Recent Progress on Sensor Networks and Embedded Computing

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Acknowledgment

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• Collaborations with Johannes Helander, Tom Blank, Mike Sinclair, Ray Bittner

• Engineering help from Jessica Miller, Darren Gehring, Piali Choudhury and MSRSUPP

• Partnership with Stewart Tansley of MSR ERP

MSR Networked Embedded Computing Group, http://research.microsoft.com/nec
Highlights

• The MSR Networked Embedded Computing Group inaugurated 3/04

• Focused on programming, tools, sensor/Web mash-up, and platforms. Published 8 papers on the new results.

• MSRSense Toolkit source code released 12/14/05, with 7000+ downloads since, and on MSR Home Page popular download list in 4/06. DVD kit ready for 7/06 Faculty Summit

• MSR Sensornet Workshop successfully held 10/10-11/05, with 50 people attending, including many leading researchers in the field. Keynotes by Kris Pister and Tony Hey. All presentation materials online.

• SenseWeb prototype demoed 5/06, with coverage in Technology Review, EE Times, InternetNews etc., hundreds of blogs, and over 130,000 hits on Google search within weeks. Portal ready for Faculty Summit.
Multi-tier net of sensornets, coupled with Internet

Characteristics:
- Variability in devices and networks
- Rich data sources - sensor, image, GIS, … - streaming, live, historical or processed
- Different administrative domains, data ownership
- Multiple, concurrent, queries
Space Monitoring Apps
Projects

• **SenseWeb**
  – Sensors meet World-Wide Web: platforms for organizing and browsing live data
    • [http://research.microsoft.com/nec/senseweb](http://research.microsoft.com/nec/senseweb)

• **MSR Sense Toolkit**
  – .NET/PC/mote tools for collecting, processing, visualizing, and archiving sensor data
    • [http://research.microsoft.com/nec/msrsense](http://research.microsoft.com/nec/msrsense)

• **SONGS**
  – Service-oriented approach to programming and managing federated devices such as sensors

• **mPlatform**
  – A ref platform design for mobile/embedded apps: reconfigurable hw/sw for power-aware processing/communication
How busy is Lowell's?

Wait time:
- Avg: 30 mins
- Min: 0 mins
- Max: 90 mins

RestaurantFinder++

Ubiquitous Sensing Infrastructure and Reality Browser:
Query physical world, live and up close, from anywhere
Potential Apps

• Environment
  – Volcano, underwater, rainforest

• Education
  – K-12 interactive learning, virtual laboratory

• Leisure
  – Virtual travel, sunny spot tracker (for Seattle!), what is the temperature at my favorite beach? what is the water algae level?

• Getting around
  – Where is the nearest available parking space? What is the traffic like on the bridge? How long is the queue at the gas station? Where is the bus?
SenseWeb

• Goal: Simplifying publishing live data on Web and querying that data (from sensors)

Indexing live data
Processing queries on the data

SenseWeb
(Indexing, query processing, caching, scalability, etc.)

• Generic functionalities implemented
  • Programmable

Query response

Data publishing
Microsoft’s Plan to Map the World in Real Time
Researchers are working on a system that allows sensors to track information and create up-to-date, searchable online maps.

By Kate Greene

Researchers at Microsoft are working on technology that they hope will someday enable people to browse online maps for up-to-the-minute information about local gas prices, traffic flows, restaurant wait times, and more. Eventually, says Suman Nath, a Microsoft researcher who works on the project, which is called SenseWeb, they would like to incorporate the technology into Windows Live Local (formerly Microsoft Virtual Earth), the company’s online mapping platform.

By tracking real-life conditions, which are supplied directly by people or automated sensor equipment, and correlating that data with a searchable map, people could have a better idea of the traffic driving on their local roads, says Nath, and make a more informed decision on the driving route to take.

“The value that you get out of [real-time data] can range from finding a parking spot in a cavernous shopping mall to finding the shortest route home,” says Nath.

A screenshot of the SenseWeb sensor mapping application. The user highlighted a geographic region (red lines and dots) and typed “Seattle Sensors” to view a variety of real-time data in the area. (Image courtesy of Suman Nath, Microsoft Research.)

News articles on SenseWeb:
• Microsoft's Plan to Map the World in Real Time, Technology Review, 5/8/06
• Adding Real-Time Info to Local Searchers, InternewNews.com, 5/11/06
• Microsoft Research showcases future technology, EETimes, InformationWeek, CRN, 5/3/06
• Microsoft Keeping Web Arsenal Well-Stocked, TheStreet.com, 5/3/06
• Over 130,000 hits on “SenseWeb” and “Microsoft” using Google search within weeks
SenseWeb Architecture

- Fine-grain, modular services as building blocks
  - Library for common tasks: data cleaning, storage, aggregation, query processing, …
- Aggregated services built upon these fine-grain services
  - Simple, unified programming abstraction
- Extensible, friendly to 3rd party services
Sensor Ontology

- OWL sensor ontology exposes the semantics associated with sensor types, groups and relationships

