Simulation Tools for Urban Search and Rescue Robotics

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Abstract

Real world experiments are critical for validating performance of new concepts and algorithms in robotics field. Yet, experiments tend to be too expensive in terms of time and resources of a research team. Moreover, it is not feasible to conduct thousands of complex experiments with a physical robot in a real environment. To check new ideas, preliminary evaluate new algorithms and interaction protocols, on first stages of a research project it is reasonable to start within a simulation. To produce relevant results, a simulator should provide adequate models of robots and environments with realistic physical properties. This paper presents an overview of our experience in using robot operating system (ROS) with Gazebo and Webots simulators for urban search and rescue robotics projects and considers constructing new models of mobile robots and complicated environments, algorithm validation and comparative analysis.

Keywords: Robotics, modelling, simulation, USAR, ROS, Gazebo, Webots

1. Introduction

Urban search and rescue (USAR) robotics was introduced at the end of the 20th century as a research a field that studies mechanics of rescue robots[1], their navigation[2], mapping[3], interaction of a human with a rescue robot[4], and other classic tasks of robotics being viewed through a prism of rescue related tasks[5]. USAR robotics is employed for searching victims in partially damaged or completely destroyed man-made structures, reconnaissance and mapping, debris penetration (e.g., with small sized ground robots) that could improve the two previous tasks' efficiency, debris removal, telepresence, hazmat contamination, and other tasks[6]. In USAR scenarios rescue teams deal with collapsed buildings and victims (which are often trapped under urban environment ruins) and wireless communication may be severely disturbed because of large volume of steel and concrete debris. A typical USAR environment contains debris that are formed by damaged construction materials, furniture, household and office items that complicate environment observation, localization and mapping[7][8]. While such conditions are natural for a real world rescue scene, it is complicated, time, resources and space consuming to create a similar to real USAR scene for experiments. Yet, in order to check new ideas, preliminary evaluate new algorithms and interaction protocols for USAR, on first stages of a research project real world conditions could be approximated virtually within a simulation.

Nowadays, simulations are extensively used in robotics, including robot design and construction[9], control algorithms validation[10], interaction protocols development[11], education[12] etc. They allow building a broad variety of virtual models of robots and environments[13] while targeting to achieve a relatively realistic behavior. We highlight the following reasons of using simulation in robotics[14]: real experiments with robots are expensive while simulations are cheap; simulation experiments take less time than real experiments; simulations are always safer than experiments in real world; simulations allow testing novel concepts and algorithms even if a required hardware is not available for a user; simulations help to quickly detect and correct conceptual errors in algorithms; finally, simulations could provide fairly reasonable and statistically valuable testing of experimental setups. Those reasons apply to all robot types and tasks. A simulator became a very progressive tool that could reproduce complicated test environments [15]; they can use user-defined physics with dynamic changes, which makes it possible to construct and use a robot model behaving acceptably similar to a real robot.

Among a broad variety of popular simulators, our research group concentrates on the Gazebo simulator that was designed specifically for simulating robots and their environment[16]. Being fully compatible with Robot Operating System (ROS)[17] Gazebo simulator allows creating and using robot models with ROS-based control systems without additional efforts. In most cases the Gazebo simulator is used together with the RViz simulator[18] as they provide a good complementary level of sensory input and motion activities visualization. Recently, our research team started using Webots[19], which enables a faster modelling and prototyping while suffering from a lower level of realism. Occasionally we employ Matlab simulator, which allows fast drafting of ideas but in terms of USAR robotics suffers from a very high level of abstraction[20]. There exist a number of other popular robotics simulators that could be used for modelling USAR scenarios including USARSim[21] and VRep (recently known as CoppeliaSim[22]).

In the next sections we briefly share our experience in employing Gazebo, RViz and Webots simulators for a robot and environment modelling, a comparative analysis of various approaches, a preliminary validation of algorithms and robots' interaction.

2. Robot modelling

We constructed a number of new models of mobile robots that correspond to real robots, which are available for our research team within the laboratory. For the Gazebo simulator car-like Avrora Unior wheeled robot[23], Servosila Engineer crawler robot[24], and PX4-LIRS UAV[25] models were developed.

