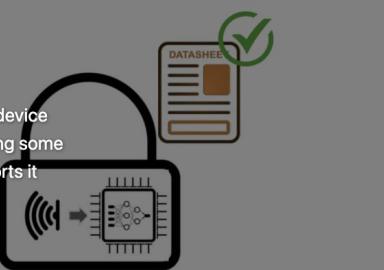
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Machine Learning Sensors

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Machine Learning Sensors



An ML sensor is a self-contained system that utilizes on-device machine learning to extract useful information by observing some complex set of phenomena in the physical world and reports it through a simple interface to a wider system.

Machine learning sensors represent a paradigm shift for the future of embedded machine learning applications. Current instantiations of embedded ML suffer from complex integration, lack of modularity, and privacy and security concerns from data movement. ML sensors provide a more data-centric paradigm for embedding sensor intelligence on edge devices to combat these challenges.

Our vision for "sensor 2.0" entails segregating sensor input data and ML processing from the wider system at the hardware level and providing a thin interface that mimics traditional sensors in functionality. This separation leads to a modular and easy-to-use ML sensor device. ML sensors increase privacy and accuracy while making it easier for system builders to integrate ML into their products as a simple component.

To learn more about our approach, check out our [whitepaper on arXiv](#).

Challenges



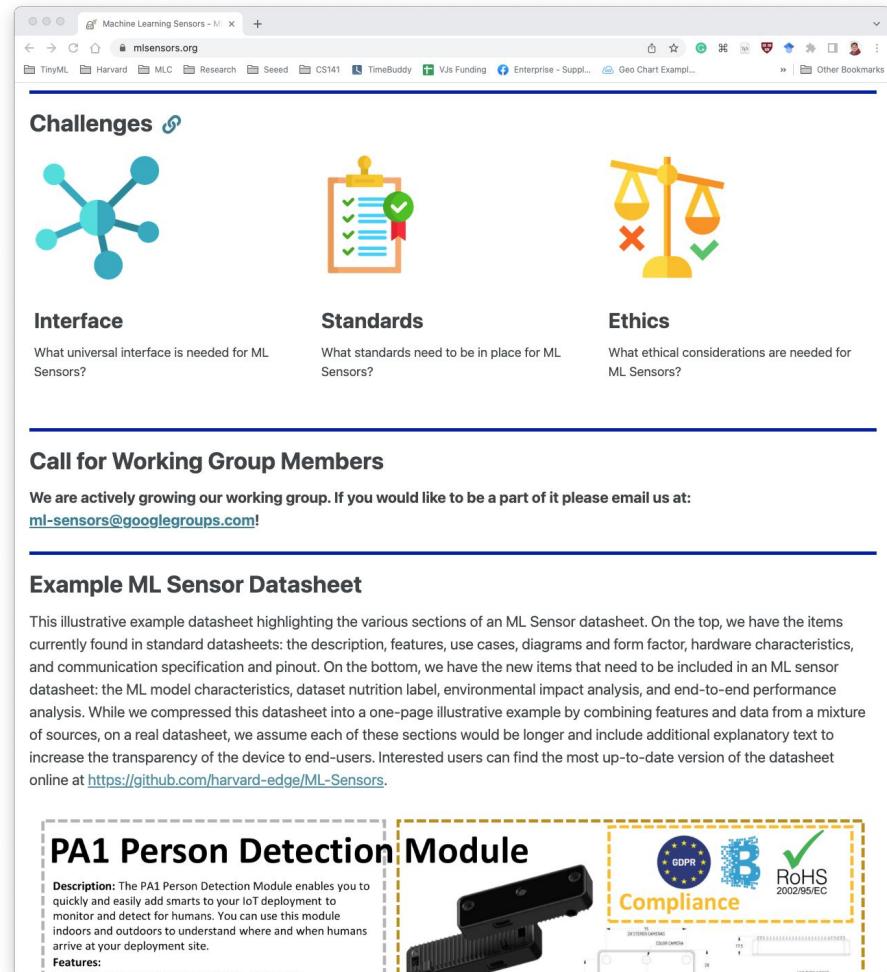
Interface



Standards



Ethics

Machine Learning Sensors - M... 

