Annual Report for Period: 09/2000 - 08/2001
Submitted on: 05/31/2001
Principal Investigator: Srivastava, Mani B.
Award ID: 0085773
Organization: U of Cal Los Angeles
Title:
ITR: Technologies for Sensor-based Wireless Networks of Toys for Smart Developmental Problem-solving Environments

Project Participants

Senior Personnel

Name: Srivastava, Mani
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Muntz, Richard
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Baker, Eva
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Alwan, Abeer
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Potkonjak, Miodrag
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Chung, Gregory
Worked for more than 160 Hours: Yes
Contribution to Project:
Greg, with his background in educational assessment techniques, is acting as the application domain expert, helping define classroom scenarios and activities for leveraging sensor instrumentation. He is also the interface between the technologists (EE, CS) and the kindergarten staff.

Post-doc

Graduate Student

Name: Locher, Ivo
Worked for more than 160 Hours: Yes
Contribution to Project:
Ivo is investigating techniques (hardware design, software, and algorithm) for wireless spatial sampling of acoustic/speech input within the sensor-instrumented Smart Kindergarten. He is funded through the grant as a Graduate Student Researcher.

Name: Savvides, Andreas
Worked for more than 160 Hours: No
Contribution to Project:
Andreas is investigating fine grained localization (i.e. real-time tracking location and orientation) of wirelessly netwroked objects in the sensor-instrumented Smart Kindergarten. His work spans algorithms, hardware design, and software develpment.

Name: Park, Sung

Worked for more than 160 Hours: No

Contribution to Project:

Sung is doing the hardware architecture and design of the ultra-lowpower wireless sensor badge we intend to deploy in the sensor-instrumented Smart Kindergarten. The badges will be worn by the kids, and allow us to wirelessly track their location at a fine scale, and sample physical information in theimmediate vicinity of each kid. Sung is also going to investigate low power wireless protocols in the context of these badges. He is currentl supported on a fellowship, but expenses relating to his design are supported by the grant.

Name: Mani, Murali

Worked for more than 160 Hours: Yes

Contribution to Project:

Murali is investigating middleware techniques for sensor data management, and contributing to the implementation of the MUSE software infrastructure.

Name: Cui, Xiaodong

Worked for more than 160 Hours: No

Contribution to Project:

Xiaodong is investigating algorithms relating to recognition of kid's speech.

Name: Slijepevic, Sascha

Worked for more than 160 Hours: Yes

Contribution to Project:

Sasa is investigating techniques for aggregation and information mining of sensor data. He is also contributing to interfacing of specific sensors to the software infrastructure.

Name: Castro, Paul

Worked for more than 160 Hours: No

Contribution to Project:

Paul is helping with the architecture of the middleware system.

Name: Perez, Uriel

Worked for more than 160 Hours: Yes

Contribution to Project:

Uriel is working on algorithms for profiling sensor data.

Name: Wong, Jennifer

Worked for more than 160 Hours: Yes

Contribution to Project:

Jennifer is developing algorithms for profiling sensor data, and also participating in defining the SmartBoard.

Undergraduate Student

Name: Kremenek, Ted

Worked for more than 160 Hours: No

Contribution to Project:

Ted is an udnergraduat student who is contributing to the software development tasks related to the MUSE middleware, including design of software wrappers for video cameras, microphones, etc. to interface these devices to the MUSE system for recording sessions within the classroom.

Name: Han, Chih-chieh

Worked for more than 160 Hours: No

Contribution to Project:

Chih-chieh (Simon) is an undergraduate student contributing to software relating to the sensor badges and localization sensing.

Research Experience for Undergraduates

Organizational Partners

University Elementary School

The Corrine A. Seeds University Elementary School (UES) serves as the laboratoy school for the UCLA Graduate School of Education and Information Sciences. In collaboration with UCLA researchers, UES teachers and administrators experiment with innovative organizational structures, decision-making processes, and instructional strategies and develop state-of-the-art curriculum based on the most recent research and using the most advanced technology.

For this projects, UES is providing its facilities to help us realize our vision of a wireless sensor-instrumented kindergarten classroom.

