Gear Wheels based Simulation of Crawlers for Mobile Robot Servosila Engineer

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Abstract: In a process of research, it is beneficial to test new theories and early stage developments in virtual worlds of an adequate realistic simulation before starting real world experiments. While modelling of wheeled mobile robots is well-studied and typically does not imply significant difficulties, a realistic modelling of a crawler robot is a complicated task. This paper discusses several existing approaches for a crawler robot modelling in Gazebo simulator and presents a new approach, which approximates each crawler with a set of gear wheels. We compared several approaches for Servosila Engineer crawler robot modelling in Gazebo by their climbing capabilities, velocity, acceleration and real time factor parameters with regard to the real robot. The comparison results demonstrated that the new approach is feasible in terms of CPU load and provides a better approximation to the real robot performance. Moreover, it successfully eliminated an issue of a crawler seizure while climbing sharp edges of obstacles, which is typical for pseudo-wheels based approaches.

1 INTRODUCTION

An unmanned ground vehicle (UGV) is a mobile robot of any type that moves through its operational environment along various types of support surfaces, which might range from a flat surface to a rough debris-like terrain. A UGV is a most widely used type of a robot for a variety of real world tasks.

A crawler (or tracked) robot is a sub-type of mobile robots that use different types of tracks as running gear. Crawler robots are employed when a task requires an extended mobility of a vehicle, including such tasks as planetary exploration, mining and urban search and rescue (USAR). Typically, crawler robots have higher level of manoeuvrability relatively to wheeled robots of similar size and power, but are inferior in terms of velocity and energy efficiency on a flat surface.

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An urban search and rescue (USAR) robotics is a most obvious example of an application that demands a high level of a robot manoeuvrability.

USAR was introduced at the end of the 20th century as a separate branch of a field robotics, which concentrates on mechanics of rescue robots, their navigation, mapping and other classic tasks of robotics as well as interaction of a human with a robot, all being viewed through a prism of rescue related tasks. One of the main tasks of USAR robotics is to search for victims in partially damaged or completely destroyed man-made structures. Therefore, a typical USAR task environment for a UGV contains piles of trash and debris formed by building materials, furniture, various appliances, household and office items that make it difficult to observe, localize and map the environment (Safin et al., 2021; Malov et al., 2019).

Simulations are widely used in many areas of robotics, including design and construction of a robot, control algorithms development, education, demonstrations, etc. (Yakovlev et al., 2015). They allow creating virtual models of robots and a broad variety of environments (Sheh et al., 2014; Simakov et al., 2019), while targeting to achieve a high level of real-

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ism in behavior of these virtual models (Borisov et al., 2016). Simulations in robotics are employed for many reasons, including a typically very high cost of a real world errors relatively to virtual world errors (Shabalina et al., 2019) and the ease of reproducing test cases (Timperley et al., 2018).

Gazebo is a simulator that was designed specifically for simulating robots and their environment (Foundation, 2021). Gazebo is fully compatible with Robot Operating System (ROS) (Quigley et al., 2009), allowing to create and use robot models with ROS-based control systems without additional labor. Other popular robotics simulators include Webots (Prabhakar et al., 2020), VRep (recently known as CoppeliaSim (Yumbla et al., 2020)) and others. We selected the Gazebo simulator because of its compatibility with ROS and high-quality physics, which are the most important characteristics for our task of a highly manoeuvrable crawler robot modelling and model validation. There are several tools available in Gazebo that are suitable for the implementation of the running gear of robots, however, most of them are intended for simulating wheeled or walking robots. Since there is no ready-made template solution for simulating active tracks, several different home-made tool-based approximations were previously used by researchers to simulate tracks of a crawler robot while employing conventional wheeled robot approaches.

In this paper we present a new method of modelling a crawler using geared pseudo wheels. The approach demonstrated a stable behaviour and an acceptable performance in terms of a CPU and memory load, which were indirectly measured via real time factor (RTF) of Gazebo simulator while using RTF=1 for the real robot as a base benchmark. Moreover, the resulting model performance parameters became close to the real Servosila Engineer robot parameters relatively to its previous models.

The rest of the paper is organized as follows. Section 2 overviews existing solutions, including the ones that were previously proposed by out team. Section 3 describes our new approach for the gear wheels based simulation of crawlers and Section 4 presents a comparison of the real robot and four different models. Finally, we conclude in Section 5.

