Annual Report for Period: 09/2007 - 08/2008
Submitted on: 08/08/2008
Principal Investigator: Lemmon, Michael D.
Award ID: 0720457
Organization: University of Notre Dame
Submitted By:
Lemmon, Michael - Principal Investigator
Title:
CSR-EHS:Integrating Decentralized Control and Real-Time Scheduling for Networked Dynamical Systems

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: Wang, Xiaofeng
Worked for more than 160 Hours: Yes
Contribution to Project:
This person is the lead in developing event-triggered and self-triggered abstractions of dynamical systems.

Name: Chantem, Thidapat
Worked for more than 160 Hours: Yes
Contribution to Project:
This person is developing real-time scheduling methods for event-triggered and self-triggered broadcasts in networked dynamical systems.

Name: Chen, Cong
Worked for more than 160 Hours: Yes
Contribution to Project:
masters level student implementing event-triggered feedback on the real-time shark kernel using a generalized elastic scheduling module

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

EmNet LLC

EmNet LLC is a small company in South Bend Indiana that was started to help build the CSOnet embedded sensor-actuator network. The results of this NSF project are of direct use to the CSOnet project. We have been working with EmNET LLC to evaluate the relevance of employing event-triggered sampling in the CSOnet system.

Other Collaborators or Contacts

As a part of this project, I've made contacts with a number of European investigators (A. Cervin, M. Heemels, and A. Bemporad). In the year 2008, these contacts resulted in an invitation to prepare an invited paper to the 2009 European Control Conference. We were also invited to present our work on CSOnet at the kick-off meeting (Sept 2008) to a EU project that is building an embedded sensor-actuator network for the water distribution network in Barcelona.

Activities and Findings

Research and Education Activities:

Project participants attended and presented papers at the following conferences and workshops.
1) IEEE Conference on Decision and Control, New Orleans, Louisiana, USA, December 2007.
2) IEEE Real-Time Systems Symposium, Tuscon Arizona, USA, December 2007
3) International Workshop on Mobile Device and Urban Sensing (MODUS), St. Louis, MO. April 2008.
4) Hybrid Systems: computation and control, St. Louis, MO. April 2008
5) American Control Conference, Seattle, WA, USA, June 2008
6) 17th International Federation of Automatic Control (IFAC) World Congress, Seoul Korean, July 2008
7) European Conference on Real-Time Systems (ECRTS), Prague, Czech Republic, July 2008.

The following journal papers were submitted for publication
1) X. Wang, and M. Lemmon, Self-triggered Feedback Control Systems with Finite Gain L2 Stability, accepted for publication to IEEE Transactions on Automatic Control.
2) T. Chantem, X.S. Hu, and M.D. Lemmon, Generalized Elastic Scheduling for Real-Time Tasks, accepted for publication in IEEE Transactions on Computers

Dr. Lemmon participated in the Cyber-Physical System (CPS) summit in St. Louis MO, April 2008.

Dr. Lemmon gave an invited presentation to IndianaÆs RF radio alliance entitled ô Notre DameÆs CSOnet Project: How to Group a Start-up from the groundö, Fort Wayne, IN, October 2007.

Dr. Lemmon served as Guest Editor on a special issue of the ACM Transactions on Autonomous and Adaptive Systems (Self-Adaptive and Self-Organizing Wireless Networks).

Dr. Lemmon and Mr. Wang worked with EmNET LLC to build a hardware testbed of the CSOnet control system. This small scale model of the CSOnet system was used to verify the distributed control system being used in CSOnet.

Dr. Lemmon, Ms. Chantem, and Mr. Chen began work implementing the generalized

elastic scheduling service in the real-time Shark kernel (University of Pisa). This platform will be used to study implementations of event-triggered and self-triggered feedback control systems.

Findings:

This project is based on the conjecture that self-triggered or event-triggered feedback could provide an extremely efficient way of implementing networked control systems over wireless communication networks. A major finding supporting this conjecture was that it is possible to obtain closed form expressions for the maximum admissible time interval (MATI) required for L2 stability in single processor real-time control systems. A remarkable feature of these bounds is that they are state dependent, thereby providing a method for the closed-loop adjustment of task period on the basis of the applicationÆs (control systemÆs) current state. Experimental results from simulation studies indicated that these bounds were very tight for linear time-invariant dynamical systems. Much tighter, in fact, that state-independent bounds for the MATI that are currently found in the open literature. These findings were reported in an IFAC conference publication and a journal version of the paper was submitted to the IEEE Transactions on Automatic Control (accepted July 2008).

