The Warehouse Robot Interaction Sim: An Open-Source HRI Research Platform

Connor Esterwood
University of Michigan
Ann Arbor, MI, USA
cte@umich.edu

Lionel P. Robert Jr
University of Michigan
Ann Arbor, MI, USA

ABSTRACT

The use of physical robots in real-world laboratories for the study of human-robot interaction is not without limitations and logistical challenges. In response, a wide range of studies have begun using virtual representations of robots. However, very few of these platforms are openly available to the HRI community. This limits reproducibility and the ability of the community to leverage existing resources for their own research. In response, this paper presents The Warehouse Robot Interaction Sim. The Warehouse Robot Interaction Sim is an open-source immersive virtual platform developed in the Unreal Engine with the goal of conducting research on trust repair in HRI. This paper summarizes the overall structure of the platform, how it can be modified, and briefly discuss how this platform has been leveraged for research. In doing so we hope to encourage other researchers in HRI to consider leveraging this platform for their own research questions and study designs.

CCS CONCEPTS

• **Human-centered computing → Laboratory experiments**; *User studies*; Interactive systems and tools.

KEYWORDS

Human-Robot Interaction, Trust Repair, Research Tools, Virtual Environments, Open Source Software

ACM Reference Format:
Connor Esterwood and Lionel P. Robert Jr. 2023. The Warehouse Robot Interaction Sim: An Open-Source HRI Research Platform. In *Companion of the 2023 ACM/IEEE International Conference on Human-Robot Interaction (HRI '23 Companion), March 13–16, 2023, Stockholm, Sweden.* ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3568294.3580086

1 INTRODUCTION & BACKGROUND

The use of physical robots in real-world laboratories for the study of human–robot (HRI) interaction is not without limitations and logistical challenges. For example, physical robots are expensive, complex, sometimes unpredictable, and often difficult to program. These challenges often limit the scope and methodological flexibility available to researchers especially when testing less developed research ideas. In response, many studies have begun using interactive virtual platforms (IVPs).

For example, a handful of different IVPs have been developed in the field of HRI. These can vary in size, scope, and accessibility. Some popular examples are SocNavBench [1], SEAN [2], and iGibson [3] which are designed to study social-robots as well as RCareWrold [4] which focuses on assistive robotics in healthcare domains. These IVPs have enabled researchers to study various aspects of robotics such as navigation, task-learning, algorithmic evaluation, mimicry, and the impacts of various non-verbal interactions. One limitation of these IVPs, however, is that they have not focused on the more social and explicitly communicative aspects of human–robot teaming nor have they fully incorporated collaborative human–robot work tasks as core elements in their designs.

As a result, researchers are faced with a lack of freely available and open source options for examining social and explicitly communicative aspects of human–robot teaming and collaborative work. This limits the opportunity for follow-on replication studies of existing work which, in turn, severely restricts the potential for cumulative science. In addition, this also increases the startup cost and time needed for HRI studies, and for researchers embedded in low-resource communities, these start-up costs can be a barrier to professional advancement.

To help alleviate these issues, this paper introduces an IVP developed and field-tested during the COVID-19 pandemic for online human-robot interaction research. We refer to this simulator as *The Warehouse Robot Interaction Sim.* In the following sections of this late-breaking report, we will introduce this IVP, summarize how it can be modified, and provide a brief discussion of how it has been leveraged for our own research. It is the goal of this paper to provide a brief but helpful showcase of this platform and to encourage the HRI community to explore ways in which to use the platform for their own research.

2 THE WAREHOUSE ROBOT INTERACTION SIM

The Warehouse Robot Interaction Sim is an interactive virtual platform developed for a series of online studies started during the COVID-19 pandemic. This platform was developed in the Unreal Engine version 4.23.1 with the goal of supporting research on human–robot trust repair in online and face-to-face settings. To accomplish this, the platform is comprised of a cooperative human–robot interaction task where one human teams with one robot in an immersive virtual environment.

