NRI: INT: COLLAB: Interactive and collaborative robot-assisted emergency evacuations

Alan R. Wagner[1], Minghui Zhu[1], and Hai Lin[2]

[1] Pennsylvania State University [2] University of Notre Dame

Introduction and Motivation

Many emergencies require people to evacuate a building quickly. During an emergency, evacuees must make quick decisions, so they tend to rely on default decision making that may put them at risk, such as exiting the way they entered, following a crowd, or sheltering in place [1].

We propose to use mobile robots to direct evacuees for a rapid and orderly evacuation [2]. Emergency response robots may save human lives by quickly guiding people to open exits [3].

Challenges and Objectives

Challenges: Emergency evacuation scenarios require synergistic efforts in planning, control, and human-robot interaction. This effort focuses on three objectives.

Objective 1. Optimal multi-robot deployment in evacuation: Coordinate the multi-robot team to optimize the overall evacuation process minimizing evacuees' travel distances, while avoiding dangerous situations.

Objective 2. Scalable multi-robot motion planning in human crowded environments: Promptly synthesize motion planners to execute the plan.

Previously built evacuation robot in research by Robinette, Howard, and Wagner

Integrated sampling-based planning algorithms and game theory are used to synthesize multi-robot planners that are computationally efficient and correct.

Objective 3. Evaluation: Verify the veracity of these models or, alternatively, suggest ways to alter the models to more closely reflect the behavior of humans during real evacuation situations. We will create robots that can communicate directions to evacuees, instilling in evacuees a sense of urgency.

Proposed Research

Design a framework that can coordinate a collection of robots so that, when an emergency alarm is generated, the robots will be deployed immediately to critical navigation points within the environment in order to guide the flow of evacuees and create an efficient evacuation process.

Our idea is to carefully position the robots given the current situation. The robots act as a type of traffic cop directing people toward the exit that minimizes evacuation time. Should a pathway become blocked or congested, the robots re-position themselves and dynamically redirect evacuees away from congestion points and toward an open exit.

This project is divided into 3 different tasks that will be accomplished over a 4 years period.

Broader Impacts

This effort provides a clear benefit to society in the form of quick, safe evacuation of people during an emergency. Knowledge of how to evacuate is becoming a necessary component of attending events such as concerts, movies, and even for children attending school. As such, this project has the potential to impact a very broad section of society. In addition to saving lives, the results from this work will contribute to crowd control, perhaps preventing stampedes and keeping families together.

Task 1: Optimal multi-robot deployment in evacuation

Coordinate the deployment of multiple robots in a dynamic environment so as to optimize the overall evacuation process while avoiding certain dangerous situations, such as clogging, jams, or unbalanced crowd densities in front of exits [4].

Task 1: Combined simulation-optimization solving. We intend to leverage the success of existing human crowd simulation models and propose to combine simulation with optimization approaches.

Task 2: Data-driven CA model refinement. Use surveillance cameras information to calibrate our CA models to improve its prediction accuracy.

Task 3: Safety guarantee through formal methods. To ensure safety, we need to make sure that the crowd densities do not exceed hazardous levels during the whole evacuation process. We, therefore, propose to use formal methods to achieve such a safety guarantee. For the evacuation

Task 4: Beyond cellular automata model. Alternatively, we will pursue a control theoretic framework and explicitly model the pedestrian and crowd dynamics. We propose to use a stochastic differential equation (SDE) to model the pedestrian dynamics and Kolmogorov equation to model the crowd dynamics [5].

Task 2: Scalable multi-robot motion planning

Once an evacuation plan is determined, each robot gets its own target positions. Then robots need to promptly synthesize motion planners to come to new set points while avoiding collisions [6].

Task 5: Multi-robot planning in human crowded environments. We propose to generalize the traveling cost in (task 3) to a weighted combination of traveling time and aggregate human density.

Task 6: Real-time robot control in human crowded environments. The proposed game theoretic planning algorithm generates a path for each robot connecting its initial location and its goal set.

- **Task 6.1: Motion learning.** We will investigate recursive learning algorithms where new estimates are generated by combining new sensing information into current estimates.

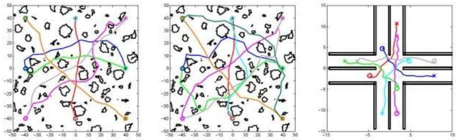

Figure 1: An illustration of game theoretic motion planning

Task 3: Evaluation

We will build robots and conduct experimental studies of human-robot interactions during an emergency evacuation. This effort will examine the fundamental issues related to situations in which the robot acts as an authority figure directing the actions of people [7].

Task 7: Creating robots that people will follow during an emergency. To evaluate if people will follow a robot's evacuation directions.

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Task 8: Robot influenced human response to congestion and blocked exits. To evaluate human subject responds to evacuation redirection resulting from congestion and/or blocked exits.

Task 9: Inform and comfort people sheltering in place. Evaluate the value of having evacuation robots provide information and/or comfort to evacuees sheltering in-place during an emergency.

Contact

Alan Wagner
Department of Aerospace Engineering
229 Hammond Building
The Pennsylvania State University
University Park, PA 16802

Minghui Zhu
School of Electrical Engineering and Computer Science
229 Electrical Engineering West
The Pennsylvania State University
University Park, PA 16802

Hai Lin
Department of Electrical Engineering
275 Fitzpatrick Hall
University of Notre Dame
Notre Dame, IN 46556

References

1. E. D. Kuligowski, The process of human behavior in fires. US Department of Commerce, National Institute of Standards and Technology Gaithersburg, 2009.
2. P. Robinette, A. R. Wagner, and A. M. Howard, "Assessment of robot guidance modalities conveying instructions to humans in emergency situations," in Robot and Human Interactive Communication, 2014 RO-MAN: The 23rd IEEE International Symposium on. IEEE, 2014, pp. 1043–1049.
3. E. Boukas, I. Kostavelis, A. Gasteratos, and G. C. Sirakoulis, "Robot guided crowd evacuation," IEEE Transactions on Automation Science and Engineering, vol. 12, no. 2, pp. 739–751, 2015.
4. J. Dai and H. Lin, "Automatic synthesis of cooperative multi-agent systems," in 53rd IEEE Conference on Decision and Control. IEEE, 2014, pp. 6173–6178.
5. M. Karimadini, H. Lin, and A. Karimoddini, "Cooperative tasking for deterministic specification automata," Asian Journal of Control, 2016.
6. E. Mueller, S. Yong, M. Zhu, and E. Frazzoli, "Anytime computation algorithms for stochastically parametric approach-evasion differential games," in IEEE/RSJ International Conference on Intelligent Robots and Systems, Tokyo, Japan, Nov 2013, pp. 3816–3821.
7. P. Robinette, A. R. Wagner, and A. M. Howard, "Investigating human-robot trust in emergency scenarios: Methodological lessons learned," in Robust Intelligence and Trust in Autonomous Systems. Springer US, 2016, pp. 143–166.