Data Analysis in the Internet of Things: IoT capabilities with MATLAB/Simulink

Dr.-Ing. Rainer Mümmler
Application Engineering Team
The MathWorks GmbH
Overview

MathWorks Provides Capabilities for All of these Steps

Data Aggregator
- Data storage
- Online analytics
- Visualization and reporting

Publish data to aggregator
Deploy analytics to aggregator

Edge Nodes
- Embedded algorithms for sensing, data reduction, and control
- Models and simulation of system behavior

Deploy algorithms to nodes/devices
Monitor and control nodes/devices

Exploratory Analysis
- Historical analytics
- Algorithm development

MathWorks Provides Capabilities for All of these Steps
IoT – Design challenges

- Streaming data management and storage
- Availability of complex analysis as services
- Ability to turn results into actions

- Embedded development is challenging
- Increasing algorithmic complexity
- Need connectivity to cloud resources

- Advanced analysis algorithms
- Tools for deployment and connectivity
Use all types of data
MATLAB Data Support

Types of Data
MATLAB handles numbers, text, time-series, categorical, and other “traditional” types

MATLAB also has deep capabilities to handle and process images, audio, RF signals, video, telemetry and other “new” sources

File I/O
- Text
- Spreadsheet
- XML
- CDF/HDF
- Image
- Audio
- Video
- Geospatial

Repositories
- Databases (SQL)
- NoSQL
- Hadoop

Real-Time Sources
- Sensors
- GPS
- Instrumentation
- Cameras
- Communication systems
- Machines:
  - embedded systems
  - fieldbus
- Financial datafeeds

Business and Transactional Data

Communication Protocols
- CAN (Controller Area Network)
- DDS (Data Distribution Service)
- OPC (OLE for Process Control)
- XCP (eXplicit Control Protocol)

Engineering, Scientific, Test and Field Data

Types of Business and Transactional Data

File I/O

Repositories

Real-Time Sources

Communication Protocols
Extensive toolboxes and apps tuned for domain experts

MATLAB Advanced Analytics Algorithms

**Analysis, Modeling, Design**
- Data visualization
- Statistics
- Regression
- Machine learning (supervised and unsupervised)
- Neural networks
- Optimization (gradient-based and stochastic)
- Symbolic computing
- Image and video analysis
- Signal processing
- Financial modeling
- Geospatial computing

**System Design**
- Linear and nonlinear control methods
- Object recognition / Speech recognition
- System simulation and design
- Mechanical modeling
- RF and communication systems
- Fixed-point arithmetic
- Phased-array and radar analysis
- Communications system design
- Thousands of community-provided algorithms

**Business and Transactional Data**

**Engineering, Scientific, Test and Field Data**

**Analytics, Design, and Development**
Access to Aggregators and Services

- Aggregators
  - ThingSpeak
  - Google Cloud
  - AWS
  - homegrown
- Web services
- Protocols (e.g., Xively)
Operationalizing Analytics in Production Environments

- Dashboards and webpages
- Hadoop servers
- Databases
- Custom environments (e.g., Google Earth)
Modeling and Simulating the Edge Behavior
from simple devices to complex systems

- **Physical components**
  - Electronic
  - Mechanical
  - Hydraulic, etc.

- **Communication protocols**
  - LTE
  - 802.11
  - DDS
  - Personal area networks

- **Algorithms**
  - Feedback control
  - Computer vision
  - Signal and image processing, etc.
Implementing Algorithms at the Nodes

- **Automatic Code Generation**
  - Embedded processors and FPGAs
  - Popular IoT devices (e.g., Arduino, Cortex M, ARM mbed)

- **Communication**
  - M2M (e.g., DDS)
  - Device to aggregator (e.g., ThingSpeak)
  - Device to analyst (e.g., XBee®)

- **Verification/Validation and Process Support**
  - Model- and Code proving
  - Lifecycle management tools
ThingSpeak, MATLAB and the Internet of Things (IoT): Collecting and Analyzing IoT Data
What is ThingSpeak?

- Free online data aggregation platform
  - Typically used to collect data from sensors ("Things")
  - Provides instant visualization of the data
  - Popular for people experimenting in IoT
  - Has more than 60,000 users

- Can be used to analyze data
  - New MATLAB integration allows users to run scheduled MATLAB code on data coming into ThingSpeak

- Can be used to act on data
  - E.g. Tweet a message when the temperature in your backyard reaches 32 degrees
ThingSpeak: Collecting Data using Channels

- For any new data, first login and create a channel in ThingSpeak
- Channels have read and write API keys and can be public or private
- A channel is made up of 8 fields and can store 8 streams of data (Temp, Humidity, etc.)
- Channels can be updated at a maximum rate of once every 15 seconds

**ThingSpeak Weather Channel**
Getting data into ThingSpeak

- Rest API
- Native Libraries
  - Particle
  - Arduino
- Simulink Support Packages
  - Raspberry Pi
  - Arduino
  - BeagleBone Black
ThingSpeak: Visualizing the Data

- Each field in each channel is provided with a default visualization which updates automatically based on the data coming in.
- The default visualization contains iFrame code which can be used to embed the visualization in other applications.
- Channel Location is also shown on Google Map.

