Trial on 3D Gaussian Splatting for Emulating Real-Life Learning Experiences in Undergraduate Educational Robotics

Arturo E. Cerón-López[1†*], Jason A. Castaño-López[2†], José G. Buenaventura-Carreón[1††], Oscar Cárdenas-Gómez[1††], Juan C. Hernández-Ríos[1††], José A. León-Navarro[1††], Max Pacheco-Ramírez[1††], Hortencia A. Ramírez-Vázquez[1††], Andrea M. Salcedo-Vázquez[1††]

Abstract— **Educational Robotics (ER) focuses on developing tools to enhance learning experiences. Simulators are recurrent in ER due to their convenience for substituting physical setups, and assist when teaching real robotics applications. However, one limitation is often the achievable level of realism. At Tec, students from the robotics major learn autonomous robots through an integration project. To expand the availability of the required test circuits, we developed a simulator featuring a photo-realistic 3DGS environment and a ROS2 interface.**

I. INTRODUCTION

Educational Robotics (ER) focuses on developing pedagogical tools and methodologies to enhance learning experiences in science and engineering. The objective is to make students engaged in exploration, hypothesis formulation, and experimentation, where they obtain feedback to allow mastering robotics concepts [1]. ER also promotes the development of critical thinking, problem-solving skills, and metacognitive abilities critical for innovation [2].

Simulators are recurrent in ER due to their convenience for substituting physical setups and for allowing remote teaching [3]. We think that they can also assist in teaching real 4D (dangerous, difficult, dirty & dull) robotics applications (e.g. infrastructure inspection [4], [5]). However, a limitation is often the achievable level of realism [6].

We propose leveraging state-of-art 3D scanning and rendering techniques that can assist in overcoming said limitation, particularly 3D Gaussian Splatting (3DGS) [7]. Due to 3DGS's efficient use of resources with respect to classical photogrammetry [8] and NeRF [9], its popularity grew explosively in less than a year from its initial publication. Latest updates include: SLAM [10], [11], 3D meshing [12], and physics integration [13]. This document describes how a simulator was developed and used to emulate the learning experiences, typically obtained when performing trials in a real environment for an undergraduate course on robotics.

II. METHODOLOGY

At Tec de Monterrey, students from the robotics major learn about control engineering, as well as classical and modern computer vision (CV) based on convolutional neural networks through a knowledge integration project. The goal of the project is to make a Puzzlebot® [14] move within a physical circuit by following a line, and enable it to make decisions based on traffic signs without human intervention [15]. The deliverable is a software with the control and CV techniques that allow the robot completing a circuit lap.

As an attempt on expanding the availability of testing environments while keeping similar learning experiences, we developed a proof-of-concept (PoC) simulator in Unity3D [16]. The PoC includes a 3DGS scene of the test circuit with traffic signs to try-out autonomous driving for the Puzzlebot®, and a communication interface for ROS2. The dataset for creating the 3DGS env. included images from a 4 min. Standard 1080p video taken by a GoPro HERO 10 Black at an illuminance range of 550 to 1500 lux. The 3DGS scene was generated utilizing NeRF Studio's gsplat [17] and default Splatfacto model with the suggested "Quality and Regularization" settings [18], post-processed to remove floating outliers using Blender 4.0 [19] (Fig. 1.a).

To validate the use of the simulator for learning the aforementioned robotics techniques, the software from two teams of students was used to control the robot in the simulator, and the performance was compared against real tests on the physical circuit. We avoided altering the teams' usage of coding tools and program logic for running on the virtual circuit to enable a 1-to-1 comparison against the real one. Finally, we assessed the quality of the simulated images.

III. FINDINGS

The validation test consisted on three trials: the first to confirm similar CV performance by detecting of the track line to be followed, and by detecting the pertinent traffic signs; the second to verify if a complete full lap of the given circuit can be run by the robot, while being driven by a PID controller aiming at the track line; and the third to assess the quality of the simulated images though color histograms.

Although parameters such as PID gains, image filter thresholds and ROIs needed adjustments due to the simplistic robot dynamics and camera model, we obtained positive results (Fig. 1.b): Both teams detected the track line and traffic signs at all times; one team ran a full lap without human intervention, while the other required limited assistance to complete a lap; and obtained an average of 50% overlap between HSV histograms from real and sim. images despite the

[1] School of Engineering and Science, Department of Computer Science, Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM) - Campus Monterrey, Ave. Eugenio Garza Sada 2501 Sur, Monterrey, NL, 64849, Mexico. * arturo.ceron[at]tec.mx

[2] Faculty of Engineering, Universidad Autónoma de Occidente,Colombia.

