# Robotics Simulation Environment in an Educational Institution According to Demands of Industry 4.0

Károly SZÉLL
Óbuda University, Alba Regia Technical Faculty, Budai út 45. H-8000 Székesfehérvár, Hungary
szell.karoly@amk.uni-obuda.hu

***Abstract*—Simulation is an inevitable step for education and prototyping of robotics. The simulator allows you to test ideas in a secure and verifiable environment, preventing robot cells and the sorrounding systems from being damaged. This paper describes a robotics simulation environment that fulfils the requirements of educational and research work.**

***Index Terms*—Robotics, Simulation, Industry 4.0, Smart Manufacturing, AGV**

## I. Introduction

Starting from the discovery of planets, industrial applications [1] to cleaning households, the application of robotics is diversified. In the simulation of robotics dynamics, informatics, control theory, sensors and actuators have to be combined, which makes modelling a real challenge [2].

With the development of processors and 3D graphics tools the possibilities in robotics simulations dramatically changed. The models may be more complex in computer simulations, and we can run real-time simulations connected to hardware (HIL) and control embedded systems from the framework.

We can compile a simulator from various open-source robotics libraries, but the architecture of the software environment play a decisive role in determining how these elements affect each other and how the overall efficiency of the system evolves. Robust simulation systems require versatility and scalability.

A robot simulator needs to provide a variety of tools at one time while the abstraction of the underlying systems. In addition, flexible control is required (portability and maintainability), generalized and scalable to different models.

Section II. discusses available open-source robotics simulation environments. Section III. introduces the main elements of V-REP. Section IV. demonstrates educational and training possibilities via V-REP. Section V. presents industrial application of V-REP.

## II. Simulation Environments

In the era of industry 4.0 the tools for digitalisation gain greater relevance [3]. For robotics simulation we can find various software environments like Open HRP [4], Webots [5], ARGoS, Gazebo or V-REP. Due to their educational relevance the paper discusses the latter three.

**ARGoS** (Autonomous Robots Go Swarming) is an open-source multi-robot simulator (the main user interface can be seen in Fig. 1). The software is designed to simulate swarm robotics. It is both effective (performance) and flexible (customizable). We have the possibility to divide the simulated space into sub-spaces that are handled by parallel running physics engines. The architecture is designed to optimize the use of multi-core processors [6].

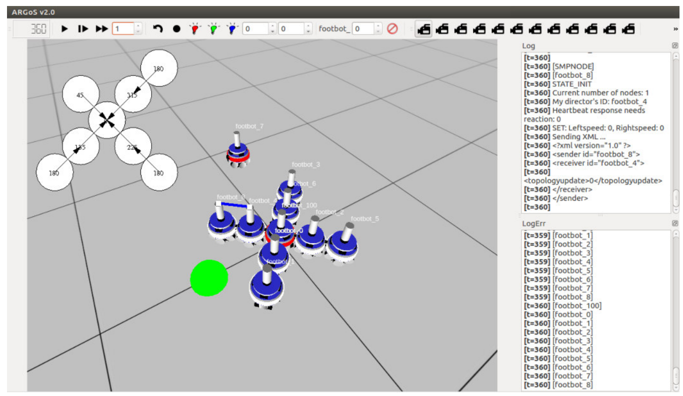

Figure 1. ARGoS[1]

**Gazebo** is a multirobot simulation, open source software environment capable of visualizing data, simulating remote environments, and supporting decryption of blackbox systems (the main user interface can be seen in Fig. 2). Gazebo is made in collaboration with Player and Stage projects [7]–[9].

Player and Stage projects started in 2001, popular in universities and industry as well. Player is a network device server, while Stage is a simulator for mobile robotics in 2 dimensions. The complement of the projects is the Gazebo as an outdoor simulator [10].

Gazebo was motivated by the spread of robotic vehicles in outdoor applications. Although the Stage is suitable for simulating interactions between indoor robots, there is a need for a simulator for modeling an outdoor environment where modeling of sensor feedback can be realistically modeled. That is why Gazebo has been developed to reproduce the dynamic environment with which a robot can meet in an outdoor environment. Based on the principles set by Player and Stage, Gazebo is open source. Thus, the Gazebo community is still active today to continuously develop the environment. This is an efficient, scalable and simple software environment that can be used for education as well.