2 EXISTING SOLUTIONS

At the time of writing this paper, there exists a number of methods to simulate crawler robots' chassis. These methods could be divided into three main groups: a brute-force generic acceleration, a wheel-based approach and a segmental tracks approach. Each approach has particular advantages and disadvantages, which are described in this section.

2.1 Brute-force Generic Acceleration

A brute acceleration force is applied directly to a robot chassis or to robot tracks, while a mobile part of the chassis (tracks) is modelled with skid runners or passive fixed wheels. This method is the most productive in terms of CPU and memory use (and thus RTF), and is easy to implement. Yet, its correspondence to a real physical robot model is questionable. This approach could allow to achieve a relatively realistic behavior of a robot model solely on a flat surface, but in other cases the behavior of the model does not correspond to the real robot (Pecka et al., 2017).

2.2 Wheel-based Approaches

This approach uses standard fixed wheels (Shabalina et al., 2018) in order to approximate a robot track. The wheels could be visible when they completely replace a rubber or a metal track, or they could be presented in a virtual form. In the virtual form, the user sees a visualization of a track while wheels, often referred as pseudo-wheels, are responsible for physical interaction with environment. In both cases, wheels are arranged in such a way that allows repeating a shape of real robot tracks. Moreover, wheels could partially overlap with each other while the physics of such collisions between the wheels is ignored. We distinguish two most popular wheel-based approaches as a single line of large fixed wheels (further refereed as a line-of-wheels) and a large number of fixed wheels that are distributed along a track (further refereed as a circumferential wheels).

Line-of-wheels approach (LWA) forms a structure where all wheels are located on a single straight line. These are standard fixed wheels of a diameter, which is equal to a height of a track. Wheels could virtually overlap each other without considering the inter-wheel collision physics (Figure 1) or could be arranged without physical intersections (Figure 2, (Pecka et al., 2017)).

LWAs, especially with a small number of large size wheels, look attractive in terms of simulation performance (CPU, memory, RTF) and development complexity. Yet, these approaches are suitable only for a flat surface, since a robot can unnaturally get stuck while climbing an obstacle if a sharp part of the obstacle gets between wheels (Sokolov et al., 2016) (Figure 4, 5). Increasing a number of intersecting wheels partially solves the problem (Pecka et al., 2017), however, more wheels inevitably reduce per-

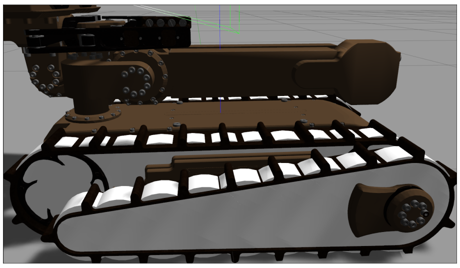


Figure 1: Line-of-wheels approach with large virtual self-intersecting wheels (one of optional models constructed by the authors).

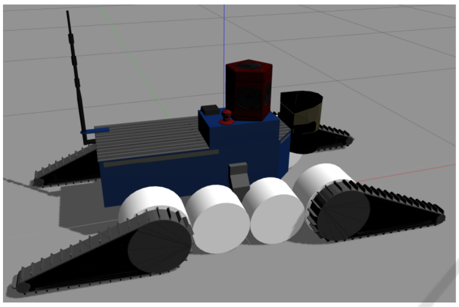


Figure 2: Line-of-wheels approach with large real non-intersecting wheels (Pecka et al., 2017).

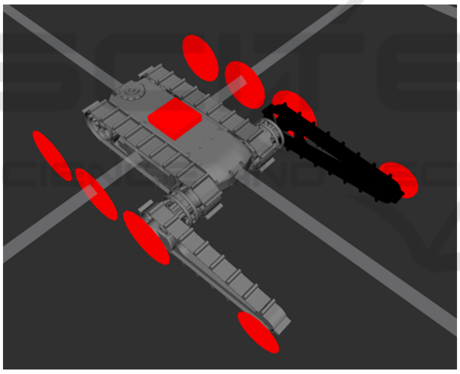


Figure 3: Line-of-wheels approach with large virtual non-intersecting wheels with broad spaces between wheels (Sokolov et al., 2016).

formance, while the robot could still get stuck in a similar way, especially if it has a large mass.

