Standard-complaint Gazebo warehouse modelling and validation

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***Abstract*—Modern robotics require high-quality simulations for robots and algorithms validation. Warehouses are the source of active robotic deployment due to high level of standardization. In this paper, we present a model of a warehouse designed entirely in accordance with GOST regulations and international practices for the ROS / Gazebo environment. It is compared with the existing solutions in terms of applicability and computational performance. Created environments are validated using robotic navigation experiments. As a result, the ready-to-use warehouse models with flexible modular design are presented.**

Keywords*— *warehouse, ROS, Gazebo, robots, GOST

I. Introduction

Modern warehouse management is a complex task with several goals to be accomplished simultaneously. This task includes multiple subtasks, such as cargo transfer, loading, and offloading monitoring [1], human personnel safety [2], goods tracking and inventory [3], [4], warehouse indoor conditions management, and many others [5]. Robotics is the way to dramatically increase the workflow's efficiency and safety level.

Robots are already applied for warehouse management tasks, e.g., they are successfully used for good packing [6], cargo sorting [7] and transfer [8]. However, the robots are still used in a very constrained manner: there should be no people around them at the operational time and the environment should be adopted for them. For example, the proper navigation of multiple transfer robots requires special markers on the entire locomotion way.

The next step for the warehouse robotics is to be deployable in the most warehouses with no or minimal environment preparation. This type of robotics is called collaborative robotics [9]. Collaborative robotics' algorithms require in-depth testing and validation before actual deployment and the simulations are the way to provide it. Thus, the proper environment should be simulated to ensure the quality of the developed robots and algorithms [10].

This paper presents the analysis of the modern warehouses' types and simulation environments created according to the best warehouse management practices. It relies on GOvernment STandards of the Russian Federation (GOST) and international standards and includes fully operational warehouse environments. Environments consist of standardized models of racks, goods, pallets with proper distances between them. Environments are created for the Gazebo 3D-simulator [11] and validated through robotic navigation and recognition tasks performed.

This paper is structured as follows. Section 2 considers the modern classification of warehouses. Section 3 is dedicated to requirements for the warehouse racks. Next, the created environments are presented. The additional tools provided with the environments (visual and RFID tags) are described in Section 5. The last section concludes the paper.

II. Types of Warehouses

Knight Frank [12] has developed a classification of storage facilities. According to this classification, all storage facilities are divided into classes:

- Class A - in turn, divided into subclasses A and A+
- Class B - also divided into subclasses B and B+
- Classes C and D

The classification mainly reflects the technical characteristics of warehouse buildings and their equipment.

Class A and A+ is a modern one-story warehouse building made of lightweight metal structures and sandwich panels, preferably rectangular, without columns or with column spacing of at least 12 m for class A+ and column spacing of at least 9 m for class A, as well as the span at least 24 m. High ceilings are required: at least 13 m for class A+ and 10 m for class A, allowing the installation of multi-level racking equipment.

Class B and B+ is a one-story warehouse building, preferably rectangular, newly built or reconstructed. High ceilings are also required: at least 8 m for class B + and 6 m for class B.

Class C is a capital industrial premise or insulated hangar with a minimum ceiling height of 4 m. Class D is a basement or civil defense (CV), unheated industrial premises, or hangars.

III. Rack Specifications

According to GOST R 55525-2013 [13], racks are divided into the following types:

- Frontal (see Fig. 1)
- Stuffed (deep, see Fig. 2)
- Cantilever (see Fig. 3)

Different racks types have different purposes. For example, stuffed (or deep) racks allow stacking several goods in a single rack level, pushing the goods deeper into the rack every time when the new cargo must be loaded into the cargo. Therefore, only the last loaded cargo is available for immediate unload and transfer. Thus, such racks are convenient when the goods are identical. This type of rack efficiently uses the warehouses' volume.

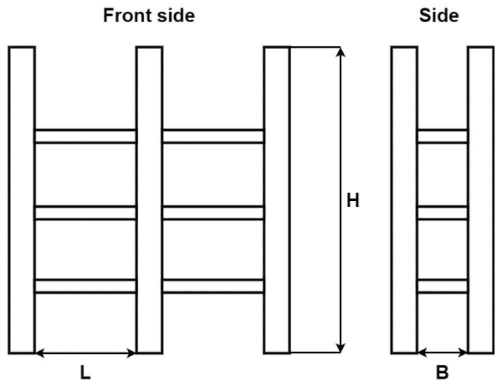

Figure 1. Frontal rack scheme.