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Challenges





Interface
What universal interface is needed for ML Sensors?

Standards
What standards need to be in place for ML Sensors?

Ethics
What ethical considerations are needed for ML Sensors?

Call for Working Group Members

We are actively growing our working group. If you would like to be a part of it please email us at: ml-sensors@googlegroups.com!

Example ML Sensor Datasheet

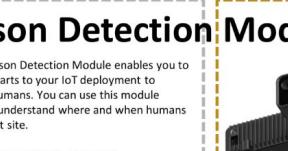
This illustrative example datasheet highlighting the various sections of an ML Sensor datasheet. On the top, we have the items currently found in standard datasheets: the description, features, use cases, diagrams and form factor, hardware characteristics, and communication specification and pinout. On the bottom, we have the new items that need to be included in an ML sensor datasheet: the ML model characteristics, dataset nutrition label, environmental impact analysis, and end-to-end performance analysis. While we compressed this datasheet into a one-page illustrative example by combining features and data from a mixture of sources, on a real datasheet, we assume each of these sections would be longer and include additional explanatory text to increase the transparency of the device to end-users. Interested users can find the most up-to-date version of the datasheet online at <https://github.com/harvard-edge/ML-Sensors>.

PA1 Person Detection Module

Description: The PA1 Person Detection Module enables you to quickly and easily add smarts to your IoT deployment to monitor and detect for humans. You can use this module indoors and outdoors to understand where and when humans arrive at your deployment site.

Features:

- Real-time Person Detection with On Device AI



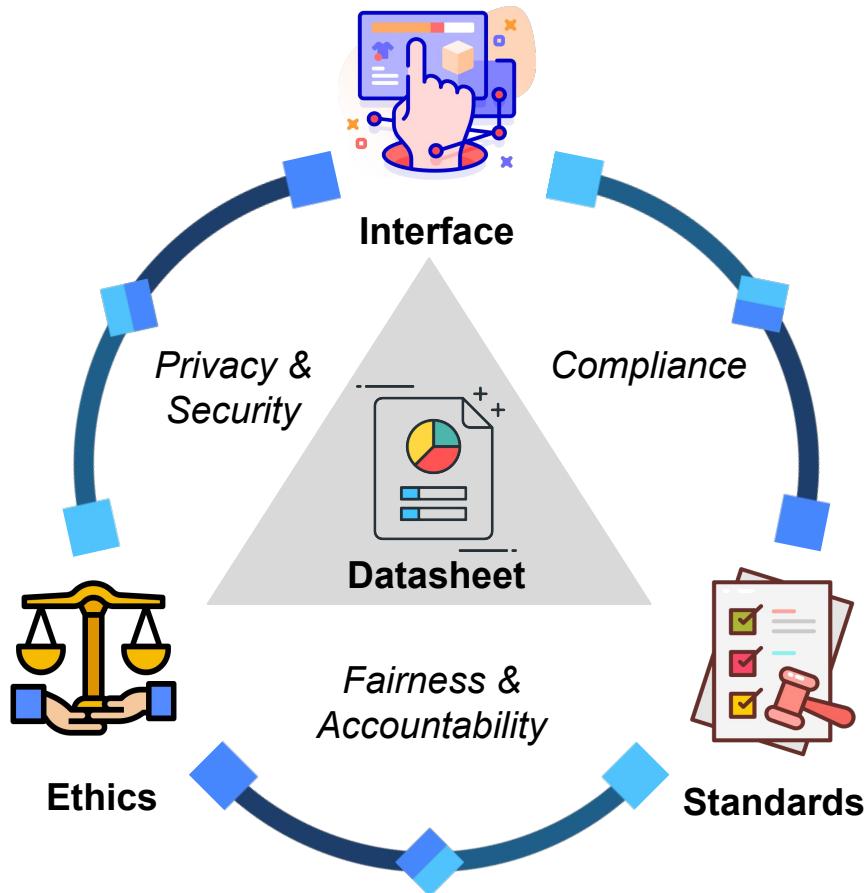

Recap of ML Sensors

1. We need to **raise the level of abstraction** to enable ease of use for scalable deployment of ML sensors; not everyone should be required to be a developer or an engineer to leverage ML sensors into their ecosystem.
2. The ML sensor's **design should be inherently data-centric** and defined by its input-output behavior instead of exposing the underlying hardware and software mechanisms that support ML model execution.
3. An ML sensor's **implementation must be clean and complexity-free**. Features such as reusability, software updates, and networking must be thought through to ensure data privacy and secure execution.
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5. We as a community should aim to **foster an open ML sensors ecosystem by maximizing data, model, and hardware transparency** where possible, without necessarily relinquishing any claim to intellectual property.

Call to Action

Radcliffe exploratory seminar to determine:

-  What ethical considerations are necessary when developing ML sensors?
-  What compliance standards must be met by ML sensor developer and manufacturers?
-  How should ML sensors interface with existing systems?



mlsensors.org

<https://github.com/harvard-edge/ML-Sensors>

arXiv:2206.03266v1 [cs.LG] 7 Jun 2022

MACHINE LEARNING SENSORS

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Zain Asgar¹ Sachin Katti¹ Vijay Janapa Reddi²

¹Stanford University ²Harvard University

ABSTRACT

Machine learning sensors represent a paradigm shift for the future of embedded machine learning applications. Current instantiations of embedded machine learning (ML) suffer from complex integration, lack of modularity, and privacy and security concerns from data movement. This article proposes a more data-centric paradigm for embedding sensor intelligence on edge devices to combat these challenges. Our vision for “sensor 2.0” entails segregating sensor input data and ML processing from the wider system at the hardware level and providing a thin interface that mimics traditional sensors in functionality. This separation leads to a modular and easy-to-use ML sensor device. We discuss challenges presented by the standard approach of building ML processing into the software stack of the controlling microprocessor on an embedded system and how the modularity of ML sensors alleviates these problems. ML sensors increase privacy and accuracy while making it easier for system builders to integrate ML into their products as a simple component. We provide examples of prospective ML sensors and an illustrative datasheet as a demonstration and hope that this will build a dialogue to progress us towards sensor 2.0.

1 INTRODUCTION

Since the advent of AlexNet [43], deep neural networks have proven to be robust solutions to many challenges that involve making sense of data from the physical world. Machine learning (ML) models can now run on low-cost, low-power hardware capable of deployment as part of an embedded device. Processing data close to the sensor on an embedded device allows for an expansive new variety of always-on ML use-cases that preserve bandwidth, latency, and energy while improving responsiveness and maintaining data privacy. This emerging field, commonly referred to as embedded ML or tiny machine learning (TinyML) [73, 18, 39, 59], is paving the way for a prosperous new array of use-cases, from personalized health initiatives to improving manufacturing productivity and everything in-between.

However, the current practice for combining inference and sensing is cumbersome and raises the barrier of entry to embedded ML. At present, the general design practice is to design or leverage a board with decoupled sensors and compute (in the form of a microcontroller or DSP), and for the developer to figure out how to run ML on these embedded platforms. The developer is expected to train and optimize ML models and fit them within the resource constraints of the embedded device. Once an acceptable prototype implementation is developed, the model is integrated with the rest of the software on the device. Finally, the widget is tethered to the device under test to run inference. The current approach is slow, manual, energy-inefficient, and error-prone.

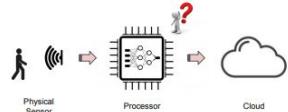


Figure 1. The Sensor 1.0 paradigm tightly couples the ML model with the application processor and logic, making it difficult to provide hard guarantees about the ML sensor’s ultimate behavior.

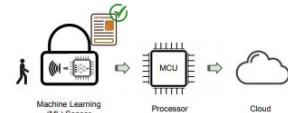


Figure 2. Our proposed Sensor 2.0 paradigm. The ML model is tightly coupled with the physical sensor, separate from the application processor, and comes with an ML sensor datasheet that makes its behavior transparent to the system integrators and developers.

It requires a sophisticated understanding of ML and the intricacies of ML model implementations to optimize and fit a model within the constraints of the embedded device.