HRI '23 Companion, March 13–16, 2023, Stockholm, Sweden

ACM ISBN 978-1-4503-9970-8/23/03…$15.00
https://doi.org/10.1145/3568294.3580086

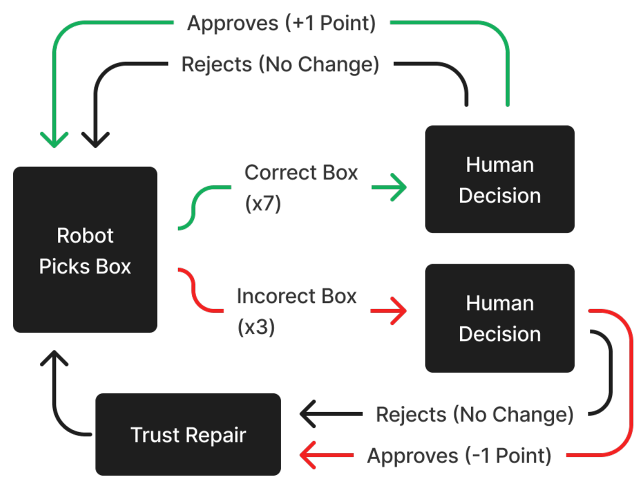

Figure 1: A visual representation of the task flow used in The Warehouse Robot Interaction Sim

Figure 2: The first-person view of the virtual environment present in The Warehouse Robot Interaction Sim as seen by participants.

2.1 Task & Environment

The overall objective of the current task setup is for a participant, assigned as a member of a one human to one robot heterogeneous human-robot team, to correctly process and place 10 boxes on a nearby conveyor belt. Boxes are processed correctly if the serial number printed on the box matches the serial number on a nearby display. It is the human's job to determine if boxes are correct or incorrect and it is the robot's job to pick a box to check and move that box to the appropriate location if it is flagged as correct or incorrect by the human. Correct boxes provide the team with 1 point and incorrect boxes deduct the 1 point. The team is also timed and the amount of time it takes to process each box and the average time processing boxes is made visible to participants. Both timing and points can be used to incentivize participant engagement and make processing of incorrect boxes and/or taking a long time to process boxes more consequential. Figure 1 illustrates this task as well as the different choices available to humans and their associated consequences.

This task is situated in an environment designed to mirror the real world. In particular, it takes place in a warehouse environment where the human is positioned behind a small table containing two computer monitors and a simple control panel. The human can freely look around but cannot move out from behind the table. Across from the human is the robot co-worker, a conveyor belt, and a series of boxes positioned on the floor and on shelves. The scene was composed using assets from the Unreal Engine Marketplace and includes ambient light and sound effects for immersion and added realism. Figure 2 shows the environment from the participant's point of view and illustrates what they would see in virtual reality or on their desktop screens.

The above task, virtual environment, and distribution options for this platform are relatively fixed and are not easily modified. This is the case as these are functionally the backbone of the platform and any modification would require a complete rework of the platform's general architecture. Three general elements of this platform, however, were developed with modification in mind. Specifically, researchers can modify the robot's performance, the robot's form or morphology, and the robot's communication. Table 1 summarizes these different options. In the following sections, we will detail each of these different options.

2.2 Deployment Options

Deployment of the simulated task and environment to study participants can be accomplished in one of two different ways. First, the platform can be packaged via Unreal Engine 4.23.1 for deployment and distribution online via HTML5 builds. This allows for web-hosting and online distribution of the simulator via data collection websites such as Amazon Mechanical Turk or similar. Subjects can then interact with the platform as they would a non-VR video game or interactive web-app on their desktop or mobile PC/Mac using a mouse and keyboard. Subsequent versions of the Unreal Engine, however, have removed this native option and future iterations of the simulator on more modern versions of Unreal may not maintain this distribution option as it is now an open–source community–supported feature [5]. As a result, we also provide the second option for distribution. In particular, users can choose to build and deploy the platform as an executable file (.exe) which can be run as a program on a local (i.e. laboratory) computer. This can then be interacted with as a traditional non-VR application or –with minimal modification– a full VR application compatible with modern off-the-shelf head-mounted displays and their associated input devices. These packaging options are available for Unreal Engine 4.23.1 and all subsequent versions of the engine.

2.3 Features and Modification

2.3.1 Modifying the Robot's Performance. The robot in this platform can be made to be either 100% correct in its choices of boxes or made to present an incorrect box for its 3rd, 6th, and 9th selection [1]. Having these two options are useful for research focused

[1]The distribution of errors at the 3rd, 6th, and 9th boxes was established to more evenly spread errors over a 10 box timeline. However, it is possible for these errors to

Feature	Options				
Robot Performance	3 Boxes Incorrect			All Boxes Correct	
Robot Form	Human-Like (Pepper)			Machine-Like (Manipulator Arm)	
Robot Communication	Apology	Denial	Promise	Explanation	No-Communication

Table 1: Summary of different features and their customization options in the current iteration of The Warehouse Robot Interaction Sim.

on trust and repair as it allows for the establishment of a baseline "ideal" trust level to compare the efficacy of different repair strategies against. For studies focusing on other aspects of HRI, however, the inclusion of a no-error condition allows these studies to leverage The Warehouse Robot Interaction Sim in different ways, namely, where errors are not central to the design of the research. For example, researchers seeking to determine how different robot morphologies impact acceptance or studies examining how different psychological predispositions impact any range of outcomes may wish to use a 100% reliable robot.

