ITR/SY: A Distributed Programming Infrastructure for Integrating Smart Sensors

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As we observed at the time of filing the annual report in August 2008, that that was really a final report on the project. The only unexpended funds at that time was the remaining in the category of REU for which NSF had given a one-year extension. Therefore, we present the work done with the undergraduates in the following section and then reproduce the contents of the annual report from August 2008 for the sake of completeness of this final report.

Work done with Undergraduates in 2008-09

ASAP System

This is a mature project that provides a middleware framework for situation awareness applications incorporating high bandwidth sensors such as cameras and low bandwidth sensors such as RFID. There is more description of this work in the body of the annual report, which follows this section. Several undergraduates were employed on this project during this NCE year and benefited tremendously from the exposure. It is worth noting that two of the students (Matthew McCawley and Brian Stebar II) who worked collaboratively on this project received **The 2009 College of Computing Outstanding Undergraduate Research Award** for their work in developing a scalable multi-party video conferencing system while receiving the REU funding from this research project. A third student (Steve Dalton) completed an undergraduate thesis on a research topic related to this NSF funded project. Steve was also the recipient of **The 2007 College of Computing Outstanding Undergraduate Research Award** for the research he did on this project.

1. **Steve Dalton (Aug 2008 to December 2008)**:
   Work Description: Distributed Feature Extraction Using Cloud Computing Resources: The goal of this project was to construct a cloud processing system that will be integrated into the distributed camera surveillance network (ASAP). The ASAP system uses a heterogeneous wireless sensor network

to collect and prioritize multiple video data streams. ASAP performs the stream processing using only the in-network computational resources. This limitation on the availability of computational resources has restricted the number of interesting applications that can be implemented. By using cloud resources to move computations out-of-network the project aimed to facilitate the construction of more computationally complex applications in the ASAP system.
Currently, Steve is a PhD student at UIUC.
Learning Outcome: Cloud computing framework, ASAP, distributed systems integration
Research Outcomes:
(a) UG thesis: **Distributed Feature Extraction Using Cloud Computing Resources**, May 2009
(b) **The 2007 College of Computing Outstanding UG Research Award**
(c) Code and documentation to be used in ongoing research

2. **Matthew McCawley (August 2008 to August 2009)**:
Work Description: Scalable video conferencing: The goal of this project was to build an efficient stream server for multi party video conferenencing. The project explored at designing prioritization and parallelization strategies for efficient bandwidth and computation management on the stream server. One example of bandwidth optimization is to control video quality based of participants based on their social network structure. Matthew looked at the web-based interface to the above system.
Learning Outcome: Actionscript and Flex programming framework, Web architecture, Distributed systems integration
Research Outcomes:
(a) **The 2009 College of Computing Outstanding UG Research Award**
(b) **Judges' First Place Award at 2009 College of Computing** *Undergraduates Research Opportunities in Computing (UROC)* **contest** for their entry entitled "Scalable Multiparty Video Conferencing."
3. **Brian Stebar II (August 2008 to May 2009)**:
Work Description: Scalable video conferencing: The goal of this project was to build an efficient stream server for multi party video conferenencing. The project explored at designing prioritization and parallelization strategies for efficient bandwidth and computation management on the stream server. One example of bandwidth optimization is to control video quality based of participants based on their social network structure. Brian looked at supporting multiple simultaneous room capability in the system.
Learning Outcome: Actionscript and Flex programming framework, Flash media server, Web architecture, Distributed systems integration
Research Outcomes:
(a) **The 2009 College of Computing Outstanding UG Research Award**
(b) **Judges' First Place Award at 2009 College of Computing** *Undergraduates Research Opportunities in Computing (UROC)* **contest** for their entry entitled "Scalable Multiparty Video Conferencing."
4. **Brandon J. Whitehead (May 2009 to August 2009)**:
Work Description: Scalable stream fusion: The goal of this project is to build a system for dynamic switching and stitching of multiple camera streams connected to a desktop.
Learning Outcome: Microsoft Directshow architecture and programming, Multimedia encoding and decoding process, Red5 open source flash media server architecture.
5. **Michael DeRosa (May 2009 to August 2009)**:
Work Description: Scalable stream fusion: The goal of this project is to build a system for dynamic switching and stitching of multiple camera streams connected to a desktop. Michael was responsible for exploring Xuggle system for its stream management capability and how it can be used for our project purpose.
Learning Outcome: Microsoft Directshow architecture and programming, Multimedia encoding and decoding process, Xuggle and Red5 system integration.