Other Collaborators or Contacts

Activities and Findings

Project Activities and Findings:

The goal of this research project is to investigate challenges in 'person to physical world' communications in deeply instrumented 'smart spaces' formed by unobtrusively imbedding ever cheaper, tinier, and lower power embedded processors, micro-sensors, and wireless network interfaces in physical objects. We are exploring the challenges of these sensor-based wireless networks in the context of a 'Smart Kindergarten' that we are developing to target developmental problem-solving environments for early childhood education. This is a natural application of the ability of deeply instrumented smart spaces that allow a fusion of the cognitive and the physical realms since young children learn by exploring and interacting with physical objects such as toys in their environment and observing how they (causally) respond.

Wirelessly networked embedded sensors create a problem solving environment that can be continually sensed in detail (kids, playthings, classroom 'woodwork' etc.). Our objective is to ultimately enable assessment of the who, what, where, when, and how of student learning by computationally relating measured physical attributes (e.g. location) of kids, teachers, and related objects in the instrumented classroom to behavioral metrics that are meaningful, credible, and in a form usable for educational assessment. The eventual system would enhance the education process by providing a childhood learning environment that is individualized to each child, adapts to the context, coordinates activities of multiple children, and allows continual unobtrusive evaluation of the learning process by the teacher.

Our research seeks to achieve the above objective via wirelessly-networked, sensor-enhanced toys and other classroom objects with back-end middleware services and database techniques.

The following summarizes our research and education activities so far:

I. SENSOR-BASED WIRELESS NETWORK ARCHITECTURE AND PROTOCOLS

The activities in this category are broadly focused on creating techniques (algorithms, protocols) and technologies (hardware, software) that would allow dense physical sampling and capturing of classroom activity via wirelessly networked sensors including student-student, student-object, student-teacher, and teacher-object interactions.

Activities undertaken so far under this category are:

* Design of a system (and underlying algorithms) for fine-grained real-time tracking of location and orientation of network nodes in an ad hoc network (objects in the smart space) using a combination of hybrid ultrasound-RF ranging, accelerometers, and magnetometers. To accommodate nodes that may not have line of sight ultrasound and radio links to beacon nodes with know positions, the algorithm is designed to operate in an ad hoc environment The distributed algorithm is based on the powerful approach of 'collaborative multilateration' whereby we are able to localize nodes in an ad hoc network with very few beacons as opposed to a traditional approach where every node needs to be in range of three beacons. For example, Figure 1 shows a network scenario that our technique is able to localize where traditional techniques would either require a centralized solution or would fail to achieve localization. Further, our algorithm estimates not only the location but also the speed of sounds so that it is robust to temperature variations. A further benefit is that unlike traditional approaches, our scheme does not require carefully placed (and therefore costly) beacon infrastructure. We are investigating further 'self-calibration' techniques. Results from an

initial hardware/software prototype show accuracies of a few centimeters, while being fully distributed and scalable. We are currently proceeding with a more refined implementation using longer-range ultrasound transceivers. The results of this activity are reported in a paper accepted for ACM Mobicom 2001 ('Dynamic Fine-Grained Localization in Ad-Hoc Networks of Sensors,' by Andreas Savvides, Chih-Chien Han, and Mani Srivastava) and paper submitted to Ubicomp 2001 ('Location Awareness in the Kindergarten of Tomorrow,' by Andreas Savvides, Sung Park, Mani B. Srivastava). Figure 2 shows the localization accuracy achieved using data from our current prototype in the presence of measurement noise and errors in beacon positions.

* Hardware design of a wireless 'SensorBadge', and a wireless 'SensorBeacons'. Together they would provide the capability to track fine-grained location and orientation of kids and large objects in the classroom, and also allow sensing of physical attributes such as sound, temperature, light, magnetic fields, and forces in the immediate vicinity of the kids/objects (with attached SensorBadges) and selected locations (with SensorBeacons pre-placed). The hardware is based around using Bluetooth radio, sensors, and low-power embedded processor. At the time of writing this report, we have completed PCB schematics of both the SensorBadge and SensorBeacon, and expect to have both the designs completed (PCB layout/routing), fabricated, and packaged over the summer so that we can 'deploy' them in the classroom in Fall. The design is based on extensive interaction with the Kindergarten teacher whose classroom we shall instrument.

