Preview of Award 0925229 - Final Project Report

Cover

Federal Agency and Organization Element to Which Report is Submitted:	4900
Federal Grant or Other Identifying Number Assigned by Agency:	0925229
Project Title:	Distributed Optimization, Estimation, and Control of Networked Systems through Event-triggered Message Passing
PD/PI Name:	Michael D Lemmon, Principal Investigator
Submitting Official (if other than PD\PI):	N/A
Submission Date:	N/A
Recipient Organization:	University of Notre Dame
Project/Grant Period:	10/15/2009 - 09/30/2013
Reporting Period:	10/01/2012 - 09/30/2013
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	N/A

Accomplishments

*** What are the major goals of the project?**

This project will investigate distributed optimization, estimation, and control of networked systems through the use of event-triggered message passing. Networked systems consist of several interconnected subsystems or agents. Communication issues have a great impact on the performance of distributed decision systems. Indi- vidual agents coordinate their actions through message exchanges. Communication is done using wireless radios where message collisions in a shared channel reduce throughput and increase message latency. These considerations degrade the ability of agents to successfully coordinate their actions, unless one increases the cost and complexity of the supporting communication infrastructure. The design of distributed decision making systems, therefore, must find ways of reducing overall message passing complexity without sacrificing too much of the overall system's performance.

This project uses a novel way of reducing the amount of communication required in the distributed optimization, control, and estimation of networked systems. The project uses an event-triggered approach to message passing. Under event triggering, each agent broadcasts its state information to its neighbors when an internal error signal exceeds a state-dependent threshold. The goals of this project are to study the advantages and limitations of event-triggering from both a theoretical and practical perspective. Theoretical analyses will characterize the fundamental limitations of event-triggering in control, estimation, and optimization. The project will apply the results of these studies to distributed of autonomous multi-robot groups, and distributed control of mesh microgrids.

*** What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?**

Major Activities: - Presentation of Papers at the following conferences

1) 2012 Conference on Decision and Control, Beijing China

2) 2013 American Control Conference, Washington DC
3) 2012 IFAC Conference on Analysis and Design of Hybrid Systems, Eindhoven, Netherlands
4) 2013 Conference on High Confidence Networked Systems, Philadelphia, PA

- Journal paper was prepared and submitted to IEEE Transactions on Automatic Control

- Worked with Accenture to develop hierarchical control architecture for microgrids

- worked with ND Bio Dept. and EmNET LLC to design and build prototype nutrient sensor for streams.

Specific Objectives: This years objectives were to graduate the student (Lichun Li) whose work was supported under this project and to complete journal papers generated by her work

Significant Results: This year's work published perhaps the first work to unify dynamic feedback quantization with event-triggering.

- L. Li, X. Wang, and M.D. Lemmon. Stabilizing bit-rates in quantized event triggered control systems. In Hybrid Systems: computation and control. Beijing, China, 2012.

This year's work resulted the publication and presentation of signifiant results on two of the project's target applications - microgrids and multi-vehicle coordination.

- Bin Hu and M.D. Lemmon (2013), Using channel state feedback to achieve resiilence to deep fades in wireless networked control systems, Conference on High Confidence Networked Systems, April 9-11, 2013, Philadelphia PA

- Z. Wang, M. Xia, and M.D. Lemmon (2013), Voltage Stability of Weak Power Distribution Networks with Inverter Connected Sources, American Control Conference, Washington D.C., 2013.

Key outcomes or Other achievements: 1)Graduated Ph.D. student, Lichun Li

2) Publication of Journal Paper: Lichun Li and M.D. Lemmon, Weakly coupled event triggered output feedback system in wireless networked control systems, Jrnl of Discrete Event Dynamic Systems, ISSN:0924- 6703 ,Springer US, pages 1-14, 2013.

*** What opportunities for training and professional development has the project provided?**

Under this project

1) training and graduation of PH.D. Student - Lichun Li

2) Training of 3rd year graduate student, Bin Hu, Zhao Wang.

2) Creation of Power Electronics Lab for senior undergraduates

*** How have the results been disseminated to communities of interest?**

Dissemination through conference and journal publications. Dissemination through interactions with business (EmNet LLC, Odyssain Technologies, GE power systems, Accenture)

Products

Journals
Lichun Li and M.D. Lemmon (2013). Weakly coupled event triggered output feedback system in wireless networked control systems. *Journal of Discrete Event Dynamic Systems*. 1.

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; ISSN: ISSN:0924-6703

Lichun Li, X. Wang, and M.D. Lemmon (). Efficiently attentive event-triggered control systems with limited bandwidth. *IEEE Transactions on Automatic Control*. .

Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Books

Book Chapters

Thesis/Dissertations
Lichun Li. *Event-triggered state estimation and control with limited communication*. (2013). University of Notre Dame.