RFID Middleware

More details on this sub-project is also in the body of the annual report that follows this section. Several undergraduates have worked on this sub-project through the life of the NSF award. The following list

includes the 2 students who worked on the RFID middleware in 2008-09 during the NCE period of this award.

1. **Brent Rowswell (January 2008 to December 2008)**:
   Work Description: The student has done extensive evaluation of the active RFID system performance in an indoor environment. He has designed and evaluated set of experiments that considers an indoor environment using active RFID technology. He has also developed some theoretical searching procedures to aid the mobility in an active RFID enabled environment.
   Learning Outcome: The student learned and contributed to programming active RFID system and conducting early experiments in the use of this technology for object localization in an indoor environment.
2. **Stewart Butler (May 2009 to present)**:
   Work Description: The student worked on developing a prototype environment that mimics an assisted living center using passive RFID tags and readers. He specifically developed a python based prototype to evaluate a small scale performance of the system. He also helped in evaluation and writing of a scholarly paper on the system named GuardianAngel.
   Learning Outcome: The student learned how to design a localization system for an indoor environment using passive RFID, as well as how to calibrate the system for unobtrusive monitoring of objects in such an environment.
   Research Outcome: The student also participated as a co-author in the writing of a paper [6] to a prestigious conference venue (IEEE Percom 2010).

Annual Report from August 2008 reproduced below

The research undertaken in this proposal is integrating sensing hardware, embedded processing and distributed system support to build a seamless programming infrastructure for ubiquitous presence applications. Fundamental invention and integration of techniques spanning programming idioms and runtime systems for distributed sensors, and building blocks for embedded processing are expected as the primary intellectual contributions of the proposed research. Interfacing these technologies to emerging applications on the one end and novel off-the-shelf sensors at the other end are secondary goals of the proposed research.

We have made the following contributions through this research:

- definition of an elaborate system architecture for prototyping sensor-based distributed applications covering distributed programming paradigm and data fusion
- issues that pertain wireless sensor networks including protocol stack, security issues, and code dissemination
- use of the technologies to construct prototype of complex cyber physical application for situation awareness

1 Activities and Findings (This Past Year 2007-08)

First we summarize the research accomplishments this past year followed by those in the previous years in Chronological order.

1.1 Research and Education

1.1.1 Systems Technologies to support Sensor Based Distributed Computing

1. e-SAFE: An Extensible, Secure and Fault Tolerant Storage System. In an ubiquitous setting it is important to ensure the integrity of remote access to information from mobile devices. This research resulted in using erasure codes to simultaneously assure the security of remote access to file systems as well as the fault tolerance when the requested data can be reconstructed even when there is partial communication in remote communication. The work [3] is part of the dissertation of Dr. Arnab Paul [38] who was supported by this award and appeared in the *First IEEE International Conference on Self-Adaptive and Self-Organizing Systems*, Boston, Mass., USA, July 9-11, 2007.

2. $Stampede^{RT}$**: Programming Abstractions for Live Streaming Applications.** Stampede is a programming system for distributed computing that is at the heart of this research. The principles behind this programming system is part of the dissertation of Dr. Sameer Adhikari [2], a student supported on this award. $Stampede^{RT}$ represents a new twist on this programming model to support live streaming applications. It was presented at the *27th International Conference on Distributed Computing Systems (ICDCS)*, 2007, and represents a part of the dissertation work of David Hilley, a student working on this project but supported by an IBM Fellowship.

3. On Improving the Reliability of Packet Delivery in Dense Wireless Sensor Networks. Reliable communication is essential in distributed sensing and this research work investigates techniques for improving the reliability for packet delivery and appeared in *16th International Conference on Computer Communications and Networks (ICCCN 2007)*, August 2007 [53]. It also represents a part of the dissertation work of Junsuk Shin, a student supported by this award.

