ROS-Based SLAM for a Gazebo-Simulated Mobile Robot in Image-Based 3D Model of Indoor Environment

Conference Paper · October 2015

DOI: 10.1007/978-3-319-25903-1_24

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ROS-based SLAM for a Gazebo-simulated mobile robot in image-based 3D model of indoor environment

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Abstract. Nowadays robot simulators have robust physics engines, high-quality graphics, and convenient interfaces, affording researchers to substitute physical systems with their simulation models in order to pre-estimate the performance of theoretical findings before applying them to real robots. This paper describes Gazebo simulation approach to simultaneous localization and mapping (SLAM) based on Robot Operating System (ROS) using PR2 robot. The ROS-based SLAM approach applies Rao-Blackwellized particle filters and laser data to locate the PR2 robot in unknown environment and build a map. The real room 3D model was obtained from camera shots and reconstructed with Autodesk 123D Catch and MeshLab software. The results demonstrate the fidelity of the simulated 3D room to the obtained from the robot laser system ROS-calculated map and the feasibility of ROS-based SLAM with a Gazebo-simulated mobile robot to its usage in camera-based 3D environment. This approach will be further extended to ROS-based robotic simulations in Gazebo with a Russian anthropomorphic robot AR-601M.

Keywords: SLAM, ROS, Gazebo, navigation, localization and mapping, image-based 3D model, laser rangefinder, robot simulator

1 Introduction

Robot simulators have been playing an important role in mobile robot research as fast, efficient and cheap tools for exhaustive testing of new concepts, methods, and algorithms in the intermediate research stages in order to pre-estimate their performance before applying to a real robot. The most popular robot simulators are Gazebo [1], Microsoft Robotics Developer Studio (MRDS) [2], USARSim [3], V-REP [4] and Webots [5].

The usual basic requirements to robot simulators are an accurate physics simulation (such as object velocity, inertia, friction, position and orientation, etc.), high quality rendering (for shape, dimensions, colors, and texture of objects), integration with ROS framework [6] and multi-platform compatibility. It provides great opportunities for modeling robots and their sensors together with developing robot control algorithms, realizing mobile robot simulation, visualization, locomotion and navigation in realistic 3D environments. The high graphical fidelity in a robot simulation is important because the sensory input to the robot perceptual algorithms comes from virtual sensors, which are also provided by the simulation [1]. For example, virtual cameras use the simulator rendering engine to obtain their images. If images from a simulated camera have poor similarity to real camera images, then it is impossible to use them for object recognition and localization. It is also true for other virtual sensors - rangefinders and depth sensors that can provide difficulties for SLAM implementation. To avoid such difficulties we use a robust and high graphical quality robot simulator - Gazebo, which is a ROS-integrated open source robotic simulation package. Gazebo uses the open source OGRE rendering engine, which produces good graphics fidelity, although it also employs the Open Dynamics Engine (ODE) [7], which is estimated as a sufficiently slow physics engine [1].

Integration with ROS gives an access to a large variety of user contributed algorithms. An overview of ROS has been presented in [2]. While various SLAM techniques have been proposed in the past decades, only a few of them are available as implementations to the ROS-community. In [1] authors proposed a two-stage ROS-based SLAM algorithm application. The first stage is a metric based iterative closest point (MBICP) position tracker, which matches successive laser scans to define the position and orientation during the robot motion. These localization data, known as the robot pose, is passed through ROS, running the second stage - an implementation of the FastSLAM algorithm [3], which generates a map of the environment. In [4] authors suggested a ROS-based SLAM algorithm which applies particle filters for a Pioneer 3-DX robot (with a laser sensor mounted on the robot with 390 mm height above the ground) in both real and self-created environments. To implement grid-based SLAM, they used open-source Rao-Blackwellized particle filters [5]. Once mapping and localization are successfully completed the navigation could be achieved. As an example, ROS-

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[1] Gazebo robot simulator, www.gazebosim.org

[2] Microsoft Robotics Developer Studio is a Windows-based environment for robot control and simulation (no longer supported), microsoft.com/robotics/

[3] Unified System for Automation and Robot Simulation, usarsim.sourceforge.net/wiki/

[4] V-REP Virtual Robot Experimental Platform, www.coppeliarobotics.com

[5] Cyberbotics Ltd. Webots robot simulator, www.cyberbotics.com/overview

[6] Willow Garage Robot Operating System (ROS) - Robotics middleware for robot software development, providing operating system-like functionality, ros.org

[7] R. Smith, Open Dynamics Engine (ODE), www.ode.org

based navigation approach for the Willow Garage Personal Robot PR2 (further referred just as PR2) locomotion without collisions, using two costmaps each for the local and global planner is realized in [6].