2.3.2 Modifying the Robot's Form. The Warehouse Robot Interaction Sim currently has two different robots capable of performing the box-sorting task discussed above. The first of these robots is a humanoid robot modeled after the Pepper robot [6]. This robot was modeled outside of the Unreal Engine and was imported into the engine and rigged for the task separately. The second robot available in The Warehouse Robot Interaction Sim is a machine-like generic manipulator arm. This robot was purchased from the Unreal Engine marketplace and contains a range of different functions and features. These two robots vary sizably in their different morphological characteristics, therefore, affording researchers the opportunity to compare how these different characteristics can impact a range of outcomes. Furthermore, these robots can be edited within the engine using different tools and plug-ins to add or remove features. This functionality, however, requires care as re-rigging and re-animating may be required. Figure 3 provides a visual representation of the two robot forms available and supported by this platform.

2.3.3 Modifying the Robot's Communication. The Warehouse Robot Interaction Sim allows for the modification of the robot's communication at three distinct time points. These communications occur after the 3rd, 6th, and 9th box. In the current iteration of the sim the communication options are different trust repair strategies. These are apologies, denials, explanations, and promises. For the apologies, the robot states *"I'm sorry I got the wrong box that time."* For denials, the robot states, *"I picked the correct box that time so something else must have gone wrong."* For explanations, the robot states, *"I see, that was the wrong serial number."* For promises, the robot states *"I'll do better next time and get the right box."* Each of these communications can be toggled on or off in the blueprints

be placed at any point during a study, and future iterations of the IPV are planned to give potential users more flexibility in this regard.

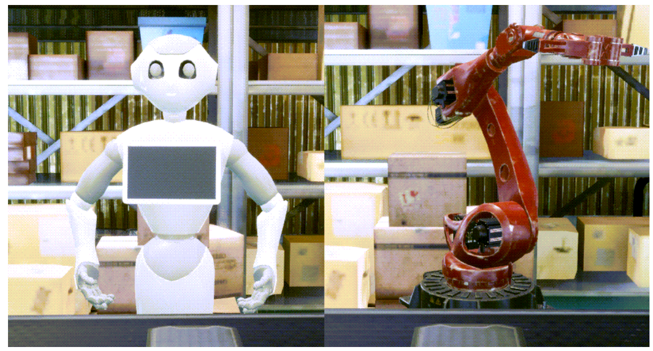

Figure 3: The two robots available in The Warehouse Robot Interaction Sim with the Pepper robot on the left and the generic manipulator arm on the right.

associated with the robots and level. Additionally, new communications can be added to the platform with relative ease using `.wav` files and linking those files to the associated nodes in the platform's code or replacing the existing `.wav` files already present. This can allow future researchers the flexibility to implement any range of different messages, voices, and other audio cues of interest to their research question.

3 ACCESSING THE WAREHOUSE ROBOT INTERACTION SIM

The Warehouse Robot Interaction Sim is available freely under a Polyform Non-Commercial Licence [7]. To access this simulator you can download it directly at `shorturl.at/aelqv`. Documentation and additional links to the sim can be found at `shorturl.at/fmtv6` or in the associated GitHub repository. The goal of this platform is to not only provide an initial starting point for research but also to help build a platform with input from multiple researchers and with the capabilities and branching features needed to support HRI research. As a result, the maintenance of this platform is currently provided by volunteers, and extensions or additions including new features or deployment methods are highly encouraged. Furthermore, the platform is open to feedback and modification with attribution, and branching and merging of different builds is welcome.

4 EXAMPLE USE CASES

To date, The Warehouse Robot Interaction Sim has been used in a handful of different research projects. For example, both [8] and

[9] used this platform to examine two possible moderators of trust repair in HRI. The first of these leveraged the simulator's capabilities regarding different types of robots. In particular, [8] used The Warehouse Robot Interaction Sim to compare the efficacy of apologies, denials, promises, and explanations from either a human-like robot or a machine-like robot. To accomplish this, 8 different conditions (1 per strategy per robot type) were implemented by altering various elements of The Warehouse Robot Interaction Sim for each condition. This resulted in a distinct HTML 5 build for each of these conditions. These builds were then deployed on networked servers and links were posted on Amazon Mechanical Turk for subject recruitment. By doing so, the study was able to examine the impact of anthropomorphism on Human–Robot trust repair at a relatively low cost and at a relatively high speed (within 6 months). Results of this showed that anthropomorphism appeared to play some role in the efficacy of different repairs [8].