- The ontology provides high-level interoperability at syntactic and semantic levels
GeoDB

• Processes queries on geographic data
  – E.g., cameras inside a region, near a route
• Sensors register themselves
  – Single rendezvous point for sensors and users
• Data indexed with Hierarchical Triangular Mesh (HTM)
  – Proximity-preserving 1D mapping of Lat/Long
  – Implemented as table valued functions in SQL Server 2005 + external library
• Simple APIs and Web Service interface to store, modify, and query the database
Aggregator (IconD)

- Aggregates sensor data, produces icons
- Aggregation at different granularities
  - Dynamically, e.g., based on zoom levels
Client-side GUI library

Java-script library to develop web-based GUI with more controls to interact with data

region  orientation  path
SensorMap demo
Publish data to the Web

- Web services, Clean semantics
- Proprietary protocols, Noisy data streams & events

Diagram showing connections between Internet, IT Infrastructure, Microservers/Gateway to Internet, Embedded Sensors/Actuators.
MSRSense: A toolkit for data publishing, archiving, visualization

- **Visualize Events/Process Data**
  - User Interface / Data Processing (Excel viz)
  - Microserver Tasking
  - Sensor Net (Tmote Sky)

- **Archiving Events**
  - Database (SQL Server 2005 or Express)
  - Raw data (XML packets)

- **Transformed XML**
  - Packet Stream Player

- **Publishing Data**
  - Gateway (MicroServer data publishing web service)
  - Status / Sensor Readings (TinyOS Packets)
Toolkit Release

- Released on 12/15/05; Latest (v0.1.4) on 6/30/06. Available from http://research.microsoft.com/nec/msrsense
  - Key components:
    - **mSEE**: The microServer Execution Environment is a component-based runtime system that can be dynamically tasked to collect and process sensor data
    - **mSIC**: The microServer Interaction Console is a user interface for tasking microservers and receiving data
    - **MoteForwarder**: This is a .NET solution for SerialForwarder found in TinyOS. MoteForwarder converts USB connections from PC to motes (base stations) into TCP socket interfaces that can be used by multiple consumers.
    - **Senscel**: The Excel extension allows users to visualize and archive streaming data from microservers through an Excel spreadsheet interface.
    - **Web service interfaces** for microservers and integrate with SenseWeb data hub.
- Very positive response from the community. On MSR Home Page popular download list in 4/06
- CD kit ready for the Faculty Summit ’06 release
- Publication
  - Spreadsheet programming and interface (IPSN/SPOTS’06)
Mote Programming

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Data Streaming Worksheet

= -39.60 + 0.01 * Raw Data

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Software release

- MSRSense toolkit available (in source code)
  - [http://research.microsoft.com/nec/msrsense](http://research.microsoft.com/nec/msrsense)
  - 12/14/05 announcement on TinyOS mailing list

- SenseWeb portal is available now
  - [http://research.microsoft.com/senseweb](http://research.microsoft.com/senseweb)
  - For browsing and data publishing
  - Available data from traffic webcams, weather, city street parking, soil, lake ecosystem
Challenges that come with the real world

• A great deal of variability
  – Variability in app requirements
    • Use scenarios (data collection, control in the loop, or in-network compression), sensing modality, data rate
  – System dynamism and heterogeneity
    • Nodes/links come and go; possibly non-replenishable resources
    • Hw heterogeneity; incremental deployment by multiple vendors with different technologies (e.g., network protocols)
  – Unreliable data
    • Uncertainty due to packet loss, sensor noise, partial observability
  – Mismatch between user queries and imperative mote programs
    • Semantic user queries such as “Tell me if you see a red car”

• As a result
  – Phil Buonadonna: “Every sensor net experiment needs 2 PhDs and 5 grad students”, or something like that
Issues to address

• Real time response
  – Handling of time-critical events

• Resource sharing and management
  – Resource (energy, bandwidth, processing, storage) models and monitoring
  – Task prioritization and scheduling

• Programming the networks as a whole
  – Interfaces between various components (e.g., SP link layer abstraction, SensorML)
  – Programming model; event driven vs. threaded

• System management
  – Tools for sys config/mgmt, for data collection and vis, for in-situ debugging
A Tasking Architecture

- Task Pool
- Application Programming
  - GUI
  - Planner
  - Excel
  - Config scripting
  - Service lib
- System Run Time Support
  - Sensor Net Deployment
- Declarative queries
- Tasking
  - Abstract services, dependencies, priorities, E-E constraints
  - Link reliability, net latency, data fidelity
  - Run time monitoring
  - Sensor tasking
    - Optimizer 1
    - Optimizer 2
  - Concrete services
  - Tasking ML
mPlatform: A clean-slate approach to reconfigurable networked embedded computing

- **Goal**
  - Re-think how hw/sw for small devices are organized, using a flexible and yet constrained platform
  - Motivated by concrete apps