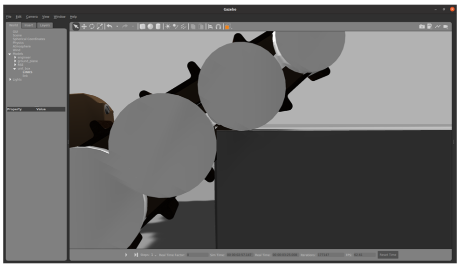


Figure 4: LWA: A robot with large wheels gets stuck on a sharp corner of an obstacle.

Figure 5: CWA: a robot with small wheels gets stuck on a sharp corner of an obstacle.

Circumferential wheels approach (CWA) employs a large number of wheels that are placed along a perimeter of each track. The wheels have typically equal radius, which is significantly smaller than a height of tracks (Figure 6, 7). Such implementation achieves greater similarity in terms of geometry without intersecting wheels, but suffers from poor simulation performance associated with a large number of wheels. It is also worth mentioning hybrid versions, which use wheels of varying sizes in order to simulate a track (Figure 8).

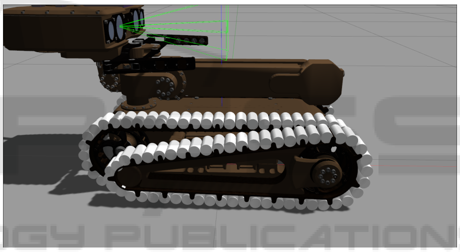


Figure 6: CWA: tightly packed small non-intersecting wheels.

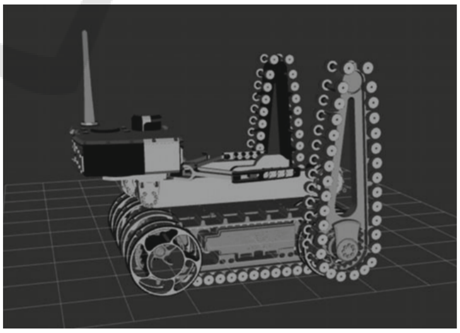


Figure 7: CWA: small wheels with spaces in-between (Moskvin and Lavrenov, 2020).

2.3 Segmental Tracks

In this approach a track is assembled from rectangular or more complex shape segments, which are linked into a single chain by passive connections. he segments are stretched between at least two active rollers

(a) The real robot.

(b) A hybrid model of the robot in USARSim.

Figure 8: Talon crawler robot and it's model in USAR-Sim (Pepper et al., 2007).

from front and rear edges of a chassis and are held there using simulation physics or programmatically (Figure 9, 10). Additional passive or active rollers could be employed. Theoretically, such approach is the most reliable since it has an almost absolute geometric similarity, but, as a rule, it has a low productivity (Morita et al., 2018).

Considering the three approaches descried in this section, segmental tracks seem to be the most attractive for developing a crawler model in terms of similarity with a real robot since geometrically such implementation is the closest one to real tracks. However, low computational efficiency and low stability of this method make it unsatisfactory in practice (Sokolov et al., 2017; Kenwright and Morgan, 2012). Moreover, a robot with segmental tracks can also get stuck if a sufficiently sharp or small obstacle gets into a gap between track's segments

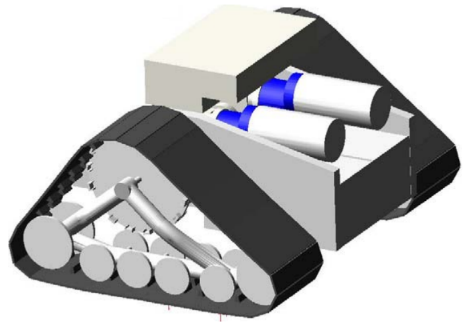


Figure 9: Dynamic segmental tracks (Morita et al., 2018).

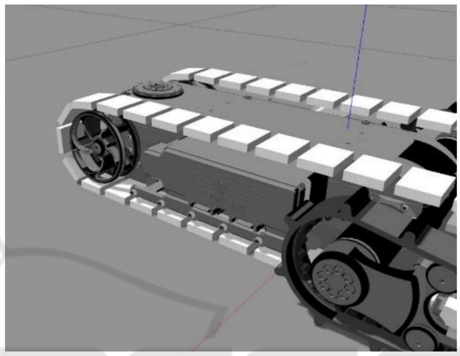


Figure 10: Another implementation of segmantal tracks (Sokolov et al., 2017).