4. Memory Optimizations for Distributed Streaming Applications. Sophisticated sensors such as cameras generate significant amounts of data. It is important to ensure that the resources are managed to contain the amount of memory resources used in streaming applications involving such high bandwidth sensors. This research uses the information in the application task graph to reduce the resource requirements in streaming applications [19, 18]. It is part of the dissertation work of Dr. Nissim Harel [17] who was supported by this award.

5. MobiGo and Chameleon: Supporting Seamless Mobility. Supporting user mobility seamlessly is important. This research devised techniques for application level (MobiGo) [58] and system level (Chameleon) [60] seamless mobility of a user in a distributed setting. This research represents part of the dissertation work of Dr. Xiang Song [55] who was supported by this award.

6. Streamline: Scheduling Streaming Applications in a Wide Area Environment. One of the premises for the project as a whole is that ambient computing infrastructure is ever available to support distributed sensing applications. This work [5] discusses a heuristic for efficiently scheduling streaming applications on a computational grid, and represents a part of the dissertation work of Bikash Agarwalla.

7. ASAP: A Camera Sensor Network for Situation Awareness. As a canonical example of sensor based distributed computing, we have built a camera sensor network for video based surveillance. The mockup uses typical security threats that may occur in an airport setting. This work was presented in the *11th International Conference On Principles Of Distributed Systems (OPODIS'07)*, Guadeloupe, French West Indies, December 17-20th, 2007. It also represents a part of the dissertation work of Junsuk Shin, a student supported by this award.

8. Mobile Virtual Sensors: A Scalable Programming and Execution Framework for Smart Surveillance. Building on the ASAP work, we are defining a platform (programming infrastructure) for the rapid prototyping of cyber-physical systems (Position Paper) . Hot EmNets 2008, The Fifth Workshop on Embedded Networked Sensors Charlottesville, Virginia, USA, June 2-3, 2008.

1.2 Training and Development

Needless to say, graduate students pursuing their doctorate are the primary focus of training and development. Please see Section 3.1 for a complete list of students at all levels who are alumni of this project.

Graduate students associated with the project have been benefiting from internships in leading research labs. In the spring of 2008, Dave Lillethun interned at Microsoft Research in Cambridge, England. In the summer of 2008, David Hilley was interning at IBM Almaden, Mung Yung Ryu was interning at Motorola Labs, and Lateef Yusuf was interning at QualComm. Dushmanta Mohapatra spent 2 semesters as an intern at AMI Corp., and Junsuk Shin is currently (in Fall 2008) interning at Microsoft Research, Redmond, Washington.

We continue to attract bright and interested graduates and undergraduates to research projects in our group. Undergraduate participation in research within the College is facilitated by the excellent UROC program (`www.cc.gatech.edu/program/uroc`), coordinated by Professor Amy Bruckman. A variety of institute-wide programs are also available (`www.undergraduateresearch.gatech.edu`) including a special fund sponsored by the president of Georgia Tech (PURA) and several NSF-sponsored projects. Since we associate these UGs to work with graduate students, it serves as a valuable tool for training our

graduate students in serving as mentors and student advisors.

In this past year, we have entertained a number of UG students as researchers in our lab. They include:

- Michael S. Slaughter (worked with Nova Ahmed on RF^2ID project in Fall 2007 and Spring 2008), Man Fung Yip (an exchange from Hongkong who worked with Nova Ahmed on RF^2ID project in Spring 2008).
- Matthew Wesley McCauley, Joseph Woo, and Robert Parker (worked with Junsuk Shin on ASAP project in Summer 2008).

1.3 Outreach

Professor Ramachandran has concluded negotiations with Samsung Electronics Corporation to establish a joint-center at Georgia Tech for carrying out collaborative research of mutual interest to Samsung and Georgia Tech. Under this agreement, Samsung will fund a number of research projects that had their roots in the ITR award. One such project is *MobiGo* that supports seamless mobility in a ubiquitous setting. A second one (to be carried out by PI Professor Irfan Essa) involves Non Photo-realistic Rendering.

