Industrial IoT and Big Data: Keeping your Plant at the Sharp Edge of the Tool

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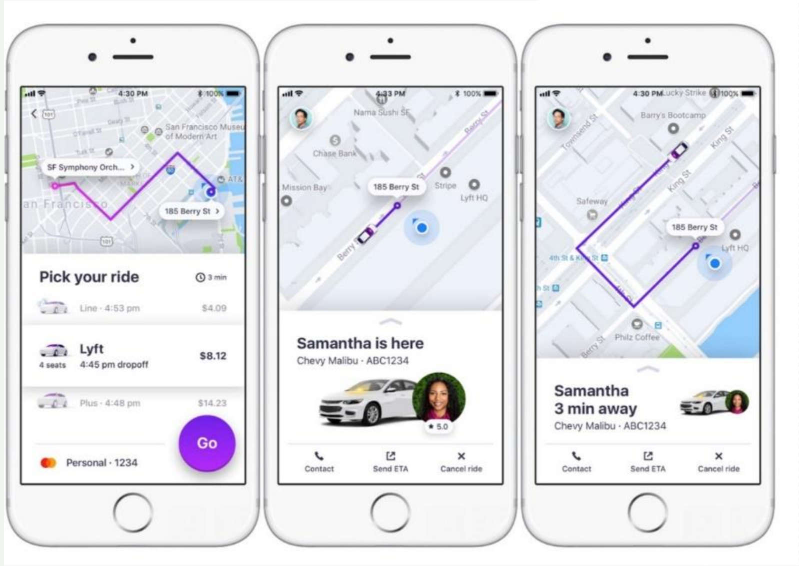
SME Southtec
Greenville, SC

IOT for the consumer sector



Complementary developments

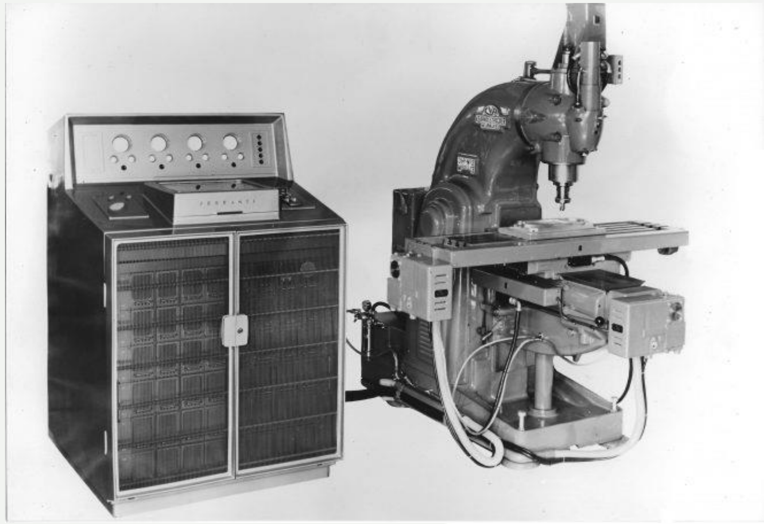
1980s

2000s

2010s

Industry 3.0 → **Industry 4.0**

1950s



1990s

2000s, 2010s

MTConnect
The Bridge to CNC Machine Data Collection
OPC UA

Manufacturing Data Problems

Georgia Tech

SOTA connectivity:

MTConnect (Ethernet)

Data types:

OEE
Utilization
Consumable levels
Process conditions
P/M

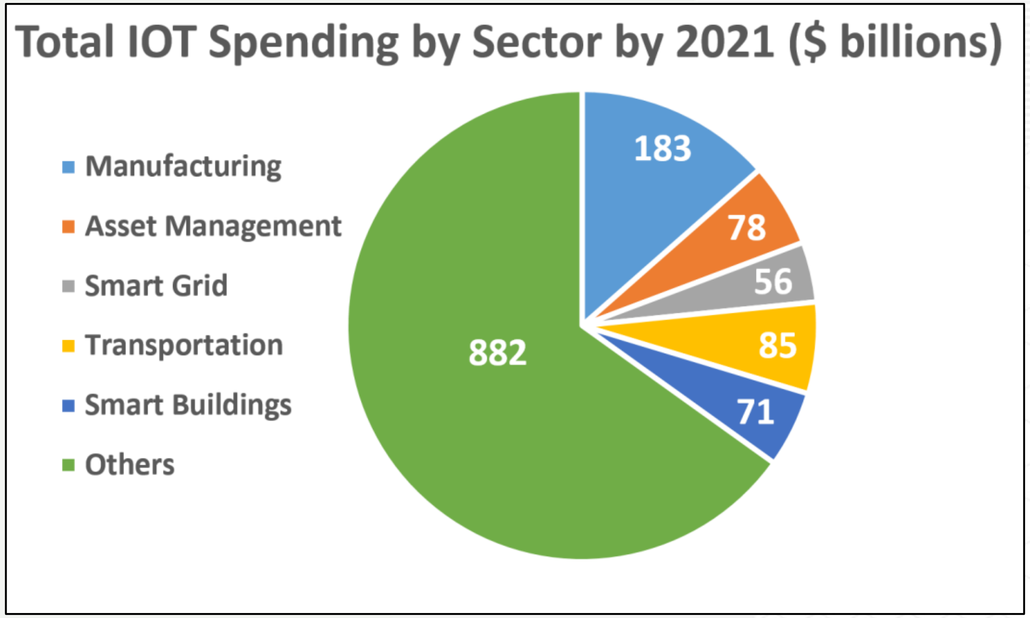
Sensor types:

Accelerometers
Strain gauges
Fluid level sensors
Thermocouples
Microphones
Imaging sensors

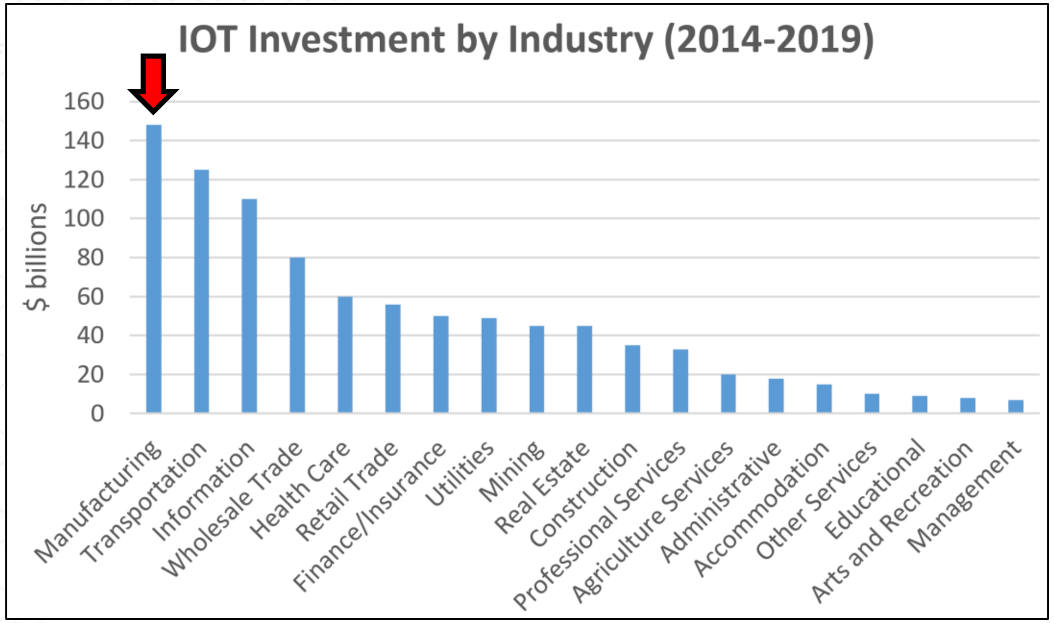
Market Opportunity for IIOT

Implications for manufacturing:

- Enhanced productivity and asset/resource utilization
- Digital thread / process monitoring and simulation
- Preventative maintenance and data analytics



IDC's Worldwide Semiannual Internet of Things Spending Guide, 2017.



Business Insider, Business Intelligence Report, 2015.

Manufacturing System Views

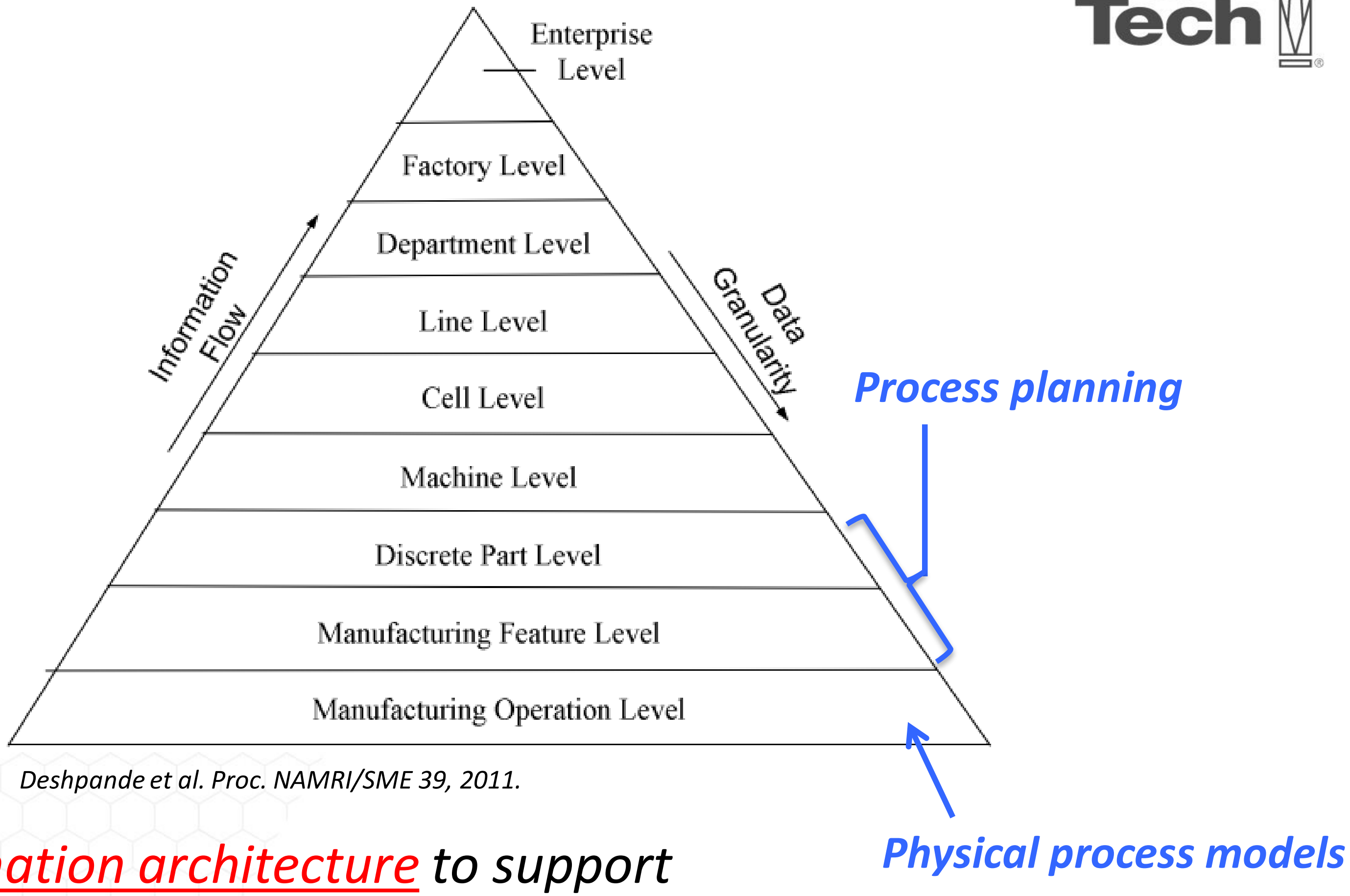
Multiple system levels

Process / machine

Cell

Facility

Enterprise



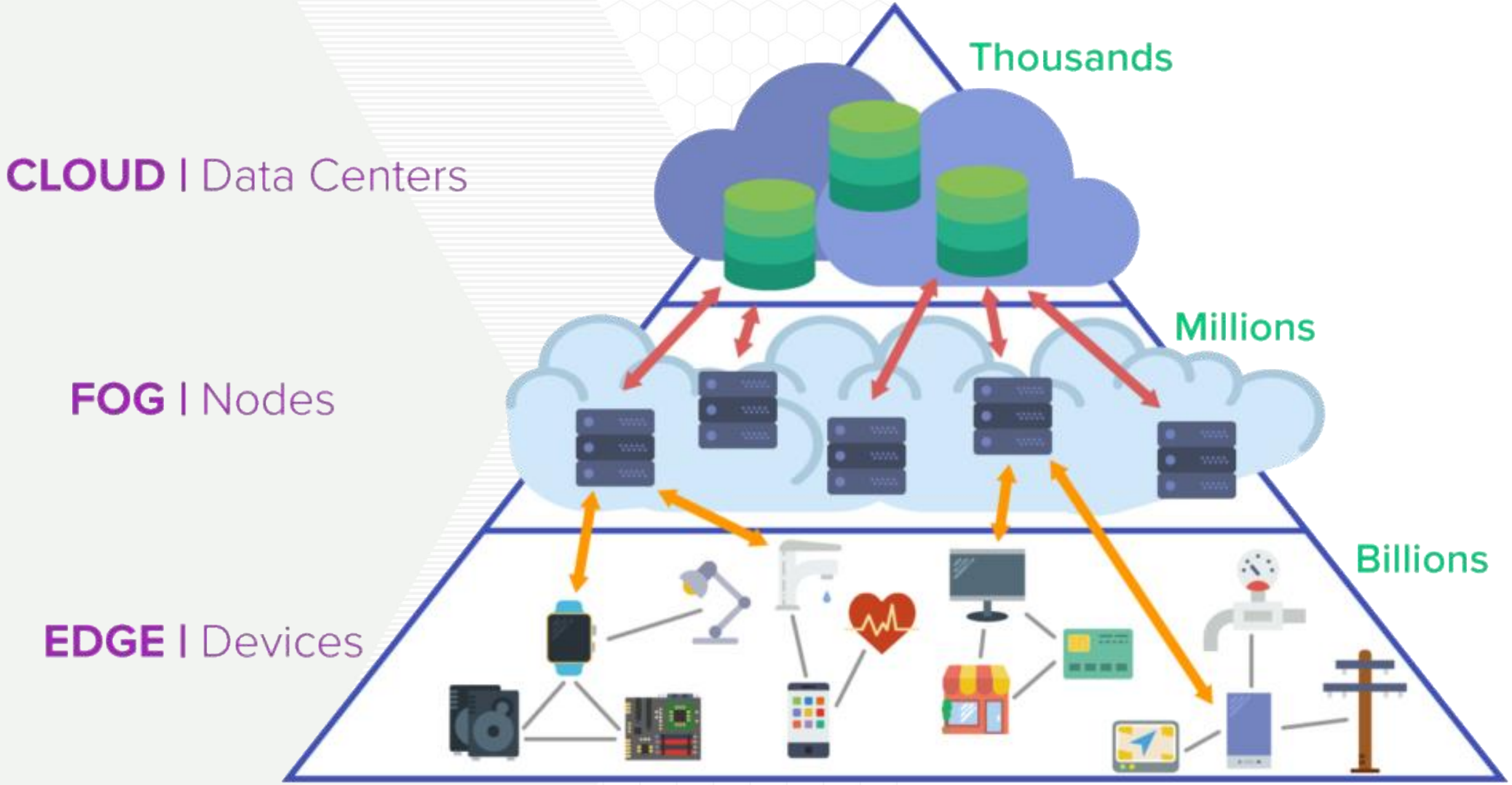
Deshpande et al. Proc. NAMRI/SME 39, 2011.