3 GEAR WHEELS BASED SIMULATION

We propose a new approach of a track modelling, which employs virtual gear wheels. Using such modification for LWA with large wheels could drastically solve the problem of getting stuck without sacrificing computational performance. We added lugs to a standard fixed wheel model, which are similar to those found on most real tracks. We refer such wheel as a gear wheel although it does not actually repeat a shape of a real gear (Figure 11).

As a starting point, we used a model of Servosila Engineer robot that was previously created by our team (Moskvin and Lavrenov, 2020) using CWA with small wheels, referred as pseudo-wheels. This model is demonstrated in Figure 7: the white circles are the pseudo-wheels (which are standard fixed wheels) and the black track is just a texture that forms a visual rubber track without any physics behind it. The actual physics of interaction with an environment (supporting plane) is delegated to the pseudo-wheels, which could be switched on/off for visualization. Next, all small pseudo-wheels were replaced by the new gear

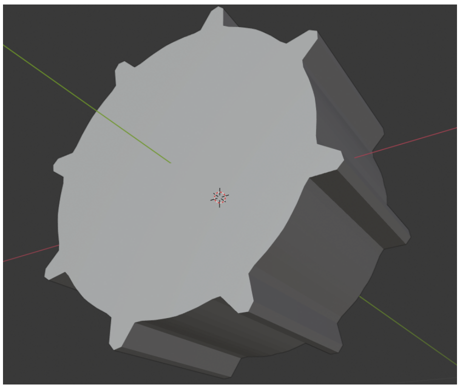


Figure 11: Single gear wheel.

wheels with of approximately the same size (Figure 12).

For virtual testing of the new track model concept as well as for further comparative testing with other models we employed a random step environment (RSE), or random stepfield, which provides a good approximation of an uneven terrain (Jacoff et al., 2008). The new model achieved a declared by the manufacturer passability and got rid of the issue of seizure while climbing sharp edges of obstacles.

Unfortunately, the obtained RTF of the new model is not acceptable for a comfortable use of the model (Abbyasov et al., 2020). In the attempt to improve the model performance in the terms of RTF, we constructed another model that uses LWA with large gear wheels, which have a similar size and shape of protrusions to those of the real robot (Figure 13).

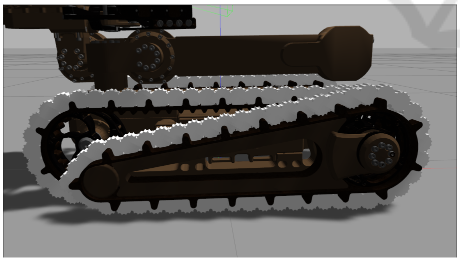


Figure 12: Servosila Engineer robot model with CWA and small gear wheels.

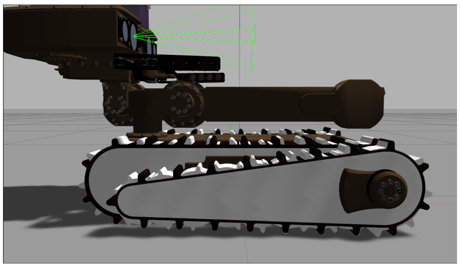


Figure 13: Servosila Engineer robot model with LWA and large gear wheels.

Initial angular position of each wheel is calculated using the following relationship:

$$x = \theta/3 * n \quad (1)$$

where θ is an angle between two nearest segments drawn from a center of a wheel to a most distant (from the wheel center) point of a protrusion on the wheel (Figure 14); n is a counting number of a wheel - the counting starts from n=1 for a last (rearmost) wheel of each side of a simulated track.

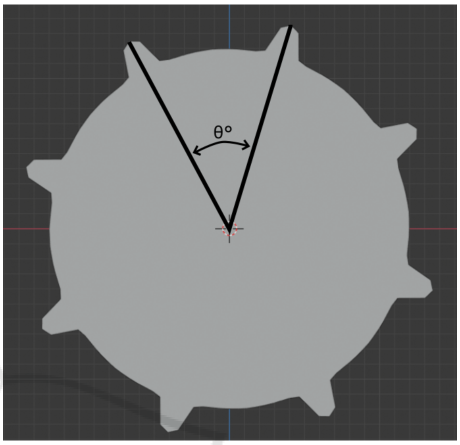


Figure 14: Angle θ for an initial position calculation.