† Participants of the Google Explore CSR / LatinX in Computer Vision (LXCV) Research Workshop 2024.

†† With an equal degree of contribution in this study.

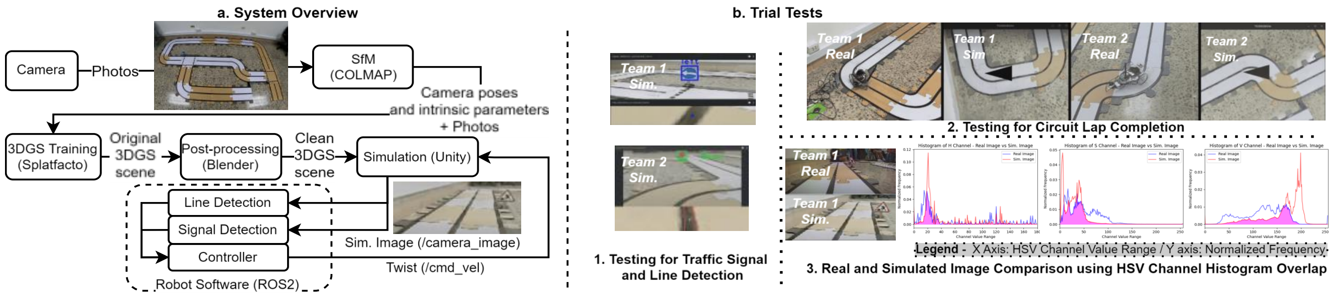

Fig. 1. (a) System Overview and (b) Trial Tests

background differences, suggesting photo-realism. Also, we identified further needs: sim. motor encoders to complement visual feedback, and dynamic assets like traffic lights.

The students' feedback suggests that the simulator accurately emulates the learning experience of the real environment. Similar issues were encountered such as light reflections on the track in certain zones of the circuit at certain camera poses, requiring solutions for assuring the correct detection of the track line, and for dealing with the natural imperfections of the track and traffic signs.

IV. CONCLUSIONS

From this experience, we think that the current PoC can become a valuable tool for learning and practicing Robot Vision (RV) techniques at the undergraduate level. Future work will enhance the simulator by leveraging the achievable simplicity of the 3DGS approach. To target more complex challenges beyond RV tasks, we will keep looking for different solutions to model the dynamics of the robot and the environment, to add system perturbations, and to enable sensors for practicing localization and navigation techniques such as Kalman Filters, SLAM and Bug algorithms.

Beyond extending the availability of test environments, we aim to study the simulator's impact on student engagement and learning outcomes when they are introduced to the techniques used in service robotics. We are also looking to potentially apply gamification techniques and the theory of mental flow [20] to enhance the educational experience further. Finally, we would like to assess the quality of the simulator through a usability study [21].

ACKNOWLEDGMENT

Special thanks for their cooperation to Profs. L. A. Muñoz Ubando & M. G. Martínez Guerrero, and the students F. Salas Porras, D. I. Vázquez Leal, J. E. Flores Martínez, D. N. Salinas Sánchez, A. G. Chapa Romero, D. G. Castañón Sarmiento, A. Carrizales Rodríguez, N. Hernández Osorio, D. A. Marín Martínez, & J. E. Soriano Campos.

REFERENCES

[1] S. Evripidou, K. Georgiou, L. Doitsidis, A. A. Amanatiadis, Z. Zinonos and S. A. Chatzichristofis, "Educational Robotics: Platforms, Competitions and Expected Learning Outcomes," in IEEE Access, vol. 8, pp. 219534-219562, 2020

[2] G. Georgiev, G. Hristov, P. Zahariev and D. Kinaneva, "Robotics in Education: A Comparative analysis of robotic platforms across educational levels," 2023 31st National Conference with International Participation (TELECOM), Sofia, Bulgaria, 2023, pp. 1-4

