The Teleworkbench – A Platform for Performing and Comparing Experiments in Robot Navigation

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Abstract—Experiments are essential ingredients of science to compare, validate or refute theories, methodologies, hypotheses and approaches. However, in robotics, the comparison of methods using experiments is difficult because of the variety of robotic platforms and experiment environments.

In this paper we describe the Teleworkbench and discuss the role it can take on the quest of creating repeatable and reproducible experiments in robot navigation, obtaining comparable results as well as evaluating and analysing results. The Teleworkbench can control up to 64 mini-robots simultaneously, log user defined quantities for post-experiment analysis and monitor the experiments via cameras mounted in the ceiling. A web interface makes the Teleworkbench accessible for remotely located users. Thus, the Teleworkbench is a platform that robotic scientists can use in order to evaluate the developed approaches quantitatively and qualitatively as well as to compare their methods amongst each other.

I. INTRODUCTION

Experiments are an important component throughout all sciences [1]. Theories, ideas, claims and methodologies are supported, confirmed, validated or refuted with the help of experiments. In particular, performance measuring and benchmarking are important instruments for making approaches qualitatively and quantitatively comparable with the work of other researchers. In order to accumulate knowledge, progress in science, choosing amongst competing hypotheses and establish reference architectures for industrial applications it is crucial that research outcomes are comparable.

In the domain of robot navigation, which includes tasks such as mapping [2], localisation, simultaneous localisation and mapping (SLAM) [3], path planning [4] and exploration [5], experiments can demonstrate that a system works, demonstrate that a system works better than competing other systems, give insights on the behaviour of a system and unveil the limits of a system’s applicability or, a mixture of those goals [6].

However, the comparison of approaches in robotic navigation is difficult because of the very nature of robotic research, where standard experimental platforms and standard environments for experiments are not common.

A. On the Problem of Experiments in Robotics

Many papers published in robotic journals and conference proceedings do not meet the requirements for publishing in traditional science domains where good practice calls for the inclusion of a detailed section that describes the materials and experimental methods that support the authors’ contribution. Moreover, a thorough comparison and a comprehensive discussion of the benefits and weaknesses of the proposed approach and other state-of-the-art methods are required.

In order to standardise experiments, other computer science disciplines such as classical artificial intelligence, machine learning or pattern recognition have established benchmark databases in order to compare methods with respect to particular evaluation criteria. For example, researchers in face recognition use benchmark databases such as FERET\textsuperscript{1} or LFW\textsuperscript{2} [7]–[9] to measure the performance of their methods with respect to a set of parameters. For robot navigation, publicly available databases such as RADISH\textsuperscript{3}, COLD\textsuperscript{4} or the Rawseeds project\textsuperscript{5} have emerged [10]–[12], or datasets are available upon request [13].

In robotics, a variety of hardware platforms, sensor equipment and actuators exist which can hardly be covered by databases. The comparison of results from experiments which were conducted with different platforms, or similar platforms with different configurations, is therefore a difficult task. Moreover, the environment, in which experiments are conducted, often severely impacts the obtained results. A navigation method may be well suited for an environment with mostly plain wall corridors, but fail in environments with many fittings and furniture.

B. The Teleworkbench

In this paper we describe the Teleworkbench, which is a platform for conducting, evaluating and analysing experiments in robotics [14], [15]. With the Teleworkbench we can control up to 64 mobile mini-robots, run up to four experiments in parallel and record experiments via monitoring cameras for on-line and post-experiment analysis. Using a gripper module, the Teleworkbench can automatically set up maze-like environments and dynamically modify environments during experiments. Robotic scientists can access the Teleworkbench through a web-interface to conduct experiments.