This approach allows avoiding an excessive unnatural shaking of the robot in motion due to a synchronous rotation of the non-round wheels. The radius of a wheel for odometrical data processing is set as a radius of a circumscribed circle for the gear wheel.

Gear wheels allowed to (almost completely) solve the problem of a crawler seizure while climbing sharp edges of obstacles that is caused by standard fixed wheels. The wheels protrusions allow a robot model, similarly a real crawler robot, to ”cling” to an obstacle surface at climbing and to achieve manoeuvrability characteristics that closely correspond to the real robot. However, due to their shape, the protrusions complicate odometry and create a robot shaking effect while moving on a flat surface. Nevertheless, the shaking effect corresponds to a real crawler robot shaking, which brings the model behavior closer to the real robot.

The LWA large wheels implementation also showed a sufficient manoeuvrability and climbing abilities without seizure. Comparatively to the CWA small wheels model, the RTF was significantly improved achieving 0.6 for static cases and 0.5 for dynamic cases when the new robot model travels through a RSE. Moreover, the LWA large wheels model is featured with a high degree of geometry similarity with the real robot.

4 COMPARISON OF MODELS

For virtual testing a number of typical for urban search and rescue environments were constructed in a form of a random step environment and four different models of Servosila Engineer were validated with the same settings in a teleoperational mode.

Table 1: Real robot dynamic characteristics.

Characteristic	Real robot	Declared by the manufacturer
Max. linear velocity	0,4 m/s[a]	1,39 m/s
Max. rotation velocity	8,5 rpm	-
Max. elevation angle	45°	35°
Stopping distance with max. linear velocity	1 cm	-

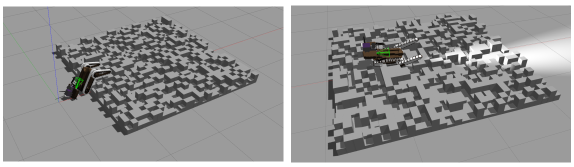
[a] We assume the velocity is limited by a low-level controller.

4.1 Virtual Testing

Virtual tests of the models were carried out using typical obstacles of RSE, 20 runs per each robot and environment. The results are presented in Table 2.

Table 2: Obstacle tests.

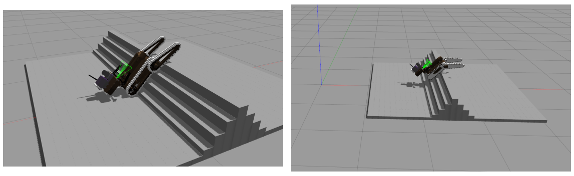
Obstacle type	Percentage of successful runs (%)		
	CWA model	LWA model	Model with gear wheels
Random RSE	0	15%	100%
Horizontal barrier	0	10%	100%
Diagonal barrier	0	0	40%



(a) CWA standard fixed wheels. (b) CWA gear wheels.

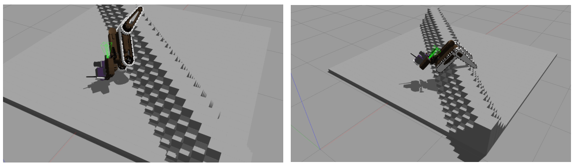
Figure 15: Robot models on a randomly generated RSE.

The dynamic characteristics and passable obstacle height of the new and previous robot models, and the real robot were measured with virtual and real environment tests that were performed in a teleoperational mode (Figure 18 a, b; Figure 19 a, b). The results are presented in Table 3.



(a) CWA standard fixed wheels. (b) CWA gear wheels.

Figure 16: Robot models on RSE with a horizontal barrier.

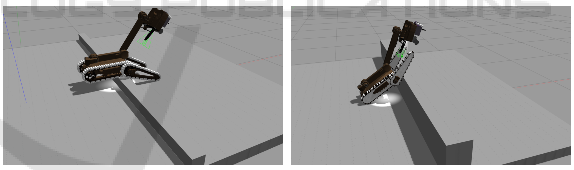


(a) CWA standard fixed wheels. (b) CWA gear wheels.

Figure 17: Robot models on RSE with diagonal barrier.

(a) Real robot overcomes 20 cm barrier (begin). (b) Real robot overcomes 20 cm barrier (end).

Figure 18: Real robot on RSE with horizontal barrier.



(a) Robot model with CWA overcomes 10 cm barrier. (b) Robot model with gear LWA overcomes 20 cm barrier.

Figure 19: Robot models on RSE with horizontal barriers.

