HuNavSim: A ROS2 Human Navigation Simulator for Benchmarking Human-Aware Robot Navigation

Noé Pérez-Higueras[1] and Roberto Otero[1] and Fernando Caballero[2] and Luis Merino[1]

***Abstract*— This work presents the Human Navigation Simulator (*HuNavSim*), an open-source tool for the simulation of different human-agent navigation behaviors. The tool, programmed under the ROS2 framework, can be employed along with regular robotics simulators like Gazebo. The main goal is to ease the development and evaluation of human-aware robot navigation systems in simulation. To do so, *HuNavSim* includes a rich human navigation behavior and a complete set of metrics for navigation benchmarking.**

I. INTRODUCTION

The evaluation of the robot skills to navigate in scenarios shared with humans is becoming essential to conceive new service robots. The development of such mobile social robots poses two main problems: first, real experimentation is costly, difficult to perform except for limited scenarios, and human participants can be in danger, mainly in initial stages. Therefore, simulating realistic human navigation behaviors for the development of robot navigation techniques is necessary. And secondly, the evaluation not only requires to assess the navigation efficiency but also the safety and comfort of the people. This latter requirement is a human feeling which is difficult to quantify through mathematical equations. Thus, there is not a solid agreement in the research community about a proper set of metrics for human-aware navigation.

Most state-of-the-art simulation approaches are based on models of crowd movement to control the behavior of the simulated human agents. Whereas this is valid to obtain a collective behavior of the agents, it losses realism at the local level since the behavior of all individual agents is exactly the same for same scenarios. Here, we then propose a set of individual human behaviors related to reactions to the presence of a robot.

Another issue is the evaluation of the human-aware navigation through metrics. Each benchmarking tool usually presents its own set of metrics. While researching in new realistic "social" metrics is needed, the absence of common well-known metrics hinder the comparison of the social navigation techniques.

With the *HuNavSim* we aim at contributing to the solutions to the two problems mentioned: providing a set of different realistic behaviors for individual agents, and presenting a compilation of metrics employed in the literature. In a nutshell, we present the following contributions:

Fig. 1: Capture of HuNav agents in the Gazebo Simulator

i) An open-source and flexible simulation tool of human navigation under the ROS2 framework [1] that can be used along with different robotics simulators.
ii) A rich set of navigation behaviors of the human agents, which includes a set of realistic individual reactions to the presence of a robot.
iii) A complete compilation of metrics from the literature for the evaluation of human-aware navigation, which is configurable and extensible.
iv) A wrapper to use the tool along with the well-known Gazebo simulator used in Robotics (see Fig. 1).

II. RELATED WORK

Different simulators and benchmarking tools for human-aware navigation problem can be found in the literature. We provide a brief review of the related existing software and we highlight the differences and similarities with our approach.

PedSimROS[1] and *MengeROS*[2] [2] are crowd simulators integrated on deprecated versions of ROS1. Besides, they do not incorporate any option for navigation evaluation.

More recent, advanced and ambitious tools are *CrowdBot*[3] [3] and *SEAN (Social Environment for Autonomous Navigation)* [4] [4], [5]. They share similar features. Both are based on the game engine Unity and ROS1; and both aim at becoming the standard for evaluating robot navigation in populated environments. In contrast to them, *HuNavSim* provides a more flexible approach that allows to use the

---

[1] Noé Pérez-Higueras, Roberto Otero and Luis Merino are with School of Engineering, Pablo de Olavide University, Crta. Utrera km 1, Seville, Spain `noeperez@upo.es, lmercab@upo.es`

[2] Fernando Caballero is with the Department of system Engineering and Automation, University of Seville, Camino de los Descubrimientos, s/n, Seville, Spain `fcaballero@us.es`

[1] https://github.com/srl-freiburg/pedsim_ros
[2] https://github.com/ml-lab-cuny/menge_ros
[3] http://crowdbot.eu/CrowdBot-challenge/
[4] https://sean.interactive-machines.com/

