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A Model-based Framework for Predicting Performance in Self-adaptive Systems

Stuart H. Young[a]*, Thomas A. Mazzuchi[b], Shahram Sarkani[b]

[a]*Army Research Laboratory, 2800 Powder Mill Rd, Adelphi, MD 20783*
[b]*George Washington University, 1776 G Street NW, Suite 101, Washington, DC 20052*

Abstract

In recent years, the Department of Defense (DoD) has sought to develop military systems with increasing levels of autonomy. There has been an increase in requirements and desired capabilities that call for the semi-autonomous or autonomous performance of tasks. Military robot systems are an example of such complex systems. As the DoD develops these complex systems it is evident, based on recent research, that in order to achieve the desired capabilities the systems must adapt and learn to improve their performance and become more autonomous. However, it is cost prohibitive and impractical to evaluate self-adaptive systems in all possible scenarios and environments. As a result, it is desirable to improve our ability to understand how autonomous systems will perform in order to influence military acquisition decisions. Prior work has sought to characterize the environment or the performance of unmanned systems based on levels of autonomy and suggested that environmental complexity is a strong predictor of performance of mobile robot systems. However performance measures of unmanned systems dealing with complex and changing environments have been difficult to measure quantitatively because it is difficult to delineate the general operational domains of the unmanned systems or how to determine if an unmanned system satisfies capability specifications or expectations. This paper describes the development of a model-based framework for predicting the performance of self-adaptive systems, specifically a navigation task for mobile military robot systems. By developing a quantitative model of performance based on the complexity of the environment, including slope and vegetation, we can estimate the performance of a

* Corresponding author. Tel.: 1-703-731-7366; fax: 1-301-394-3903.
E-mail address: syoung1@gwu.edu

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system in new regions based on performance in known regions. Using simulation and data from prior experiments, we demonstrate the ability to predict the performance in environments that have not been tested. In order to validate our model, we compare the model results to data from previous DARPA-led research experiments.

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1. Introduction

The development of complex adaptive systems has accelerated rapidly over the past decade. The Department of Defense (DoD) has led the way in developing military systems with increasing levels of autonomy, from semi-autonomous to autonomous. Unmanned air systems and unmanned ground systems, are an example of complex systems that are increasingly being equipped with more autonomous and adaptive behaviours, thus reducing the level of human interaction[1]. In order for these systems to perform generally, in all environments, recent research has suggested that they must be programmed to adapt and learn to achieve the desired capabilities instead of the behaviours being hard-coded[2,3]. As a result, these systems employ machine-learning techniques that enable them to adapt and react to their operating environments in order to achieve these desired capabilities[2,3,4]. Research programs, such as those conducted by DARPA, have taken the lead in evaluating the performance of autonomous ground robot systems[5,6,7], however, it is cost prohibitive and impractical to evaluate self-adaptive systems in all possible scenarios and environments, both static and dynamic. Therefore, it is desirable to improve our ability to understand how autonomous systems will perform in order to influence military acquisition decisions, not only for operational considerations, but also for testing, as the DoD evaluates these systems in advance of fielding.

Given our present understanding of complex behavior, truly complex systems, cannot be designed with the degree of confidence that is acceptable given our current expectations. Consequently, the discipline of systems engineering must investigate this issue as a matter of priority and urgency and seek to develop approaches to respond to the challenge[8]. The approach in this paper, attempts to address this point by attempting to quantify the complexity of the operating environment as an indicator of complex system performance; in this case, autonomous mobile robot systems. We contend that even the relatively simple robot task of autonomous navigation is a complex interaction of systems involving perception of the environment, and decision-making by the robot's control system to meet the objectives of a human operator. Engineering design is a problem-solving process that produces an engineered product. Part of that process is to answer the question, how confident are we? That is, how do we know that our engineering judgments are correct and what is the predicted behavior of the system when introduced in the real world[8]?

We therefore developed a model-based framework for quantifying the environmental complexity and predicting the performance of complex, self-adaptive systems, specifically mobile military robot systems. In order to validate our model, we compare the model results to data from previous DARPA-led research experiments. This paper explores the development of a quantitative model of performance based on environmental complexity, and provides a measure of environmental complexity for autonomous robot navigation in rough terrain. Section 2 presents related work. Section 3 presents our approach, and Section 4 describes preliminary results of our approach to date. Finally, discussion and conclusions are presented in Section 5.

2. Related Work

Prior work has sought to characterize the performance of unmanned systems in terms of levels of autonomy[9] and through experimental efforts to assess performance. However measuring the performance of unmanned systems dealing with complex and changing environments has been difficult to determine quantitatively. Recent research has suggested that environmental complexity is a strong predictor of performance in mobile robot systems; we therefore examine related work in these areas.