The techniques used in bounding the MATI for single processor real-time control systems were extended to distributed networked control systems in two papers that were presented at the Hybrid Systems: computation and control workshop as well as at an invited session at the 2008 American Control Conference. The results in these papers show that we can obtain similar state-dependent bounds on the time interval between successive broadcasts. The consequence of this finding is that it provides a firm analytical basis for scheduling access to the communication medium. Future work will examine how we can use these bounds to develop efficient and reliable medium access control protocols in support of networked control applications.

An additional finding, whose development was partially supported by this grant, was that we can extend the elastic scheduling framework developed by G. Buttazzo to a much larger set of task models. In particular, we were able to show that ButtazzoÆs elastic scheduling algorithm actually solves a specific optimization problem. With this observation, we were able to show that the elastic scheduling paradigm could be applied to a variety of other task models and other optimization objectives. In particular, a recent paper (accepted for publication in the IEEE Transactions on Computers) developed an elastic scheduling algorithm for periodic task models in which the deadline was less than the period. One possible application of these results would be to schedule event-triggered control tasks using the MATI bounds developed by this project. We are currently working to implement this system in the real-time Shark kernel developed by the University of Pisa.

Training and Development:

Through our interaction with EmNET LLC, we've been able to provide the graduate students working on this NSF project with a practical real-life platform upon which to base their theoretical research.

One of the students (Xiaofeng Wang) will be teaching a graduate level 'optimal control' course in the Fall 2008 semester at Notre Dame

Outreach Activities:

Have participated in the Indiana RF Alliance (a small consortium of Indiana-based industries

and agencies) to educate that group about the use of distributed feedback control in the CSOnet project.

Journal Publications

Chantem T.; Hu X.; Lemmon M., "Generalized Elastic Scheduling for Real-time Tasks", IEEE Transactions on Computers, p. , vol. , (2008). Accepted,

Wang X.; Lemmon M., "Self-triggered Feedback Control Systems with Finite-Gain L2 Stability", IEEE Transactions on Automatic Control, p. , vol. , (2008). Accepted,

T. Chantem; X. Wang; Lemmon M.; Hu X., "Period and Deadline Selection for Schedulability in Real-time Systems", Proceedings of the European Conference on Real-time Systems (ECRTS), p. , vol. , (2008). Published,

Wang X. ; Lemmon M., "Decentralized Event-triggered Broadcast over Networked Systems", Proceedings of Hybrid Systems: computation and Control, p. , vol. , (2008). Published,

Wang X. ; Lemmon M., "State based Self-triggered Feedback Control Systems with L2 Stability", Proceedings of the IFAC World Congress, p. , vol. , (2008). Published,

Wang X. ; Lemmon M., "Event-triggered Broadcasting across Distributed Networked Control Systems", Proceedings of the American Control Conference, p. , vol. , (2008). Published,

Montestruque L. ; Lemmon M., "CSOnet: a metropolitan scale wireless sensor-actuator network", International Workshop on Mobile Device and Urban Sensing(MODUS), p. , vol. , (2008). Published,

X. Wang and M.D. Lemmon, "Event Design in Event-Triggered Feedback Control Systems", Proceedings of the IEEE Conference on Decision and Control, p. , vol. , (2008). Accepted,

Books or Other One-time Publications

Web/Internet Site

URL(s):

http://www.nd.edu/~lemmon/projects.html

Description:

This site briefly describes and links to papers generated by Dr. Lemmon's active projects. This NSF project is included on that site.

Other Specific Products

Contributions

Contributions within Discipline:

The findings of this project have contributed to the field of digital-control by deriving state-dependent estimates of sampling periods required for L2 system stability.

The findings of this project have contributed to the field of real-time scheduling theory by developing an elastic scheduling algorithm for periodic tasks where deadline is less than period.

Contributions to Other Disciplines:

The distributed control techniques being developed in this project are being applied to civil-engineering applications controlling water distribution and wastewater flows.

Contributions to Human Resource Development:

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

Special Requirements

Special reporting requirements: None

Change in Objectives or Scope: None

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Any Book

Any Product

Contributions: To Any Human Resource Development

Contributions: To Any Resources for Research and Education

Contributions: To Any Beyond Science and Engineering