[3] A. S. Alves Gomes, J. F. Da Silva and L. R. De Lima Teixeira, "Educational Robotics in Times of Pandemic: Challenges and Possibilities," 2020 Latin American Robotics Symposium (LARS), 2020 Brazilian Symposium on Robotics (SBR) and 2020 Workshop on Robotics in Education (WRE), Natal, Brazil, 2020, pp. 1-5

[4] T. Ishida, Y. Matsui, S. Hirose, M. Guarnieri, P. Debenest, A. E. Ceron-Lopez, U. Imtiaz, "Improvements for the workability and scope of application of the bridge inspection robot BridgeView," (in Japanese) Proc. of the 74th Annual Scientific Meeting of the Japan Society of Civil Engineers, Shikoku, Japan, 2019, VI-152

[5] G. Jing, X. Qin, H. Wang and C. Deng, "Developments, challenges, and perspectives of railway inspection robots," in Automation in Construction, vol. 138, pp. 104242, 2022

[6] A. E. Ceron-Lopez, R. Ranjan and N. Koganti, "Realism Assessment for Synthetic Images in Robot Vision through Performance Characterization," 2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Kyoto, Japan, 2022, pp. 13089-13096

[7] B. Kerbl, G. Kopanas, T. Leimkühler, G. Drettakis, "3D Gaussian Splatting for Real-Time Radiance Field Rendering," in ACM Transactions on Graphics, vol. 42, issue 4, July 2023

[8] C. Griwodz et al., "Alicevision Meshroom," in Proc. of the 12th ACM Multimedia Systems Conference, pp. 241–247, Jun. 2021

[9] B. Mildenhall, P. P. Srinivasan, M. Tancik, J. T. Barron, R. Ramamoorthi, R. Ng,"NeRF: Representing scenes as neural radiance fields for view synthesis," in Comm. of the ACM,vol.65,issue 1,pp.99-106,2021

[10] N. Keetha et al., "SplaTAM: Splat Track & Map 3D Gaussians for Dense RGB-D SLAM", Proc. of the IEEE/CVF Conf. on Computer Vision and Pattern Recog., pp. 21357-21366, 2024

[11] Y. Fu, S. Liu, A. Kulkarni, J. Kautz, A. A. Efros, X. Wang, "COLMAP-Free 3D Gaussian Splatting", Proc. of the IEEE/CVF Conf. on Computer Vision and Pattern Recog., pp. 20796-20805, 2024

[12] A. Guédon, V. Lepetit, "SuGaR: Surface-Aligned Gaussian Splatting for Efficient 3D Mesh Reconstruction and High-Quality Mesh Rendering," Proc. of the IEEE/CVF Conf. on Computer Vision and Pattern Recog., pp. 5354-5363, 2024

[13] T. Xie et al., "PhysGaussian: Physics-Integrated 3D Gaussians for Generative Dynamics," Proc. of the IEEE/CVF Conf. on Computer Vision and Pattern Recog., pp. 4389-4398, 2024

[14] Manchester Robotics, "Puzzlebot," Retrieved June 27, 2024, URL: https://manchester-robotics.com/puzzlebot/

[15] L. A. Muñoz-Ubando, A. Amigud and E. Sirazitdinova, "Computer simulation and hands-on labs: A case study of teaching robotics and AI", Intl. J. of Mechanical Eng. Education, 2024

[16] A. Pranckevičius, "Gaussian Splatting playground in Unity," Retrieved June 27, 2024, URL: https://github.com/aras-p/UnityGaussianSplatting

[17] V. Ye and A. Kanazawa, "Mathematical Supplement for the gsplat Library," arXiv preprint arXiv:2312.02121, 2023, URL: https://arxiv.org/abs/2312.02121

[18] Nerfstudio Team, "Splatfacto," Retrieved June 27, 2024, URL: https://docs.nerf.studio/nerfology/methods/splat.html

[19] A. Carlier, et al., "3D GS Blender Addon," Retrieved June 27, 2024, URL: https://github.com/ReshotAI/gaussian-splatting-blender-addon

[20] S. W. Vann and A. A. Tawfik, "Flow Theory and Learning Experience Design in Gamified Learning Environments," in Learner and User Experience Research: An Introduction for the Field of Learning Design & Technology. EdTech Books, 2020

[21] J. Brooke, "SUS-A quick and dirty usability scale", Usability evaluation in industry, vol. 189, issue 194, pp. 4-7, 1996