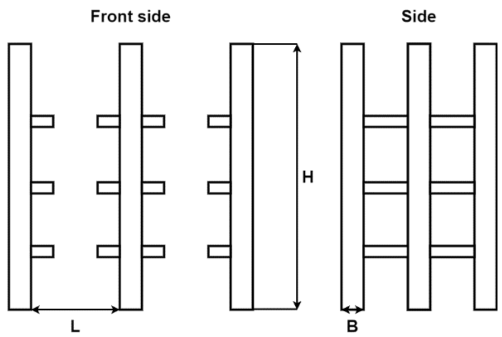

Figure 2. Stuffed (deep) rack scheme.

Cantilever racks have simpler construction, however, their loading capacity is limited. Frontal racks are commonly used in commercial warehouses for their robustness and ease of goods inventory. Goods loaded into frontal racks are visible from the passages and inventory could be performed using QR-codes, RFID tags, etc.

A. Rack layout

Standards introduced by GOST 16140-77 [14] define the minimum distance between the racks and the warehouse wall (including the passage necessary for the loader to travel) — it must be at least 0.7 m. This width is sufficient to allow people and loading equipment to pass along the rack.

Front-loading systems installation is regulated by the requirements of GOST R 55525-2013 and is carried out in the following ways:

- Wide passage - the width varies from 2.5 to 3.7 m; the area of the corridor allows the loader to turn freely.

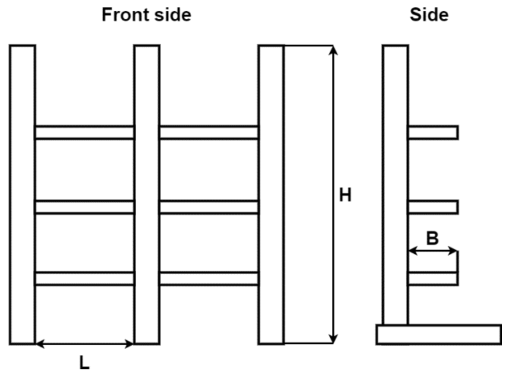

Figure 3. Cantilever rack scheme.

- Narrow aisle - dimensions in the range from 1.5 to 1.9 m, transport passage must be used to turn the transport.

B. Pallets placement

The placement of pallets on racks is also regulated by the requirements of GOST R 55525-2013. Table 1 includes the minimum technological gap values depending on the height of the cargo. The scheme on Fig. 4 defines the layout of pallets on racks.

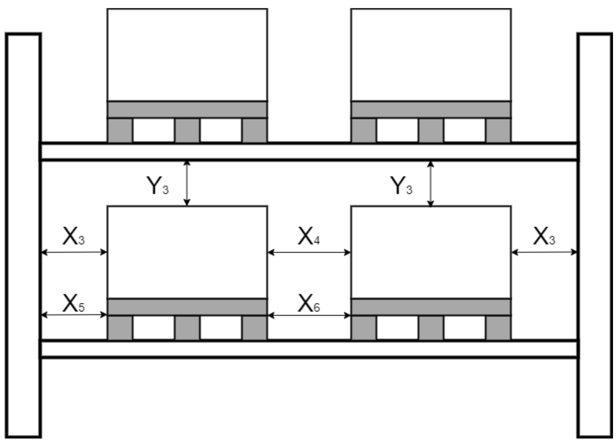

Figure 4. Layout of pallets on the rack. The distance requirements are defined in Table 1.

TABLE I. Technological gaps depending on the height of the cargo

Cargo placement height H, mm	Wide aisle storage system		Narrow Aisle Storage System			
			Class A		Class B	
	X3, X4, X5, X6, mm	*Y3, mm*	*X3, X4, X5, X6, mm*	*Y3, mm*	*X3, X4, X5, X6, mm*	*Y3, mm*
3000	75	75	75	75	75	75
6000	75	100	75	75	75	100
9000	75	125	75	75	75	125
12000	75	150	75	75	100	150
15000	75	175	75	75	100	175

IV. Gazebo Environment

A. Amazon solution

AWS Robotics has recently introduced its warehouse model for the Gazebo simulator [14]. The warehouse has a size of 14x21 m and has 4 large racks and 6 small racks (shown in Fig. 5). Unfortunately, this environment is small-scale and does not follow cargo storage guidelines. It could be used for simulation in a limited number of situations.

