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Final Report: Proposal Description: Trust-based Optimal Guidance and Navigation for Multiple Manned-Unmanned Vehicles

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14. ABSTRACT
This project aims at establishing trust-based optimal control, dynamic pairing and real-time scheduling algorithms for multiple manned and unmanned vehicles teaming as a foundation for next generation survivable systems.
There are 4 tasks for this project:
1) PI will investigate on how to navigate a team of vehicles passing through desired routes and reduce human workload by choosing optimal autonomy level and designing optimal control law simultaneously.
2) PI will explore and establish quantitative measures for human workload and performance.

15. SUBJECT TERMS
Trust; Manned-Unmanned Teaming; Optimal Control; Switched Systems; Scheduling; Autonomy

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
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					19b. TELEPHONE NUMBER
					864-656-5632

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Report Title

Final Report: Proposal Description: Trust-based Optimal Guidance and Navigation for Multiple Manned-Unmanned Vehicles

ABSTRACT

This project aims at establishing trust-based optimal control, dynamic pairing and real-time scheduling algorithms for multiple manned and unmanned vehicles teaming as a foundation for next generation survivable systems.
There are 4 tasks for this project:
1) PI will investigate on how to navigate a team of vehicles passing through desired routes and reduce human workload by choosing optimal autonomy level and designing optimal control law simultaneously.
2) PI will explore and establish quantitative measures for human workload and performance.
3) PI will investigate simultaneously trust-based optimal switching rules and switching control laws to achieve balanced human workload and vehicle navigation accuracy.
4) PI will create dynamic pairing and real-time scheduling for multiple manned-unmanned vehicles teaming.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received	Paper
06/13/2017	1 Hamed Saeidi, Dariusz G. Mikulski, Yue Wang. Trust-Based Leader Selection for Bilateral Haptic Teleoperation of Multi-Robot Systems, 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). 24-SEP-17, Vancouver, Canada. : ,
TOTAL:	**1**

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received	Paper
TOTAL:	

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received	Paper
TOTAL:	

Number of Manuscripts:

Books

Received	Book

TOTAL:

Received	Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
Hamed Saeidi	0.40
FTE Equivalent:	**0.40**
Total Number:	**1**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Yue Wang	0.11	
FTE Equivalent:	**0.11**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED	DISCIPLINE
Hamed Saeidi	0	Mechanical Engineering
FTE Equivalent:	**0.00**	
Total Number:	**1**	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME	
Total Number:	

Names of personnel receiving PHDs

NAME	
Hamed Saeidi	
Total Number:	**1**

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

(1) Statement of the problem studied

This project develops trust measures for multi-robot systems, and use trust analysis for the optimal control, dynamic pairing and real-time scheduling for multiple manned and unmanned vehicles teaming in reconnaissance, surveillance, and target acquisition (RSTA) missions. It is expected that the joint human multi-robot system performance will be improved by combining both the strengths of manual and autonomous operations. The vehicle trustworthiness under uncertainty are developed based on the RoboTrust algorithm. Trust-based optimal switching control algorithms are developed to decide the operation mode. Dynamic pairing and real-time scheduling algorithms are developed to allocate each human-vehicle pair. ROS and Matlab simulations combing UGVs with a human-in-the-loop are conducted to validate the proposed algorithms with potential applications in weapon systems.

(2) Summary of the most important results

In [Saeidi et. al.], we develop a trust-based leader switching strategy for multi-robot bilateral teleoperation. A framework is presented for trust-based bilateral haptic teleoperation for mobile multi-robot systems. We utilize the Robotrust model developed in [D. G. Mikulski et. al.] for the computational and dynamic models for human-to-robot and robot-to-human trusts. The Robotrust model is inspired by human's trust and evaluates trust towards a team-mate or robot via a cumulative observation of their behaviour. A discrete-time acceptance function is first created based on the observations of human and robot performance, which then accumulates and forms the history of acceptance functions. The Robotrust algorithm then computes the bidirectional human-to-robot trust and robot-to-human trust based on the history of acceptance functions. The main idea is to get a worst-case estimate of trusts using the average trust over a range of time windows. We further develop a continuous-time version of the trust dynamics to apply the trust model in near real time with a high frequency (e.g. 100 Hz or above). A trust-based leader switching policy is then developed, under which a human operator can be always collaborate with the most trusted robot in order to improve the overall task performance. The stability of the entire closed-loop system under the effects of delay, and trust-based variable scaling and switching is guaranteed via different passivity-based techniques. A case study is conducted to control the formation and motion of a 6 robot team and visit some checkpoints and return to the base as fast and accurately as possible. A GUI is provided to the operator, which shows the camera view of the leader robot and also provides some suggestions to the operator to switch to different leaders to accomplish the task more efficiently. Our robot simulation in ROS showed that the proposed trust-based leader selection strategy can reduce task completion time by 35.25% and formation error by 41.64% compared to a nonleader switching strategy.

A journal paper [Ahirrao et. al.] is being prepared to extend the above results by
(a) incorporating learning algorithms to extend the Robotrust algorithm and give more accurate estimate of multi-robot trust;
(b) conducting through statistical analysis for the robot simulation with multiple human subjects.

We are also preparing another journal paper [Li et. al.] focusing on the control and scheduling part of the project. The application in consideration is multi-vehicle trajectory tracking under human guidance. A vehicle dynamic model is developed to capture change of vehicle lateral dynamics under external disturbances, which hence necessitates the need of human intervention. The SLQR algorithm from our previous work [Spencer and Wang] is used to select the optimal operation mode for each vehicle in the team, i.e. autonomous navigation or manual guidance. Once the manual mode is deemed optimal, a scheduling algorithm based on our previous work [Wang et. al.] is developed to allocation the human resources among multiple vehicles requesting human collaboration.

(3) Bibliography

H. Saeidi, D. G. Mikulski, and Y. Wang, “Trust-Based Leader Selection for Bilateral Haptic Teleoperation of Multi-Robot Systems”, 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2017), Vancouver, Canada, September 24–28, 2017, under review.

D. G. Mikulski, F. L. Lewis, E. Y. Gu, and G. R. Hudas, “Trust Method for Multi-Agent Consensus”, SPIE Defense, Security, and Sensing, Baltimore, MD, pp. 83870E1-83870E14, 2012.

S. Ahirrao, D. G. Mikulski, and Y. Wang, “Trust-Based Human Multi-Robot System Interaction in Bilateral Haptic Teleoperation”, Robotics and Autonomous Systems, in preparation.

F. Li, D. G. Mikulski, J. Wagner, and Y. Wang, “Trust-based Optimal Control and Scheduling for Manned-Unmanned Vehicles Teaming”, IEEE Transactions on Control System Technology, in preparation.

D. A. Spencer and Y. Wang. "SLQR suboptimal human-robot collaborative guidance and navigation for autonomous underwater vehicles." American Control Conference (ACC), 2015. IEEE, 2015.

X. Wang, Z. Shi, F. Zhang, and Y. Wang, "Dynamic Real-Time Scheduling for Human-Agent Collaboration Systems Based on Mutual Trust", Cyber-Physical Systems (CPS), Taylor & Francis, 2015.

Technology Transfer

The PI has been collaborating with Dr. Dariusz Mikulski at ?US Army TARDEC on developing the RoboTrust algorithm for multi-robot coordination in navigation and trajectory tracking applications by extending the results from his previous research to this project.