* Network architecture definition and preliminary protocol development of the overall network architecture composed of multiple Bluetooth Pico nets for speech and sensor data transmission, and overlayed wireless high-speed wireless network for collecting video streams. The architecture is 'ad hoc augmented infrastructure' in that the individual nodes can be multiple hops away from one or more ad hoc deployed gateways to the backbone wired network. We are investigating techniques for disseminating queries to, and sensor data from sensor-equipped objects named via attributes. In addition, we are investigating MAC scheduling techniques to cope with the high density of nodes and timing synchronization needed for ranging during hybrid RF-ultrasound localization, and the interaction of MAC with power-management techniques based on coordinated node shutdown.

* One of the technical challenges in this project is robustly sending speech of a large number of kids (acquired through sensor badges and embedded wireless microphones) over the wireless network in a quality robust enough for remote automatic speech recognition (ASR). We are developing and evaluating two different approaches to the remote speech recognition problem. The first approach involves coding the speech signal and then transmitting the data. Standard coders such as ADPCM, EFR GSM, and a CELP coder will be used. In the second approach, feature extraction is first performed, and then the feature vectors are compressed and transmitted to the recognizer. In both approaches, compressed speech (or feature vectors) is protected against wireless channel errors. Preliminary results from our activity on remote recognition across wireless links were published as papers at ICASSP in May 2001. In the paper 'An efficient and scalable 2D DCT-based feature coding scheme for remote speech recognition' by Zhu and Alwan we presented a 2D DCT-based approach to compressing acoustic features for remote speech recognition applications. The 2D DCT together with entropy coding can be used to compress feature vectors effectively at low bitrates available over the wireless link. In the paper 'Source and channel coding for remote speech recognition over error-prone channel' by Bernard and Alwan we presented source and channel coding techniques for remote ASR. The channel coding technique is specifically designed for remote ASR and outperforms commonly-used hard decision decoding in terms of error correction and error detection. We will continue our work by further examining how to best recognize speech that has been compressed by standard coders or that parameterized by quantized features. In addition, we will be adapting our recognition engine to handle children's voices.

II. SENSOR DATA MANAGEMENT AND MIDDLEWARE SERVICES

The activities in this category are focused on creating the software infrastructure and algorithms for (a) capturing and storage management of sensor data to provide concurrent applications with shared/mediated access to sensor data, (b) detection and reconstruction of complex spatio-temporal events, (c) aggregating and composing often noisy sensor data into higher level sensor information and behavioral metrics useful for educational assessment, and (d) mining the sensor information to identify cause-effect relationships useful for assessment.

Activities undertaken so far under this category are:

* Development of the middleware software infrastructure, MUSE, for use in this and other projects. Besides providing the usual service discovery and proxy mechanisms, MUSE provides ability to deal with quality of information issues, and composing higher order virtual sensor services from underlying noisy, uncertain, and failure-prone sensors. Figure 3 shows the MUSE architecture.

* Design of software wrappers for video cameras, microphones, etc. to interface these devices to the MUSE middleware system for sensor data recording sessions within the classroom.

* Study of XML query languages suitable for stream data as obtained from sensors. Design an implementation of XML representation for sensor data. Acquired and investigated the use of IBM tools for storing and accessing XML documents in DB2. We also investigated other

tools for storing, indexing and querying data originating in XML.

* Study of indoor tracking system using radio signal strength, and evidential reasoning techniques to provide location information along with a measure of confidence in the response. Also investigated various optimization strategies and ways of combining information from other sources to improve the localization performance available using only the signal strength measurements. An initial implementation has been done using WaveLAN access points as range sensors, and Bayesian service model and proxies in Muse to localize people to granularity of small rooms. Results of this activity have been submitted as papers to IEEE Computer Special Issue on Location Systems ('Nibble: A Component-based Location System' by Paul Castro, Ted Kremenek, Richard Muntz) and to the Ubicomp 2001 conference ('A Probabilistic Location Service for Wireless Network Environments' by Paul Castro, Patrick Chiu, Richard Muntz).