First models of the Servosila Engineer robot[26] suffered from an incompleteness and a high level of abstraction. A second generation of the model approximated tracks with a varying number of pseudo-wheels[24] and significantly improved the performance, yet had issues with a real time factor (RTF) of the simulation and a number of locomotion issues that caused seizing at sharp edges of an environment. Next, a comparative analysis[27] of an optimal number of pseudo-wheels for each track simulation allowed to find a tradeoff between the model complexity and performance in terms of RTF. To increase RTF further, Servosila Engineer model was improved via CAD files' analysis and their systematic simplification[28]. In[29] we proposed a novel approach of modelling Servosila Engineer robot's crawlers as a set of gear wheels, which had a better RTF and solved the seizing problem. While starting with ROS Indigo and Gazebo 2.2.3 simulator, gradually the robot model has been evolved to ROS Noetic and Gazebo 11 simulator[30]. Figures 1-5 demonstrate the evolution of the Gazebo model: the real robot (Fig.1), the first model in Gazebo and RViz (Fig.2), the track approximation with arrays of the pseudo-wheels (Fig.3) and the gear-wheels (Fig.4), the latest version of the model in Gazebo 11 (Fig.5).

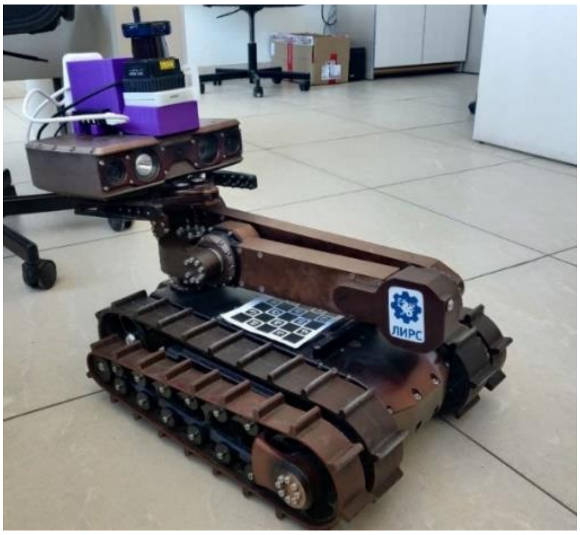

Fig.1. Servosila Engineer robot at Laboratory of Intelligent Robotic Systems (LIRS), Kazan Federal University

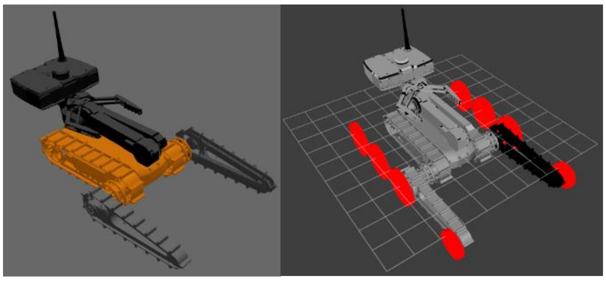

Fig.2. The first version of Servosila Engineer robot model in Gazebo 2.2.3 (left) and in RViz (right). Imaginary pseudo-wheels are shown in red[26].

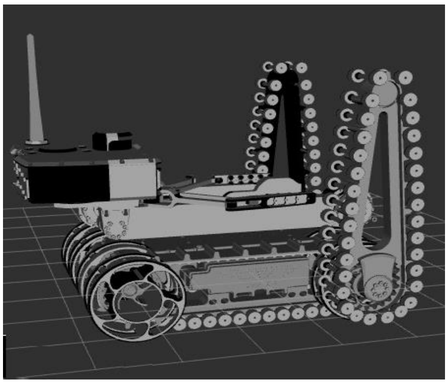

Fig.3. Track approximation with arrays of pseudo-wheels[27]

Fig.4. Track approximation with arrays of gear-wheels: small-sized (top) and large-sized wheels (bottom)[29]