The joint-center will have engineers from Samsung visiting on a year-round basis and working closely with the faculty and students in the College of Computing. So far, the agreement has resulted in funding 5 research projects at Georgia Tech. Please visit http://www.star.cc.gatech.edu.

We are in communication with the City of Baton Rouge and their department of Homeland Security. They are interested in serving as a beta-site for the camera sensor network technology we have developed for video-based surveillance.

We have similar ongoing dialogue with the IT department of the Hartsfield-Jackson International Airport in Atlanta to deploy our camera sensor network.

1.3.1 Research Commercialization

Georgia Tech has active interest in research commercialization. *Venture lab* is an entity that identifies research work in Georgia Tech that are worthy of consideration for commercialization. The *SensorStack* dissertation work performed by one of the students (Rajnish Kumar) funded by this ITR award has been chosen for research commercialization. We have developed an architecture for *priority aware situation awareness* with the SensorStack at its core. Potential application of this technology includes airport surveillance and critical infrastructure protection. Rajnish Kumar, research scientist, has been hired expressly to oversee the development of these technologies for application in such scenarios.

1.4 Activities and Findings in previous Years

The research in previous years have resulted in the generation of a number of technologies for distributed sensing. Here are few highlights:

- Distributed Programming idioms including the Stampede [48] and D-Stampede [1] programming systems.
- Middleware for data fusion called DFuse [28, 45], and a sophisticated yellow pages for match-making of sensors and actuators to applications called MediaBroker [34, 47].
- Technologies for making our programming infrastructure available on a variety of platforms including .NET [56].
- Technologies for marrying ambient HPC infrastructure with distributed sensing [4].
- Middleware for increasing the reliability of RFID deployments [7].

We also initiated a number of activities including the formation of a sensor lab that allows undergraduates to come and experiment with sensing technologies, and outreach to industries and potential consumers once this kind of technology matures.

All of these activities are well documented in the annual reports of the previous years. Rather than itemize the activities and findings from previous years, we simply present the web pointers to the previous years

- Web URL for the project:
  http://www.cc.gatech.edu/ rama/ITR-PROJECT/

- Year 2001-02 Annual report
  http://www.cc.gatech.edu/ rama/ITR-PROJECT/2001-02.pdf
- Year 2002-03 Annual report
  http://www.cc.gatech.edu/ rama/ITR-PROJECT/2002-03.pdf
- Year 2003-04 Annual report
  http://www.cc.gatech.edu/ rama/ITR-PROJECT/2003-04.pdf
- Year 2004-05 Annual report
  http://www.cc.gatech.edu/ rama/ITR-PROJECT/2004-05.pdf
- Year 2005-06 Annual report
  http://www.cc.gatech.edu/ rama/ITR-PROJECT/2005-06.pdf
- Year 2006-07 Annual report
  http://www.cc.gatech.edu/ rama/ITR-PROJECT/2006-07.pdf
- Year 2007-08 Annual report
  http://www.cc.gatech.edu/ rama/ITR-PROJECT/2007-08.pdf

2 Publications and Products

2.1 Publications

See the references at the end of this document for publications that appeared in the period that covers this project.

2.2 Web Site

Please visit the project web site at http://www.cc.gatech.edu/ rama/ITR-PROJECT/

3 Contributions

The activities we have undertaken in this project have resulted in a significant number of publications and software artifacts. These are listed in the references at the end of this report.

3.1 Human Resource Development and Student Placement

In the course of this project, every year roughly 10 graduate students worked on the project on an average. In addition, we hosted at least half a dozen undergraduates on the project, either as RAs supported by the REU program or for course credit. Students at all levels, who are alumni of this project, are sought after for summer internships by leading industries and get very good placements when they graduate.