Acknowledgment of Federal Support = No

Conference Papers and Presentations
Lichun Li and M.D. Lemmon (2013). *Polynomial approximations of optimal event triggers for state estimation problems using SOSTOOLS*. American Control Conference. Washington DC.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Lichun Li and M.D. Lemmon and X. Wang (2012). *Stabilizing Bit-rates for in Quantized event-triggered control systems*. Hybrid Systems: computation and control. Beijing, China.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Lichun Li, X. Wang and M.D. Lemmon (2012). *Stablizing bit-rates for perturbed event-triggered control systems*. IFAC conference on Analysis and Design of Hybrid Systems. Eindhoven, Netherlands.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Z. Wang, M. Xia, and M.D. Lemmon (2013). *Voltage stability of weak power distribution networks with inverter connected sources*. American Control Conference. Washington DC.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Bin Hu and M.D. Lemmon (2013). *Using channel state feedback to achieve resiilence to deep fades in wireless networked control systems*. Conference on High Confidence Networked Systems. Philadelphia, PA.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Other Publications

Technologies or Techniques
Nothing to report.

Patents

Nothing to report.

Inventions
Nothing to report.

Licenses
Nothing to report.

Websites

Title: Distributed Optimization, Estimation, and Control of Networked Systems through Event-triggered Message Passing

URL: http://www3.nd.edu/~lemmon/projects/NSF-05-1518/

Description: This project's homepage

Other Products

Product Type: Educational aids or Curricula

Description: Power Electronics Course - EE40442

http://www3.nd.edu/~lemmon/courses/ee40442

Other:

Participants

Research Experience for Undergraduates (REU) funding

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Zhao Wang	Graduate Student (research assistant)	3
Bin Hu	Graduate Student (research assistant)	2
Michael D Lemmon	PD/PI	3
Lichun Li	Graduate Student (research assistant)	12

What other organizations have been involved as partners?
Nothing to report.

Have other collaborators or contacts been involved? Y

Impacts

What is the impact on the development of the principal discipline(s) of the project?

This project proposed and studied a novel approach for reducing the amount of communication required in the distributed optimization, control, and estimation of networked control systems. The project studied an event-triggered approach to message passing that early work suggested could greatly reduce the communication traffic while maintaining acceptable

levels of control performance. As a result there has been a great deal of interest and activity in the control systems and cyber-physical systems (CPS) community regarding event-triggered feedback schemes. This project's work had a significant impact within the control systems community. This project's work was the first to demonstrate that event triggered message passing could reduce the communication needed in distributed optimziation by an order of magnitude [1]. This project produced one of the first journal papers to deal with event-triggering in distributed control systems [2]. The work sponsored in this project was some of the first work to quantitatively consider the impact of dropouts and delays in event-triggered systems[3]. The work sponsored by this project was probably the first work to unify dynamic feedback quantization with event-triggering [4]. Work done under this project led to publication of one of the first rigorous papers on self-triggered control [5].

[1] P. Wan and M.D. Lemmon. Event-triggered distributed optimization in sensor networks. In Information Processing in Sensor Networks (IPSN)2, San Francisco, CA, USA, 2009.

[2] X. Wang and M. Lemmon. Event-triggering in distributed networked control systems. Auto- matic Control, IEEE Transactions on, 56(3):586–601, 2011.

[3] X. Wang and M.D. Lemmon. Event-triggering in distributed networked systems with data dropouts and delays. In Hybrid Systems: computation and control, San Francisco, CA, USA, 2009.

[4] L. Li, X. Wang, and M.D. Lemmon. Stabilizing bit-rates in quantized event triggered control systems. In Hybrid Systems: computation and control. Beijing, China, 2012.

[5] X. Wang and M.D. Lemmon. Self-triggered feedback control systems with finite-gain L2 stability. IEEE Transactions on Automatic Control, 54(3):452–467, 2009.

What is the impact on other disciplines?

The event-triggered research in this project has been applied to distributed power dispatching in electrical microgrids (power) and multi-vehicle formation control (automotive engineering)

What is the impact on the development of human resources?

Provided opportunities for research, teaching, and mentoring in science and engineering areas

Improved skils of women (Lichun Li) in engineering

developed new curriculum at ND on power electronics

What is the impact on physical resources that form infrastructure?
Nothing to report.

What is the impact on institutional resources that form infrastructure?
Nothing to report.

What is the impact on information resources that form infrastructure?
Nothing to report.

What is the impact on technology transfer?
Nothing to report.

What is the impact on society beyond science and technology?
Nothing to report.

Changes

Changes in approach and reason for change
Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them
Nothing to report.

Changes that have a significant impact on expenditures
Nothing to report.

Significant changes in use or care of human subjects
Nothing to report.

Significant changes in use or care of vertebrate animals
Nothing to report.

Significant changes in use or care of biohazards
Nothing to report.