This case proves that proper warehouse simulation is still required for commercial purposes and has significant practical value.

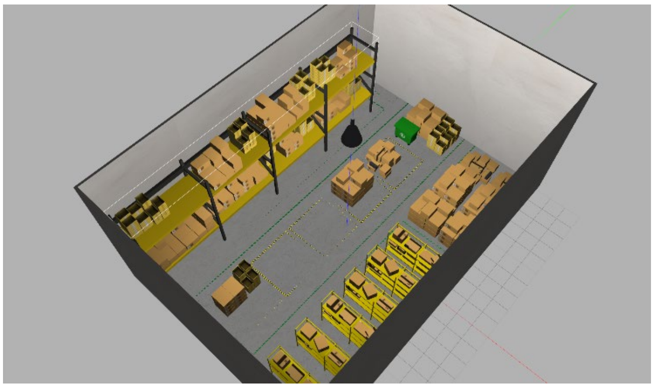

Figure 5. AWS Robotics warehouse.

B. Proposed enviroments

Two GOST-compliant schemes of the warehouses were developed (Fig. 6, 7). Warehouse #1 has dimensions of 16.5x50.5 m and a height of 8 m, which corresponds to the warehouse of a Class B standard. It contains 28 racks of the size 5700x1350x6000 mm (the diagram is shown in Fig. 9). The distance from the wall of the warehouse to the rack is 0.7 m, and the width of the corridor is 3 m. Warehouse #2 has dimensions 29x32.5 m and height 8 m, which also corresponds to the class B standard. The warehouse contains 8 racks of 28100x1350x6000 mm in size. The distance from the wall of the warehouse to the rack is 0.7 m, and the width of the passage is 3.7 m.

Created racks models and warehouses' views are shown in Fig. 6,10.

Figure 6. Rack with pallets model for Gazebo.

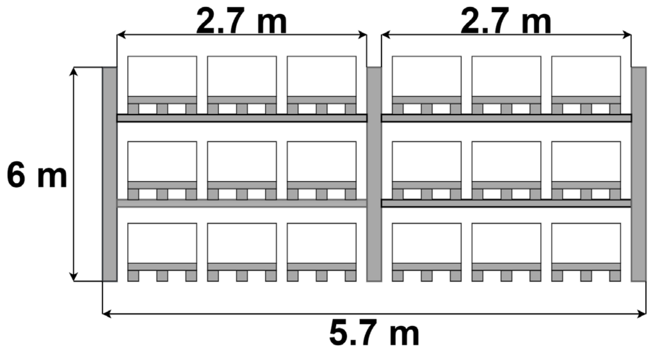

Figure 7. Goods and pallets layout on the racks.

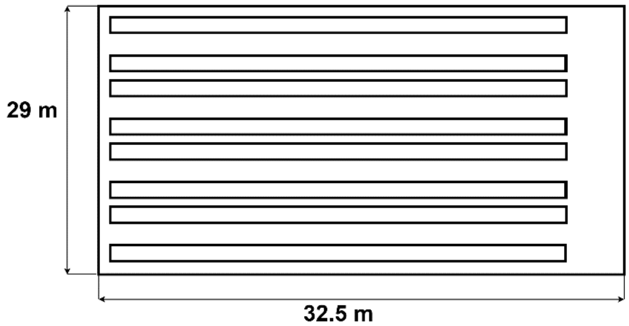

Figure 8. Scheme of a warehouse measuring 29x32.5 m.

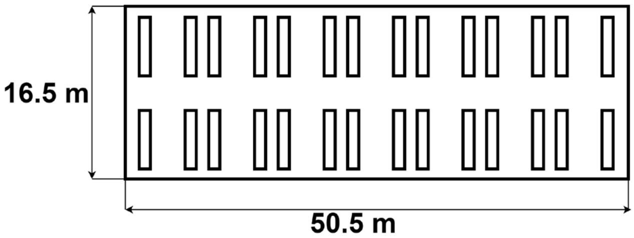

Figure 9. Scheme of a warehouse measuring 16.5x50.5 m.