* Investigating batch query processing where a query can be expressed in terms of a belief network. In this case, database tuples are 'evidence' and the result is a probabilistic conclusion about some inferred variable. We are investigating, for example, the ordering of tuples as well as evaluation of the belief network in an attempt to optimize computation time. This work will later be applied to similar problems in temporal sequences from sensors.

* As part of another project, we designed and started an implementation of a proxy that can interface between the IEEE 1451 standard for network attached sensors and the Jini service discovery mechanism utilized by MUSE in the more capable wired network. (The proxy is assumed to run on an Internet enabled platform ... which often has a wireless IP connection.) This proxy uses the IEEE 1451 protocol to discover the available sensors and provides interfaces for controlling data acquisition. The design of this proxy is being reevaluated to better serve the Smart Kindergarten environment which has some significant differences, e.g., a more dynamic Bluetooth environment in which sensors will dynamically connect to different Internet enabled platforms as children and object move around the room. Also there are two levels of wireless communication (Bluetooth and a wireless LAN) which may suggest further functional decomposition.

* We also worked on algorithms for profiling in sensor networks. Specifically, our activity spanned two components of the eventual middleware: profiler, and recommender. Profiler builds a predictive model of the behavior of an object in the space. Recommender is system that recommends which actions have to be undertaken, in order to accomplish some tast. In order to gain better insights into the problem and to make our research well founded in practice, we focussed our attention on the following four profilers: individual movement, n-person interaction, and item and space usage. Our activities included (i) extraction of parameters such as coordinates, speed, light intensity etc. for use by profiler, (ii) development of stochastic and non-parametric statistical models for profiling, (iii) development of environment for acquisition of data to feed to profilers, (iv) techniques for profilers validation, and (v) development of interface with applications.

III. APPLICATION

The activities in this category are focused on application-level issues such as defining metrics that are useful to teachers while being derivable from sensor data, and the pragmatics of 'deploying' our technology in the classroom.

Activities undertaken so far under this category are:

* We have been observing the target classroom to gather information about how students interact with each other, and with the teacher, and with physical objects. We have observed children in different instructional contexts: Whole group (teacher-led) activities, small group activities, free play, and independent work. The purpose of this activity is to identify potential measurement opportunities and problems related to the available sensor technology. For example, we have observed that in general, the children are constantly moving—squirming around during whole-group activities, often do not face directly the speaker (i.e., teacher or other student), swinging their legs during seatwork. We have also observed that students are relatively still when they appear to be concentrating on a task (e.g., during a drawing task there is far less swinging leg motion). We expect to continue the classroom observation to better understand the environment as well as perform cognitive walkthroughs of potential measures prior to formally operationalizing the measures via our sensor-based wireless network.

* We extensively interacted with the Kindergarten classroom teacher and the technology specialist at the University Elementary School to define 'deployment scenarios' and identify measurable metrics, user interface issues, and parental concerns regarding monitoring via sensors. We have defined the details of our initial experiment, with the goal of (a) validating preliminary versions of our hardware and software, (b) collecting some sensor data for algorithmic analysis, and (c) simply familiarizing ourselves with the details of working with small kids, teachers, and parents. We anticipate this first experiment to take place either in mid-June (prior to summer holidays), or as soon as the school opens in September. The uncertainty arises from availability of certain equipment needed for interfacing sensors to our middleware servers. The architecture that we have defined includes wireless cameras, seismic sensors on the floors, wireless microphones for spatial sampling of speech, and a small number of wireless tags for fine-grained localization, with all the sensor data streaming to our middleware. If due to equipment delays we are unable to experiment in June, we shall conduct the experiment in September together with the SensorBadges and SensorBeacons that we are developing as described earlier. The initial experiment will also provide us with speech data for developing/refining the speech

recognition middleware service.