Data characteristics

Information flow, Granularity

Need computational methods and information architecture to support integration of data from predictive models across system hierarchy to optimize manufacturing performance

Computing for Manufacturing (IIOT)



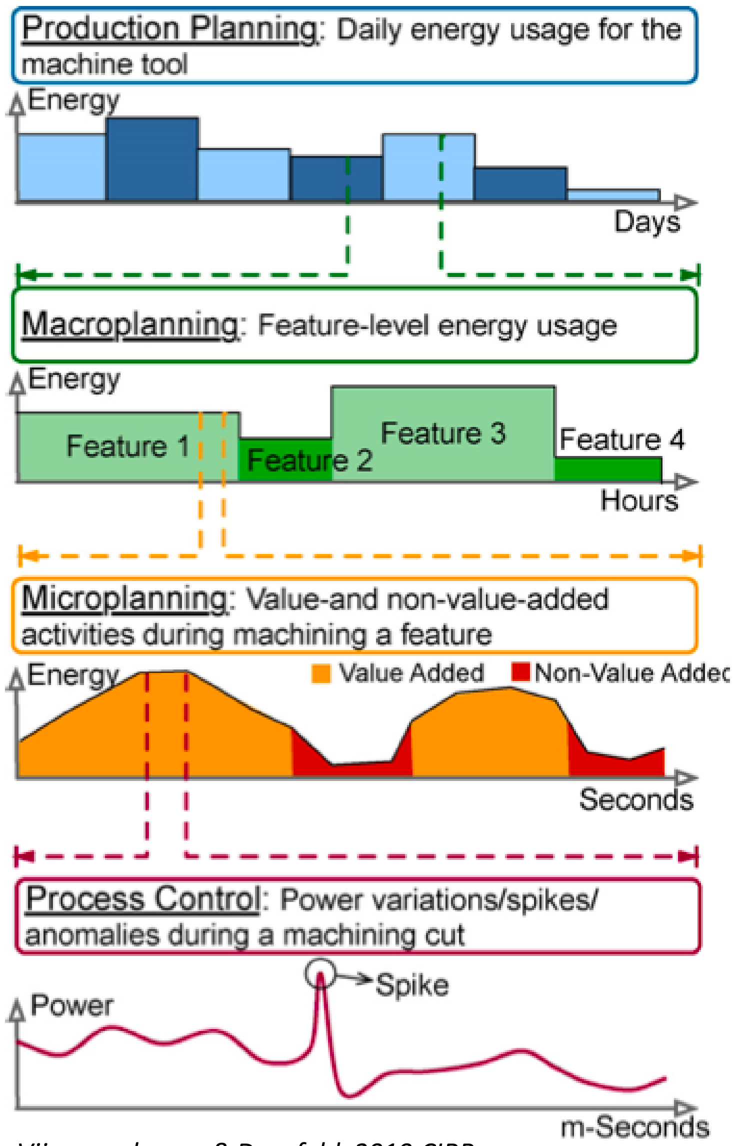
Smart Manufacturing and Sensing

Sensing modalities:

- Indirect versus direct measurements
- Post-process versus in situ sensing

Example: energy usage monitoring/planning

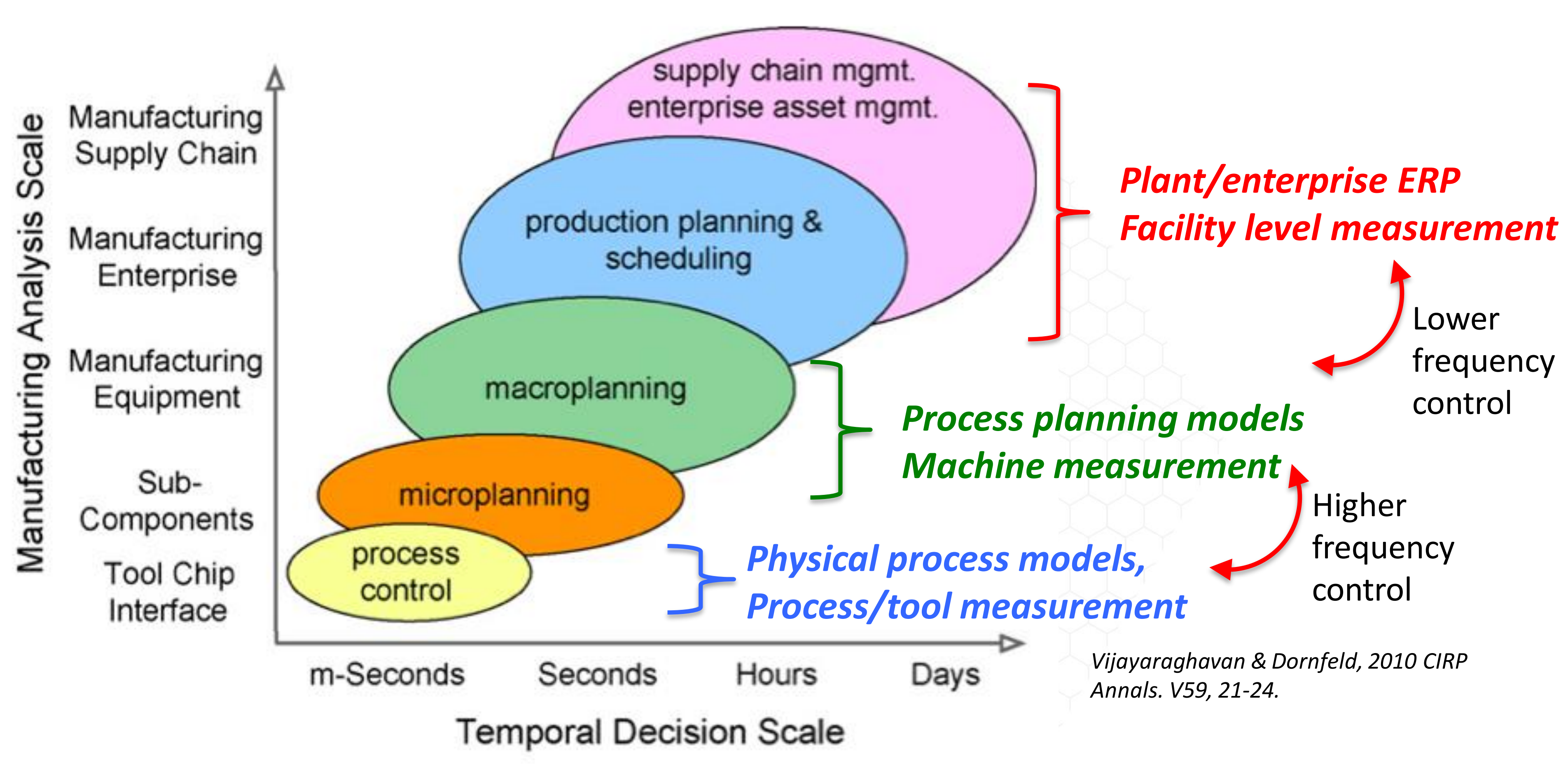
- Concurrent monitoring energy use with process data
- Standardized data sources
- Scalable architecture for large data volumes
- Modular architecture to support analysis across different manufacturing scales



Vijayaraghavan & Dornfeld, 2010 CIRP Annals. V59, 21-24.

Role of Process Modeling/Measurement

Georgia Tech



Vijayaraghavan & Dornfeld, 2010 CIRP Annals. V59, 21-24.

Need protocols for linking physical process models/measurements with process planning/control systems

Modern vs. Legacy Equipment

MTConnect-compatible
Web-accessible
2010-present
More common at LEs

Zero connectivity
Hardware retrofits needed
1980s-present
Major base at SMEs and LEs

Connectivity Landscape

Technology cases: retrofit vs. native compatibility

Equipment needs: broad diversity in mix of equipment platforms and technologies

Data needs: significant variability in terms of what data is needed, as well as how and when these data should be sensed

Security: poor integration of industrially hardened cybersecurity network equipment platforms for decoupling sensitive and costly capital equipment from network intrusion and associated malware risks

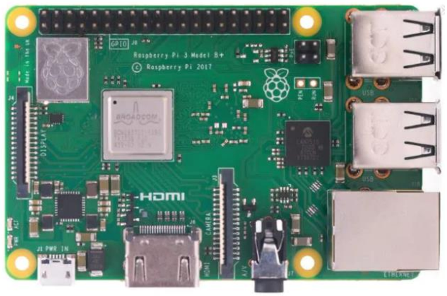
Low Cost Machine IIOT Retrofit

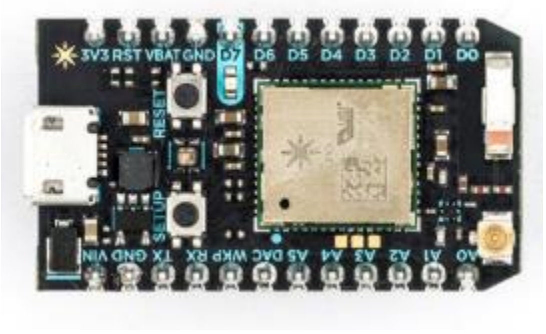
Goal: Deploy network-secured, scalable retrofit kit for flexible machine sensing in a range of production environments with legacy and/or modern machine equipment.

Architecture: Reconfigurable retrofit kit (RRK) built upon an industrially hardened communications platform for isolating machine tools from network intrusion and will facilitate reconfigurable sensing using wired and/or wireless protocols.

Use case: Low cost retrofit, <$1000 per machine cost

Implementation: Data Acquisition





IoT Devices

- Low cost microprocessors
- Raspberry Pi/Arduino/Particle
- Open source platform, large user base
- Can act as Gateway to message broker

Sensors

- Quality sensors depending on needs
- Integrated into kit that can deployed directly on a machine

Machine Interfaces

- MTConnect/OPC-UA communication protocol
- IoT Device interfaces with machine to transmit data

Implementation: Data Storage

Physical server bank

- Upfront initial cost, little to no operating cost
- Requires real estate in production facility
- Finite storage/processing capacity

Cloud based computing (AWS/Azure)

- Virtual machines (VMs) in cloud
- Flexible infrastructure, VMs can be started/stopped as needed
- High operating cost—charged for machine use hours and amount of data transmitted

Implementation: Software

Majority free Open Source platforms

Node Red

- Flow based programming using JavaScript
- Deployed on both edge devices and user interfaces

Python

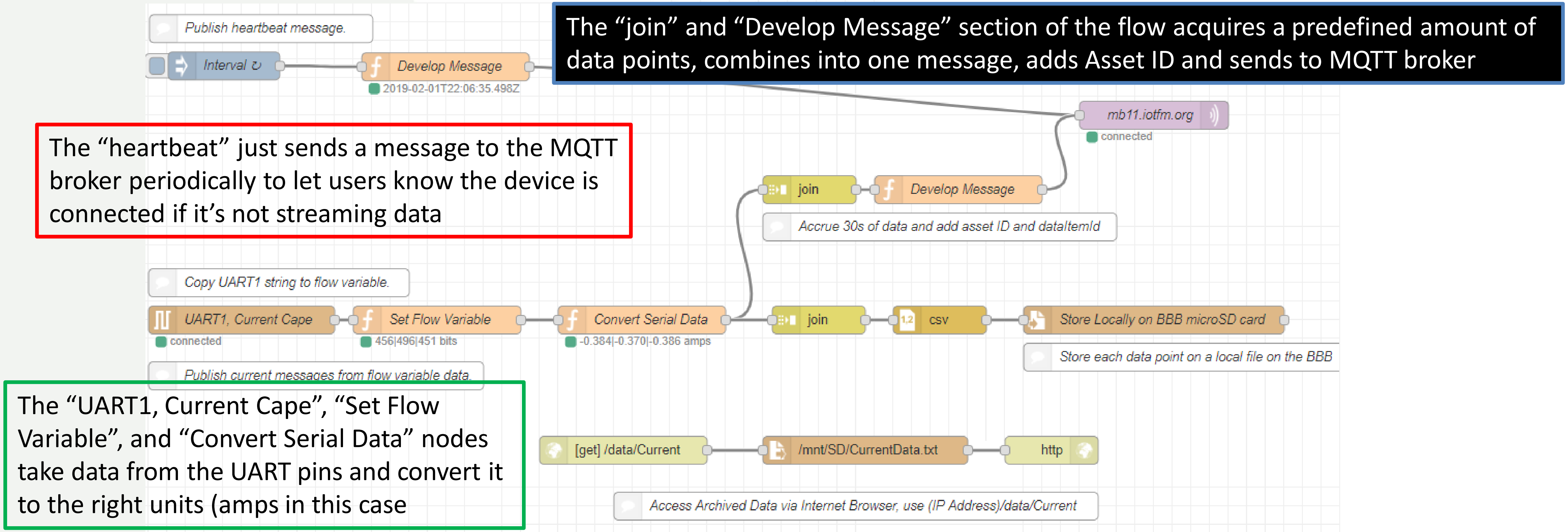
- Intuitive programming language

MySQL

- Simple commands as mentioned earlier

Implementation: Software

Node Red Programming Environment



Implementation: Connectivity

Wired (Ethernet or offline data acquisition)