[1]http://iridia.ulb.ac.be/supp/IridiaSupp2017-008/index.html

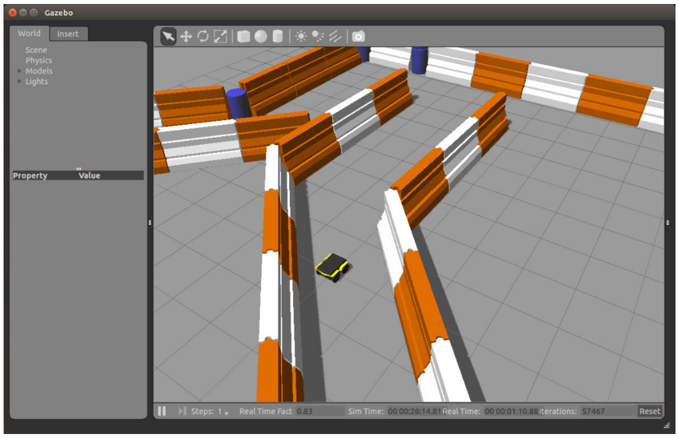

Figure 2. Gazebo[2]

**V-REP** (Virtual Robot Experimentation Platform) [11] (the main user interface can be seen in Fig. 3) is a versatile and scalable general purpose simulation framework. This is a portable and flexible framework that allows direct control of different control techniques. By reducing the complexity of the simulation model, simulations and simulation models have become more accessible to a much more comfortable community. Further improvements include built-in functionalities, as well as a variety of programming options [2].

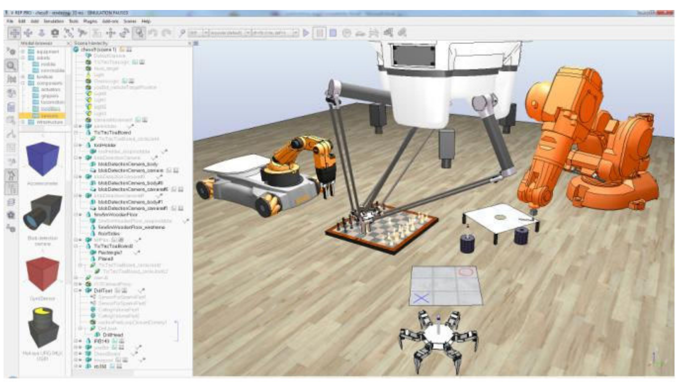

Figure 3. V-REP[3]

Main advantages of the three simulation environments based on speed, model detail and available features [12]:

- **V-REP** is very rich in features, includes editor for scenes and models, and many built-in models. It is available for educational purposes for free.
- **ARGoS** is a special option for swarm robotics.
- **Gazebo** is an intermediate solution between V-REP and ARGoS.

V-REP is the most complex of them. However, it offers a number of useful features, so it is an excellent choice for detailed and good looking simulations running on high performance machines. There are several types of physical engines available, a comprehensive model library is available, the user can change the environment while simulating the environment, video recording is available and there is an excellent documentation. V-REP offers excellent optimization options to simplify the model's network, which means that computing resource requirements are relatively easy to reduce without using third-party 3D modeling software. In addition, V-REP automatically generates new threads for multiple CPU core so that it can reach the full CPU resource if needed [12].

Based on these advantages the paper discusses the application of V-REP in the necxt sections.

## III. V-REP

V-REP is easy to learn, supported by tutorial projects. The main simulation loop is a simple Lua script ("main script") [13]. The user can choose from the following programming techniques:

- Embedded scripts (Lua)
- Add-ons
- Plug-ins
- Remote API clients
- ROS nodes [14]
- BlueZero nodes

Controllers can be written in C/C++, Python, Java, Lua, Matlab or Octave.