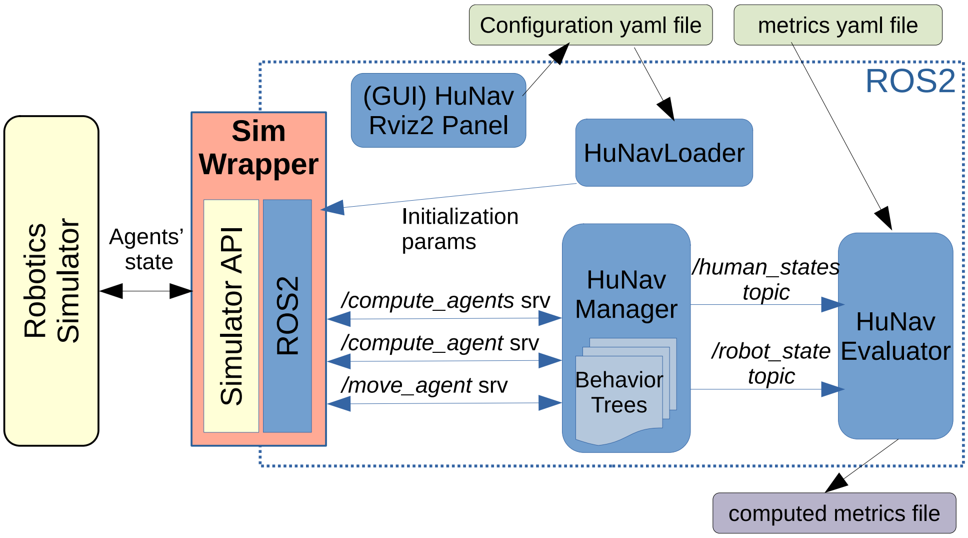

Fig. 2: Diagram of the HuNav Simulator. In blue color the modules of the *HuNavSim*. Base robotics simulator modules in light yellow color. Green boxes indicate the configuration input data. Output evaluation metrics are indicated in light purple color.

tool along with different simulators and provides a set of individual and realistic human reactions to the presence of a robot. Moreover, these tools present a closed set of metrics while *HuNavSim* includes a larger compilation of metrics which is easily configurable and extendable.

Another interesting simulator is the *Intelligent Human Simulator (InHuS)* [6], [7]. This simulator is meant to control the movement of the human agents simulated in another simulator. And it also includes a small set of human individual behaviors, as HuNavSim does. However, it is based on ROS1 and, mainly, it employs a navigation system devised for robots, *HATEB2* [8], to lead the human movements. This could lead to more unrealistic crowd movement than simulators based on specific crowd movement models.

SocNavBench[5] [9] is another different approach. It is a simulator-based benchmark with pre-recorded real-world pedestrian data replayed. The main drawback of this tool is that pedestrians trajectories are replayed from open-source datasets and, therefore, the effects of robot motions in pedestrians' paths is not considered. That makes difficult to obtain a realistic evaluation of the human-aware navigation.

Finally, there are interesting evaluation tools like *BARN (Benchmark for Autonomous Robot Navigation)*[6] [10] and *Bench-MR*[7] [11]. However, those are oriented to the general problem of navigation in cluttered environments without considering the "social" component of spaces shared with humans.

III. Human Navigation Simulator (HUNAVSIM)

A. *Architecture of the simulator*

The general architecture of the simulator can be seen in Fig. 2. *HuNavSim* is in charge of properly controlling the human agents spawned in another base simulator like Gazebo, Morse, or Webots, which also must simulate the scenario and the robot. Therefore, a wrapper to communicate with the base simulator is required.

Initially, the number and characteristics of the agents to be simulated (like individual behavior, list of goals, etc) must be provided by the user. It can be specified through a configuration yaml file, or through a graphic user interface based on a ROS2 RViz panel.

Then, at each execution step, the simulator wrapper sends the current agent status to the *hunav_manager* module through ROS2 services. According to the current states, the system decides the next state of the agents which are returned to the wrapper, and thus updated in the base simulator.

Finally, the *hunav_evaluator* module records the data of the experiment and computes the evaluation metrics at the end of the simulation. The information about each simulation and the desired set of metrics to be computed can be specified through a yaml file. The module generates an output result file with the simulation info, and the names and values of the computed metrics.

The full documentation and code of the HuNavSim is available in: `https://github.com/robotics-upo/hunav_sim`

B. *Human navigation modeling*

The HuNavSim is primarily based on the use of the well-known Social Force Model (*SFM*) [12] and its extension for groups [13], [14], to lead the human agents movement, alike others crowd simulators. However, we extend this model to provide a set of realistic individual navigation reactions of

---

[5] `https://github.com/CMU-TBD/SocNavBench`

[6] `https://www.cs.utexas.edu/~attruong/metrics_dataset.html`

[7] `https://github.com/robot-motion/bench-mr`

the agents to the presence of the robot. That allows to enrich the navigation scenarios and to challenge the navigation algorithms with more diverse and realistic human behaviors. The set of behaviors included are the following:

- *regular*: the human treat the robot like another human.
- *impassive*: the human deal with the robot like a static obstacle.
- *surprised*: when the human sees the robot, he/she stops walking and starts to look at the robot.
- *curious*: the human abandons the current navigation goal for a while and starts to approach the robot slowly.
- *scared*: the human tries to stay far from the robot.
- *threatening*: the human tries to block the path of the robot by walking in front of it.