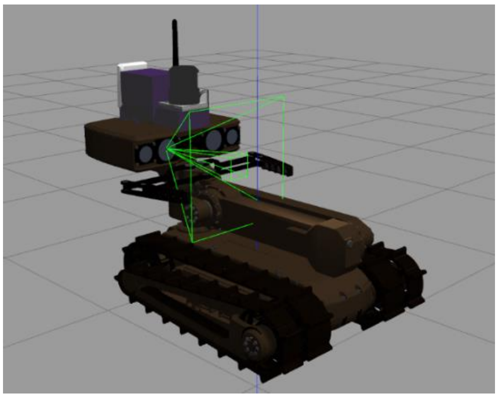

Fig.5. Gazebo 11 simulation model[30]

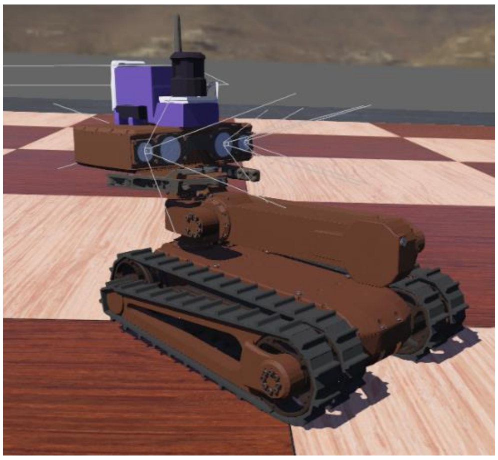

Fig.6. Webots simulation model[31]

Servosila Engineer robot[31] and its onboard sensory system[32] were modelled in Webots simulator in order to diverse virtual validation of algorithms that use the robot with a different simulator. Fig.6 demonstrates the Webots model of the robot.

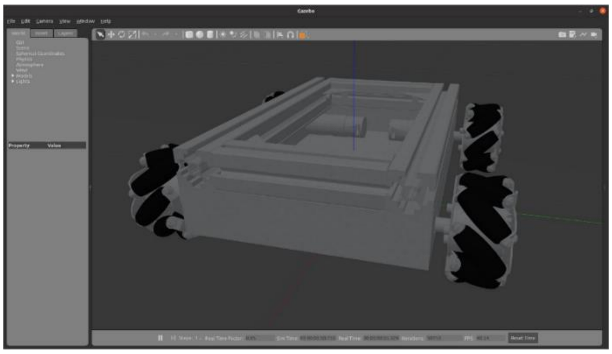

Fig.7. ArtBul chassis in the Gazebo[33]

While previously mentioned UGV and UAV models considered a recreation of existing real robots in the simulator, in[33] we presented a reverse approach of modelling chassis for omnidirectional wheeled robot *ArtBul* (Fig.7) that is still under development (Fig.8). The model was constructed using Blender software for Gazebo 11 and ROS Noetic. Next, an open-source plugin for omni-wheels was created[34].

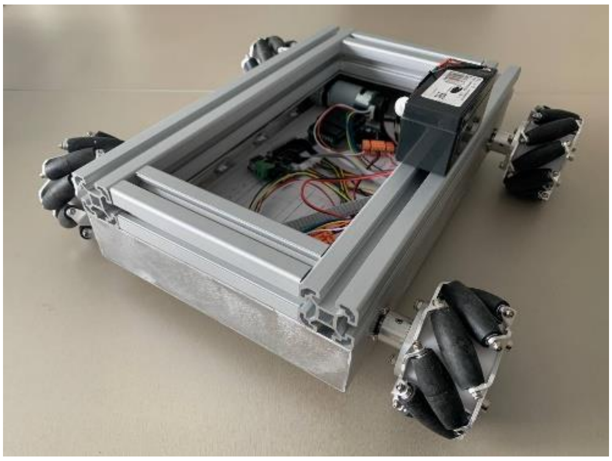

Fig.8. Current state of ArtBul chassis development[33]

3. Environment modelling

Two main approaches to environment modelling are a manual modelling and an automated modelling. For the manual modelling that targets, for example, for a raw testing of a navigation or mapping algorithm idea, a user can employ existing models of objects that come together with the Gazebo and construct rather simple flat landscapes filled with obstacles (Fig.9, [35]). A process of such environment construction is simple, but it could take several hours even for an average complexity and an average size of an environment.