As a direct result of this grant, we have graduated the following students who are well placed in industries and/or academia:

1. Zack Kurmas: Graduation Date: 8/2004
   Thesis title: “Generating and Analyzing Synthetic Workloads using Iterative Distillation”
   Position: Assistant Professor, Department of Computer Science & Information Systems, Grand Valley State University, Michigan.
2. Sameer Adhikari: Graduation Date: 12/2004
   Thesis title: “Programming Idioms and Runtime Mechanisms for Distributed Pervasive Computing”
   Position: Intel Corp., Portland
3. Arnab Paul: Graduation Date: 5/2005
   Thesis title: “Application of Error Correcting Codes to Distributed and Pervasive Computing”
   Position: Intel Corp., Portland
4. Josh Fryman: Graduation Date: 8/2005
   Thesis title: “Power management in embedded devices”
   Position: Intel Corp., Santa Clara
5. Matthew Wolenetz: Graduation Date: 8/2005
   Thesis title: “Characterizing Middleware Mechanisms for Future Sensor Networks”
   Position: Microsoft Corp.

6. Nissim Harel: Graduation Date: 12/2006
   Thesis title: "Memory Optimizations for Distributed Stream-based Applications"
   Position: Jambool - Startup
7. Hasnain Mandviwala: Graduation Date: 12/2008
   Thesis title: Capsules: Expressing Composable Computations in a Parallel Programming Model
   Position: Software Engineer Ask.com
8. Rajnish Kumar: Graduation Date: 12/2006
   Thesis title: "Protocol Architecture for Future Sensor Network"
   Position: Research Scientist II, Georgia Tech
9. Xiang Song: Graduation Date: 08/2008
   Thesis title: "Seamless Mobility in Ubiquitous Computing Environments"
   Position: Microsoft Corp.

There are several more students at advanced stages of their dissertation research who have been funded by this award including, and expected to finish in the next 9-12 months:

1. Bikash Agarwalla
2. Nova Ahmed
3. David Hilley

Alumni of this project at MS and BS level include:

1. Kirill Mechitov, BS 2001, Grad Student UIUC
2. Durga Devi Mannaru, MS 2001, IBM Research Triangle Park, NC.
3. Ansley Post, BS 2002, Grad Student Rice U.
4. Rajat Sharma, MS 2003, Verizon Wireless
5. Zaib Talat, BS 2003
6. Ilya Bagrak, BS 2004, Grad Student UC-Berkeley
7. Martin Modahl, MS 2004
8. Sam Young, BS 2007, Amazon
9. Steven French, BS 2007, Microsoft
10. Vladimir Urazov, MS December 2007, Citadel Investment Group

During the course of the award, we also entertained one post-doctoral visitor (Dr. Jin Nakazawa, Keio University, Japan, Oct 2004–October 2005; and one sabbatical visitor Professor HeonChang Yu, Associate Professor, Korea University, Seoul, S. Korea, Jan 2004–Jan 2005.

3.2 Software

Students working Dr. Ramachandran's group, developed a toolchain for Federal Reserve Bank, Atlanta, that allows scheduling applications on a cluster. The tool chain is built using the Stampede programming system, which was developed in this project. This tool-chain called *EcoSys* [49] is used by the economists at Federal Reserve Bank, who are domain experts in their area for utilizing cluster computing resources.

3.3 Impacting Education

The research artifacts from the project have found their way into graduate courses and we have had significant undergraduate participation in project-related research. We have funded a number of undergraduates through the REU supplement attached to this ITR grant, sponsored a number of independent undergraduate research projects for course credit (CS 4903), and have sponsored capstone senior design projects (CS 3901) that each result in a poster presentation at the annual Undergraduate Research Symposium.

The ITR project has reinforced the connectedness of hardware and software and the need to train students in system architecture quite early in their undergraduate preparation. With this in mind, Professor Ramachandran embarked on writing a set of course notes [46] for use in the sophomore level course on systems and networks. The course notes were well received by the students. In Spring 2006, he has signed a contract with Addison-Wesley to have the book published as a textbook. A custom edition is already in use at Georgia Tech [46], and a regular edition is expected in Spring 2009. A paper describing the pedagogical approach

underlying this textbook is appeared in WCAE 2007 [50].

4 Special Requirements

We have received permission from the Program Director (Dr. Helen Gill) for expending the remaining REU funds in the project by August 2009.

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