* We have defined specific metrics and models that we would derive from the sensor data during the initial experiment. From the location tracking traces we intend to derive Hidden Markov Models for the mobility and interaction of kids. Our intention is that these models would better reveal correlations between mobility / group interaction statistics and academic performance. For example, we seek to able to answer question such as: Do kids who mix more with other kids perform better academically? Do kids who hang out together perform similarly?

* Working with the Kindergarten classroom teacher we have also identified classroom activities that are candidates for tighter coupling with the sensor instrumentation infrastructure. We have also defined a sensor-equipped wirelessly-networked SmartBoard that will use special sensors to identify id and location of blocks and cards placed on it by kids. The idea is that these SmartBoards will be incorporated in commonly used classroom activities involving spelling, counting, pattern matching etc. using cards and blocks. The SmartBoard will not only feed data to the middleware system regarding the sequence of events as a kid (or groups of kids with interconnected SmartBoards) solves a problem, but also provide feedback as specific goals are achieved. While we have defined the conceptual details of the SmartBoard, we are yet to address the fabrication of the SmartBoard.

* Another activity in this area was to review the literature for potential measures of physical interaction and the relationship between these measures and outcomes such as literacy, problem solving, and pro-social development. One challenge we have faced is arriving at the appropriate grain size for the measures. The use of the sensor technology is a completely novel application to the measurement of student behavior; thus, there is little precedent to base the development of the measures. Typically, physical-interaction measures are ignored altogether and student assessment based on performance on tasks administered by the teacher to each student, one-on-one. Or, when physical interaction is measured, it is done by an observer looking for the presence of particular behaviors (i.e., using a rubric to code behaviors). In our case, the observation is via sensors that provide data at different grain-sizes, with different degrees of fidelity, and different types. Thus, the challenge is to simultaneously consider these constraints to arrive at a set of measures that can discriminate between students who engage in different behaviors and to have these behaviors associated with substantive outcomes such as literacy skills and problem solving.

IV. PRESENTATIONS

We made two very well-received presentations on the overall project, one at the 2000 Annual Conference of the National Center for Research on Evaluation, Standards, and Student Testing (CRESST) ('Fusing physical and cognitive spaces: Using wireless networked sensors to assess the who, what, where, when, and how of student learning' by Gregory Chung and Mani Srivastava), and a second at the 2001 UCLA Computer Science Department Research Review ('Sensor-based Wireless Networks for Developmental Problem Solving Environments: The Smart Kindergarten Project' by Mani Srivastava).

A paper describing the overall networking and sensor data management challenges being addressed by the project has been accepted as a 'Challenge Paper' for the prestigious ACM Mobicom conference to be held in July 2001 ('Smart Kindergarten: Sensor-based Wireless Networks for Smart Developmental Problem-solving Environments,' by Mani Srivastava, Richard Muntz, and Miodrag Potkonjak).

In addition, two more papers describing specific technical problems being addressed under the project have also been accepted for the 2001 ACM Moibcom ('Dynamic Fine-Grained Localization in Ad-Hoc Networks of Sensors,' by Andreas Savvides, Chih-Chien Han, Mani Srivastava; and, 'Locating Application Data Across Service Discovery Domains,' by Chatschik Bisdikian, Paul Castro, Benjamin Greenstein, Parviz Kermani, Richard Muntz, Maria Papadopouli).

We wish to highlight the fact ACM Mobicom 2001 has an acceptance rate of 10% (31 papers out of nearly 300), and publications related to this project account for 3 of those papers.

Besides the above papers, we also have three papers submitted, one published at a workshop on the localization related work done under the project, and two published at ICASSP on wireless transmission of speech for remote speech recognition.

Project Training and Development:

The project is still in its early stages, and therefore obviously we are far from our eventual goal of aggregating and mining physical data obtained from wirelessly networked sensors into behavioral metric useful to the teachers. However, in the process of investigating the underlying technologies needed for our system, we have contributed the following findings:

- The first middleware infrastructure capable of handling streaming sensor data, and letting it be shared by multiple concurrent applications in a mediated fashion.

