Annual Report for Period: 09/2009 - 08/2010
Submitted on: 07/06/2010
Principal Investigator: Lemmon, Michael D.
Award ID: 0931195
Organization: University of Notre Dame
Submitted By:
Lemmon, Michael - Principal Investigator
Title:
CPS: Small: Dynamically Managing the Real-time Fabric of a Wireless Sensor-Actuator Network

Project Participants

Senior Personnel

Name: Lemmon, Michael
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Hu, Xiaobo
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Graduate Student

Name: Hong, Shengyan
Worked for more than 160 Hours: Yes
Contribution to Project:
Development of elastic scheduling algorithms in wireless networks

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

EmNet LLC
EmNet LLC builds and deploys wireless sensor-actuator networks that are designed to operate in harsh environments for extended periods (2-3 years) of time. This company has provided wireless networking equipment used in their wireless sensor-actuator networks as well as details regrading their current customer's applications.

Odyssian Technology
Odyssian Technology is a small business that is developing distributed wireless controllers for electrical microgrids. Odyssian is providing financial support to the PI with regard to a supervisory power dispatch controller for these small power systems. The system is implemented over a wireless communication network. The PI is providing technical assistance with regard to wireless communication and power dispatch control algorithms.

Other Collaborators or Contacts

The project has made contact with Dr. Qiang Ling (University of Science and Technology China - Hefei P.R.C.). Dr. Ling is an expert in quantized feedback control and has worked with Dr. Lemmon to examine some aspects of quantized control under dropouts.

Activities and Findings

Research and Education Activities:

Activities Report - 0931195 - Sept 2009 - July 2010

Project Participants attended and presented papers at the following conferences and workshops

1) [CDC09] IEEE Conference on Decision and Control, Shanghai, China, December 2009

2) [RTSS09] IEEE Real-time Systems Symposium, Washington DC, USA December 2009

3) [ECC09] European Control Conference, Budapest, Hungary, August 2009

4) [ACC10] American Control Conference, Baltimore, MD, July 2010

5) [ECRTS10] Euromicro Conference on Real-time Systems (ECRTS), Brussels, Belgium, July 2010.

The following conference papers were presented

1) [Hong09] Shengyan Hong, X.S. Hu and M.D. Lemmon, An adaptive approach to reduce control delay variations, Real-time Systems Symposium, work-in-progress session, Washington D.C., December 2009.

2) [Hong10] S. Hong, X.S. Hu, and M.D. Lemmon, Reducing delay jitter of real-time control tasks through adaptive deadline adjustments, Euromicro Conference on Real-time Systems (ECRTS10), Brussels, Belgium, July 2010

3) [Ling10] Q. Ling and M.D. Lemon, Input-to-state stabilizability of quantized linear control systems under feedback dropouts, Proceedings of the American Control Conference, Baltimore, MD, June 29 - July 2, 2010.

The following course materials were developed

1) [Lemmon10] M.D. Lemmon, Formal Methods in the Design and Verification of Cyber-Physical Systems, Spring semester 2010, Dept. of Electrical Engineering and Dept. of Computer Engineering, University of Notre Dame, http://www.nd.edu/~lemmon/courses/cps/

The following journal papers were accepted for publication

1) [Yi10] J. Yi, C. Poellabauer, X.S. Hu, and L. Zhang, Minimum bandwidth reservations for periodic streams in wireless real-time systems, accepted for publication in IEEE Transactions on Mobile Computing (2010).

2) [Ling10a] Q. Ling and M.D. Lemmon, A necessary and sufficient feedback dropout condition to stabilize quantized linear control systems with bounded noise, accepted for publication in IEEE Transactions on Automatic Control, Nov. 2010.

Findings:

A major theme in this project concerns the ability of control applications to dynamically adjust the real-time resources they require. Resource utilization is usually a function of task parameters such as period and deadline. Nontraditional approaches, however, can be employed in which the controller adjusts the task size by changing feedback quantization levels or in which the controller breaks apart the feedback task into a number of dependent subtasks. Findings for 2009 examined these nontraditional approaches to real-time task management.

The first major findings [Hong09,Hong10] examined feedback controllers in which the control task was divided into a set of dependent subtasks. For control applications this involves
partitioning the control task into at least three subtasks, an initial subtask that measures the system state, one or more subtasks that compute the control, and a final subtask that generates the actual control output. It was shown that this task model allowed a significant reduction in control task jitter. In building wireless networks for real-time applications, it therefore makes sense to again partition the feedback stream into a group of dependent subtasks. This should provide greater flexibility in scheduling transmissions over the network so it becomes easier to meet real-time scheduling constraints.