We are motivated to apply a realistic environment to robot simulation in Gazebo for testing ROS-based mapping, localization and autonomous navigation algorithms for our bipedal robot AR-601M. This work is based on a robust simulation model of AR-601M for robot locomotion [7], which is currently a work-in-progress.

As a first step toward an anthropomorphic AR-601M robot SLAM analysis we use the existing simulation model of the PR2 robot, which has similar characteristics being a human-like android equipped with laser range finders and stereo cameras. We apply the existing ROS-based SLAM software for PR2 robot, simulating the robot locomotion in Gazebo. The realistic indoor environment is obtained by photographing a room with an ordinary camera (or a conventional smartphone), and then combining the images into a 3D model with following meshing and texturizing by Autodesk 123D Catch software.

We consider ROS-based SLAM simulation using OpenSLAM GMapping algorithm[8] based on the particle filters [5]. Our particle filter-based SLAM uses a laser rangefinder LRF_B which is mounted on the PR2 robot base, whereas another LRF (LRF_T) is located on a tilting platform (robot torso) below the pan-tilt robot head and applied for 3D environment visualization. For SLAM task, the robot interprets data from LRF_B sensor in order to produce a map of an unknown environment and performs simultaneous self-localization within this map. The main goal of our paper is to demonstrate the feasibility of ROS-based SLAM which is realized on the particle filters and LRF measurements for a Gazebo-simulated mobile robot locomotion in 3D model of a realistic indoor environment obtained by camera shots.

The paper is organized as following. Section 2 describes the system setup of PR-2 and AR-601M robots for their simulation in Gazebo. Section 3 considers the image-based 3D modeling of indoor environment. Section 4 presents the SLAM for PR2 mobile robot using ROS and Gazebo in camera-based 3D environment. Finally we conclude and discuss the future steps of our research.

2 System setup

This chapter describes why the PR-2 robot was chosen for simulation in Gazebo, and emphasizes the main features of PR-2 and AR-601M robots, their similarities and differences.

2.1 Choice of a robot for simulation in Gazebo

One of our long-term research goals is an application of SLAM algorithm in the Gazebo robot simulator for simulation model of our bipedal robot AR-601M [7]

[8] OpenSLAM GMapping algorithm, www.openslam.org/gmapping.html

with algorithm's further implementation on the real robot. Being a work-in-progress, a complicated AR-601M simulator is not yet fully compatible with ROS and therefore we are currently testing our localization, mapping and navigation algorithms with the PR-2 robot, which has the human-like upper parts (a torso, manipulators, and a head), similar sensor system and open-source ROS-based software.

2.2 PR-2 robot description and simulation

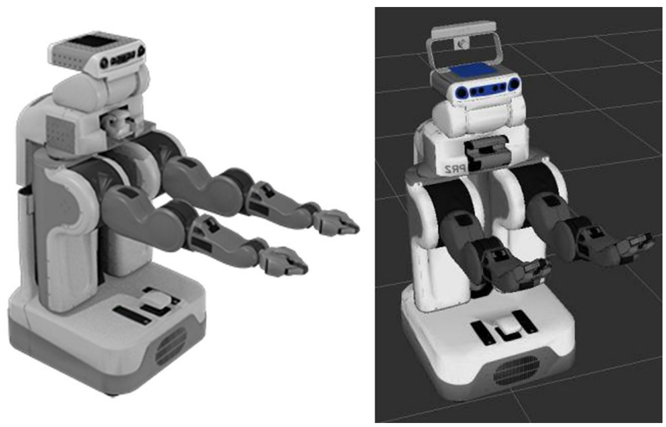

Fig. 1. Willow Garage PR2 robot (left) and its 3D model (right). Courtesy of Willow Garage company.