- The first fine-grained localization system for finding location and orientation of nodes in ad hoc networks without the use of GPS and without

Research Training:

1. The project has participation from two undergraduate students, who have been involved in software implementation relating to the sensor middleware framework, and the fine-grained localization system. The project enriched their experience in ways that go beyond the courses. For example, the student working on the fine-grained localization has been exposed to implementation of protocols under real-time OS on embedded processors.

2. The project has also contributed to technical and research skills of the graduate students invlolved. For example, three of the students have participated in the design of the SensorBadge and SensorBeacons hardware, exposing them to valuable skills related to transitioning algorithms to real embedded hardware implementation.

3. Results and experience from the research conducted under the project are already impacting our graduate coursework. For example, the research under this project on sensor networks in general and on fine-grained localization in ad hoc has already been introduced by the PI into his graduate course EE206A on wireless systems.

Outreach Activities:

Journal Publications

Books or Other One-time Publications

Mani Srivastava, Richard Muntz, Miodrag Potkonjak, "Smart Kindergarten: Sensor-based Wireless Networks for Smart Developmental Problem-solving Environments", (2001). Conference Proceedings, Accepted
Collection: Proceedings of the ACM SIGMOBILE 7th Annual International Conference on Mobile Computing and Networking, Rome, Italy, July 2001
Bibliography: To be published.

Andreas Savvides, Chih-Chien Han, Mani Srivastava, "Dynamic Fine-Grained Localization in Ad-Hoc Networks of Sensors", ( ). Conference Proceedings, Accepted
Collection: Proceedings of the ACM SIGMOBILE 7th Annual International Conference on Mobile Computing and Networking, Rome, Italy, July 2001
Bibliography: To be published.

Chatschik Bisdikian, Paul Castro, Benjamin Greenstein, Parviz Kermani, Richard Muntz, Maria Papadopouli, "Locating Application Data Across Service Discovery Domains", (2001). Conference Proceedings, Accepted
Collection: Proceedings of the 7th Annual International Conference on Mobile Computing and Networking, Rome, Italy, July 2001
Bibliography: To be published.

Paul Castro, Richard Muntz, "An Adaptive Approach to Indexing Pervasive Data", (2001). Workshop Proceedings, Published
Collection: Proceedings of the International Workshop on Data Engineering for Wireless and Mobile Access, Santa Barbara, CA, May 2001
Bibliography: Santa Barbara, CA, May 2001

Paul Castro, Ted Kremenek, Richard Muntz, "Nibble: A Component-based Location System", (2001). Book, Submitted
Collection: IEEE Computer (special issue on location systems)
Bibliography: Submitted.

Paul Castro, Patick Chiu, Richard Muntz, "A Probabilistic Location Service for Wireless Network Environments", (2001). Conference Proceedings, Submitted
Collection: Proceedings of Ubicomp 2001
Bibliography: Submitted.

Andreas Savvides, Sung Park, Mani B. Srivastava, "Location Awareness in the Kindergarten of Tomorrow", (2001). Conference Proceedings, Submitted
Collection: Proceedings of Ubicomp 2001
Bibliography: Submitted.

Gregory Chung, Mani B. Srivastava, "Fusing physical and cognitive spaces: Using wireless networked sensors to assess the who, what, where, when, and how of student learning", (2000). Conference Presentation, Published
Collection: Annual Conference of the National Center for Research on Evaluation, Standards, and Student Testing (CRESST)
Bibliography: Poster presentation.

Q.Zhu and A.Alwan, "An efficient and scalable 2D DCT-based feature coding scheme for remote speech recognition", (2001). Conference Proceedings, Published
Collection: Proc. IEEE ICASSP
Bibliography: May 2001

A.Bernard and A.Alwan, "Source and channel coding for remote speech recognition over error-prone channel", (2001). Conference Proceedings, Published
Collection: Proc. IEEE ICASSP
Bibliography: May 2001

Web/Internet Site

URL(s):

http://nesl.ee.ucla.edu/projects/smartkg/

Description:

This web site is for external dissemination of information related the project.