The V-REP simulation contains several objects that are assembled in a tree-like hierarchy. The following types are supported:

- Joints
  Link two or more elements. They can be in force mode or inverse kinematics mode.
- Shapes
  V-REP uses meshes of triangles for visualisation and rigid body simulation.
- Proximity sensors [15]
- Vision sensors
  Integrated filtering and image processing features allow complex filters to be created.
- Force sensors
- Graphs
- Cameras
- Lights
  Directly affect cameras and vision sensors.
- Paths
  They allow definition of complex spatial movements, such as for controlling a welding robot to move along a certain track.
- Dummies
- Mills
  Customizable convex volume elements that simulate cutting operations such as milling, laser cutting, etc.

Objects of the scene are seldom used by themselves, they work with other objects. V-REP offers a number of computing

[2] http://www.clearpathrobotics.com/assets/guides/jackal/_images/gazebo-jackal-race.png

[3] https://ai2-s2-public.s3.amazonaws.com/figures/2017-08-08/b127edeb5bb407920e3fc8315f574bdf7351758b/1-Figure1-1.png

modules that can work directly on one or more objects. The following are the most important computing modules:

- Kinematics module
  Performs forward and inverse kinematics calculations for branched or closed mechanisms as well [16].
- Dynamics module
  Performs rigid body dynamics via Bullet Physics Library [17], Open Dynamics Engine [18], Vortex Dynamics [19] or Newton Dynamics [20].
- Collision detection module [21]
- Mesh-mesh distance calculation module
- Path/motion planning module [22]

## IV. Education

Practical experience is always a pivotal point in university studies. To raise a real industrial environment within the walls of the university is not only expensive but also can be dangerous or impossible (depending on the university's capabilities, possibilities) [23]. It is not avoidable but it can be well prepared and reduced to the lowest possible extent by the use of simulation environments like V-REP. Besides the classroom studies the digitalised environment can be used for home work, blended learning and e-learning purposes. It is actually the "digital twin" (based on Siemens terminology) of the represented industrial environment. In Fig. 4 a classroom modell of a sorting machine can be seen, while in Fig. 5 the V-REP modell can perform the same tasks.

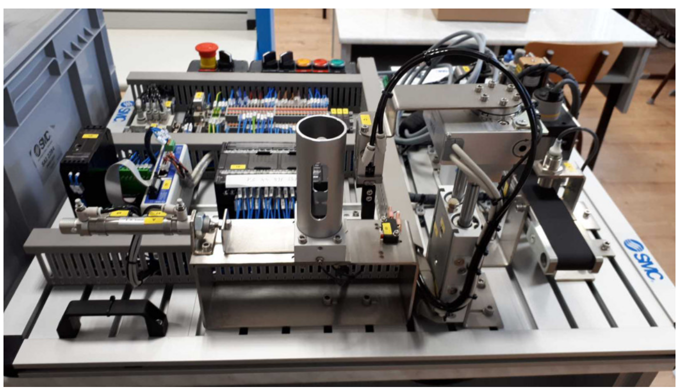

Figure 4. Sorting machine

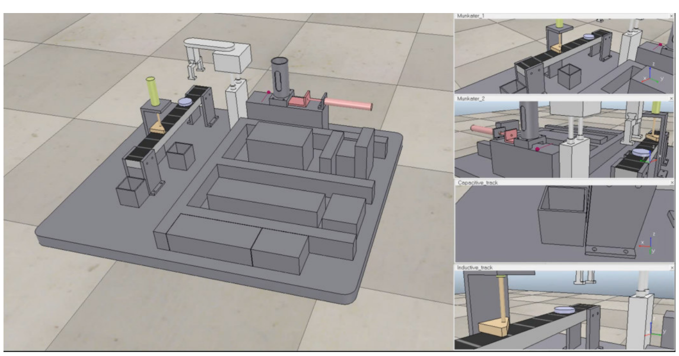

Figure 5. Simulation of sorting machine

The simulation environment amongst others gives the opportunity of education of the following subjects:

- robotics
- automation
- programming
- process planning
- control theory
- logistics [24]

## V. Industrial Application

V-REP provides a good starting point also for industrial research. Obuda University as a part of a consortium takes part in the development of an automated forklift fleet based on automated guided vehicles (AGVs). The main goals of the project:

- Raise automated intralogistics systems to a higher level of service by maximizing added value.
- Development of vehicles and navigation solutions suitable for both indoor and outdoor application.
- Comprehensive integration of the AGV system into the corporate IT environment: from ERP to onboard management.