The Willow Garage PR2 robot [9] was presented in 2010 as a personal robot, which is still available on the consumer market. It has 2 manipulators with grippers, a head, a spine and an omni directional base on 4 steered and driven casters, which supports a speed of up to 1 m/s. PR2 robot has in total 20 degrees of freedom (DoF). PR2's variety of sensors includes base and tilting lasers; head cameras: wide color stereo camera, narrow monochrome stereo camera, gigabit camera and textured light projector; global shutter camera in every forearm; gripper sensors, etc. Both base and torso lasers (LRF_B and LRF_T respectively) are Hokuyo Top-URG UTM-30LX rangefinders with 30 m and 270 degrees scanning range. LRF_B is used in ROS-based SLAM method (described in Chapter 4). LRF_T is mounted on a tilting platform located just below the head and can sweep the scanning laser through 135 degrees; it is applied for visualization. The total robot weight is 220 kg, the height is 133-165 cm (depending on the particular extension of a telescoping spine). The software on the PR2 is based on ROS. The PR2 robot and its 3D model in RViz software is shown in Fig. 1,

[9] Willow Garage PR2 robot, http://www.willowgarage.com/pages/pr2/overview

where the simulated model of PR2 robot also has Microsoft Kinect sensor [10] attached to the robot head. This Kinect sensor is used to obtain 3D point cloud of environment during the PR2 robot navigation.

2.3 AR-601M robot description and simulation

The anthropomorphic robot AR-601M (Fig. 2) is being developed by Russian company "Android Technics" [11]. It is a human-like anthropomorphic robot of 144 cm height and 65 kg weight, with 57 DoFs (41 active DoFs). The robot has a torso, a head, two manipulators with gripping fingers and two legs. A built-in multi-sensor system includes a stereo camera, rear-view camera, 2 Hokuyo UTM-30LX sixteen IR sensors located on robot's wrists and feet, feet pressure sensors, and gyroscopes. Detailed specifications of AR-601M robot could be found in [7].

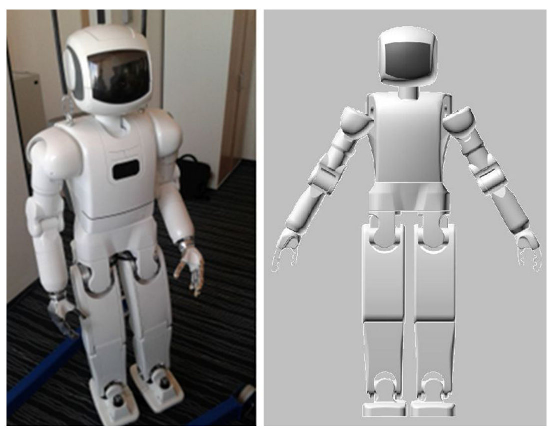

Fig. 2. Android Technics AR-601 robot (left) and its 3D model (right). Courtesy of Android Technics company.

3 Camera-based 3D model of indoor environment

This chapter presents 3D model building process which was based on camera shooting and multi-image processing technique for indoor environment by Autodesk 123D Catch software.

[10] Microsoft Kinect, www.microsoft.com/en-us/kinectforwindows/default.aspx

[11] Androidnaya Tehnika (Android Technics), AR-601M belongs to a AR-600 series of robots, http://en.npo-at.com/products/ar-600

3.1 Indoor environment shooting with camera

Nowadays, the precise reconstruction of real 3D environment from camera-based dataset using computer vision techniques is widely used in 3D simulators. This image-based 3D modeling technique often applies to low cost or open source software, like Autodesk 123D Catch [12], which is used in our research. This type of web based software (ARC3D, 123D Catch, Hyp3D, my3Dscanner) uses a power of cloud computing to carry out a semi-automatic data processing [8] in the contrast with the elder desktop systems approaches.

It gives the advantage of overcoming the PC slowing-down because of hardware overloading, but as a drawback may be significantly effected by a limited speed of the Internet connection while performing online image processing. Comparison of 3D models from the image-based technique of Autodesk 123D Catch and a terrestrial LIDAR demonstrates encouraging results with the 123D Catch software technology [8]. However, the quality of a 3D model for the camera-based technique strongly depends on image quality (image resolution; brightness homogeneity; constancy of illumination conditions; shadowing; absence of transparent, reflective or glossy objects; presence of multiple color labels, etc.), and photo shooting correctness (photo overlapping; occlusion avoidance; photographing static objects, etc.).