Other Specific Products

Product Type: Software (or netware)

Product Description:

MUSE, a sensor middleware software infrastructure, has been developed in a shared effort with another project. Besides providing the usual service discovery and proxy mechanisms, MUSE provides ability to deal with quality of information issues, and composing higher order virtual sensor services from underlying noisy, uncertain, and failure-prone sensors.

Sharing Information:

We make the software available to interested researchers who approach us. The software is not mature and stable enough to be widely distributed.

Product Type: Hardware design of wireless sensor nodes

Product Description:

We have developed hardware designs (PCB schematics) of two types of wireless sensors nodes: a wireless sensor badge to be worn on person, and a wireless sensor beacon node that has multiple ultrasound transceivers to function as a beacon node for localization.

Sharing Information:

We make our designs available as file in Protel (a widely used pCB design tool) format for selected groups that ask us. Already we have contributed parts of our design to another NSF project at UCLA, and to an effort towards an 'open source wireless sensor node' that is emerging among researchers from USC, UCLA, MIT, and Berkeley. Eventually (once we have tested our design) we will put the design files on the project website along with associated firmware/software.

Contributions

Contributions within Discipline:

The project is still in its early stages, and therefore obviously we are far from our eventual goal of aggregating and mining physical data obtained from wirelessly networked sensors into behavioral metric useful to the teachers. However, in the process of developing the underlying technologies needed for our system, we have made following significant contributions:

- The first middleware infrastructure capable of handling streaming sensor data, and letting it be shared by multiple concurrent applications in a mediated fashion.

- The first fine-grained localization system for finding location and orientation of nodes in ad hoc networks without the use of GPS and without requiring a calibrated infrastructure.

Contributions to Other Disciplines:

Contributions to Human Resource Development:

Contributions to Science and Technology Infrastructure:

Contributions: Beyond Science or Engineering:

Special Requirements

Special reporting requirements: None
Change in Objectives or Scope: None
Unobligated funds: $ 150,000.00

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Activities and Findings: Any Outreach Activities
Any Journal
Contributions: To Any Other Disciplines
Contributions: To Any Contributions to Human Resource Development
Contributions: To Any Science or Technology Infrastructure
Contributions: Beyond Science or Engineering

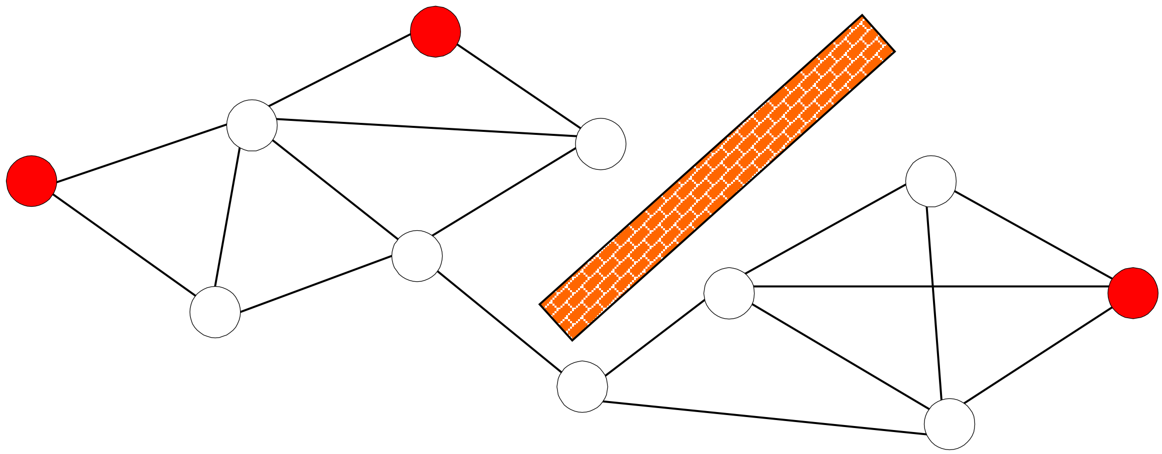

Figure 1: Scenario where collaborative multilateration localizes, while traditional approaches fails