- More stable connection
- Faster transmission
- Less versatility in machine integration

Wireless (WiFi connected)

- Less stable connection (low coverage areas)
- Slower transmission
- High versatility for machine integration

Implementation: Connectivity

Internet vs. Intranet

- Largely the same digital architecture
- Internet: devices/users connected globally
    - Higher risk of security breach
    - Data is accessible globally
    - Enables use of cloud computing
- Intranet: device/users kept on local network
    - Lower risk of security breach
    - Data only available if on local network
    - Requires use of hardware servers

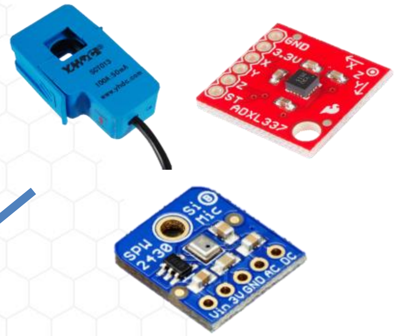
Reconfigurable Sensing Solutions

<u>RRK user-specific data</u>

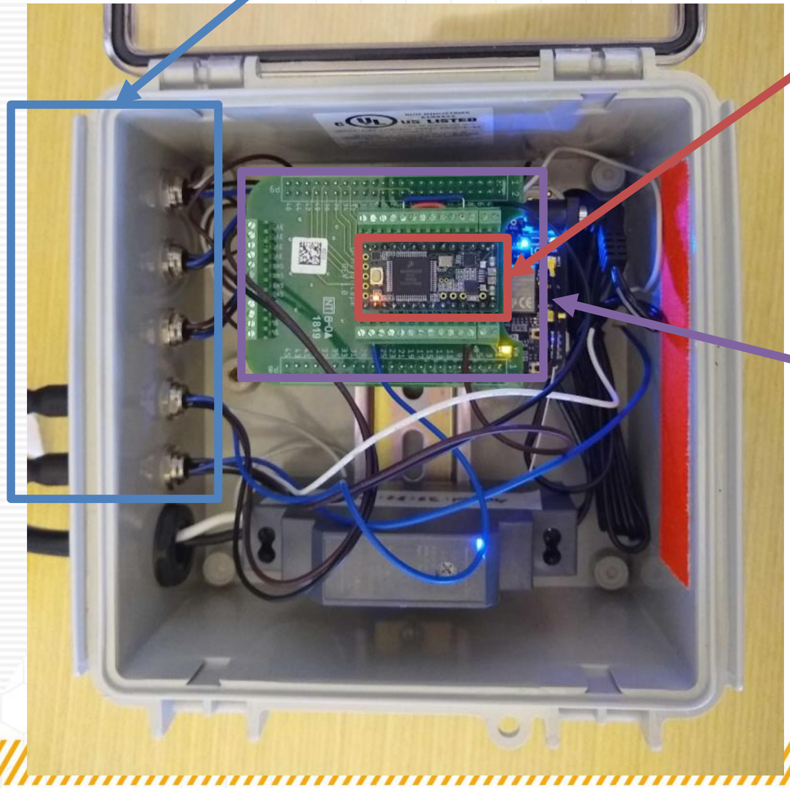
Spindle diagnostics
Process dynamics
Crash detection
Fluid monitoring

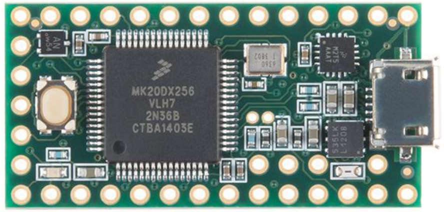
Multifunctional IIOT sensor kit

Georgia Tech

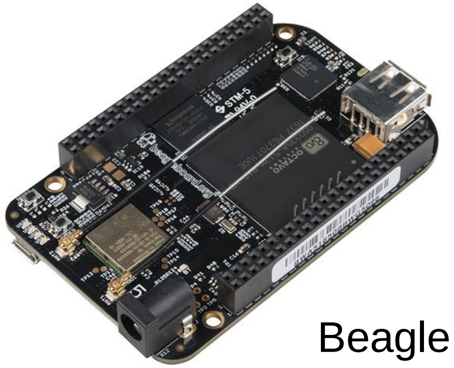


Sensor Ports
(Supports up to 5 analog or digital sensors using standard communication protocols)





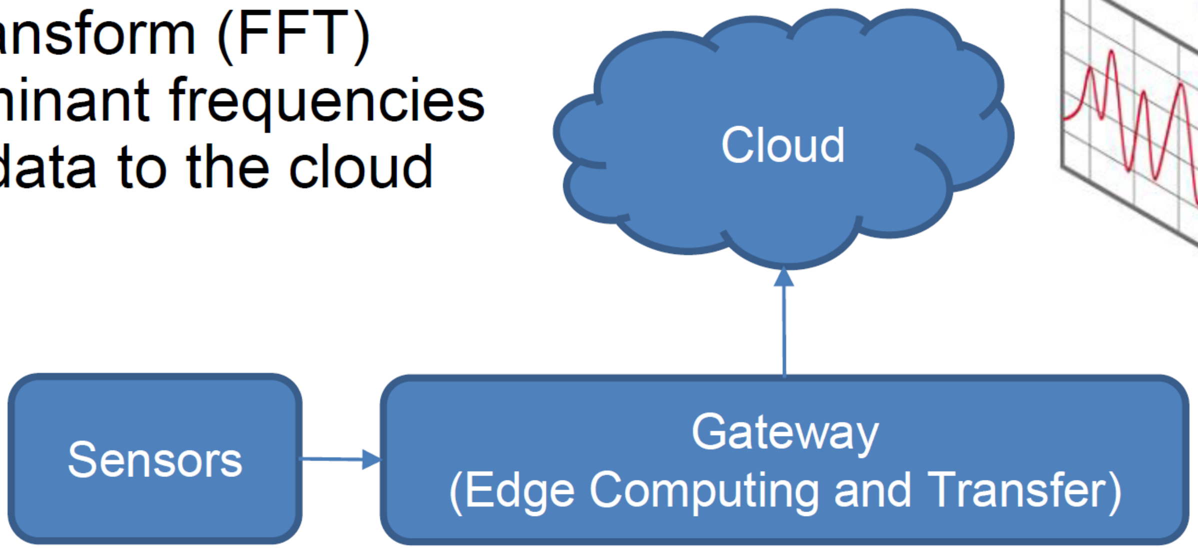
Teensy 3.2
(I/O Device)

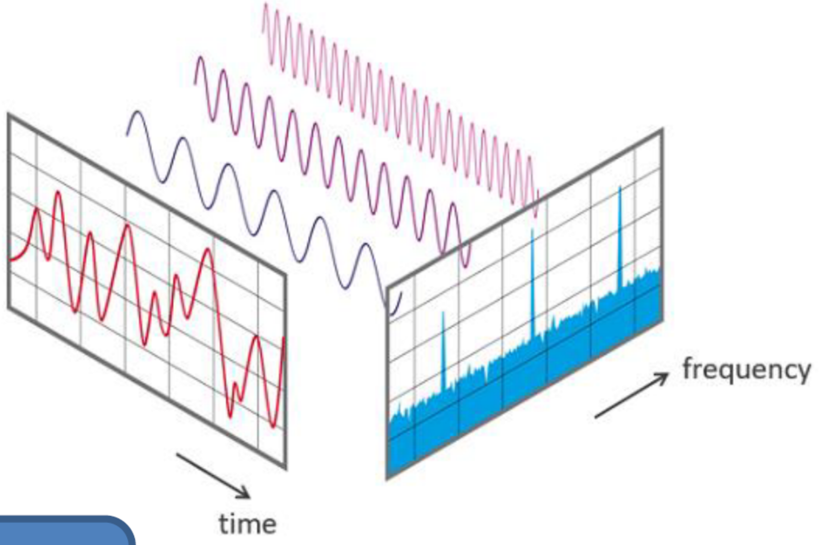


BeagleBone Wireless
(Edge Computing and Data Transmission)

Edge Spindle Vibration IoT Kit

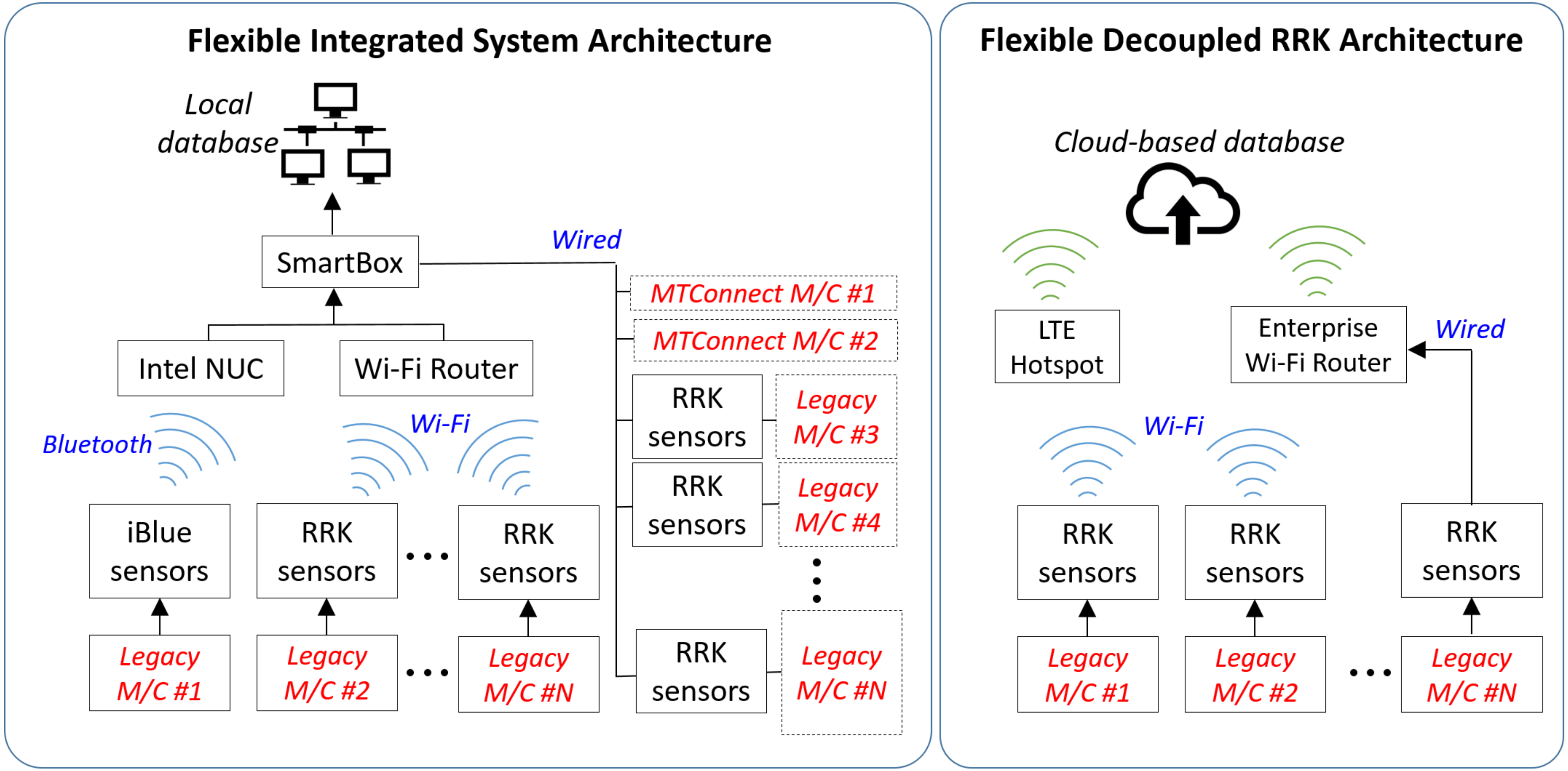
- Standalone sensor packs, compatible with legacy machines
- Shock monitoring
  - Detect shocks more than a specified threshold
  - Send alerts, publish the data to the cloud
- Fast Fourier transform (FFT)
  - Find out dominant frequencies
  - Publish the data to the cloud