A second major finding concerned the relationship between the stability of quantized control systems and the sequence of dropped feedback packets [Ling10, Ling10a]. These results showed that a meaningful real-time QoS constraint for feedback controllers should be based on a windowed characterization of the dropout rate (rather than an average dropout rate). Since this is consistent with traditional firm real-time task models, it suggests that our wireless network QoS requirements should also focus on maintaining firm real-time guarantees on packet delivery.

Another major component of this project involves controlling the wireless network to maximize the real-time capacity of the network. Initial modeling efforts assumed that packet routing was fixed. NS2 simulations made it apparent, however, that interference between competing routes plays a major role in limiting the real-time performance of these networks. It was therefore realized that the project would need to adopt a more realistic physical model for interference. Since real-time performance relies on ensuring some degree of determinism within the network, it was decided that the project should actively control interference using distributed price-based power control algorithms. By controlling interference, one essentially provides a 'stable' environment in which it becomes possible to support firm real-time traffic. The project is currently studying how to build such power control algorithms for firm real-time systems with the long-term goal of formalizing the notion of a network's real-time capacity.

Training and Development:

This project has trained a graduate student (S. Hong) in research skills unifying the development of real-time systems in wireless communication networks.

Outreach Activities:

The project's outreach activities have revolved about interactions with Notre Dame's department of biological sciences. The PI has helped guide the introduction of sensor network technology into projects attempting to control nutrient loading in streams and lakes due to agricultural runoff (http://www.nd.edu/~lemmon/projects/ND-ECI/). This project is a collaboration between biological sciences (J. Tank - Notre Dame), department of economics (M. Lipscomb - ND), dept. of electrical engineering (M.D. Lemmon - ND), and the nature conservancy.

Journal Publications

Q. Ling and M.D. Lemmon, "A necessary and sufficient feedback dropout condition to stabilize quantized linear control systems with bounded noise", IEEE Transactions on Automatic Control, p. , vol. , (2010). Accepted,

J. Yi , C. Poellabauer, X.S. Hu, and L. Zhang, "Minimum bandwidth reservations for periodic streams in wireless real-time systems", IEEE Transactions on Mobile Computing, p. , vol. , (2010). Accepted,

Books or Other One-time Publications

Shengyan Hong, X. S. Hu, and M.D. Lemmon, "An adaptive approach to reduce control delay variations", (2009). conference paper, Published
Bibliography: Proceedings of the Real-time Systems Symposium - work-in-progress session, Washington DC, December 2009

S. Hong, X.S. Hu, and M.D. Lemmon, "Reducing Delay Jitter of Real-time Control Tasks through Adaptive Deadline Adjustments", (2010). Book, Published
Collection: Euromicro conference on real-time systems (ECRTS10), Brussels, Belgium, July 2010
Bibliography: Euromicro conference on real-time systems (ECRTS10), Brussels, Belgium, July 2010

Q. Ling and M.D. Lemmon, "Input-to-state stabilizability of quantized linear control systems under feedback dropouts", (2010). conference paper, Published
Bibliography: Proceedings of the American Control Conference, Baltimore, 2010

Web/Internet Site

URL(s):
http://www.nd.edu/~lemmon/projects/NSF-08-611/
Description:
This is the project's website.

Other Specific Products

Contributions

Contributions within Discipline:
The findings of this project are relevant to three different communities; control systems, wireless networking, and real-time systems. The contribution of this project's findings to these areas is itemized below

1. Deadline jitter is reduced by breaking apart a control task into smaller dependent subtasks (real-time systems) [Hong09,Hong10]

2. Firm real-time QoS constraints provide a realistic method for ensuring closed-loop control system performance (control systems and real-time systems) [Ling10,Ling10a].

3. Reservation-based access provide a more effective means of achieving real-time guarantees than contention based access in wireless networks (real-time systems and wireless networking) [Yi10].

Contributions to Other Disciplines:
This project's findings are contributing to power system applications. The PI is helping a small business (Odyssian LLC) to develop wireless networks for economically dispatching power in electrical microgrids. This work is being done in collaboration with power groups at the University of Wisconsin Madison (R. Lasseter) and University of Illinois - Urbana-Champaign (P. Krein).

Contributions to Human Resource Development:
Contributions to Human Resource Development are listed below:

1) Training of graduate student S. Hong

2) Development and web dissemination of course materials for graduate course on Cyber-Physical Systems (http://www.nd.edu/~lemmon/courses/cps/)

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

Conference Proceedings

Special Requirements

Special reporting requirements: None
Change in Objectives or Scope: None

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Any Product
Contributions: To Any Resources for Research and Education
Contributions: To Any Beyond Science and Engineering
Any Conference