\textsuperscript{1}http://www.itl.nist.gov/iad/humanid/feret/
\textsuperscript{2}http://vis-www.cs.umass.edu/lfw/
\textsuperscript{3}http://radish.sourceforge.net/
\textsuperscript{4}http://cogvis.nada.kth.se/COLD/
\textsuperscript{5}http://www.rawseeds.org/home/
In particular, we discuss the role that the Teleworkbench can take in investigating the robustness of robot navigation methods towards a variety of parameters and in making the obtained results comparable. With the Teleworkbench we aim to provide a platform for robotic experiments that goes one step beyond databases. Rather than offering a recorded dataset, the Teleworkbench provides access to the ingredients of an experiment in robot navigation: the robot platforms and the properties of the environment.

The Teleworkbench offers scientists to upload programs to the robots on the experiment field in order to actively control the robots’ behaviours such as the navigation strategies and the robots’ parameters (velocities, sampling frequencies, etc.). While datasets from publicly available databases are static, the robots on the Teleworkbench are able to actively interact with the surrounding during navigation. Moreover, the gripper module supports setting up environments so that the robustness of navigation methods towards particular configurations of the environment can be analysed.

In the remainder of this paper we briefly describe the system architecture of the Teleworkbench (Section 2) and discuss the role the Teleworkbench takes in fulfilling the principles of experimental methodology in mobile robot navigation. Section 4 summarises the main points of the paper and presents ideas for further work on the Teleworkbench.

II. ARCHITECTURE OF THE TELEWORKBENCH

This section describes the hardware components and functionalities of the Teleworkbench as well as the programming interface.

A. Hardware Components

An overview of the system architecture of the Teleworkbench is given in Figure 1.

1) Experiment Field: The Teleworkbench comprises a main experiment field of 3.6×3.6m. The main experiment field is partitionable into sub-fields of 1.8×1.8m which may be used independently for experiments. Thus, the Teleworkbench supports the execution of up to four experiments in parallel. Maze-like environments are created on the experiment field by arranging plastic blocks of different sizes. Setting up environments using a defined set of items ensures that experiments are repeatable and that the obtained results are comparable.

On the experiment field, we can set up environments that exhibit particular properties. For example, in topological SLAM, one is particularly interested in loop-closing [16], [17]. While loop-closures are not very common in real-world environments, we can build surroundings on the Teleworkbench that contain many loops.

2) Gripper Module: The Teleworkbench is equipped with a gripper module (see Figure 2). The gripper module has four degrees of freedom: x, y, z-translation and rotation around the z-axis. The user models an environment through a customised software interface in a drag-and-drop fashion. The gripper then maps the model onto the experiment field by automatically positioning the plastic blocks at the predefined locations and with the predefined orientations. Moreover, the gripper deploys robots at specific positions to start their missions or picks them up when an experiment is finished.

The gripper enables us to modify the environment during an experiment in a highly dynamic fashion. So, unlike static scenarios that are captured in most datasets, the Teleworkbench is able to model scenarios in which the agent must adapt to new situations and overcome possibly unpredictable obstacles.

Moreover, in order to test a robot’s ability to recover from localisation failures, the functionality of the gripper helps us to perform a kidnapped-robot situation [18]. That means, a robot is moved to an arbitrary location without the robot being aware of the move.

3) Robot Platforms: Three different robotic platforms are currently used on the Teleworkbench: Khepera II, Khepera III from K-Team Corporation and the BeBot [19] (see Figure 4). Those robots offer sufficient perceptual abilities as well as computational performance for autonomous behaviour, have a moderate price to purchase and are small enough to perform navigation tasks on the Teleworkbench.
We have configured and extended the Stage simulator such that we are able to emulate the functionalities of the Teleworkbench such as position estimation, communication and data logging. Specific drivers emulate the behaviour and the sensor readings of robot platforms in the Stage simulation environment. Thus, the transfer of the developed application from the simulation to the Teleworkbench is simplified.

III. EXPERIMENTATION USING THE TELEWORKBENCH

Amigoni et al. have identified four important principles, namely reproducibility, repeatability, comparison and explanation, for good experimenting practice in mobile robot navigation [6]. In this section we describe the role of the Teleworkbench in experimentation that fulfils those principles.

