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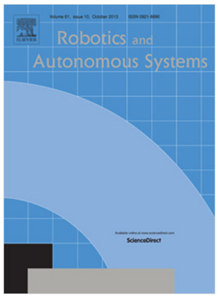

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Performance Verification for Robot Missions in Uncertain Environments[1]

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***Abstract*— Establishing a-priori mission performance guarantees is crucial if autonomous robots are to be used with confidence in missions where failure could incur high costs in life and property damage. Automatic mission software verification, in addition to simulation and experimental benchmarking, is a key component of the solution for establishing performance guarantees. This component requires automatically verifying that the software constructed by the mission designer when executed in a partially known environment will adhere to the performance guarantee. In prior work we developed VIPARS, a unique approach to verifying performance guarantees for autonomous behavior-based robot software based on a combination of static analysis and Bayesian networks. While that approach produced fast and accurate verification of single robot missions with robot motion uncertainty, it did not address multiple-robot missions or any form of uncertainty related to environment geometry.**

This paper addresses the challenges involved in building a software tool for verifying the behavior of a multi-robot waypoint mission that includes uncertainly located obstacles and uncertain environment geometry as well as uncertainty in robot motion. An approach is presented to the problem of a-priori specification of uncertain environments for robot program verification. Two approaches to modeling probabilistic localization for verification are presented: a high-level approach and an approach that allows run-time localization code to be embedded in verification. Verification and experimental validation results are presented for several autonomous robot missions, demonstrating the accuracy of verification and the mission-specific benefit of localization.

Keywords-component; Probabilistic Verification, Validation, Multi-robot Missions, Behavior-Based Robots.

1 INTRODUCTION

It is crucial to be able to establish an a-priori guarantee of mission success for robots deployed in critical missions such as counter weapons of mass destruction (C-WMD) and other missions where failure brings serious consequences to life and property. In other, less critical applications it is highly desirable to have a-priori guarantees of performance to reduce overall mission costs. In prior work for the Defense Threat Reduction Agency (DTRA) [1], we have developed an approach to automatic verification of performance guarantees for autonomous behavior-based robot mission software operating in uncertain environments. We developed a unique combination of static analysis and Bayesian networks for efficient and automatic verification of performance guarantees for missions developed in the *MissionLab* [2] robot mission design toolkit, and demonstrated by experimental validation that the approach produced trustworthy results. While that work detailed the foundation of the approach, it only addressed the single-robot scenario, and it assumed operation in an open space, with no unexpected obstacles. This paper leverages that prior work [1] to also address the challenges of automatic verification of performance guarantees for single and multi-robot missions in environments with uncertain geometry.

Verification of robot software is related to general purpose software verification in its objective of taking a program as input and automatically determining whether that program achieves a desired objective or not [3]. It differs in that a robot program continually interacts with its uncertain and dynamic environment – which therefore must be included as part of the verification problem. In fact, this is rarely done in robot program verification and was one of the novel contributions of our prior work [1]; so, rather than addressing computational verification problems such as absence of deadlock or absence of run-time errors [4] [5] (important, but typically addressed in software verification), we have focused on establishing performance guarantees for the mission software with a complex and uncertain environment model. Also, like [6], we have focused on verification of behavior-based autonomous robots, a modular approach capable of robust performance in uncertain environments.

One contribution of this paper is an approach to the problem of a-priori specification of uncertain environments for robot program verification, in particular, to specifying an environment which may or may not contain obstacles with locations specified probabilistically. A consequence of this environment model is that verification must consider variable values that result from the robot encountering an obstacle at some location with some probability and not encountering the obstacle there. Therefore, a second contribution is a novel method to extend the Bayesian Network formulation of [1] to reason about random variables with different subpopulations.

We also apply our technique to a behavior-based robot program that includes *probabilistic localization* using the Adaptive MonteCarlo Localization algorithm (AMCL)

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