Local Shop Network Architectures

System elements and configuration



Machine Monitoring Architecture

Two methods of communication

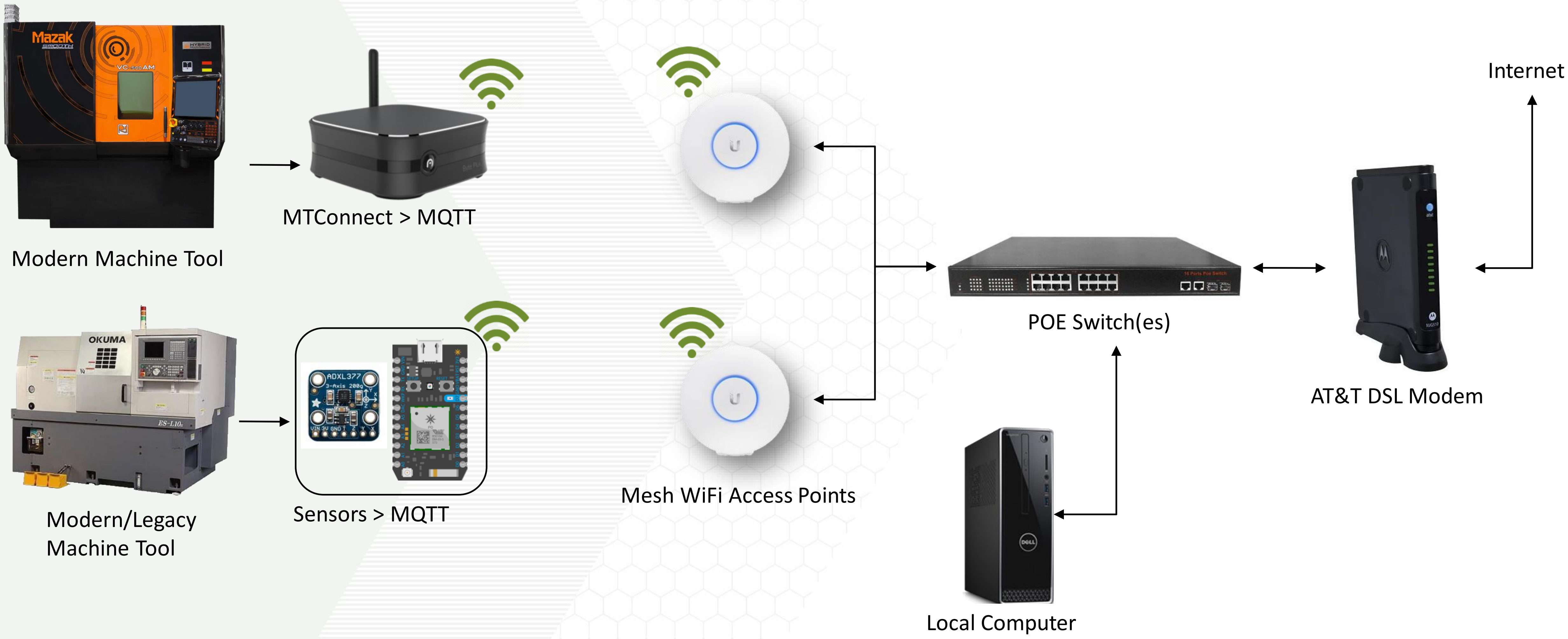
- Industry standards
- Wireless sensors


```xml
<?xml version="1.0" encoding="UTF-8"?>
<?xml-stylesheet type="text/xsl" href="/styles/Streams.xsl"?>
<MTConnectStreams xmlns:m="urn:mtconnect.org:MTConnectStreams:1.3" xmlns="urn:mtconnect.org:MTConnectStreams:1.3" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="urn:mtconnect.org:MTConnectStreams:1.3 /schemas/MTConnectStreams_1.3.xsd">
  <Header creationTime="2017-04-13T14:47:50Z" sender="mtcagent" instanceId="1490681234" version="1.3.0.9" bufferSize="131072" nextSequence="322198611"
firstSequence="322067539" lastSequence="322198610"/>
  <Streams>
    <DeviceStream name="VMC-3Axis" uuid="000">
      <ComponentStream component="Rotary" name="C" componentId="c1">
        <Samples>
          <SpindleSpeed dataItemId="c2" timestamp="2017-04-13T14:47:37.365095" name="Sspeed" sequence="322198610" subType="ACTUAL">0.0000000000</SpindleSpeed>
          <SpindleSpeed dataItemId="c3" timestamp="2017-04-13T14:44:44.275173" name="Sovr" sequence="322143236" subType="OVERRIDE">100.0000000000</SpindleSpeed>
          <Load dataItemId="cl3" timestamp="2017-03-28T06:07:14.731817Z" name="Cload" sequence="15">UNAVAILABLE</Load>
        </Samples>
```

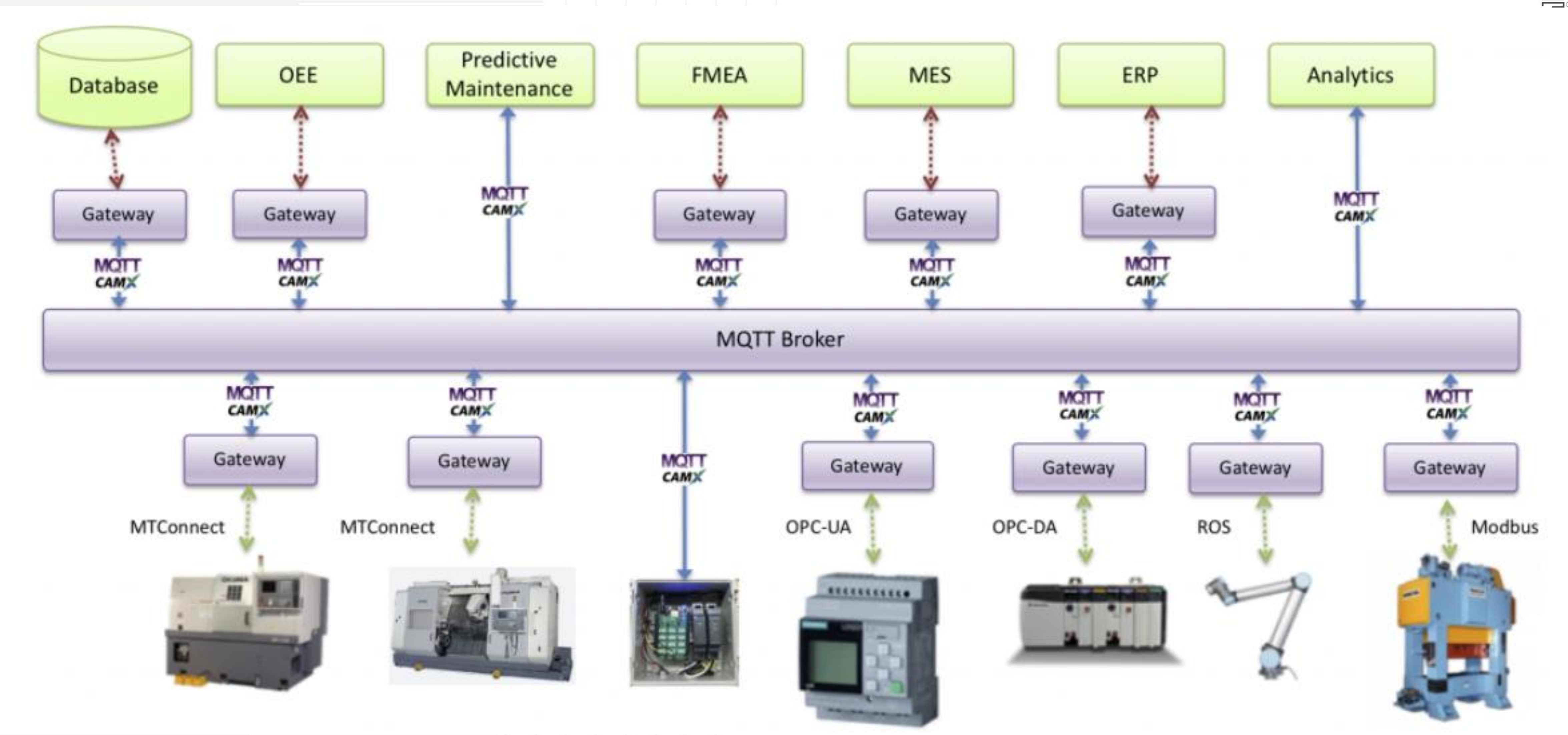

Hybrid monitoring approach

- MTConnect-compatible sensors for legacy machines
- Leverage existing MTConnect data streams
- Create efficient, adaptable architecture for supporting multiple communication protocols

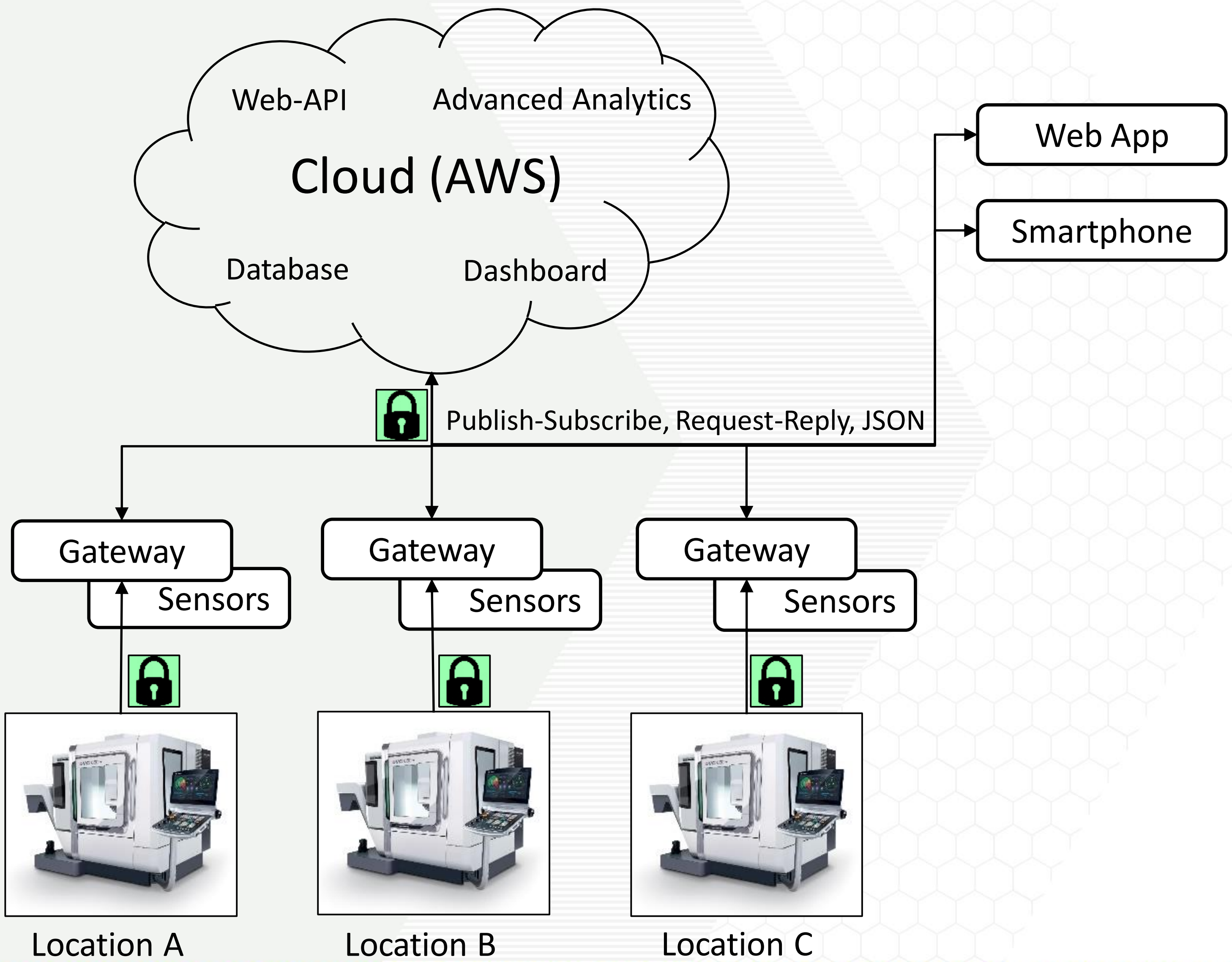
Local Shop Network Architectures



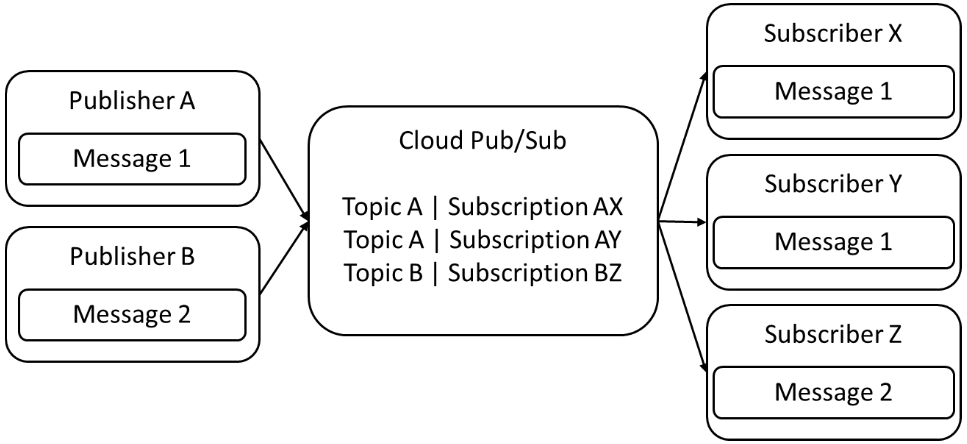
Decoupled Digital Architecture



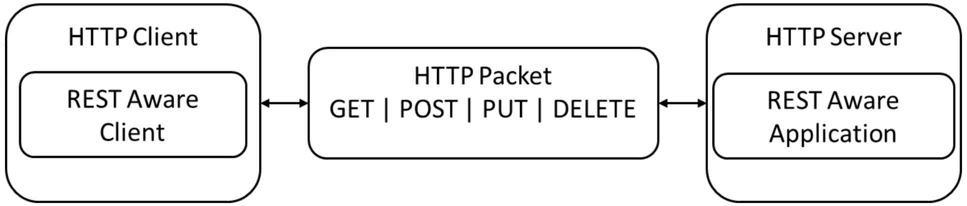
Cloud-Shop Architectures

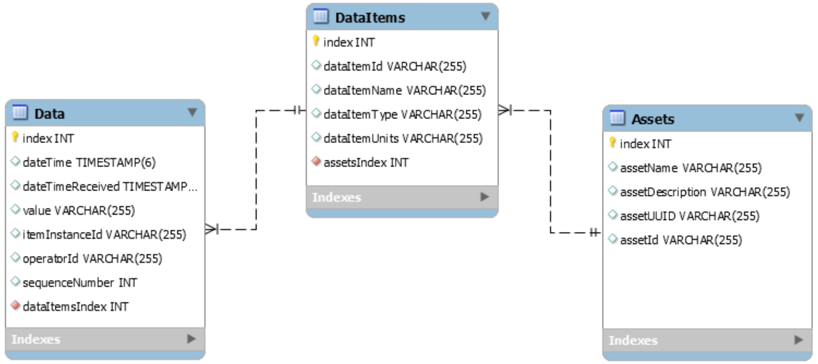


Publish-Subscribe e.g. Message Queue Telemetry Transport (MQTT)



Representational State Transfer (REST)



