Beyond the Desktop: Embedded Modeling and Cloud Based Real-Time Monitoring and Control

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Beyond the Desktop: Embedded Modeling and Cloud Based Real-Time Monitoring and Control

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Overview

• Background:
  – Initial Research Problem
  – The Internet-of-Things (IoT)
  – Types of Cloud Computing
  – Development of the IoT for Infrastructure Monitoring and Control (DRTC/OptiRTC)

• Modeling-as-a-Service (MaaS)

• What does all of this look like in the real world?

• Closing thoughts
Initial Research
Problem

• Find the least expensive most flexible means for monitoring and controlling the physical environment and integrating internet based datastreams.

Patent # 60/850,600 and 11/869,927
Internet-of-Things (IoT)

• Definitions:
  – Extending the virtual internet to physical objects
  – Physical computing
  – Enabled through IP based field deployed gateways

Source: Constellation Research
http://press.teleinteractive.net/media/blogs/tialife/InternetofThingsVector.svg
Perspectives on Internet-of-Things

- National Intelligence Council - “Disruptive civil technologies: six technologies with potential impacts on US interests out to 2025”
- Likely rapid adoption and ubiquity in a number of civil environments (e.g., water)
- Cisco IBSG predicts there will be 25 billion devices connected to the Internet by 2015 and 50 billion by 2020.
Types of Clouds

- **Private (On-Premise)**
  - Applications
  - Runtimes
  - Security & Integration
  - Databases
  - Servers
  - Virtualization
  - Server HW
  - Storage
  - Networking

- **Infrastructure (as a Service)**
  - Applications
  - Runtimes
  - Security & Integration
  - Databases
  - Servers
  - Virtualization
  - Server HW
  - Storage
  - Networking

- **Platform (as a Service)**
  - Applications
  - Runtimes
  - Security & Integration
  - Databases
  - Servers
  - Virtualization
  - Server HW
  - Storage
  - Networking

**You manage**

**Managed by vendor**
OptiRTC Service Platform

Internet Based Weather Forecast or other internet data sources (Web service API)

Azure Tables/Blobs

OptiRTC Data Aggregator and Decision Space

Data Logging and Telemetry Solutions

Field Monitoring and Control (Sensors, Gauges, and Actuators)

Rapid Deployment Field “Kits” With Wireless Sensors

User Interface Web Services and User Dashboards

Alerts
Email
Tweet
SMS
Voice Autodial
Architecture Highlights

• Redundant across all cloud infrastructure.
• Fully virtualized for fast recovery and upgrades without downtime.
• Capable of allocating Compute resources differently for different tasks (web services, data harvesting, real-time and non real-time processing.
• Reliable, flexible, accessible, secure, and proactively adaptive IT basis in Windows Azure.
OptiRTC Architecture

Windows Azure

- Publish/subscribe communications system

Load balancer

- Web Roles
- Data Harvesting Worker Roles
- Data Processing Worker Roles
- Non Real-Time Processing Roles

Data Services/Sensors/Actuators

- IoT Gateway

Clients, Field Technicians, and Consultants

3rd-party Services

- Relational, Post-Relational, and Distributed File System Data Storage Services with Geo-redundancy
Data Processing Roles
“Post-Actions”

• Algorithms within .NET implementations compliant with the OptiRTC post-action sequence interface.
• Include simple logical operations, remote control operations, alerting and email notifications
• ...and complete advanced modeling routines.
• This is just “Modeling-as-a-Service” (MaaS)
• Shift from thinking that models are “products”
MaaS SWMM Implementation

- Downloaded SWMM 5.0.022 computational engine from [http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/swmm50022_engine.zip](http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/swmm50022_engine.zip)
- Re-targeted compilation at x64 platform
- Rebuilt SWMM engine for 64-bit Windows environment
- Added startup installation of 64-bit C++ runtime library to OptiRTC DataProcessor VM image
- Developed C# wrapper around SWMM engine interface
- Configured DataProcessor VM emulation of NFTS file system to provide cache for SWMM engine I/O
Example Use Case for SWMM MaaS