- **Lego-like, extensible multi-board hardware**
  - Multiple radios (Zigbee/BlueTooth/WiFi/GPRS) and processors (MSP430/ARM7/PXA), add-ons (sensors)
  - Real-time handling of time-critical events
  - Programmable inter-connects between boards

- **Reconfigurable, modular software platform**
  - Uniformity in on/off node messaging
  - Dynamic tasking
  - Power-aware scheduling
A reconfigurable, extensible multi-board design

• A collection of stackable boards
• Each board has enough buffer storage and processing power to handle time critical events
• A shared clock signal enables system-wide synchronization

Advantages:
– Can design, build, and test independently
– Flexible hardware configuration

Prototype boards for mPlatform
Programming the ensemble

React to events/messages
- handshaking
- locks and monitors
- interrupt services
- pulling sensors

Cross-board and cross-node programming
SONGS: **Service Oriented Networked ProGramming of Sensors**

**Service Abstraction and Interface**

**Service Planning**

\[ \text{histogram}(S, x, y, z) \]

\[ \text{car}(X) \rightarrow \text{speed}(X, S) \]

\[ \{S>30\} \]

**Service Embedding**

**Service Scheduling and Execution**

\[ \text{histogram}(S, \text{car}(X), \text{speed}(X, S)) \]

\[ \{S>30\} \]
Example of services and their composition

**Counting vehicles with a sensor array**

- Extract edges from break beam detections
- Sort edges into consecutive detections
- Detect vehicles based on timing relations among detections
- Count vehicles
- Generate an arrival histogram report
Another Example:
where is the elevator?
Automatic Service Planning

- Declarative specification
- Automatic resource sharing and reuse
- Reasoning about space/time constraints
- Execution monitoring and re-planning
- Constraint-based trade-offs

```
sensor( magSensor,  [[60,0,0],[70,10,10]]).
sensor( camera,      [[40,0,0],[55,15,15]]).
sensor( breakSensor, [[10,0,0],[12,10,2]]).

service(  breakService (Region),
          needs(  sensor (breakSensor,Region) ),
          creates(  break (X), detected (X,T,Region) )).
```

User Query

car(X), speed(X,S), histogram(S), {S>30}.

Given a service composition tree (workflow) and a physical network of nodes, how to map logical services onto the devices?
Example: Monitoring a Garage

**Kinetically Stable Assignment**: Assign data collection tasks to microservers, to minimize overall cost of task migration for all future steps of interest.

- K tasks,
- N uServers,
- T time window
- Server capacity limit
- Cost of task migration
- Uncertainty in environment
Kinetically Stable Assignment (KSA)

Deterministic Bipartite Graph per Time Step

Time = 0

Time = 1

Time = 2

Time = 3

Probabilistic Bipartite Graph per Time Step

Time = 0

Time = 1

Time = 2

Time = 3

“Kinetically Stable Task Assignment for Networks of Microservers.” IPSN’06.
Working with the research community
Sensor Networks Workshop 2005
Woodinville, Washington, USA
Willows Lodge

http://research.microsoft.com/workshops/sensorws2005
Wireless Sensor Networks for Soil Ecosystem Studies
Katalin Szlavecz, Earth and Planetary Sciences, Johns Hopkins University
Sensor Networks for Human Activity Inferencing
Gaetano Borriello, University of Washington
Integrating Sensor Networks into Medical Care Using Web Services
Matt Welsh, Harvard

EMS / 911 Dispatch
Hospital staff
Hospital Information Systems

Web Services Proxy Server

Dispatch
Location, severity

Patient info
Triage

Caseload
Bed availability

Vital signs, location
Triage, transport

CodeBlue networks at disaster sites
SensorMap RFP (provisional)

- The goal is to build an open sensor data repository and interesting scientific applications on top of that, leveraging the SensorMap platform as well as other tools developed by the community.

- We expect this RFP (Request for Proposals) will result in a broad selection of supported university research projects whose purpose will be to explore the next-generation sensor networks that interface with the internet and enterprise networks.

- We anticipate accepting proposals in the Fall – please await our formal announcement before submitting proposals! Thank you for your patience.

- Questions: Stewart Tansley (stansley@microsoft.com)
Summary

• We have focused on programming models, system tools, and web and query interfaces. **Research results** presented in:
  – "SenseWeb: Browsing the Physical World in Real Time", Demo Abstract, IPSN’06.
  – "Kinetically Stable Task Assignment for Networks of Microservers." IPSN’06.
  – "Greedy is Good: On Service Tree Placement for In-Network Stream Processing." ICDCS’06.
  – "A Spreadsheet Approach to Programming and Managing Sensor Networks." SPOTS’06.

• **SenseWeb** prototype demoed 5/06, with articles in *Technology Review, EE Times, InternetNews* etc., hundreds of blogs, and over 130,000 hits on Google search within two weeks.

• MSRSense **Toolkit** released 12/14/05, with 7000+ downloads since. DVD kit available at Faculty Summit

• MSR Sensornet **Workshop** successfully held 10/05, with 50 people attending. Keynotes by Kris Pister and Tony Hey. All presentation materials online.