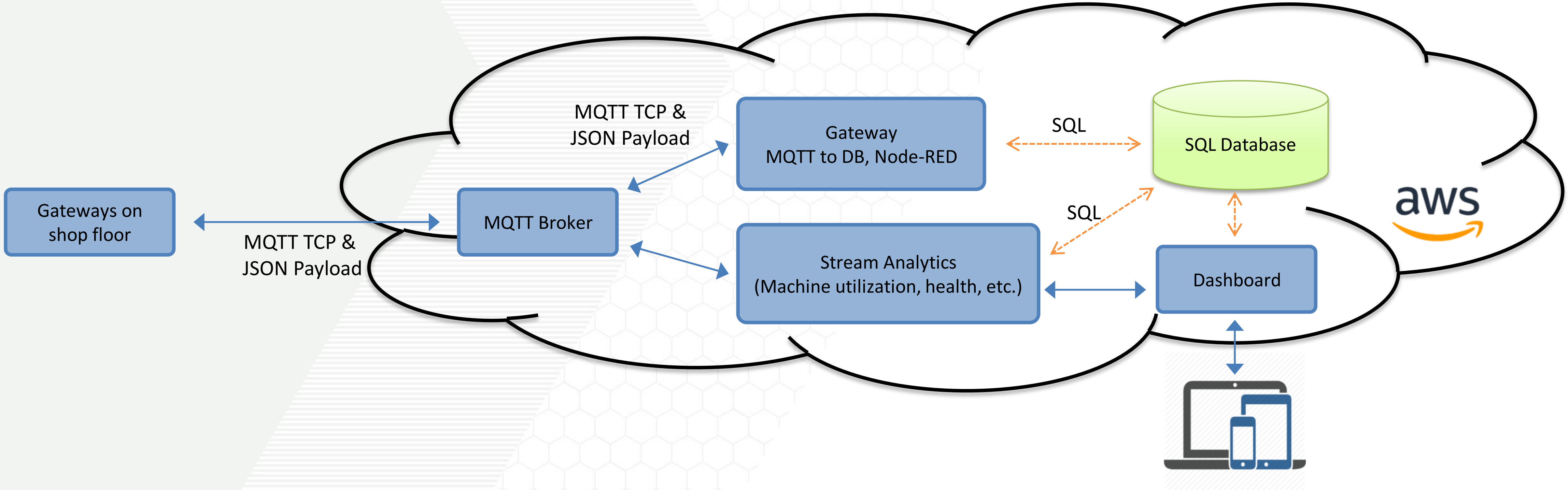


Cloud-based Analytics and Storage

SQL databases hosted on Amazon Web Services (AWS)

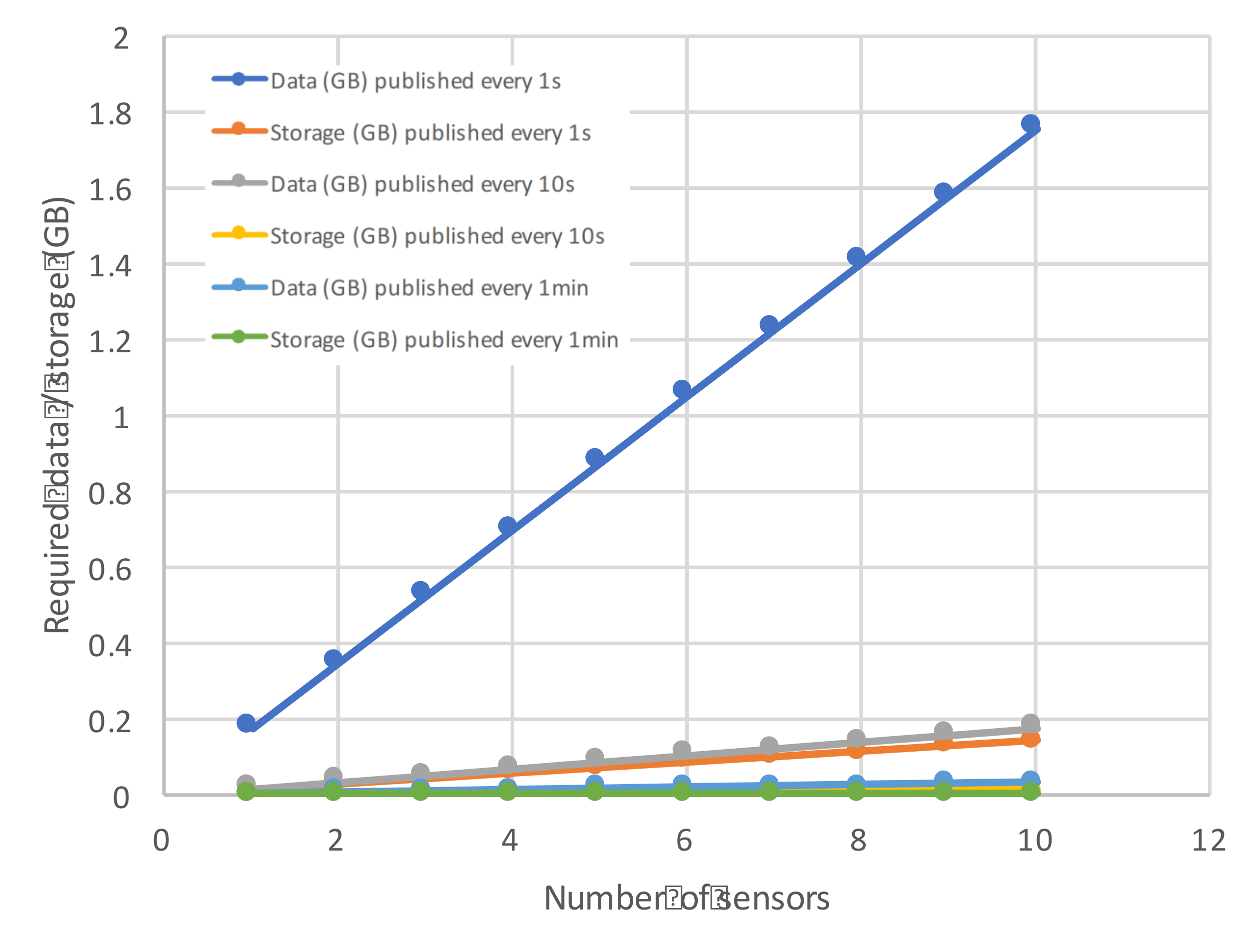
- Data is received within 1 second of transmission