4.1.1 Results

The real robot parameters in Table 1 and performance in RTF were used as a benchmark for the virtual tests, which were described in the previous subsection. The results of the tests are presented in Tables 2 and 3.

Virtual testing revealed the following qualitative characteristics of the proposed gear wheel based approaches:

Table 3: Comparison of models and real robot.

Model	Max velocity	Max obstacle height[b]	Max angular velocity	Max braking distance	Acceleration	RTF
Real robot	0,4 m/s[c]	20 cm[d]	8,5 rpm	0,02 m	0,2 m/s^2	1.0
CWA, small standard fixed wheels	0,5 m/s	10 cm	4 rpm	1 m	0,1 m/s^2	0.2
LWA, large standard fixed wheels	0,4 m/s	15 cm	2 rpm	1 m	0,1 m/s^2	0.65
CWA, small gear wheels	0,4 m/s	20 cm[d]	2 rpm	0,5 m	0,1 m/s^2	0.18
LWA, large gear wheels	0,4 m/s	20 cm[d]	4 rpm	0,3 m	0,2 m/s^2	0.65

[b] A parallelepiped obstacle on a flat surface. The robot moves without rocking or any other tricks that allow to overcome a higher obstacle.
[c] Presumably the velocity is limited programmatically on a low-level. In the robot specifications, the manufacturer announces a maximal velocity of 5 km/h, which is 1,39 m/s
[d] Technically, it is possible to overcome a height of up to 60 cm, but this requires to employ certain movement patterns and balance control, which is very difficult in a teleoperational mode.

- The models correspondence with dynamics and geometry of the real robot is significantly higher than for any previously developed standard fixed wheels solutions. Yet, a model that could be constructed using segmental method might allow achieving even a better correspondence.
- The robot seizure problem while climbing sharp edges of obstacles is eliminated.
- The performance in terms of Gazebo simulation RTF is acceptable for LWA large gear wheels, while the implementation for CWA small gear wheels should be improved.

5 CONCLUSIONS

While modelling of wheeled mobile robots is well-studied and typically does not imply significant difficulties, a realistic modelling of a crawler robot is a complicated task. This paper discussed several existing approaches for a crawler robot modelling in Gazebo simulator and presented a new approach, which approximates each crawler with a set of gear wheels. We compared several approaches for Servosila Engineer crawler robot modelling in Gazebo by their climbing capabilities, velocity, acceleration and real time factor parameters with regard to the real robot. The real robot parameters and performance were used as a benchmark for the tests. For virtual testing a number of typical for urban search and rescue environments were constructed and four different models of Servosila Engineer were validated with the same settings in a teleoperational mode. The comparison results demonstrated that two new gear wheels based approaches are feasible in terms of CPU load and provide a better approximation to the real robot performance. Moreover, they successfully eliminated an issue of a crawler seizure while climbing sharp edges of obstacles, which is typical for pseudo-wheels based approaches.

As a part of our future work we plan to take a deeper look at the physics of the model relatively to the real robot and to consider typical issues of a crawler robot slipping and turning.

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REFERENCES

Abbyasov, B., Lavrenov, R., Zakiev, A., Yakovlev, K., Svinin, M., and Magid, E. (2020). Automatic tool for gazebo world construction: from a grayscale image to a 3d solid model. In *2020 IEEE International Conference on Robotics and Automation (ICRA)*, pages 7226–7232. IEEE.

Borisov, A., Kuznetsov, S., Mamaev, I., and Tenenev, V. (2016). Describing the motion of a body with an elliptical cross section in a viscous uncompressible fluid by model equations reconstructed from data processing. *Technical Physics Letters*, 42(9):886–890.

Foundation, O. S. R. (2021). *Gazebo official site*. http://gazebosim.org/.

Jacoff, A., Downs, A., Virts, A., and Messina, E. (2008). Stepfield pallets: Repeatable terrain for evaluating robot mobility. In *Proceedings of the 8th Workshop on Performance Metrics for Intelligent Systems*, pages 29–34.

Kenwright, B. and Morgan, G. (2012). Practical introduction to rigid body linear complementary problem (lcp) constraint solvers. In *Algorithmic and Architectural Gaming Design: Implementation and Development*, pages 159–201. IGI Global.

Malov, D., Edemskii, A., and Saveliev, A. (2019). Proactive localization system as a part of a cyberphysical smart environment. In *2019 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM)*, pages 1–5. IEEE.