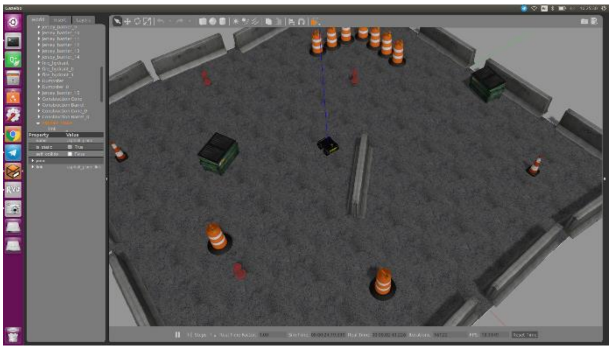

Fig.9. Robot Husky in a flat outdoor environment, which is filled with existing standard models of Gazebo objects[35]

If a user demands to recreate an existing in a real world environment (while targeting for a careful algorithm validation before transferring it from the simulator onto a real robot), precise measurements of the environment are important. The user spends at least several days making the measurements and then employs a software for constructing CAD models of the environment. In some cases, existing epura of a building could significantly speed up the process. Such approach produces lower complexity models, but it is extremely time and resource consuming. An example of manual construction based on an epura and manually performed measurements is presented in Fig.10 [36].

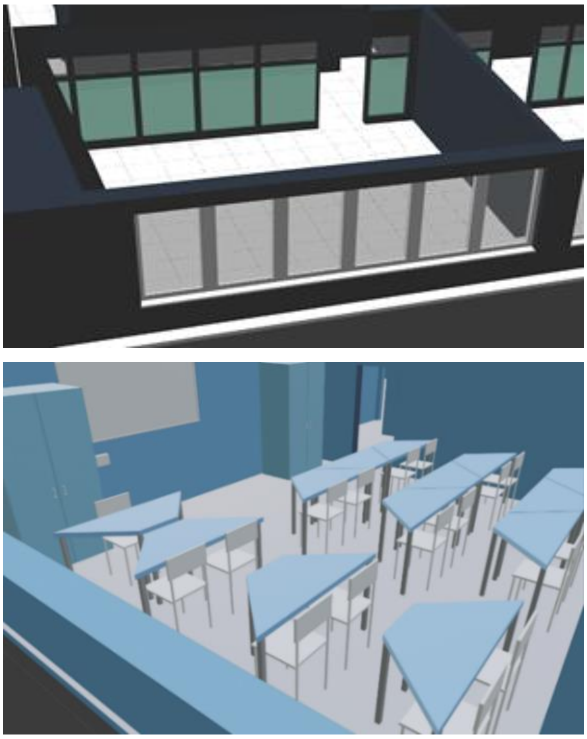

Fig.10. A part of 14-th floor environment of Department of Intelligent Robotics at Kazan Federal University: transparent glass and tinted glass windows (top) and a virtual classroom (bottom) [36]

Automated modelling is useful when a user needs to quickly create a large number of varying environments that will allow exhaustive testing of his/her algorithms in different situations and will provide statistically sufficient results for a deep further analysis. Our first attempts to automate environments' generation resulted in a low-efficiency tool that constructed voxel-environments with a high memory load and a low RTF [37]. Next, the tool was significantly modified and it is currently capable to automatically construct 3D solid model Gazebo worlds from a grayscale image and a user-selected texture[38]. Yet, not for every particular environment case a complicated software is required. For example, for a very high-structured so-called *random step environment* (RSE, [39]), which is broadly used for robot mobility evaluation within research and RoboCup rescue competitions. To automatically construct 3D RSE worlds for the Gazebo we created a user-friendly tool *LIRS-RSEGen* with a graphical user interface[40]. The tool is open-source and it allows constructing RSE worlds that could be further edited or directly used within the Gazebo. Moreover, LIRS-RSEGen can construct non-standard RSE models, for example, with different block sizes. Constructed by LIRS-RSEGen worlds were validated for their applicability in the Gazebo using virtual models of TurtleBot3 wheeled robot and Servosila Engineer crawler robot. Virtual tests demonstrated effectiveness of constructed RSE worlds in terms of the RTF, CPU and memory load, which had acceptable values even for a relatively large RSEs of 80x80 block size. Fig.11 demonstrates the Servosila Engineer robot within a generated by LIRS-RSEGen environment.