Node-RED intermediaries used to perform stream analytics

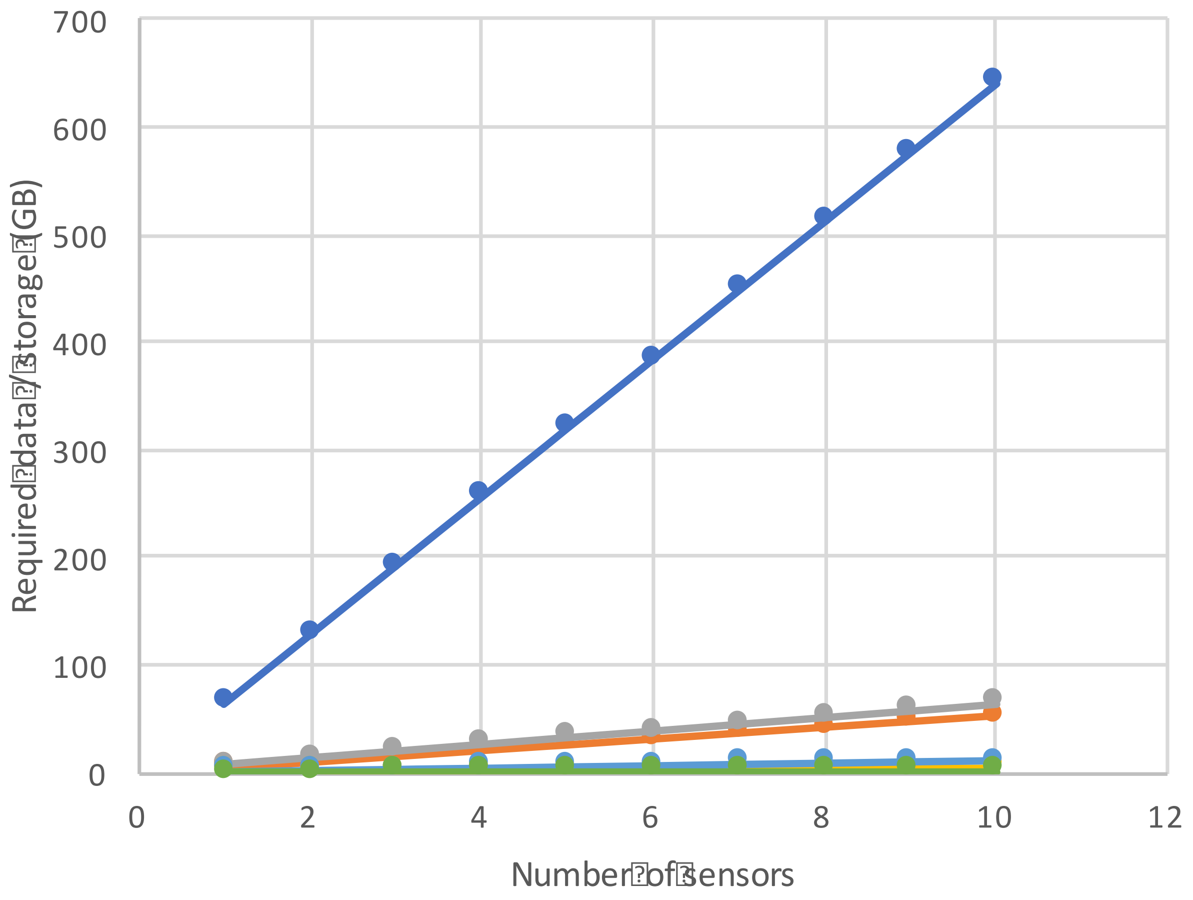


Cloud-Shop Architectures

Daily requirements

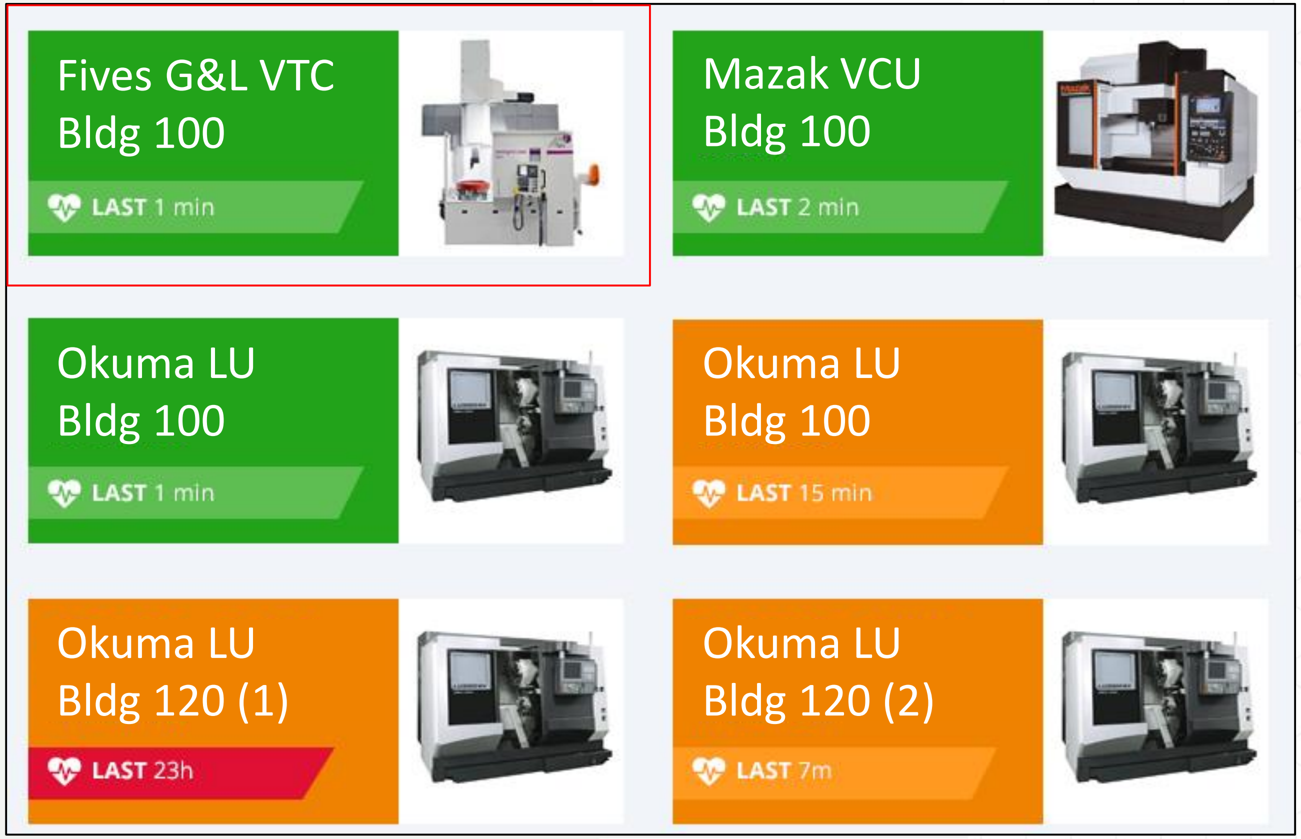


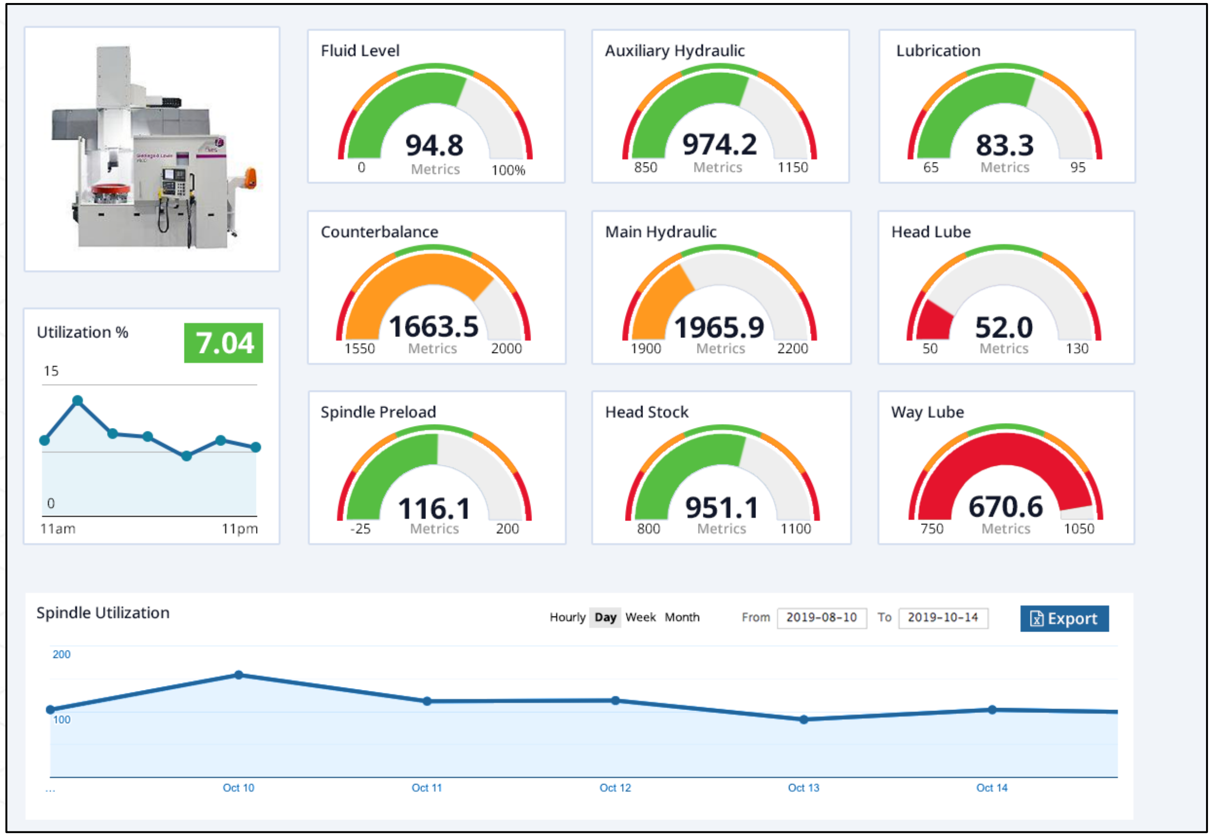
Annual requirements



Web-Based Machine Monitoring

Production-facing dashboards

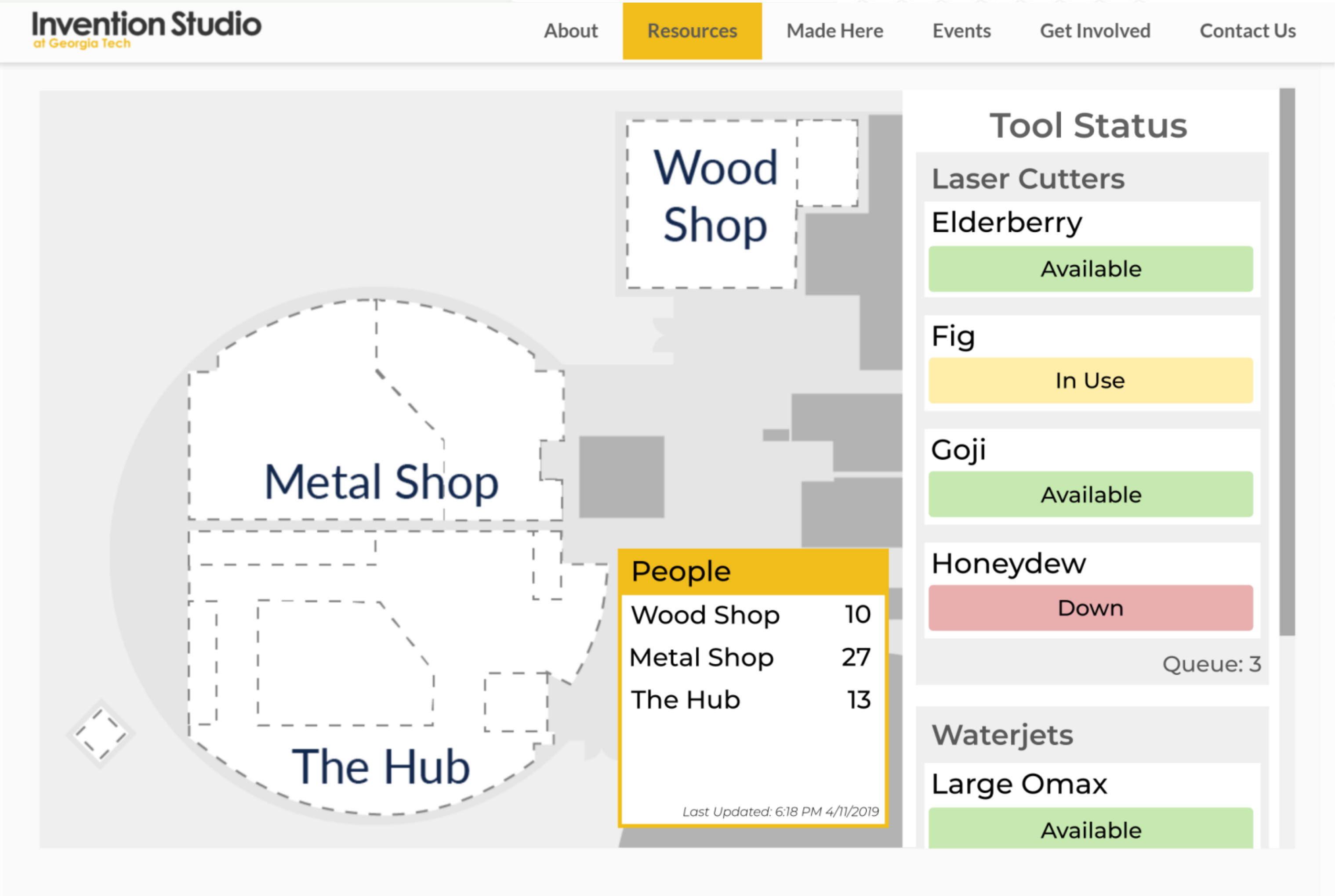




- Machine status condition (running/idle, heartbeat, alarm)
- Machine consumables levels

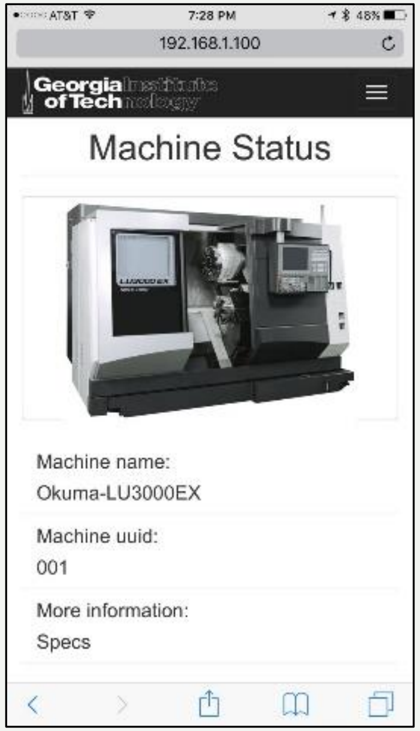
Web-Based Machine Monitoring

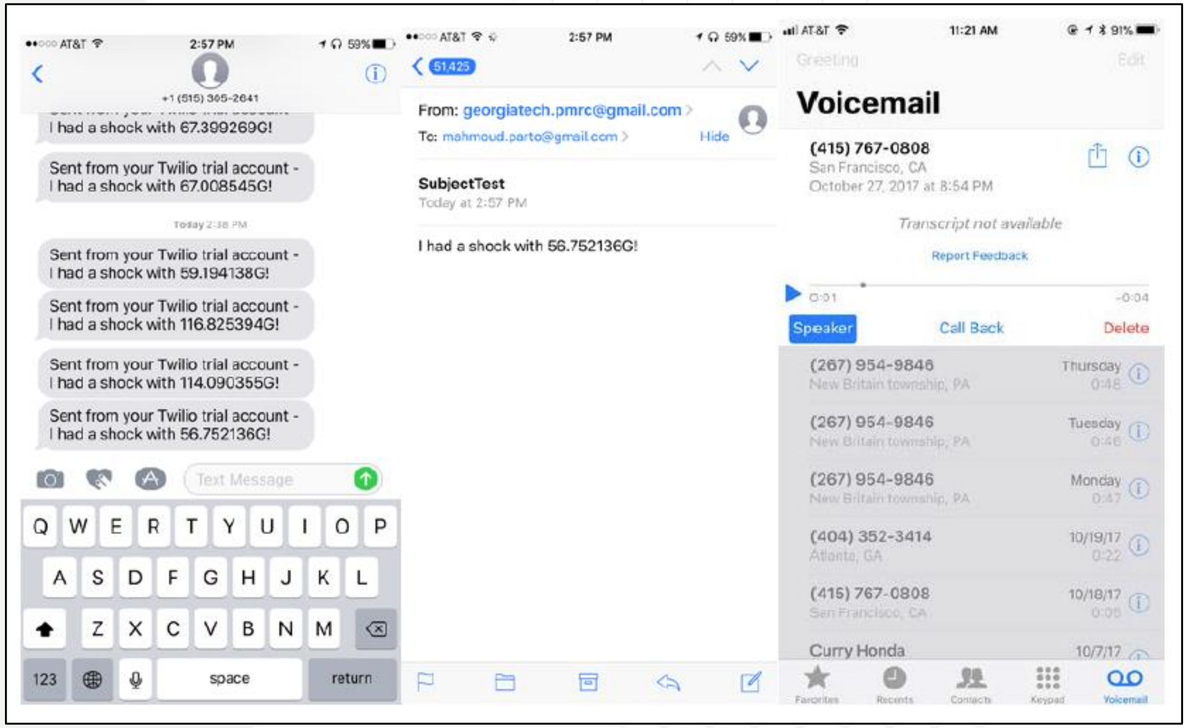
User-facing dashboards



- Machine status condition (running/idle)
- Consumables levels
- Support/PI requests

Mobile-Based Machine Monitoring





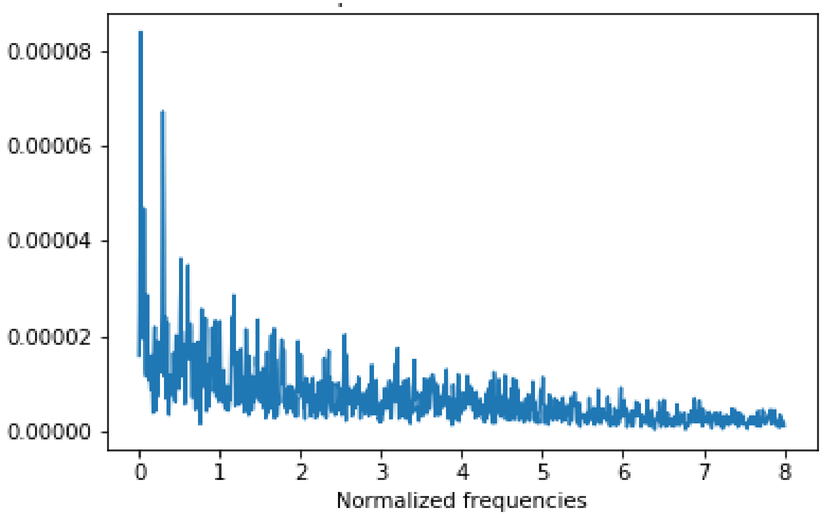
Slack integration

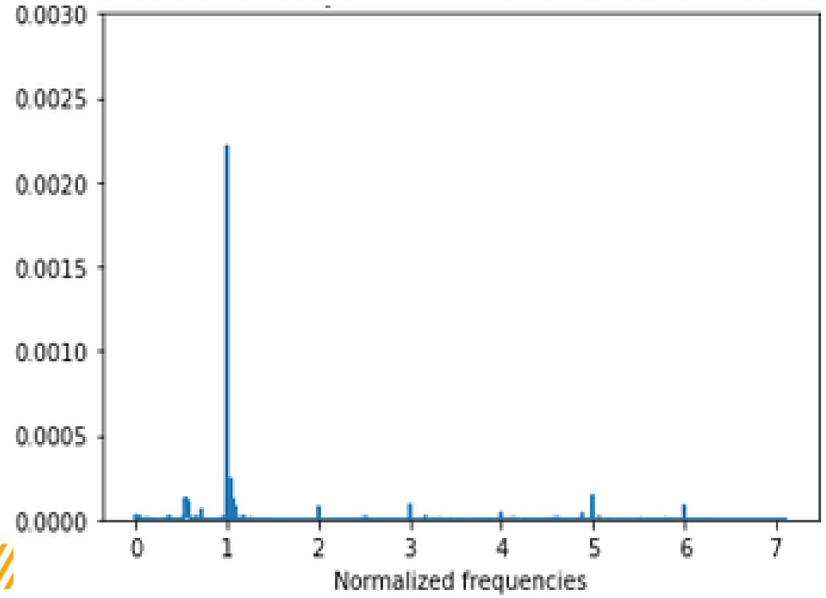
- Mobile-based monitoring applications
- Process interrupt notification
- Integration with third party applications

Example 1: automated defect detection

<u>Short-term goal:</u> Identify BPFO/BPFI defects automatically on large roll bearings

- Manufacturer monitoring hundreds of bearings
- Currently bearing defects are caught very late at the stage of failure with RMS detection
- Experienced engineers visually determine presence of BPFO/BPFI faults
- Cloud-based architecture for storing high bandwidth data (expensive, difficult to manage)
- Approach: train ML models for analysis approach