Morita, S., Hiramatsu, T., Niccolini, M., Argiolas, A., and Ragaglia, M. (2018). Kinematic track modelling for fast multiple body dynamics simulation of tracked vehicle robot. In *2018 23rd International Conference on Methods & Models in Automation & Robotics (MMAR)*, pages 910–915. IEEE.

Moskvin, I. and Lavrenov, R. (2020). Modeling tracks and controller for servosila engineer robot. In *Proceedings of 14th International Conference on Electromechanics and Robotics "Zavalishin's Readings"*, pages 411–422. Springer.

Pecka, M., Zimmermann, K., and Svoboda, T. (2017). Fast simulation of vehicles with non-deformable tracks. In *2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 6414–6419. IEEE.

Pepper, C., Balakirsky, S., and Scrapper, C. (2007). Robot simulation physics validation. In *Proceedings of the 2007 Workshop on Performance Metrics for Intelligent Systems*, pages 97–104.

Prabhakar, M., Paulraj, V., Dhanraj, J. A., Nagarajan, S., Kannappan, D. A. K., and Hariharan, A. (2020). Design and simulation of an automated guided vehicle through webots for isolated covid-19 patients in hospitals. In *2020 IEEE 4th Conference on Information & Communication Technology (CICT)*, pages 1–5. IEEE.

Quigley, M., Conley, K., Gerkey, B., Faust, J., Foote, T., Leibs, J., Wheeler, R., Ng, A. Y., et al. (2009). Ros: an open-source robot operating system. In *ICRA workshop on open source software*, volume 3, page 5. Kobe, Japan.

Safin, R., Lavrenov, R., and Martínez-García, E. A. (2021). Evaluation of visual slam methods in usar applications using ros/gazebo simulation. In *Proceedings of 15th International Conference on Electromechanics and Robotics" Zavalishin's Readings"*, pages 371–382. Springer.

Shabalina, K., Sagitov, A., and Magid, E. (2018). Comparative analysis of mobile robot wheels design. In *2018 11th International Conference on Developments in esystems Engineering (dese)*, pages 175–179. IEEE.

Shabalina, K., Sagitov, A., Su, K.-L., Hsia, K.-H., and Magid, E. (2019). Avrora unior car-like robot in gazebo environment. In *International Conference on Artificial Life and Robotics*, pages 116–119.

Sheh, R., Jacoff, A., Virts, A.-M., Kimura, T., Pellenz, J., Schwertfeger, S., and Suthakorn, J. (2014). Advancing the state of urban search and rescue robotics through the robocuprescue robot league competition. In *Field and service robotics*, pages 127–142. Springer.

Simakov, N., Lavrenov, R., Zakiev, A., Safin, R., and Martínez-García, E. A. (2019). Modeling usar maps for the collection of information on the state of the environment. In *2019 12th International Conference on Developments in eSystems Engineering (DeSE)*, pages 918–923. IEEE.

Sokolov, M., Afanasyev, I., Lavrenov, R., Sagitov, A., Sabirova, L., and Magid, E. (2017). Modelling a crawler-type ugv for urban search and rescue in gazebo environment. In *Artificial Life and Robotics (ICAROB 2017), International Conference on*, pages 360–362.

Sokolov, M., Lavrenov, R., Gabdullin, A., Afanasyev, I., and Magid, E. (2016). 3d modelling and simulation of a crawler robot in ros/gazebo. In *Proceedings of the 4th International Conference on Control, Mechatronics and Automation*, pages 61–65.

Timperley, C. S., Afzal, A., Katz, D. S., Hernandez, J. M., and Le Goues, C. (2018). Crashing simulated planes is cheap: Can simulation detect robotics bugs early? In *2018 IEEE 11th International Conference on Software Testing, Verification and Validation (ICST)*, pages 331–342. IEEE.

Yakovlev, K., Baskin, E., and Hramoin, I. (2015). Grid-based angle-constrained path planning. In *Joint German/Austrian Conference on Artificial Intelligence (Künstliche Intelligenz)*, pages 208–221. Springer.

Yumbla, F., Yumbla, E. Q., and Moon, H. (2020). The bioloid gp robot with different configurations for simulation in v-rep controlled by the robot operating system (ros). In *2020 6th International Conference on Control, Automation and Robotics (ICCAR)*, pages 54–58. IEEE.