An interesting feature, it that all these behaviors are controlled by behavior trees [15]. They allow to efficiently structure the switching between the different tasks or actions of the autonomous agents. Moreover, they are easily programmable and new behaviors can be added or modified effortlessly. Specifically, we use the engine *BehaviorTree.CPP*[8]

C. Wrapper for Gazebo Simulator

A wrapper to use *HuNavSim* along with the Gazebo simulator is also provided. Figure 3 shows the wrapper modules (red square) and the communication with the Gazebo simulator and *HuNavSim*.

The control of the agent movement has been programmed as a Gazebo plugin that must be included in the Gazebo world file, as well as the agents are included as a Gazebo actors. For that reason, a *world_generator* module has been included. It is in charge of reading the agents parameters, and to write the proper plugin and agents in the base Gazebo world file. Then, the plugin communicates with *HuNavSim* to update the agents' status.

A set of typical scenarios shared with humans is included: a cafeteria, a warehouse and a house.

The wrapper documentation and code is publicly available here: `https://github.com/robotics-upo/hunav_gazebo_wrapper`

IV. METRICS

With the aim of tackling the problem of selecting the best metrics for evaluation of the human-aware navigation, we decided to maintain an evaluation system as open as possible.

First, we reviewed the literature in order to collect most of the metrics applied to the issue. Then, we let the user to select the metrics to be computed for each simulation. Finally, the system also permits to easily add new metrics to the evaluation. The input of all the metric functions are two arrays with the poses, velocities and other data of the agents and the robot for each time step.

This way, *HuNavSim* presents a reliable and flexible evaluation system in contrast with the fixed evaluation systems found in the literature.

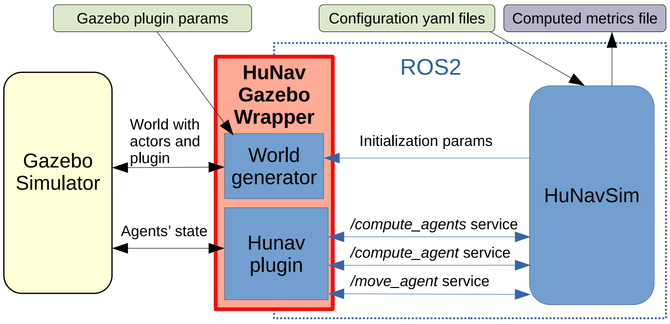

Fig. 3: Diagram of the Gazebo wrapper for HuNav Simulator. The red square encapsulates the two modules of the wrapper, which intermediates between the Gazebo simulator and the *HuNavSim*.

At the moment of writing this work, the metrics implemented were those employed in our previous work [16] and the *SEAN* simulator [4]. Table I shows an example of some human-aware navigation metrics of this set obtained from an example trajectory in the cafeteria scenario (Fig. 1).

The metrics from the *SocNavBench* [9], *Crowdbot* [3] and the compilation indicated in the work of Gao et al. [17], are being studied and included.

TABLE I: An example of some social navigation metrics obtained automatically from the the tool.

Time to reach goal (s)	105.0
Path length (m)	6.70
Cumulative heading changes (rad)	5.46
Avg distance to closest person (m)	1.19
Intimate space intrusions (%)	40.00
Personal space intrusions (%)	17.27
Social space intrusions (%)	42.13
Group intimate space intrusions (%)	0.0
Robot on person collisions ($times$)	1.0
Person on robot collisions ($times$)	0.0

V. CONCLUSIONS AND FUTURE WORK

We have briefly introduced a new open-source software to simulate human navigation behaviors. The system, programmed under the new ROS2 framework, can be employed to control the human agents of different general robotics simulators. Moreover, it presents other novelties like a set of realistic individual human navigation behaviors directed by behavior trees; and a complete and flexible compilation of evaluation metrics.

Future work includes the addition of the whole set of metrics commented as well as the development of a GUI to select the metrics to be computed. Replacing the 3D human agents, employed in the Gazebo wrapper, by a higher-quality models is being studied. The addition of more individual behaviors and the development of wrappers for other simulators besides Gazebo will be also considered.