3.2 Image-based 3D modeling of indoor environment

Depending on results of automatic image processing, the manual correction and 3D model improvements may be required. Such image matching is based on use of image features (e.g., color labels) and usually is time consuming. In the worst case, 3D model may contain significant geometric distortions, which are unacceptable and require to re-shoot the scene completely. Typically, for large and medium scale structures a 3D model after reconstruction has the metric accuracy of 1-2 cm, which depends on mesh quality, resolution of dataset and image quantity [8]. In a room-size environment this accuracy is less than 0.5% which is sufficient for the further use in a 3D robot simulator. Relatively to simple 3D point cloud data the camera-based 3D model reconstruction may contain more information about environment which might be valuable for building 3D semantic maps of indoor household environments for methods of multi-object map creation from sensory data (e.g., [9]).

We are interested in shooting indoor environment and further feeding it into SLAM algorithm implementation. For our research we selected as a trial 3D model the room proposed by Glenn Smooth[13] (from Autodesk 123D image galleries[14]). The room contains of a guitar as an obstacle, which is convenient to use for SLAM purpose. The photo of the room, the 3D view from Autodesk 123D

[12] Autodesk 123D Catch software, www.123dapp.com/catch
[13] Glenn Smooth's bass guitar room, www.123dapp.com/obj-Catch/bass-guitar-room/1250335
[14] 3D Models gallery from Autodesk 123D Catch, www.123dapp.com/Gallery/catch

Catch, and 3D view of meshing results in MeshLab[15] are presented in Fig. 3 (from left to right).

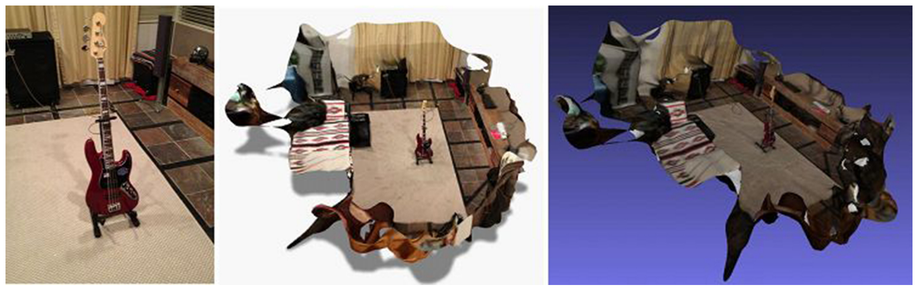

Fig. 3. 3D model of Glenn Smooth's bass guitar room for 3D Gazebo simulation; from left to right: a room photo, 3D view in 123D Catch, and 3D view in MeshLab. Courtesy of Glenn Smooth (www.123dapp.com/obj-Catch/bass-guitar-room/1250335).

4 ROS-based SLAM using Gazebo in image-based 3D model of indoor environment

This chapter considers the ROS-based SLAM utilizing Rao-Blackwellized particle filter method and laser data to locate the Willow Garage PR2 mobile robot in image-based 3D model of indoor environment and to build a map using Gazebo robot simulator.

4.1 Robot simulation in Gazebo

Robot simulation is an essential tool of robotics research. A well-designed simulator allows to obtain: 1) the robot and the environment modeling, 2) sensor data and odometry, 3) realistic scenarios of robot locomotion, 4) the implementation of sophisticated algorithms (like SLAM and autonomous navigation), and 5) their fast testing.

Gazebo robot simulator has a number of significant advantages: robust physics engine, high-quality graphics, open-source code, convenient customer and graphical interfaces. It allows to substitute the real robot by its simulation model, providing the calculation of the robot locomotion through odometry and sensor data. Using Gazebo simulator affords to import existing simulated robots and environments, or to create their new 3D model with geometrical primitives.

The simulator's feature is that the environment represents a static model while a robot is a dynamic object. Sensors in Gazebo are the abstract devices with lack of a physical representation, which only give embodiment when they

[15] MeshLab - an open source 3D mesh processing software, meshlab.sourceforge.net

are incorporated into a model. Both passive and active sensors are processed separately from the dynamic simulation in Gazebo – as far as the first only collect data, and the later ones emit and collect data [10]. This feature allows to escape risks of confusion in robot and sensor simulations during robot locomotion. In Gazebo there are three main types of sensor implementation including odometry sensors, ray proximity, and a camera. Odometry is calculated through integration of the traveled distance. The ray proximity sensor returns the contact point of the closest object along the ray's path, that is why it is used to simulate both a scanning laser rangefinder and depth sensor (like Kinect). Finally, the camera renders a scene using OpenGL [10] from the perspective of the model that it is attached to. In SLAM and autonomous navigation we use all three sensor types, performing the sensory data visualization with RViz software[16].