• Use SWMM 5 to evaluate pre-development hydrologic conditions for a site in real-time
  – Use pre-development SWMM model
  – Use historical site precipitation record
  – Add last 48 hours conditions to calculate expected state. (or generate hot-start file from previous conditions)

• Report output to Data Processor Roles
  – Real-time dashboard reporting
  – Use in distributed infrastructure control
  – “Match” Pre-development conditions (above Qc and below Qmax)
  – Distribution and publication via OptiRTC HTTP API
Example of MaaS Workflow - Setup

- Edit model .INP input file to allow for run-time configuration of file system directory structure
- Upload input file and necessary input data files to OptiRTC cloud storage
- Determine real-time data source to use as current precipitation record
- Determine which model objects to report
- Link results datastreams via control post-actions
- Eventually completely through web API as well
MaaS SWMM Process in OptiRTC

1) On-site rainfall data collected in real-time via IoT web services

2) Pre-development SWMM model run with last 3 days of on-site rainfall data input

3) Contingent on SWMM output, real-world infrastructure state automatically changed in real-time

Virtual file system

4) Time-series results extracted from SWMM output and persisted in cloud-based data store.

5) Public-facing web dashboards display recent system history and provide manual override options.
Some Other Use Cases for MaaS

- Self-calibration of models from streaming empirical data
- Hydrologic/Hydraulic forecasting and control
  - DSS
  - Reservoir Operation
  - Light weight flood warning systems
- Batch Model Processing (scale up/scale down)
- Other boundary conditions (stream flow)
- Adaptive management
- “time shifted” hydrology
- Integrated QA/QC – everything is preserved
- There are many more....
What does this look like in the real world?

Collaborators
Technology Application: Advanced Rainwater Harvesting and Harvesting System Retrofits
Technology Application:
Advanced Rainwater Harvesting

Simplest Definition: Drain storage in advance of predicted rainfall or other trigger
Pilot System: NC State
Advanced Rainwater Harvesting
Pilot System: NC State Advanced Rainwater Harvesting

Internet Gateway (Powered by ioBridge and OptiRTC)

Cisterns

Overflows from Tanks

Automatic Drain Valve

Irrigation Pump
NC State Pilot

System Behavior Week of 9/20/2011

QPF and POP Forecast Datastream (Threshold of 70%)
NC State Pilot – Dashboard (1-min refresh)
System Behavior Week of 4/5/2012 2:06 PM
NC State Pilot – Dashboard (1-min refresh)
System Behavior Week of 4/6/2012 12:14 AM
NC State Pilot – Monitoring Results
10/9/11-2/2/12
NC State Pilot
Analysis of Monitoring Results

• 3.5 month period
• Captured 90.6% of the total runoff volume.
• Conventional rainwater harvesting system with same demand profile would have captured 48.7% of the total runoff volume.
NC State Pilot – Dashboard (1-min refresh)
System Behavior 9/18/2012 9:16 AM
Pilot Site: Washington, DC
Engine House #3
Pilot Site: Washington, DC - Engine House #3: Design
Inverted Siphon Downspout Design
(Note: location of cistern is shown close to building for illustrative purposes only)

- Proposed Flow Splitter Box Installed on Existing Downspout
- Proposed Inverted Siphon Downspout Pipe (Extends 8’-10’ Above Ground Level)
- Flow During Emergency Bypass
- Flow During Typical Use
- Existing Downspout Connection to Combined Sewer
- 4” Automatic Drain Valve Open During Automated Cleaning Cycle and When Cistern is Full
- Flow During Cleaning Cycle or When Cistern Full
- Proposed Connection to Combined Sewer
Engine House 25
DDOE Pilot as Potential Prototype
Conceptual Rendering of Site in Kansas City, MO
Project Site: Rainwater Harvesting Site Locations
St. Louis, MO
Renaissance Place

Pre-construction
Renaissance Place

Geo-fabric placement

Pad compaction
Renaissance Place

Initial excavation

Cistern placement (10,000 gal)
Harvesting system cisterns

Controlled discharge valve
Technology Application: Detention/Retention/Flood Control Retrofits
Depth Time Series and Average Hydraulic Residence Time for Passive Outlet

