Data collection from simulated multi-robot systems

Master's Thesis

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Starting date: 15.07.2018

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Context

Modern software systems, like cyber-physical systems, are built to be used in dynamic environments using configuration capabilities to adapt to internal and external, or environmental uncertainties. In a self-adaptation context, we are often interested in reasoning about the performance of the systems under contextual influences and different configurations. Usually, in order to predict the performance of the system under a specific configuration, we learn a black-box model based on real measurements. However, as today's emerging systems become more complex, there are many configuration parameters that may interact and which leads to learning an exponentially large configuration space. Usually, this does not scale when relying on real measurements in the actual changing environment. Ideally, instead of getting the information from a real system, the information required to build the initial model is collected from sources with lower costs, for example a simulation, which approximates well the performance of the real system [2]. Additionally, running a real system, for example a robot, may involve severe risks for the system itself and its surrounding [1].

Facing these issues, simulation presents a viable alternative to real-life execution. By providing a virtual yet, physically correct representation of the execution environment and the robot with its sensors and actuators, data can be generated without aforementioned drawbacks.

There are numerous simulators with very different features available. In some cases, they are designed for a very specific purpose whereas others rather serve as a general-purpose platform for various different kinds of robots. Steady advances in the field of simulation made robotic simulators a subject to constant change in the last several years. As a result, it is hard for developers and researchers to make a well-founded decision on an appropriate simulator for their respective needs.

Goal

This thesis shall contribute to overcoming one of the major challenges concerning the availability and collection of data needed for building the initial models described in the previous section.

It should provide an overview of major available simulators with regards to sensor and (multi-) robot simulation. Especially, simulators' capabilities and limitations will be examined.

To demonstrate the data generation potential of simulators, multi-robot use case will be considered. The problem of multi-robot exploration requires a group of robots to explore an unknown environment in cooperation [3].

The main purpose of simulating the exploration tasks is reaching and considering situations where the system is failing or has a high risk of failure, as well as the failure frequency.

System's failure, that potentially alters the overall system functionality, can be for example a deadlock situation, due to physical space constraints of the robots. Usually, failures originate from two different sources of uncertainties:

1. Internal uncertainties, for example, sensor imprecision and sensor failure
2. External/environmental uncertainties, for example, the impact that deployed robots have on each other and the construction of the environment that they are exploring.

Working Plan

1. Familiarize yourself and provide an overview of different simulators that are capable of simulating mobile multi-robot operations, with focus on:
   (a) Sensor simulation and data logging support
   (b) Fundamentals of simulators (Architecture, Physics Engines, Rendering Engines, Simulation frameworks...)
   (c) Simulator complexity, extensibility and ease of development
   (d) Simulators' OS, API and Middleware Frameworks (ROS, YARP, Orca, etc.)
   (e) Used resources (CPU, memory...)

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2. Select the most convenient simulator, that fulfills the majority of the above-described requirements and the anticipated use case requirements
   (a) Putting sensors modeling in the prime focus
   (b) The implementation shall rely on a robotics middleware framework so it can be easily ported to a real system.
3. Simulate use case where two robots need to explore a given environment
   (a) Set up a multi-robot exploration system where the risk of failure and the frequency of failure are taken into consideration
   (b) Implement multi-robot communication algorithm, proposed in [3]
   (c) Implement multi-robot mapping algorithm, proposed in [3]
4. Data collection and logging decision evaluation, based on:
   (a) Generated data variations considering changing different environmental obstacles
   (b) Generated data variations considering different environment complexities
   (c) The maximum amount of data generated by a simulated sensor considering the hardware restrictions of its physical equivalent
   (d) How logging impacts the overall performance
   (e) Examination of the impact of the chosen logging granularity and strategy on the system, considering the trade-off between information gain and performance loss.
5. Write the final thesis document containing:
   (a) Introduction including the description of the problem, research objectives and motivation for the chosen use cases
   (b) Related work
   (c) Theoretical background
   (d) Multi-robot exploration use case description
   (e) Data collection evaluation and logging decision
   (f) Conclusion and future work

Deliverables

- Simulation data repository and source code of the implementation.
- Technical report with comprehensive documentation of the implementation, i.e. design decision, architecture description, API description and usage instructions.
- Final thesis report written in conformance with TUM guidelines.

References

[1] Daniel Cook, Andrew Vardy, and Ron Lewis. A survey of auv and robot simulators for multi-vehicle operations. In *Autonomous Underwater Vehicles (AUV), 2014 IEEE/OES*, pages 1–8. IEEE, 2014.

[2] Pooyan Jamshidi, Miguel Velez, Christian Kästner, Norbert Siegmund, and Prasad Kawthekar. Transfer learning for improving model predictions in highly configurable software. In *Software Engineering for Adaptive and Self-Managing Systems (SEAMS), 2017 IEEE/ACM 12th International Symposium on*, pages 31–41. IEEE, 2017.

[3] Zhi Yan, Luc Fabresse, Jannik Laval, and Noury Bouraqadi. Team size optimization for multi-robot exploration. In Davide Brugali, editor, *Simulation, modeling, and programming for autonomous robots*, volume 8810 of *Lecture notes in computer science Lecture notes in artificial intelligence*, pages 438–449. Springer, Cham, 2014.