Although it is possible to create a simulated robot model manually with geometric primitives (boxes, spheres, cylinders, planes, etc.), currently a large set of robot models is available in Gazebo, including Willow Garage PR2 robot. The Gazebo-simulated PR2 robot is "equipped" with two Hokuyo laser rangefinders, Kinect sensor, forearm cameras and stereo camera sensors that reasonably replicates a real PR2 robot. The environment modeling could also be created with geometric shapes with appropriate rendering properties such as color, texture, transparency, etc.(e.g., [9]), but we have prepared the real indoor environment based on camera shooting to 3D model for Gazebo simulator.

The results of the Gazebo robot simulation with measurements from a system of two scanning lasers (red lines) and Kinect sensor (a white point cloud) in the room (see Section 3.2) are visualized by RViz and shown in Fig. 4, at the beginning (left) and at the end (right) of SLAM algorithm run.

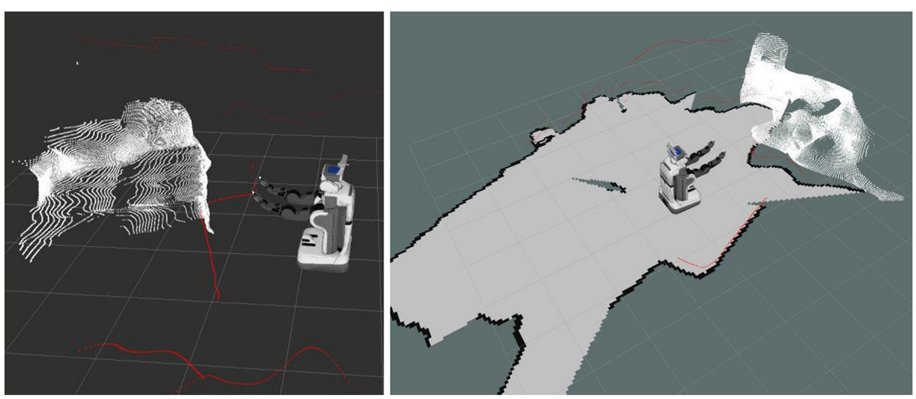

Fig. 4. RViz visualization of Gazebo-simulated PR2 robot locomotion in 3D model of a room at the beginning (left) and at the end (right) of SLAM algorithm run

[16] RViz - 3D visualization tool for ROS, wiki.ros.org/rviz

4.2 ROS-based SLAM simulation in Gazebo

The integration of the open-source robot simulator with ROS provides access to a variety of user contributed algorithms. In our study, for SLAM task the PR2 robot must interpret laser data to localize itself and simultaneously produce a map of an unknown environment. The environment to be mapped in this instance is a room with obstacles, shown in Fig. 3.

In a cluttered environment, particle filters have been used as an effective solution to the SLAM problem. In this study we implement the OpenSLAM GMapping algorithm based on the Rao-Blackwellized particle filters. The particle filter uses the probabilistic approach with the distribution represented by a set of random particles with associated weights, where each particle has an own weight assigned to represent the probability of that particle being sampled from the probability density function [11]. According to the approach in [5], each particle in the filter carries an individual map of the environment. Therefore the task of particles quantity reduction is really essential. GMapping filter presents adaptive techniques to decrease the number of particles in Rao-Blackwellized particle filter for learning grid maps. It uses an approach to compute an accurate proposal distribution taking into an account not only the robot locomotion but also the observation history. This way it dramatically decreases the uncertainty of the robot's pose in the filter prediction step [5].

Our implementation of ROS-based SLAM method with Gazebo simulation and RViz visualization has the following steps:

1. ROS starts simulation in Gazebo.
2. Gazebo simulates the robot locomotion and sensor measurements, and exports the simulation results to ROS.
3. ROS calculates the robot localization and mapping (SLAM).
4. RViz imports and visualizes the simulation data from ROS (not only immediate robot localization and mapping, but also real-time sensor data).

The laser data is sent via the ROS node running particle filter in OpenSLAM GMapping, and the system produces the robot trajectory (Fig. 5, the red curve) and a map of the simulated environment, which is visualized in RViz (as a plan view).

