IOT for the consumer sector
Complementary developments

Industry 3.0
- 1950s
- 1990s

Industry 4.0
- 1980s
- 2000s
- 2010s

- 2000s, 2010s
Manufacturing Data Problems

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

Manufacturing System Views

Multiple system levels
- Process / machine
- Cell
- Facility
- Enterprise

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

Role of Process Modeling/Measurement

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
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
The "heartbeat" just sends a message to the MQTT broker periodically to let users know the device is connected if it’s not streaming data.

The “UART1, Current Cape”, “Set Flow Variable”, and “Convert Serial Data” nodes take data from the UART pins and convert it to the right units (amps in this case).

The “join” and “Develop Message” section of the flow acquires a predefined amount of data points, combines into one message, adds Asset ID and sends to MQTT broker.
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

RRK user-specific data
Spindle diagnostics
Process dynamics
Crash detection
Fluid monitoring
Multifunctional IIOT sensor kit

- 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

Sensors → Gateway (Edge Computing and Transfer) → Cloud
Local Shop Network Architectures

System elements and configuration
Machine Monitoring Architecture

Two methods of communication

- Industry standards
- Wireless sensors

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

Modern Machine Tool

MTConnect > MQTT

Sensors > MQTT

Mesh WiFi Access Points

POE Switch(es)

Local Computer

AT&T DSL Modem

Internet

Modern/Legacy Machine Tool

Local Shop Network Architectures
Decoupled Digital Architecture
Cloud-Shop Architectures

Publish-Subscribe e.g. Message Queue Telemetry Transport (MQTT)
- Publisher A
  - Message 1
- Publisher B
  - Topic A | Subscription AX
  - Topic B | Subscription BZ
- Cloud Pub/Sub
  - Message 1
- Subscriber X
  - Message 1
- Subscriber Y
  - Message Y
- Subscriber Z
  - Message Z

Representational State Transfer (REST)
- HTTP Client
  - REST Aware Client
  - GET | POST | PUT | DELETE
- HTTP Packet
- HTTP Server
  - REST Aware Application

Cloud (AWS)
- Database
- Dashboard
- Publish-Subscribe, Request-Reply, JSON

Web-API
- Sensors
  - Location A
  - Gateway
  - Sensors
  - Gateway
  - Sensors
  - Gateway
  - Sensors

Advanced Analytics
- Gateway
- Cloud (AWS)
- Web App
- Smartphone
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

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

Slack integration
Example 1: automated defect detection

Short-term goal: 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

MQTT-controlled Andon light

AWS Server

MQTT Message Broker
light status topic

Publish command to light status topic

MQTT Client Application

Plain-text entry of desired light status

JSON payload
Commanded light status

via MQTT protocol subscribe to light status topic

GPIO Signal Commands
Python GPIO & light control libraries

Control signals

Publish command to light status topic
Example 3: monitoring/improvement

Digital twin / digital thread

Sensor data – accel / temp / power / disp
Example 3: monitoring/improvement

Toolpath: Face1

Chatter Detected: Stable

Discrete FFT Plot
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?
  II. Setting Up for Amazon RDS:
  III. Creating a MySQL Instance and Connecting to a Database on a MySQL DB Instance
  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芦ALLOW_INVALID_DATES';

-- Schema set
CREATE SCHEMA IF NOT EXISTS 'mydb' CHARACTER SET latin1;
USE mydb;

-- Table 'mytable'
CREATE TABLE IF NOT EXISTS mytable (id INT(11) NOT NULL AUTO_INCREMENT,
timestamp DATE TIME NOT NULL DEFAULT CURRENT_TIMESTAMP ON UPDATE CURRENT_TIMESTAMP,
name VARCHAR(45) NOT NULL,
email VARCHAR(45) NOT NULL,
phone VARCHAR(45) NOT NULL,
address VARCHAR(45) NOT NULL,
website VARCHAR(45) NOT NULL,
birthdate DATE NOT NULL);
ENGINE = InnoDB;
AUTO_INCREMENT = 1107773
```

HTTP POST with JSON Payload
Workforce Development - Training

Content: sensor pack assembly procedures, logical programming/modification

Specifications:

### Specifications for low bandwidth sensor pack

- **Photon spec**
  - Particle P3 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)
  - 8 Mixed-signal GPIO and advanced peripherals
  - Open source design
  - Real-time operating system (FreemOS)
  - Soft AP setup
  - FCC, CE and IC certified

- **Sensor spec**
  - ADXL123
    - 2-axis accelerometer
    - ±1.7g
  - DHT 22
    - Humidity 0-100%RH; temperature -40°~80 Celsius
  - MAX1655
    - 14-Bit, 0.25°C Resolution Converter
    - Common Thermocouple types supported

- **Assembled pack**
  - Weight: 17g (w/o sub cord or adapter)
  - Dimension L x W x H: 12cm x 6cm x 4.5cm

### Specifications for high bandwidth sensor pack

- **Photon spec**
  - Particle P3 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)
  - 8 Mixed-signal GPIO and advanced peripherals
  - Open source design
  - Real-time operating system (FreemOS)
  - 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 sub cord or adapter)
  - Dimension L x W x H: 7.5cm x 5.2cm x 3cm

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Physical Diagram:

- Cloud-based service
- Database
- 4G LTE mobile wifi hot spot
- Sensor Packages
- Legacy Machine #1
- Legacy Machine #2
Workforce Development for IIOT (EPICS)

Process design and modeling

Embedded systems

Data science
**Workforce Development for IIOT (EPICS)**

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

**Framework**: 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.

**Training**: embedded systems, process modeling, data science, cloud-based systems design

**Target projects**: 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

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