**Average Hydraulic Residence Time (hrs)**

13 days

Depth Time Series and Average Hydraulic Residence Time for Actively Controlled Outlet

**Average Hydraulic Residence Time (hrs)**

24 days
Brooklyn Botanical Garden – Pond Control for CSO Mitigation
Pond RTC Outlet Control Retrofit – Austin, TX
Existing Pond Outlet Control Structure – Austin, TX
Technology Application: Active Blue and Green Roofs
Technology Application: Active Green Roof

- Make real-time forecast based decisions on when and how much to drain or irrigate the roof
- Make storage volume available for stormwater volume and peak control
- Reduce irrigation waste
Active Irrigation Valve

Actively Controlled Green Roof - SAP Headquarters
(Collaboration with Roofmeadow)
Technology Application: Controlled Underdrain Bioretention
Technology Application:
Controlled Under Drain Bioretention
Gwinnett County, GA
Controlled Underdrain Bioretention and Cistern Retrofit
Technology Application:
Portable and Wireless Sensor RTC Monitoring
Wireless OptiRTC

Permanent Install Wireless

Portable Field Kits
Cost/Benefit Analysis and Research
WERF/GLPF
Cost/Benefit Analysis

**Objective Function — Maximize Benefits:**

\[
Z = \sum_{t=1}^{T} S_t R_{ht,t} + \sum_{t=1}^{T} S_t R_{gt,t} - \sum_{t=1}^{T} C_O R_{ot,t} - \sum_{t=1}^{T} C_S R_{st,t}
\]

**Constraints:**

\[
S_{t+1} = S_t + Q_t + G_t - R_{gt,t} - R_{ht,t} - R_{ot,t} - R_{ct,t} - R_{st,t}
\]

\[
R_{ot,t} \geq 0 \quad R_{ht,t} \leq I_{Dht}
\]

\[
R_{ct,t} \geq 0 \quad R_{ct,t} \leq R_{Cmax,t}
\]

\[
K_{st,t} \geq 0 \quad K_{ot,t} \leq K_{Omax,t}
\]

\[
S_t \geq 0 \quad S_t \leq I_v
\]

**Where,**

\[
S_t = \text{savings of irrigation outflow} = \$0.01/\text{ft}^3
\]

\[
C_O = \text{cost of overflow outflow} = \$0.05/\text{ft}^3
\]

\[
C_S = \text{cost of spill} = \$0.10/\text{ft}^3
\]

\[
R_{ot,t} = \text{greenhouse pump outflow at time } t
\]

\[
R_{ot,t} = \text{overflow of tank outflow at time } t
\]

\[
R_{st,t} = \text{spilled outflow of tank at time } t
\]

\[
R_{gt,t} = \text{grass area pump outflow at time } t
\]

\[
S_t = \text{storage of water in tank at time } t
\]

\[
I_{Dht} = \text{irrigation demand of greenhouse at time } t
\]

\[
K_{st,t} = \text{grass area pump outflow at time } t
\]

\[
R_{ot,t} = \text{overflow of tank outflow at time } t
\]

\[
R_{ot,t} = \text{controlled outflow of tank at time } t
\]

\[
R_{ot,t} = \text{spilled outflow of tank at time } t
\]

\[
G_t = \text{inflow into cistern from grass area overflow at time } t
\]

\[
Q_t = \text{inflow into cistern from roof and parking lot runoff at time } t
\]

\[
R_{max} = \text{maximum controlled outflow at time } t = 3120 \text{ ft}^3
\]

\[
R_{max} = \text{maximum overflow outflow at time } t = 9450 \text{ ft}^3
\]

\[
I_v = \text{tank volume}
\]
Comparison of maximum benefit vs. tank storage capacity of controlled and passive system.
Comparison of maximum benefit vs. tank storage capacity of controlled and passive system with tank costs incorporated ($5.00/ft³)
Closing

• Much more fundamental research to be done
• Solve the general case (if possible)
• Low-cost, reliable, and highly functional sensors and sensor platforms will change everything
• Do not fear “dis”-integration and web API strategies.