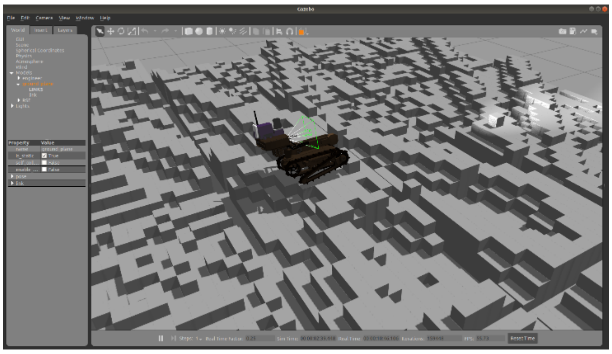

Fig.11. Gazebo 11 model of the Servosila Engineer robot within a generated by LIRS-RSEGen RSE[40]

Quality of automatically created models fells behind manual ones (e.g., large amount of generated triangles of a mesh increases a model's complexity and resource consumption, which in turn dramatically affect RTF), but automated modelling approach saves a huge amount of researchers' time and efforts.

4. Activities modelling in a virtual world of the Gazebo

This section demonstrates examples of employing simulators in order to compare and validate algorithms, methods and protocols. In[41] our team employed the Gazebo simulator for evaluation of visual SLAM methods in USAR applications. Validations of partially [42] or entirely[43] unknown environment exploration algorithms for a mobile robot were successfully performed in the Gazebo.

In[44] we presented a new concept of *Embedded ArUco* fiducial marker that allowed a high precision UAV landing. The marker performance was validated in the Gazebo. In[45] we proposed testing procedures architecture for establishing a fiducial marker recognition quality in UAV-based visual marker tracking task in the Gazebo. In general, the Gazebo simulator is critical when a large number experiments is required, e.g., we successfully employed it for exhaustive simulation approach for a virtual camera calibration evaluation[46] and automated fiducial marker comparison in the Gazebo environment[47].

The Gazebo could be successfully applied in human-robot related activities preliminary studies, e.g., human-following by a mobile robot in an indoor scenario[48] (which was initially tested in a virtual world and then validated in real world experiments[49]) or robot control using gestures[50]. The Gazebo simulator significantly facilitated a preparatory stage of real-world experiments in a humanoid robot assisted English language teaching[51], which allowed saving time and resources both for our research team and for experiments' participants. Moreover, the simulator is useful in large concepts' modelling, e.g., we used it to check an idea of a TurtleBot3 based delivery system for a smart hospital environment[52], which is expected to become a near future of pandemic mitigation approaches[53].

In[54] the Gazebo was used for comparative analysis of ROS-based centralized methods for conducting collaborative monocular visual SLAM using a pair of UAVs, which is important for large-size outdoor territory surveillance in a USAR scenario. In[55] we modelled a stairs recognition algorithm for a mobile robot navigation in 3D environments, which targets for stairs negotiation in indoor surveillance in a USAR mission. Two approaches for employing external infrastructure's IoT cameras were explored using the Gazebo: a single UGV based indoor localization[56] and an IoT cameras network application for an UAV Control via a GUI[57].

5. Conclusion

This paper overviewed our experience in using the Gazebo and Webots simulators for urban search and rescue (USAR) robotics projects. We presented particular examples of simulators' applications for constructing new models of existing mobile robots as well as modelling of a new robot that was still under development, capabilities of the simulators for manual and automated generation of virtual environments for virtual testing, their applicability for algorithm validation and comparative analysis. Overall, the Gazebo and Webots simulators demonstrated that they could significantly contribute to a broad variety of projects in USAR, human-robot interaction and other fields in terms of dramatically reducing research teams' time and resources consumption.

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