System of Systems Engineering Collaborators Information Exchange (SoSECIE)

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Test and Evaluation of Autonomous Multi-Robot Systems

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Abstract
Robots can enhance the capabilities of the war fighter in two ways: (1) as an extension of the individual, permitting the individual to do and perceive more, and to have a more comprehensive awareness of the battle space and operations of relevance to their mission, and (2) as a quasi-substitute of the individual for missions that are dangerous, such as IED investigations, reconnaissance of hostile terrain and checkpoint manning in theater. To maximize robotic effectiveness in dynamic and unpredictable environments, however, they need to operate as heterogeneous multi-robot teams, primarily for two reasons: they cannot dynamically and dramatically alter their physical characteristics to adapt to terrain and obstacles, and mission performance improves by combining diverse robot types.

System designs with targeted functionalities typically function better, in terms of being more reliable and/or cost-effective, than more general-purpose systems. In order for this potential to be realized, there is a pressing need for a paradigm shift in human control of robotic systems from human teleoperation of robots to humans and robots being co-participants in a joint coordinated operation. Reviews of robot failures have identified human perception and judgment error as being responsible for provoking many robotic failures. Robots cannot function as enhancers of war fighter capabilities when they require human attention to teleoperate them. Further, to guarantee the reliability of the human operator in guiding and using the robot, multiple humans are required to teleoperate a single robot, when it would be more effective if proportions were reversed: multiple robots under the direction of a single human.

Autonomy can make this paradigm shift happen: let the robot determine the best way to control itself and operate in its own environment. In the case of multi-robot missions, let the robots autonomously coordinate amongst themselves in order to effectively manage shared cyber-physical resources such as time, space, energy, and communications bandwidth. Humans need to be able to understand and predict — to “trust” — the behaviors of autonomous multi-robot systems. Having a means of bounding, identifying, quantifying, measuring, evaluating and predicting autonomous robotic behaviors is the key by which that understanding and those expectations can be formed, evaluated, used, and managed.

Traditionally, reliability engineering has been a discipline that provides the tools for such evaluations. A robot, as a cyber-physical system of systems, needs to socio-technically cooperate autonomously with other robots, under the guidance of humans and probably in interaction with other software systems. Traditional approaches to systems engineering, hardware reliability engineering and software reliability engineering are all applicable, yet not enough. Work to date on hardware reliability engineering has evaluated a robot as a physical component with a useful life and a likelihood of failure. Multi-robot missions can be evaluated in terms of how many robots are necessary to ensure likely completion of a mission by a subset, given a likely rate of failure. Further research along that vein explored how to further reduce estimated costs of multi-robot missions if individual robots could be cannibalized to replace failed components on “elected” robots.

Software reliability engineering has had a similar focus of attempting to identify undesirable states in software and discovering paths to reach them. This has led to the development of sophisticated methods of model checking, to exhaustively explore the state space of software. The system of systems assurance case presumes a static and complete description of system claims that need to be proven to levels of justified confidence, but depends on models of component assemblies. While all relevant, in part, to individual autonomous robots, these reliability engineering disciplines fail to model and predict autonomous robotic behaviors of relevance to missions.

This presentation will report on two synergistic efforts to develop quantifiable assurance techniques for autonomous and coordinated multi-robot systems. After an introduction of key terms and models by which principal components of coordinated and autonomous multi-robot systems are bounded and evaluated, the two efforts will be described. One effort is to develop robotic reliability analysis techniques. A specific study to estimate sequentially coordinated multi-robot mission performance will be described. The other effort seeks to apply reliability measures and estimates of individual robot performance predictively, through the use of probabilistic model checking. Abstraction and compositionality are used to limit the model checking state space.

Biography

Mr. Joseph A. Giampapa (**http://www.cs.cmu.edu/~garof/**) is a Senior Project Scientist at the Carnegie Mellon University Robotics Institute. In addition to developing and teaching new graduate courses for the Robotics Institute, he is also pursuing research in process-oriented dialogue understanding for human-agent-robot teamwork, the development of quantifiable assurance techniques of individual and group autonomous behaviors, and in the development of innovative applications of autonomous agents and multi-agent systems.