---

[8] `https://github.com/BehaviorTree/BehaviorTree.CPP`

REFERENCES

[1] S. Macenski, T. Foote, B. Gerkey, C. Lalancette, and W. Woodall, "Robot operating system 2: Design, architecture, and uses in the wild," *Science Robotics*, vol. 7, no. 66, p. eabm6074, 2022. [Online]. Available: https://www.science.org/doi/abs/10.1126/scirobotics.abm6074

[2] A. Aroor, S. L. Epstein, and R. Korpan, "Mengeros: a crowd simulation tool for autonomous robot navigation," in *AAAI Fall Symposia*, 2017.

[3] F. Grzeskowiak, D. Gonon, D. Dugas, D. Paez-Granados, J. J. Chung, J. Nieto, R. Siegwart, A. Billard, M. Babel, and J. Pettré, "Crowd against the machine: A simulation-based benchmark tool to evaluate and compare robot capabilities to navigate a human crowd," in *2021 IEEE International Conference on Robotics and Automation (ICRA)*, 2021, pp. 3879–3885.

[4] N. Tsoi, A. Xiang, P. Yu, S. S. Sohn, G. Schwartz, S. Ramesh, M. Hussein, A. W. Gupta, M. Kapadia, and M. Vázquez, "Sean 2.0: Formalizing and generating social situations for robot navigation," *IEEE Robotics and Automation Letters*, vol. 7, no. 4, pp. 11 047–11 054, 2022.

[5] N. Tsoi, M. Hussein, J. Espinoza, X. Ruiz, and M. Vázquez, "Sean: Social environment for autonomous navigation," in *the 8th International Conference on Human-Agent Interaction (HAI '20)*, 11 2020, pp. 281–283.

[6] A. Favier, P.-T. Singamaneni, and R. Alami, "Simulating Intelligent Human Agents for Intricate Social Robot Navigation," in *RSS Workshop on Social Robot Navigation 2021*, Washington, United States, July 2021.

[7] ——, "An Intelligent Human Simulation (InHuS) for developing and experimenting human-aware and interactive robot abilities," June 2021, working paper or preprint.

[8] P. Teja S. and R. Alami, "Hateb-2: Reactive planning and decision making in human-robot co-navigation," in *2020 29th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*, 2020, pp. 179–186.

[9] A. Biswas, A. Wang, G. Silvera, A. Steinfeld, and H. Admoni, "Socnavbench: A grounded simulation testing framework for evaluating social navigation," *ACM Transactions on Human-Robot Interaction*, jul 2022. [Online]. Available: https://doi.org/10.1145/3476413

[10] D. Perille, A. Truong, X. Xiao, and P. Stone, "Benchmarking metric ground navigation," in *2020 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR)*, Abu Dhabi, UAE, 2020, pp. 116–121.

[11] E. Heiden, L. Palmieri, L. Bruns, K. O. Arras, G. S. Sukhatme, and S. Koenig, "Bench-mr: A motion planning benchmark for wheeled mobile robots," *IEEE Robotics and Automation Letters*, vol. 6, no. 3, pp. 4536–4543, 2021.

[12] Helbing and Molnár, "Social force model for pedestrian dynamics." *Physical review. E, Statistical physics, plasmas, fluids, and related interdisciplinary topics*, vol. 51 5, pp. 4282–4286, 1995.

[13] M. Moussaïd, D. Helbing, S. Garnier, A. Johansson, M. Combe, and G. Theraulaz, "Experimental study of the behavioural mechanisms underlying self-organization in human crowds," *Proceedings. Biological sciences*, vol. 276, no. 1668, p. 2755—2762, August 2009.

[14] M. Moussaïd, N. Perozo, S. Garnier, D. Helbing, and G. Theraulaz, "The walking behaviour of pedestrian social groups and its impact on crowd dynamics," *PLoS One*, vol. 5, no. 4, 2010.

[15] M. Colledanchise and P. Ögren, *Behavior Trees in Robotics and AI: An Introduction*, ser. Chapman & Hall/CRC Artificial Intelligence and Robotics Series. Boca Raton, US: CRC Press, 2018.

[16] N. Perez-Higueras, F. Caballero, and L. Merino, "Teaching Robot Navigation Behaviors to Optimal RRT Planners," *International Journal of Social Robotics*, vol. 10, no. 2, pp. 235–249, 2018.

[17] Y. Gao and C.-M. Huang, "Evaluation of socially-aware robot navigation," *Frontiers in Robotics and AI*, vol. 8, 2022. [Online]. Available: https://www.frontiersin.org/articles/10.3389/frobt.2021.721317