The tasks of Obuda University in the consortium are the following:

- Development of vision based navigational strategies.
  Support for positioning.
  Identification and avoidance of obstacles, security features.
- Optimal sensorfusion in positioning.
  Selection of parallel sensor systems.
  Development of an optimal filtering algorithm.
  Support for outdoor and indoor navigation capabilities.

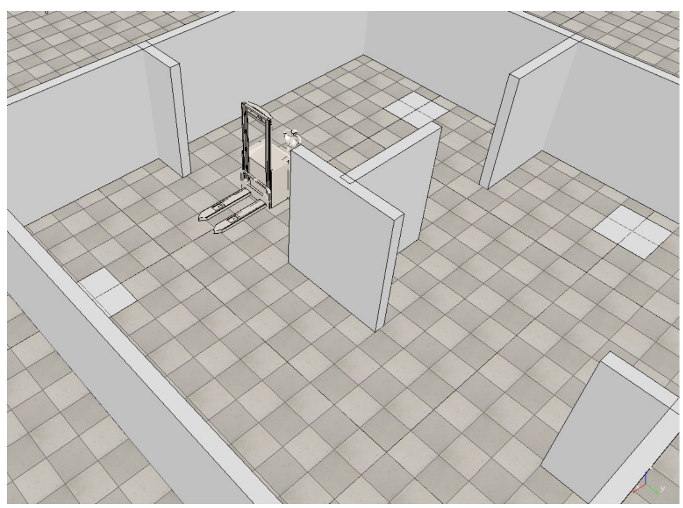

Figure 6. Layout for AGV simulation

## VI. Conclusion

V-REP provides a wide range of possible applications and therefore it is suitable for univerity studies and research activities:

- fast algorithm development
- system verification
- rapid prototyping
- safety double-checking
- remote monitoring systems
- robotics related training and education
- hardware control
- factory automation simulation

Several projects have been developed both for educational and industrial purposes.

## VII. Acknowledgement

The author wish to thank the support to the Arconic Foundation.

## References


[1] J. Cselényi, B. Illés, and L. Rádai, "Control strategy of the palette movements on the storing-levels in block-storing multi-level car parking systems," in *Miskolcer Gespräche 2003, Die neuesten Ergebnisse auf dem Gebiet Fördertechnik und Logistik"*, 2003, pp. 169–174.

[2] E. Rohmer, S. P. N. Singh, and M. Freese, "V-REP: a Versatile and Scalable Robot Simulation Framework," in *Proc. of The International Conference on Intelligent Robots and Systems (IROS)*, 2013.

[3] G. Györök and B. Beszédes, "Fault-tolerant software solutions in micro-controller based systems," in *AIS 2017 - 12th International Symposium on Applied Informatics and Related Areas*, 2017, pp. 7–12.

[4] H. Hirukawa, F. Kanehiro, and S. Kajita, "OpenHRP: Open Architecture Humanoid Robotics Platform," in *Robotics Research*, R. A. Jarvis and A. Zelinsky, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2003, vol. 6, pp. 99–112.

[5] O. Michel, "Cyberbotics Ltd. Webots TM : Professional Mobile Robot Simulation," *Int. Journal of Advanced Robotic Systems*, vol. 1, pp. 39–42, 2004.

[6] C. Pinciroli, V. Trianni, R. OGrady, G. Pini, A. Brutschy, M. Brambilla, N. Mathews, E. Ferrante, G. Di Caro, F. Ducatelle, M. Birattari, L. M. Gambardella, and M. Dorigo, "ARGoS: a modular, parallel, multi-engine simulator for multi-robot systems," *Swarm Intelligence*, vol. 6, no. 4, pp. 271–295, Dec. 2012. [Online]. Available: http://link.springer.com/10.1007/s11721-012-0072-5

[7] R. T. Vaughan, B. P. Gerkey, and A. Howard, "On device abstractions for portable, reusable robot code," in *Proceedings 2003 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2003) (Cat. No.03CH37453)*, vol. 3, Oct. 2003, pp. 2421–2427 vol.3.