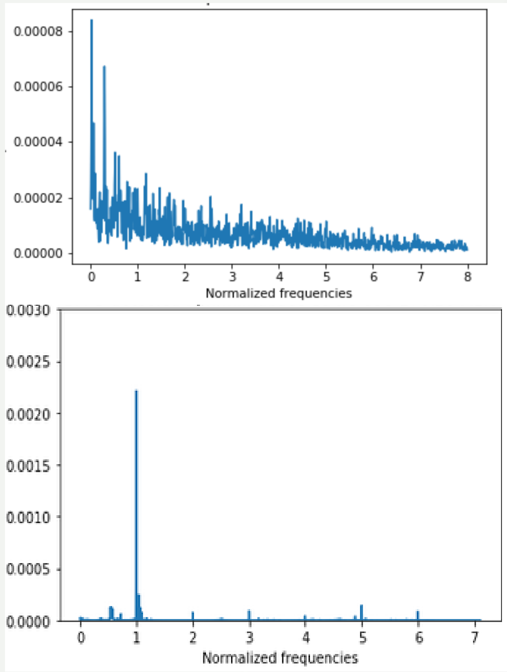


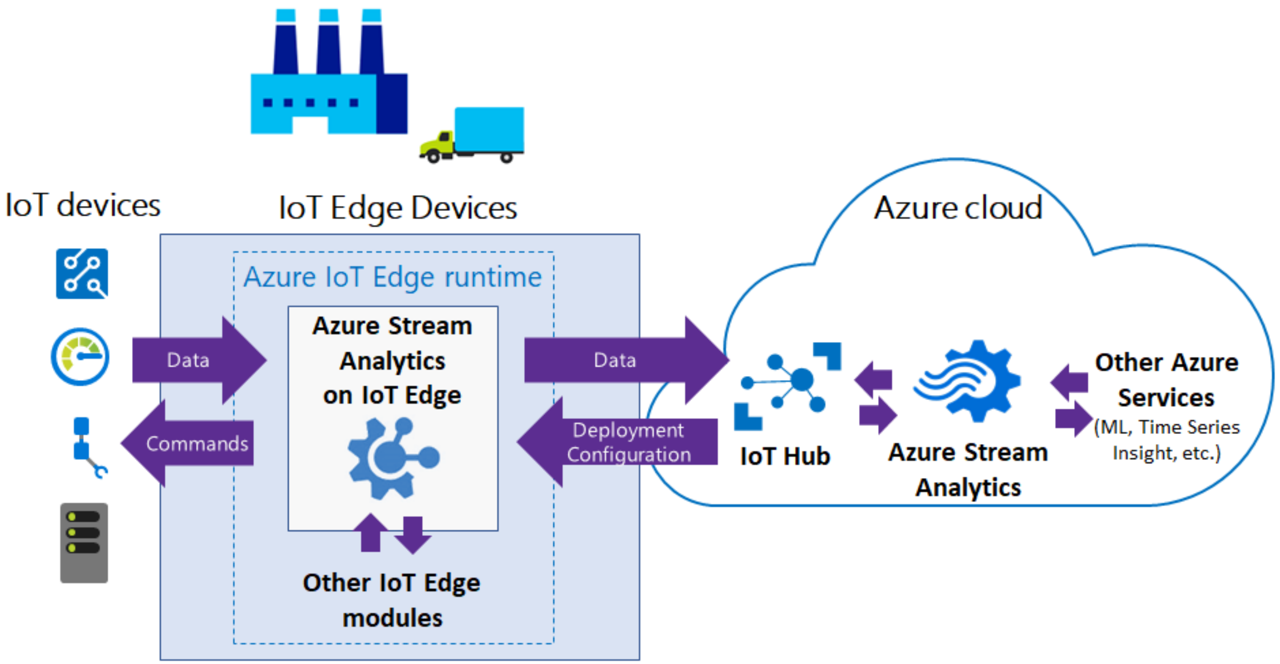


Example 1: automated defect detection

Long-term goal: Identify defects automatically *using edge-based devices*

- Deploy trained models on IOT edge devices, reduce internet traffic needs
- Eliminate need for large data lakes
- Improve response time for fault detection





Example 2: other retrofit deployables

Georgia Tech

MQTT-controlled Andon light

AWS Server

MQTT Message Broker
light status topic

JSON payload
Commanded light status

via MQTT protocol
subscribe to light status topic

GPIO Signal Commands
Python GPIO & light control libraries

Publish command to *light status topic*

MQTT Client Application

Plain-text entry of desired light status

Control signals

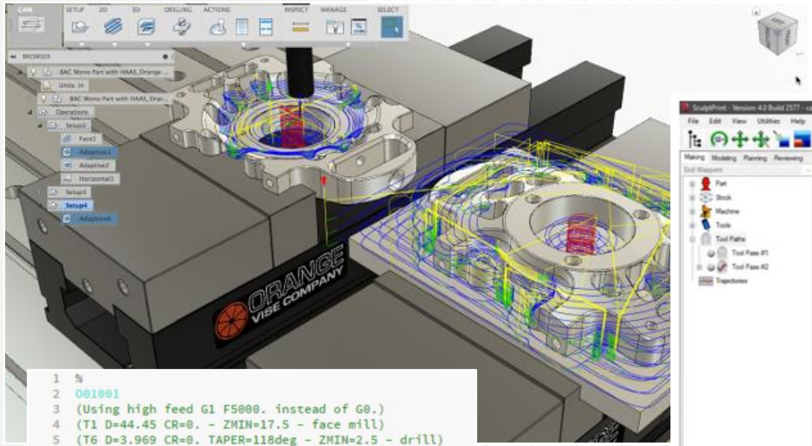
Example 3: monitoring/improvement

Georgia Tech

Digital twin / digital thread

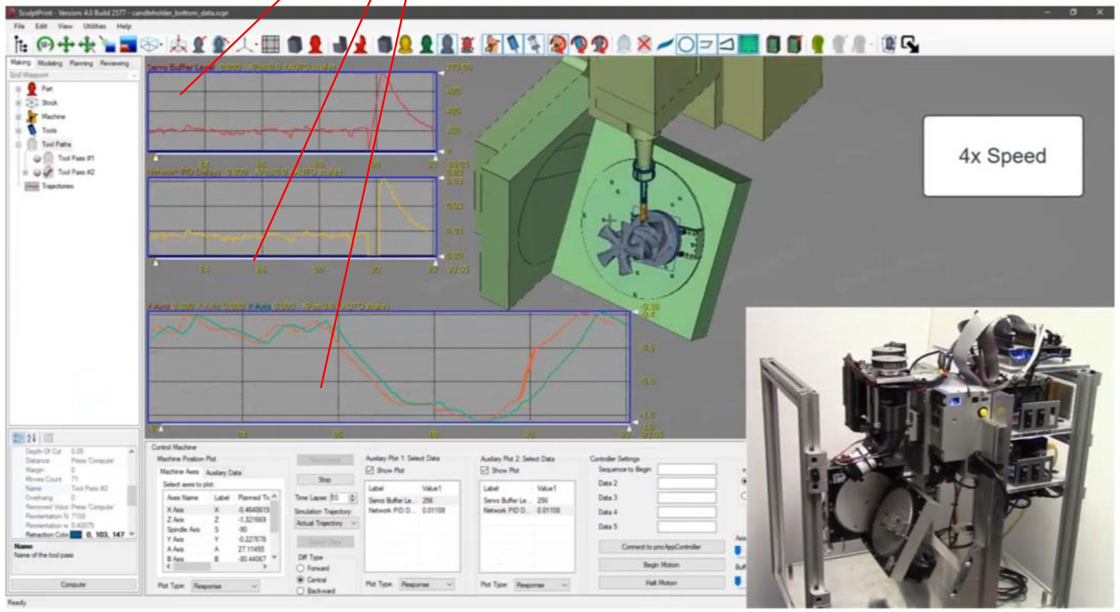
Sensor data – accel / temp / power / disp

CAM



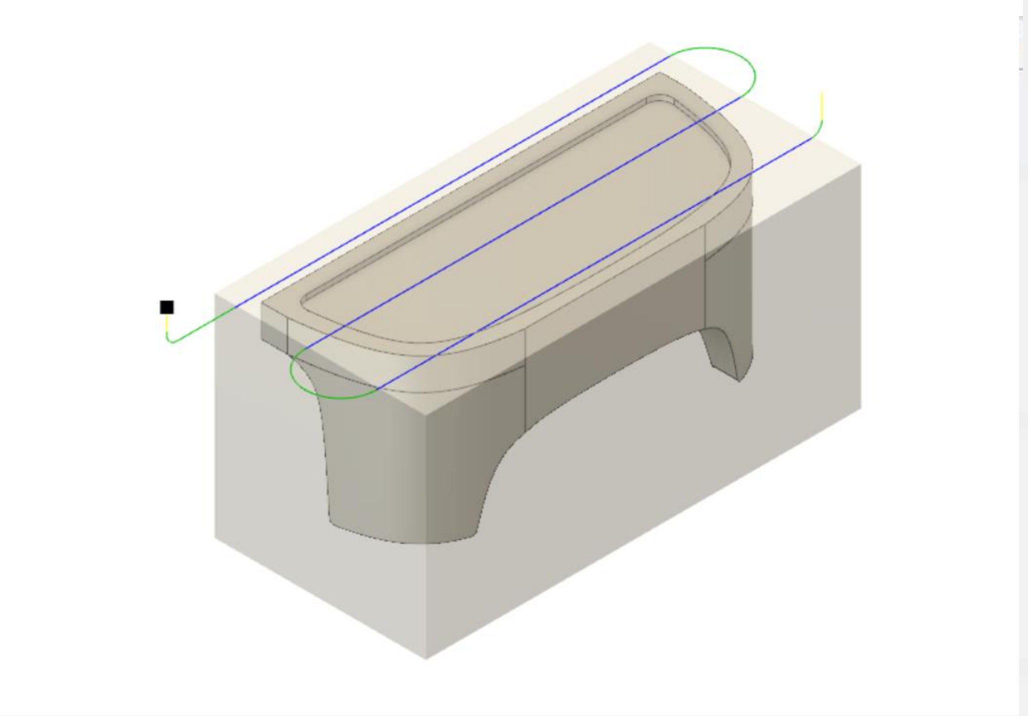

```
%
O01001
(Using high feed G1 F5000. instead of G0.)
(T1 D=44.45 CR=0. - ZMIN=17.5 - face mill)
(T6 D=3.969 CR=0. TAPER=118deg - ZMIN=2.5 - drill)
(T9 D=6.35 CR=0.381 - ZMIN=2.5 - bullnose end mill)
N10 G90 G94 G17
N15 G21
N20 G53 G0 Z0.

(Face3)
N30 T1 M6
(Aluminum Only Max Depth of Cut = 0.100")
N35 S7000 M3
N40 G54
N45 M8
N60 G0 X170.092 Y32.02
N65 G43 Z37. H1
N70 T9
N75 G0 Z27.
N80 G1 Z21.945 F1016.
N85 G18 G3 X165.647 Z17.5 I-4.445 K0.
N90 G1 X141.2
N95 X11.2 F2667.
N100 G17 G2 Y60.442 I0. J14.211
N105 G1 X141.2
N110 G3 Y88.864 I0. J14.211
N115 G1 X11.2
N120 G18 G3 X6.755 Z21.945 I0. K4.445 F1016.
N125 G0 Z37.

(Face3)
```

Monitoring



Example 3: monitoring/improvement

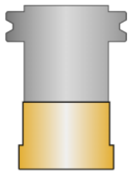
Toolpath: Face1



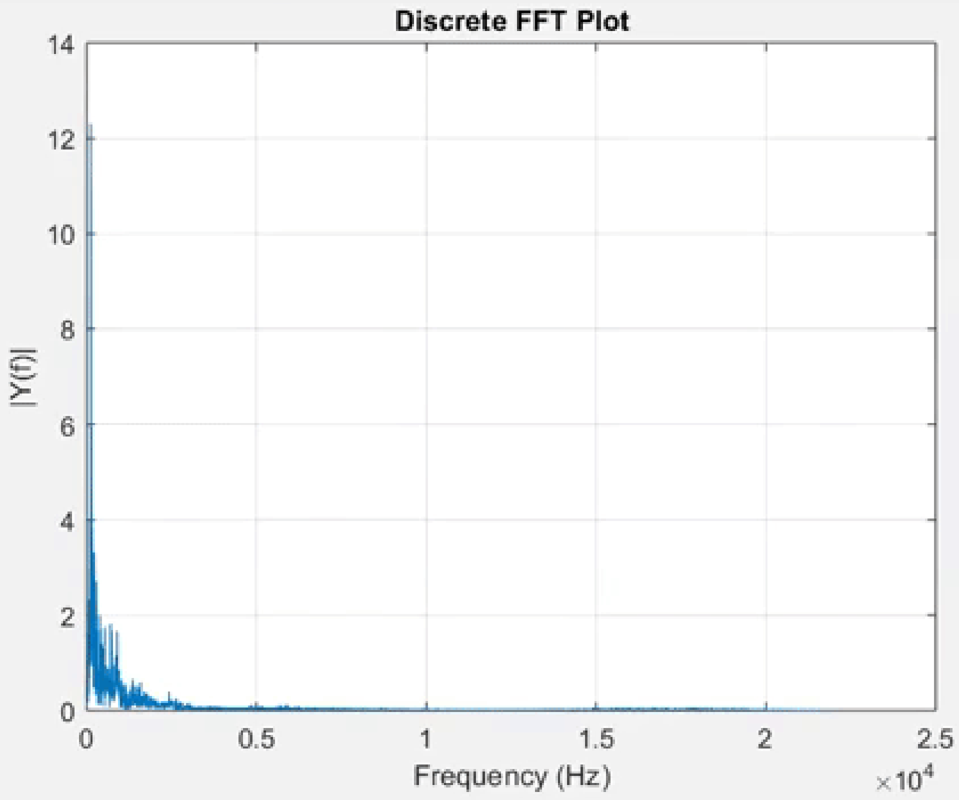
Operation 1/1
Description: Face1
Strategy: Facing
WCS: #0
Tolerance: 0in
Maximum stepover: 1.841in

Maximum Z: 0.6in
Minimum Z: -0.05in
Maximum Spindle Speed: 7000rpm
Maximum Feedrate: 105in/min
Cutting Distance: 30.672in
Rapid Distance: 0.853in
Estimated Cycle Time: 19s
Coolant: Flood

T171 D171 L171
Type: face mill
Diameter: 1.968in
Corner Radius: 0.015in
Length: 1.391in
Flutes: 5
Description: 2" Face Mill
Comment: Aluminum Only Max Depth of Cut = 0.100"
Vendor: MariTool Face Mill Holder MSAP16-D050A05Rx25.4
Product: Aluminum Only Inserts APET160508PDFRSN-DLC100



Chatter Detected: **Stable**



Start

Done

Workforce Development - Training

Content: configuration of cloud resources (REST API, AWS RDS)