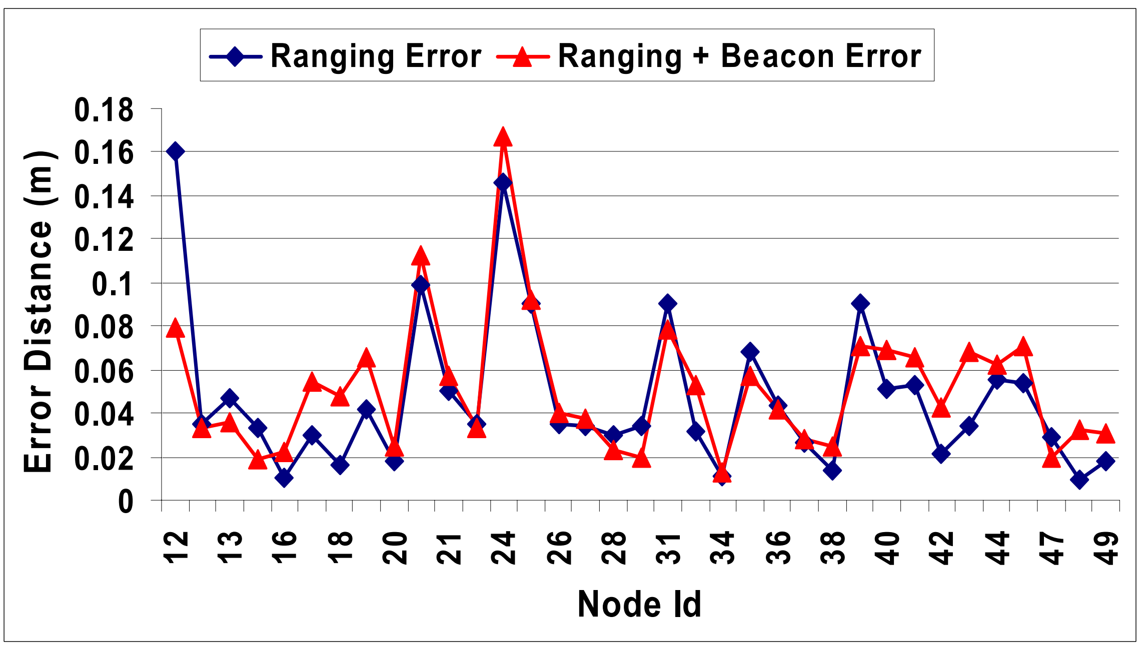

Figure 2: Accuracy of iterative multilateration approach

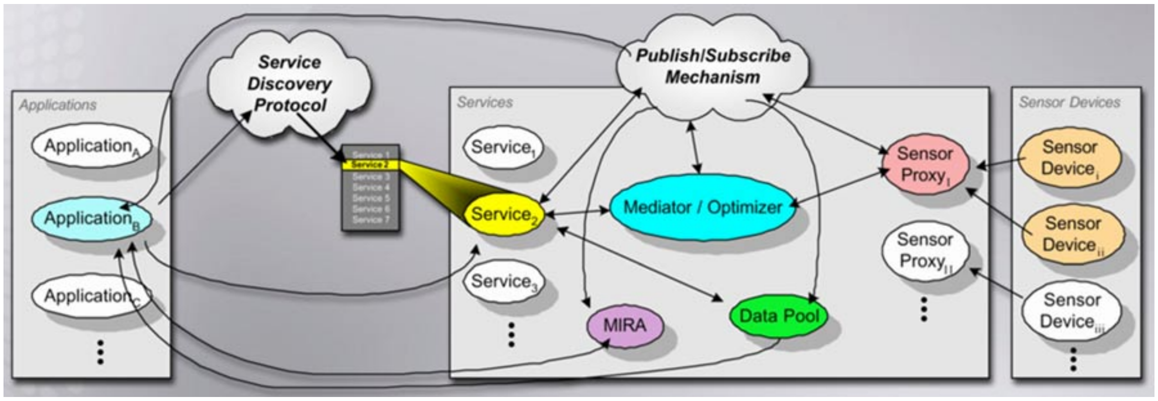

Figure 3: MUSE middleware software infrastructure for sensor data management