C. Possible extensions

The developed warehouse models can be used together with fiducial and RFID systems to simulate inventory and navigation tasks in the ROS / Gazebo environment[15].

For example, autonomous navigation could be performed using fiducial markers attached to the racks. Such navigation technique could recovery after localization fails and, thus, it is more robust than existing commercial solutions. Also, with the sensors for human detection, robots could navigate through the environment collaboratively with the human personnel.

RFID systems are possible to use for goods inventory tasks. Our simulation reflects the cargo layout in real warehouses and could be used for autonomous inventory algorithms validation.

V. Virtual Model Evaluation

All warehouse models described in this article were evaluated in the Gazebo simulator with various robots, such as TurtleBot 3 [16] and PMB-2 [17] from PAL Robotics. These robots are equipped with different sensors such as laser scanners, visual cameras, odometry sensors, and others. Therefore, their usage requires a proper sensor and physics simulation. This loads the CPU and imitates the real usage of the created environments.

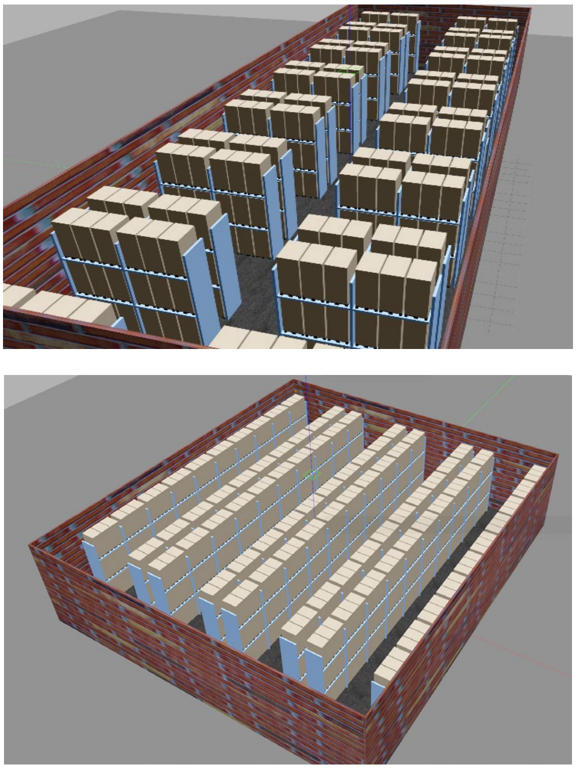

Figure 10. Warehouse environments in Gazebo. Warehouse 16.5x50.5 m (on the top). Warehouse 29x32.5 m (on the bottom).

We used Real Time Factor (RTF)[18] metrics to estimate the CPU load. This metrics is built-in to the Gazebo and shows the ratio between the simulated time and the real-time required to compute the simulation. For example, if the RTF value equals to 0.5, that means a single simulation second requires two real-time seconds to be processed. Each warehouse was entirely mapped using gmapping [18] algorithm. Minimum RTF values during the mapping are provided in comparative Table 2.

TABLE I. MINIMUM RTF VALUE DEPENDING ON THE SELECTED ROBOT AND WAREHOUSE MODEL

Robot model	**Warehouse model**		
	Warehouse 16.5x50.5 m	***Warehouse 29x32.5 m***	***Warehouse AWS Robotics, 14x21 m***
TurtleBot 3	0.97	0.93	0.98
PMB-2	0.77	0.70	0.95

As it is shown, the warehouse model by AWS Robotics has better RTF in cases of both robots. Our developed models show lower RTF; however, they have a significantly larger area and a higher number of the objects located. Moreover, the RTF does not decrease further and remain stable even if the warehouse changes dramatically.

VI. CONCLUSION

This paper is dedicated to warehouse environment Gazebo simulations and their validation. Environments are designed according to the analyzed classifications, international and national standards. Created environments demonstrate high performance and have a modular structure that could be used further for different environments creation.

Presented environments properly interact with common robotic sensors and navigation methods [19, 20]. They are ready for robotic algorithms deployment and validation. Future work includes increasing the variety of objects and dynamic objects (such as people, trucks, etc.) addition. All the presented materials are available open-source.

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