In addition to examining the effect of different robot types, The Warehouse Robot Interaction Sim was also used by [9] to examine a different moderator, namely, how positive attitudes might impact the efficacy of different repairs. This later study focused on only the human-like robot but made use of all other elements of The Warehouse Robot Interaction Sim. Specifically, the study took advantage of the online distribution method used in [8] to test 6 conditions (2 controls & 4 repairs). The moderator was part of a pre-test survey and its impact was assessed through an analysis of covariance. Results of this study showed that positive attitude did moderate the impact of trust repairs and that this effect varied over time and by strategy [9].

Taken together, both of these studies illustrate how The Warehouse Robot Interaction Sim can be used to examine different moderators of trust repair but, this platform is by no means limited to trust repair alone. For example, The Warehouse Robot Interaction Sim could be used to examine the impact of different styles of communication during this cooperative task. Alternatively, researchers could also modify different elements of the robot's voice (deeper, faster, slower, accented, gendered, etc.) or even physical appearance to determine how these elements impact human's experiences.

5 CONCLUSION & FUTURE WORK

This paper introduces *The Warehouse Robot Interaction Sim*, provides a summary of its architecture, how it can be modified, how it can be accessed, and how it has already been leveraged to examine trust repair in HRI. We hope that by presenting this platform to the HRI community that future researchers may be encouraged to adopt and modify the platform as needed for their own research purposes. By doing so we hope to not only lower the startup costs of new research in HRI but also to allow for greater replication and reproducibility. This latter point is especially important given the growth in virtual representations of robots and the difficulty of reproducing the stimuli used within these studies.

While The Warehouse Robot Interaction Sim has several strengths there are still a number of areas where future work could improve this platform. First, *The Warehouse Robot Interaction Sim* is in the early stages of distribution and has yet to be fully evaluated with external users outside of the original study team. While two projects are in progress that leverage this platform outside of the study team, future work is still needed that incorporates feedback from these other projects to further improve the IVP's future iterations. Second, while there is variety in the IVP's scenarios in terms of communication, robot form, and robot performance, there is little variety in terms of task, number of agents, and the virtual environment. Therefore future iterations of this IVP should expand the options available to potential users by adding more variety in terms of tasks, number of agents, and environments. This could include designing scenarios that can be adapted to different interaction domains and operational contexts, thus providing a more comprehensive platform that can better assist HRI researchers across more specific disciplines. Such initiatives could leverage the existing framework and developed blueprint code to assist in this work. Furthermore, additional options to the existing variation present in terms of performance are needed that allow users full freedom to choose when robots commit errors and how frequently.

REFERENCES

[1] 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 (THRI)*, vol. 11, no. 3, pp. 1–24, 2022.

[2] N. Tsoi, M. Hussein, O. Fugikawa, J. D. Zhao, and M. Vázquez, "An approach to deploy interactive robotic simulators on the web for hri experiments: Results in social robot navigation," in *2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2021.

[3] C. Li, F. Xia, R. Martín-Martín, M. Lingelbach, S. Srivastava, B. Shen, K. Vainio, C. Gokmen, G. Dharan, T. Jain *et al.*, "igibson 2.0: Object-centric simulation for robot learning of everyday household tasks," *arXiv preprint arXiv:2108.03272*, 2021.

[4] R. Ye, W. Xu, H. Fu, R. K. Jenamani, V. Nguyen, C. Lu, K. Dimitropoulou, and T. Bhattacharjee, "Rcare world: A human-centric simulation world for caregiving robots," in *2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2022, pp. 33–40.

[5] UnrealEngineHTML5, "Unrealenginehtml5/documentation." [Online]. Available: https://github.com/UnrealEngineHTML5/Documentation

[6] "Pepper(robot)," Jun 2022. [Online]. Available: https://en.wikipedia.org/wiki/Pepper(robot)

[7] "Polyform noncommercial license 1.0.0." [Online]. Available: https://polyformproject.org/licenses/noncommercial/1.0.0

[8] C. Esterwood and L. P. Robert, "Do you still trust me? human-robot trust repair strategies," in *2021 30th IEEE International Conference on Robot & Human Interactive Communication (RO-MAN)*. IEEE, 2021, pp. 183–188.

[9] ——, "Having the right attitude: How attitude impacts trust repair in human-robot interaction," in *Proceedings of the 2022 ACM/IEEE International Conference on Human-Robot Interaction (HRI 2022)*. ACM/IEEE, 2022.