[8] B. P. Gerkey, R. T. Vaughan, and A. Howard, "The Player/Stage Project: Tools for Multi-Robot and Distributed Sensor Systems," in *In Proceedings of the 11th International Conference on Advanced Robotics*, 2003, pp. 317–323.

[9] B. P. Gerkey, R. T. Vaughan, K. Stoy, A. Howard, G. S. Sukhatme, and M. J. Mataric, "Most valuable player: a robot device server for distributed control," in *Proceedings 2001 IEEE/RSJ International Conference on Intelligent Robots and Systems. Expanding the Societal Role of Robotics in the the Next Millennium (Cat. No.01CH37180)*, vol. 3, 2001, pp. 1226–1231 vol.3.

[10] N. Koenig and A. Howard, "Design and use paradigms for gazebo, an open-source multi-robot simulator," vol. 3. IEEE, 2004, pp. 2149–2154. [Online]. Available: http://ieeexplore.ieee.org/document/1389727/

[11] "Coppelia Robotics V-REP: Create. Compose. Simulate. Any Robot. http://www.coppeliarobotics.com/." [Online]. Available: http://www.coppeliarobotics.com/

[12] "V-REP, Gazebo or ARGoS? A robot simulators comparison :: LENKASPACE ::." [Online]. Available: http://lenkaspace.net/tutorials/programming/robotSimulatorsComparison

[13] "The Programming Language Lua." [Online]. Available: https://www.lua.org/

[14] M. Quigley, B. Gerkey, K. Conley, J. Faust, T. Foote, J. Leibs, E. Berger, R. Wheeler, and A. Ng, "ROS: an open-source Robot Operating System," p. 6.

[15] F. Marc, O. Fumio, and M. Nobuto, "(11) Collision Detection, Distance Calculation and Proximity Sensor Simulation using Oriented Bounding Box Trees(Sensing and Data Fusion,Session: MA1-A)," 2004.

[16] C. W. Wampler, "Manipulator Inverse Kinematic Solutions Based on Vector Formulations and Damped Least-Squares Methods," *IEEE Transactions on Systems, Man, and Cybernetics*, vol. 16, no. 1, pp. 93–101, Jan. 1986.

[17] "Bullet Real-Time Physics Simulation | Home of Bullet and PyBullet: physics simulation for games, visual effects, robotics and reinforcement learning." [Online]. Available: https://pybullet.org/wordpress/

[18] "Open Dynamics Engine - home." [Online]. Available: http://www.ode.org/

[19] "Simulators and Simulation Software." [Online]. Available: https://www.cm-labs.com/

[20] "Newton Dynamics About Newton." [Online]. Available: http://newtondynamics.com/forum/newton.php

[21] S. Gottschalk, M. C. Lin, and D. Manocha, "OBBTree: a hierarchical structure for rapid interference detection." ACM Press, 1996, pp. 171–180. [Online]. Available: http://portal.acm.org/citation.cfm?doid=237170.237244

[22] J. Kuffner and S. LaValle, "RRT-connect: An efficient approach to single-query path planning," vol. 2. IEEE, 2000, pp. 995–1001. [Online]. Available: http://ieeexplore.ieee.org/document/844730/

[23] G. Györök and B. Beszédes, "Adaptive optocoupler degradation compensation in isolated feedback loops," in *IEEE 12th International Symposium on Applied Computational Intelligence and Informatics (SACI 2018)*, 2018, pp. 167–172.

[24] J. Cselényi, B. Illés, and L. Rádai, "Tömbtárolásos automatizált gépkocsiparkoló rendszerek tárolási szintjén történő mozgások irányítási stratégiájának kiegészítése a rendszer blokkolódása esetén," in *Doktoranduszok Fóruma : Miskolci Egyetem Gépészmérnöki Kar Szekciókiadványa*, 2003, pp. 212–218.