**ThingSpeak Car Counter Channel**
ThingSpeak: Custom Analysis with MATLAB Analysis App

- ThingSpeak is integrated with MATLAB in the Cloud
- Use the Apps Tab to use MATLAB inside ThingSpeak

Example: Calculate Dew Point on Live Data
ThingSpeak: Custom Analysis

- Create a new analysis
- Use code examples as a template
- Code examples use data sources that are already live in ThingSpeak
ThingSpeak: Custom Visualization with MATLAB Visualizations Apps

Apps

ThingSpeak channels store data. Upload data from the web or send data from devices to a ThingSpeak channel. Use these apps to transform and visualize data or trigger an action. See the tutorial: ThingSpeak and MATLAB to create a channel. Learn more about MATLAB inside ThingSpeak.

MATLAB Analysis
Explore and transform data.

MATLAB Visualizations
Visualize data in MATLAB plots.

Plugins
Display data in gauges, charts, or custom plugins.

MATLAB Plot Output

Traffic Volume in 15 seconds for last 48 hours

Example 1: Monitoring Weather

Objectives
- Measure, explore, discover weather patterns
- Provide niche weather service

Solution
- Arduino station with weather sensors
- Cloud-based aggregation and analysis
- Full example available at makerzone.mathworks.com
Example 2: Monitoring Traffic

Objectives
- Measure, explore, discover traffic patterns
- Provide live local traffic information service

Solution
- RaspberryPi + webcam
- Automated deployment of vision algorithms on embedded sensor
- Full example available at makerzone.mathworks.com
Traffic sensor – step 1
Design a car counter in Simulink
Traffic sensor – step 2
Port it to Raspberry Pi
IoT Solutions Examples

**Exploratory Analysis**
- Historical analytics
- Algorithm development

![Diagram of IoT solutions with examples](image-url)
Industrial Customer Examples

Online optimization of building energy use
- Real-time, cloud-based system
- Combines analytics with optimization for predictive control of single-building HVAC
- Energy consumption reduced 15-25%

Online engine health monitoring
- Real-time analytics integrated with enterprise service systems
- Predict sub-system performance (oil, fuel, liftoff, mechanical health, controls)
- Improve aircraft availability and reduce maintenance costs

Cloud-based wheeze analysis
- Medical device to monitor and manage asthma and COPD
- Leverages analytics in cloud and embedded system
Customer Study: BuildingIQ
Predictive Energy Optimization

Opportunity

• **Real-time, cloud-based system** for commercial building owners to reduce energy consumption of HVAC operation

Analytics Use

• **Data:** 3 to 12 months of data from power meters, thermometers, and pressure sensors, as well as weather and energy cost, comprising billions of data points

• **Machine learning:** SVM regression, Gaussian mixture models, k-means clustering

• **Optimization:** multi-objective, constrained

Benefit

• Typical energy consumption reduced 15-25%
Customer Study: iSonea

Cloud and Embedded Analytics

Opportunity
• Develop an acoustic respiratory monitoring system for wheeze detection and asthma management

Analytics in cloud and embedded
• Captures 30 seconds of windpipe sound and processes the data locally to clean up and reduce ambient noise
• Invokes spectral processing and pattern-detection analytics for wheeze detection on iSonea server in the cloud
• Provides feedback to the patient on their smartphone

Benefit
• Eliminates error-prone self-reporting and visits to the doctor
Customer Study: iSonea

Cloud and Embedded Analytics

Opportunity

• Develop an acoustic respiratory monitoring system for wheeze detection and asthma management

Spectral processing and pattern-detection analytics for wheeze detection

Windpipe sound capture and processing to clean up and reduce ambient noise
MATLAB & Simulink Capabilities for IoT

Physical Component Modeling
- Electronic
- Mechanical
- Hydraulic, etc.

Communications Protocol Modeling
- LTE, Zigbee, 802.11, etc.

Automatic Code Generation
- Programmable chips (MCU, DSP, etc.)
- FPGAs

Verification/Validation and Process Support
- Model- and Code proving
- Lifecycle management tools

Deployment
- .NET, COM components
- Java components
- Multicore and GPU systems
- Spreadsheet plug-ins
- Database plug-ins
- Hadoop
- Cloud services (AWS)
- ThingSpeak Apps
- Smartphone/tablet integration

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- OPC
- XCP

Data Clean-up
- Filtering
- Image processing
- Signal processing
- Telemetry
- RF sampling

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Summary

- MATLAB and Simulink provide a broad range of capabilities for IoT
  - Performing interactive and advanced analytics
  - Deploying analytics to production environments
  - Developing real-time systems, from sensing and control nodes to complex devices
  - Designing communications, including simulation and real-time connectivity

- An open-system architecture
  - User-extensible, with well-documented APIs
  - Can be integrated with third-party edge-node platforms, aggregators, and production IT systems
IoT Web Resources

Discovery/ Landing Pages
- Internet of Things Overview
- Developing and Testing Edge Node Devices
- Accessing and Aggregating IoT Data
- Analyzing IoT data and building predictive algorithms
- ThingSpeak Support from Desktop MATLAB

Articles
- Counting Cars and Analyzing Traffic with a Raspberry Pi, a Webcam and ThingSpeak
- MathWorks Weather Station – Revisited
- Real-Time Tide Gauge to Tweet Tidal Alerts
- Weather Station Data Analysis
- Soda Machine Analyzer

User Stories
- iSonea Develops Mobile App for Wheeze Detection and Asthma Management
- BuildingIQ Develops Proactive Algorithms for HVAC Energy Optimization in Large-Scale Buildings

Videos
- MATLAB and the Internet of Things (IoT): Collecting and Analysing IoT Data (Highlights)
- MATLAB and the Internet of Things (IoT): Collecting and Analysing IoT Data (Full Video)
- Introduction to ThingSpeak
- Signal Processing and Machine Learning Techniques for Sensor Data Analytics
- Data Analytics with MATLAB