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Getting it right the first time: Verification of Autonomous Behavior-based Multirobot Missions

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In research being conducted for the Defense Threat Reduction Agency (DTRA), we are concerned with Counter-Weapons of Mass Destruction (C-WMD) robot missions that may only have a single opportunity for successful completion, with serious consequences if the mission is not completed properly. Typical scenarios consist of situations where the environment may be poorly characterized in advance in terms of spatial layout, and have time-critical performance requirements. We have developed a set of specialized software tools to provide performance guarantee guidance operator/commander prior to deployment of a robot tasked with such a mission [1] [2] [3].

Researchers have effectively leveraged model-checking techniques [4] to address the *correct-by-construction* robot controller synthesis problem [4]. Our problem differs from the correct-by-construction problem, and is similar to the general-purpose software verification problem, in that our input is mission software designed using the *MissionLab* toolkit [5], and our objective is to verify that this software abides by a performance constraint. It is similar to the correct-by-construction problem in that we require a model of the mission environment.

However, our problem differs from both in needing to efficiently process probabilistic software and environment models, continuous environment characteristics and asynchronous and concurrent environment dynamics. These problem aspects are troublesome for model-checking approaches. Our approach to the problem focuses on avoiding an explicit state-space and we leverage a process-algebra representation [6] to develop a solution in which the program is translated to a set of equations over the program variables, which include random variables with mixture of Gaussian distributions. This translation is based on the structure of behavior-based programs in *MissionLab*. We construct solutions to these equations by mapping them to a Dynamic Bayesian Network and applying a filtering algorithm.

Because we are verifying probabilistic systems, it is crucial to validate our predicted performance guarantees by carrying out physical robot experimentation. Calibration data is collected on

the robots and sensors used in missions, and suitable environment models constructed. We have verified and validated single and multiple waypoint missions, exploration style missions, and multiple robot missions, including multiple robot missions requiring obstacle avoidance.

The environment model in each case includes motion uncertainty for a Pioneer 3-AT moving in a flat indoor surface and we verify a selected performance guarantee for the mission. Because the system is probabilistic, typically representing environment uncertainty, the verification answer is not a binary yes/no, but a probability landscape capturing the system's performance. The mission is validated by carrying out multiple physical runs and collecting performance statistics on real robots. We compare the validation and verification results to evaluate the quality of our verification prediction. Figure 1 shows an example of the validation/verification comparison, in this case for various completion times and spatial success criterion for a multirobot bounding overwatch mission.

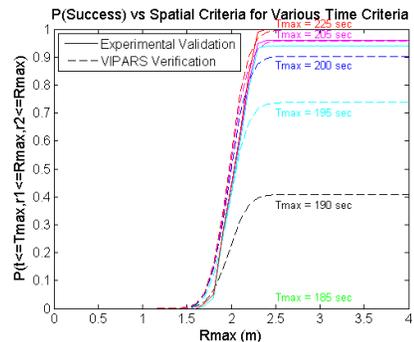


Fig.1: Verification & Validation of Spatial Criterion at various T_{max}

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