❖ Setting up the Amazon Relational Database (AWS RDS)

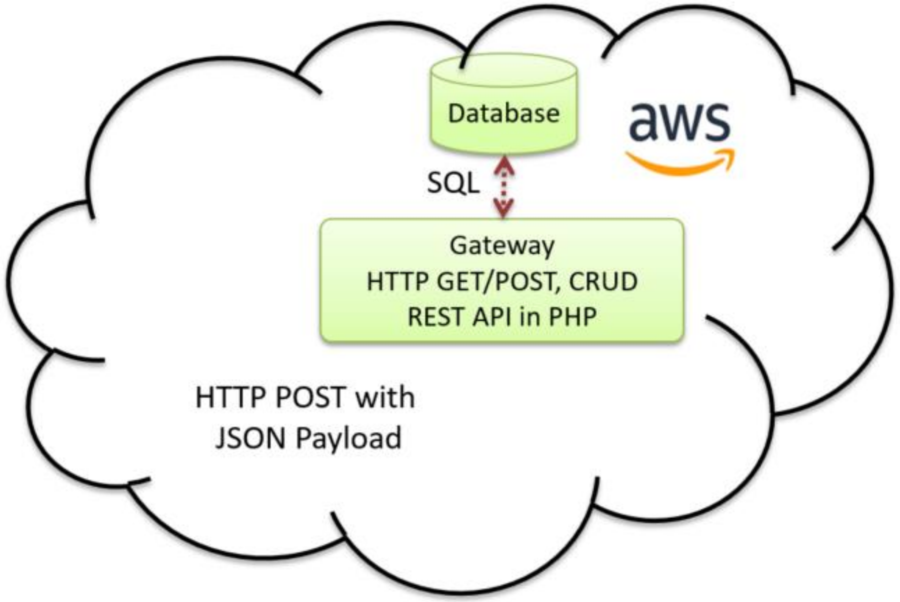
I. How do I create and activate a new Amazon Web Services account?
https://aws.amazon.com/premiumsupport/knowledge-center/create-and-activate-aws-account/

II. Setting Up for Amazon RDS
https://docs.aws.amazon.com/AmazonRDS/latest/UserGuide/CHAP_SettingUp.html

III. Creating a MySQL DB Instance and Connecting to a Database on a MySQL DB Instance
https://docs.aws.amazon.com/AmazonRDS/latest/UserGuide/CHAP_GettingStarted.CreatingConnecting.MySQL.html

IV. Install MySql Workbench, connect to the database, and run the following query block:

```
SET @OLD_UNIQUE_CHECKS=@@UNIQUE_CHECKS, UNIQUE_CHECKS=0;
SET @OLD_FOREIGN_KEY_CHECKS=@@FOREIGN_KEY_CHECKS,
FOREIGN_KEY_CHECKS=0;
SET @OLD_SQL_MODE=@@SQL_MODE,
SQL_MODE='TRADITIONAL,ALLOW_INVALID_DATES';

-- -----------------------------------------------------
-- Schema iot
-- -----------------------------------------------------
CREATE SCHEMA IF NOT EXISTS `iot` DEFAULT CHARACTER SET latin1 ;
USE `iot` ;

-- -----------------------------------------------------
-- Table `iot`.`data`
-- -----------------------------------------------------
CREATE TABLE IF NOT EXISTS `iot`.`data` (
  `id` INT(11) NOT NULL AUTO_INCREMENT,
  `timestamp` DATETIME NOT NULL DEFAULT CURRENT_TIMESTAMP ON
UPDATE CURRENT_TIMESTAMP,
  `assetId` VARCHAR(45) NOT NULL,
  `dataItemId` VARCHAR(45) NOT NULL,
  `value` VARCHAR(45) NOT NULL,
  `dataItemId2` VARCHAR(45) NOT NULL,
  `value2` VARCHAR(45) NOT NULL,
  PRIMARY KEY (`id`))
ENGINE = InnoDB
AUTO_INCREMENT = 1107753
```



Workforce Development - Training

Content: sensor pack assembly procedures, logical programming/modification

Specifications:

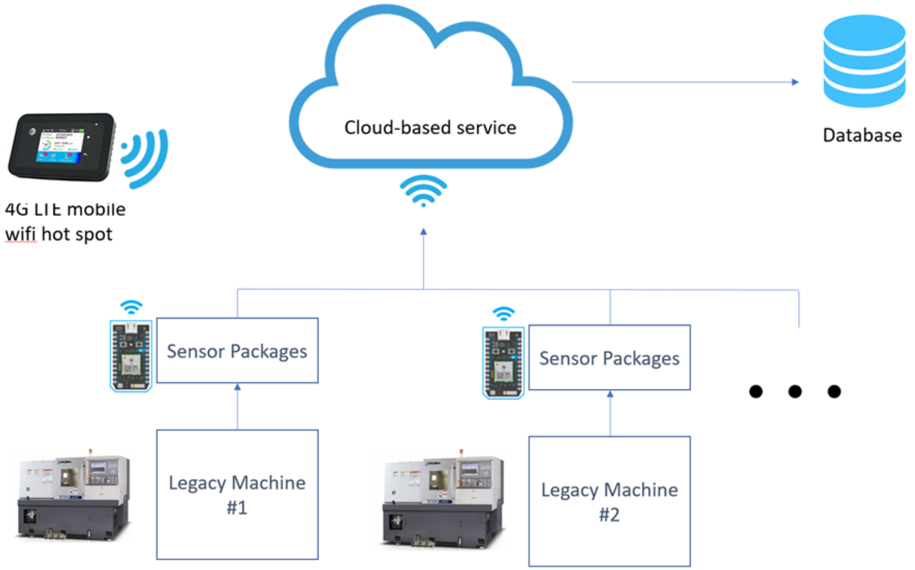
Specifications for low bandwidth sensor pack

- Photon spec
  - Particle PØ Wi-Fi module
    - Broadcom BCM43362 Wi-Fi chip
    - 802.11b/g/n Wi-Fi
    - STM32F205RGY6 120Mhz ARM Cortex M3
    - 1MB flash, 128KB RAM
  - On-board RGB status LED (ext. drive provided)
  - 18 Mixed-signal GPIO and advanced peripherals
  - Open source design
  - Real-time operating system (FreeRTOS)
  - Soft AP setup
  - FCC, CE and IC certified
- Sensor spec
  - ADXL203
    - 2-axis accelerometer
    - +- 1.7g
  - DHT 22
    - humidity 0-100%RH; temperature -40~80 Celsius
  - MAX31855
    - 14-Bit, 0.25°C Resolution Converter
    - Common Thermocouple types supported
- Assembled pack
  - Weight: 173g (w/o usb cord or adaptor)
  - Dimension (L x W x H): 12cm x 6cm x 4.5cm

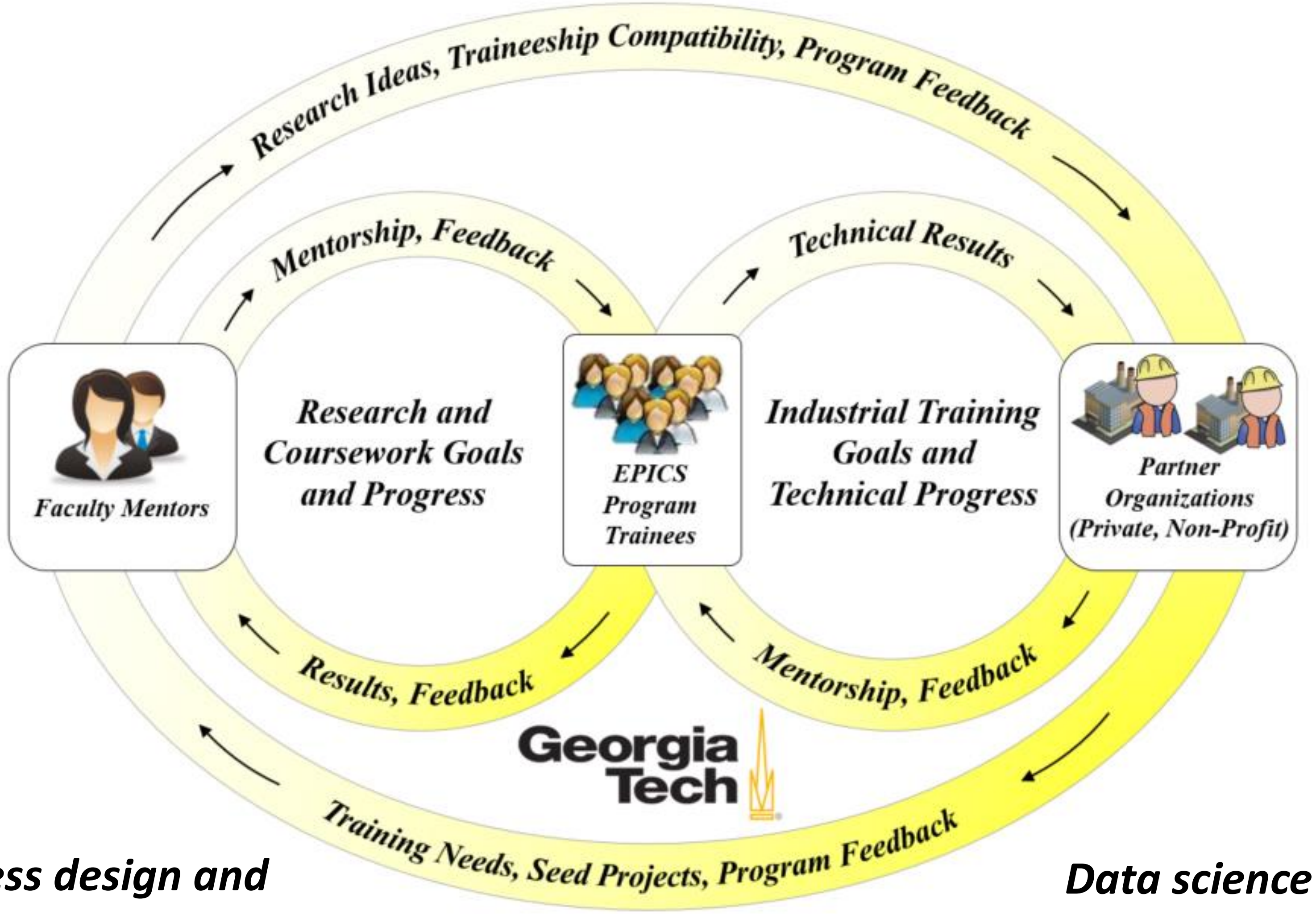
Specifications for high bandwidth sensor pack

- Photon spec
  - Particle PØ Wi-Fi module
    - Broadcom BCM43362 Wi-Fi chip
    - 802.11b/g/n Wi-Fi
    - STM32F205RGY6 120Mhz ARM Cortex M3
    - 1MB flash, 128KB RAM
  - On-board RGB status LED (ext. drive provided)
  - 18 Mixed-signal GPIO and advanced peripherals
  - Open source design
  - Real-time operating system (FreeRTOS)
  - Soft AP setup
  - FCC, CE and IC certified
- Sensor spec
  - ADXL377
    - 3-axis accelerometer
    - +- 200g
  - MAX9814
    - Automatic Gain Control (AGC)
    - Low Input-Referred Noise Density of 30nV/√Hz
    - Low THD: 0.04% (typ)
- Assembled pack
  - Weight: 118g (w/o usb cord or adaptor)
  - Dimension (L x W x H): 7.5cm x 5.2cm x 3cm

Physical Diagram:



Workforce Development for IIOT (EPICS)



Process design and modeling

Data science

Embedded systems

Workforce Development for IIOT (EPICS)

Georgia Tech

<ins>Need</ins>: Opportunities exist for realizing transformative advances in productivity and reductions in energy footprint through ubiquitous sensing in manufacturing environments.

<ins>Framework</ins>: 2-year projects with MS students, industrially-driven project topics. Students rotate to internships in summer semester to work on scoping and implementation at project partners.

<ins>Training</ins>: embedded systems, process modeling, data science, cloud-based systems design

<ins>Target projects</ins>: sensor retrofit, process monitoring, root cause analysis, sensor fusion

Workforce Development for IIOT (EPICS)

ENHANCED
PREPARATION FOR
INTELLIGENT
CYBER MFG.
SYSTEMS

2110 Competition
Atlanta, GA
15 November 2019

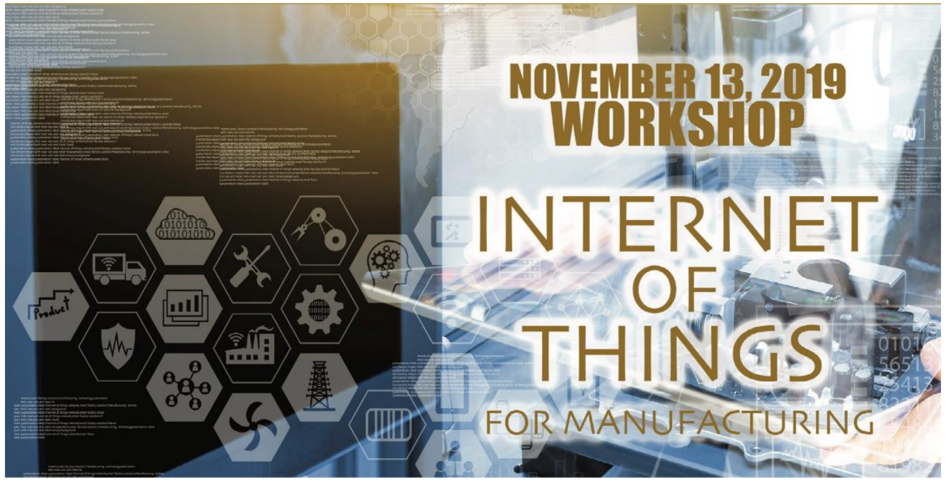
IIOT for Manufacturing

Technical focus areas:

Low cost instrumentation and hardware retrofit
Communications, data and cloud computing architecture
Data analytics for manufacturing processes
Mobile and web application development
Manufacturing process control and sensor deployment
Digital thread for manufacturing
Workforce development and training for IIOT (EPICS)

Example topics:

Spindle diagnostics and monitoring
In-process structural deformation measurements
Fluid level and quality sensing
Machine learning from process image data



https://ws19.fis.gatech.edu/

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