Figure 5 demonstrates the operating scenario of SLAM algorithm run-time in the static environment. The robot starts from the bottom left corner of the room, bypasses the obstacle (the guitar) in the room center, and targets to reach the bottom right corner. Next, upon the arrival to its destination, the robot navigates itself back to the start (using the obtained at the SLAM stage map) while following the same trajectory within the SLAM-map. Figure 6 (left) represents the Gazebo-simulated PR2 robot locomotion in the real environment together with indications of scanning laser rangefinders (the base laser LRF_B on the top-center and the tilting laser LRF_T at the bottom-center of picture) at the end of the robot path. Figure 6 (right) shows the RViz visualization of the same PR2 robot pose in the simultaneously obtained map of the room environment. Figure 6 qualitatively demonstrates the fidelity of the simulated 3D model of the

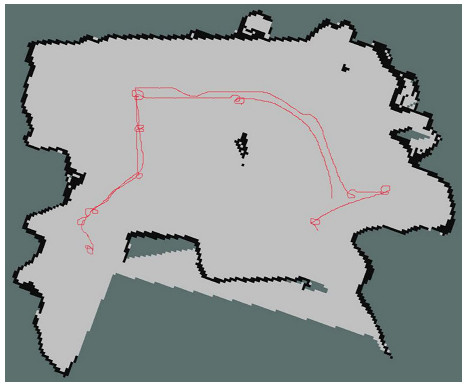

Fig. 5. ROS-based SLAM simulation in Gazebo for the indoor environment 3D model; in the operating scenario the robot has been moving from right to left and back

room with obstacles (at the left) to the sensory map (at the right). That proves the feasibility of ROS-based SLAM of a Gazebo-simulated mobile robot to its usage in camera-based 3D model of a realistic indoor environment.

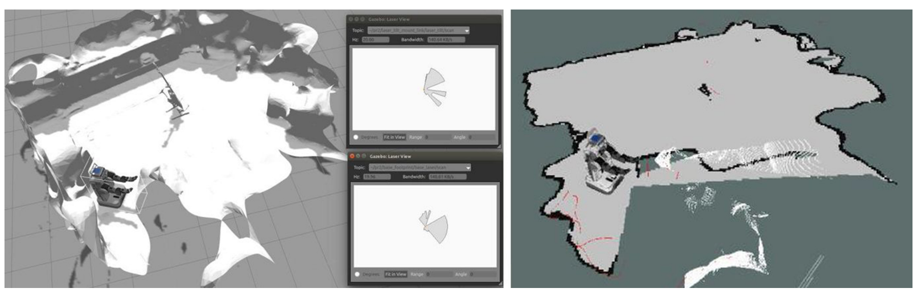

Fig. 6. PR2 robot simulation in Gazebo for 3D model of indoor environment: PR2 locomotion in the real environment (left), LRF_T scan (top-center), LRF_B scan (bottom-center), RViz visualization (right)

Conclusions and future work

This paper is focused on verifying the feasibility of ROS-based SLAM for a Gazebo-simulated mobile robot (with a scanning laser), moving in 3D model of a realistic indoor environment. In this paper we have introduced AR-601M and PR2 robots with their simulation models, presented image-based 3D model of real indoor environment and described the results of ROS-based SLAM of the Gazebo-simulated PR2 robot. The image-based 3D model of a real room was obtained by camera shots and implemented in Autodesk 123D Catch software with meshing in MeshLab. The ROS-based SLAM applies Rao-Blackwellized particle filters and laser data to the Willow Garage PR2 robot localization and mapping. The obtained fidelity of the simulated 3D model of the room with obstacles to its sensory map have demonstrated the feasibility of ROS-based SLAM of the Gazebo-simulated mobile robot to its usage in camera-based 3D model of the realistic indoor environment.

In the next stages of our long term research we will extend the verified ROS-based SLAM approach from Gazebo-simulated PR2 robot model to AR-601M robot model. Also a currently exploited 3D realistic indoor environment will be rebuilt using on-board sensors of AR-601M robot in order to replicate our laboratory environment and investigate sensor data matching of the proposed SLAM approach with new algorithms of autonomous robot navigation.

Acknowledgements

This research has been supported by Russian Ministry of Education and Science as a part of Scientific and Technological Research and Development Program of Russian Federation for 2014-2020 years (agreement 14.609.21.0004, research grant ID RFMEFI60914X0004) and by Android Technics company, the industrial partner of the research.

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