A. Reproducibility

Reproducibility refers to the ability of independently reproducing, or replicating an experiment in order to verify results from a given experiment. Other researchers are only able to reproduce experiments, if the parameters of the experimental setup were reported in detail.

When experimenting on the Teleworkbench, one has access to all ingredients of an experiment setup. Given the implementation details, specifications of the environment setup, hardware specifications and the settings of the sensitive parameters, one is able to reproduce any experiment that was run on the Teleworkbench.

B. Repeatability

Repeatability is concerned with the fact that the result of a single experiment is not sufficient to validate a theory, or ensure the success of a method. Natural sciences require multiple performances of the same experiment in order to avoid drawing wrong conclusions due to errors in measurements. In contrast, comprehensive experimentation in mobile robot navigation should be performed in several different environments to demonstrate the benefits of a particular approach.

The Teleworkbench supports setting up many different environments so that one is able to examine the robustness of an approach and inspect a robot’s behaviour in many different scenarios and situations. Thus, researchers are able to thoroughly analyse approaches and methods in order to derive correct implications. Moreover, in order to deal with the variability of probabilistic or randomised algorithms, multiple repeats of an experiment can be conducted on the Teleworkbench so that one is able to report average values and variances of the results.

C. Comparison of Results

Comparison refers to the possibility of accurately comparing results of independent experimentations. Results of different experiments in mobile robot navigation are usually compared by analysing at least one of a variety of quantities such as computational time, accuracy or usefulness of the constructed map, localisation error, duration for exploring an environment or visual inspection.

The Teleworkbench is designed for logging as many of those parameters and quantities as possible. As mentioned earlier, one is able to specify particular parameters to be stored for analysis. The logged data enables researchers to compare results with others.

D. Explanation

Clearly, it is not sufficient to collect and report as much precise data as possible for reporting results of experiments. In addition, one is required to draw well justified conclusions based on the experiments and to interpret the obtained results.

The Teleworkbench supports both, the collection of data for a quantitative analysis, and the visual inspection of robotic behaviour for qualitative interpretations. Thus, researchers are able to draw solid conclusions from experiments and explain the obtained results.

IV. DISCUSSION

In this paper we have described the Teleworkbench system and outlined the role it can take in experimentation in mobile robot navigation.

With the Teleworkbench one can easily set up various different environments so that the testing of algorithms is not bound to a specific environment. Moreover, the gripper module enables us to dynamically change environments during experiments. The Teleworkbench provides a vision-based indoor GPS that can be used not only by the robots during experiments but also as ground truth for evaluation purposes. In order to simplify the development of new algorithms, the functionality of the Teleworkbench as well as the currently supported robots are emulated using the Player/Stage simulation environment.
Scientists can submit experiments via a web-interface and monitor the experiment. When submitting an experiment particular parameters and data sources (e.g. communication between robots or sensor measurements) are to be specified for logging. After the experiment, the specified data can be retrieved from the web-interface for evaluating the experiment. The data logging features as well as the recordings of the experiments through the monitoring cameras support researchers to analyse experiments in a thorough qualitative and quantitative manner in order to draw well justified and solid conclusions.

Given knowledge about an experiment setup, one is able to reproduce experiments on the Teleworkbench and to change particular components such as the investigated algorithm. Thus, the Teleworkbench supports the benchmarking of algorithms and methods.

At this stage experiments on the Teleworkbench are limited to blocks-world environments. We use plastic blocks for environment modelling as our current robot platforms are equipped with range sensors such as sonar and infrared, but we plan on creating real-world-like miniature urban environments on the experimental field by placing miniature houses and other items from model railways for research in visual navigation.

In conclusion, the Teleworkbench is a comprehensive tool that offers high flexibility in experimenting and thorough reporting of results for interpretation. The Teleworkbench fulfils the principles of experimental methodology that are considered as useful for robot navigation by Amigoni et al. to a high extent [6].

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REFERENCES