Simulating Intelligent Human Agents for Intricate Social Robot Navigation

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***Abstract*—Simulators are very effective tools in testing and debugging robotic systems before real-world deployment. In the context of social robot navigation, simulated human agents are required to test various settings. However, simple and reactive human agents may not be sufficient to simulate some complex indoor scenarios. Such scenarios require intelligent human agents that can analyse the situation and decide a navigation behavior. Our current work [1] presents an Intelligent Human Simulator (InHuS) that provides a generic architecture for simulating intelligent human agents and its application in social robot navigation. In this work, we present an extension of InHuS, which enhances the navigation of the human agents and also enables the simulation of different navigation behaviors. This is achieved by integrating InHuS with a modified human-aware planning system. The results in various simulated scenarios show clear improvements in the human agent's navigation. Furthermore, results also present some interesting navigation behaviors of the human agent that are simulated by simple parameter tuning.**

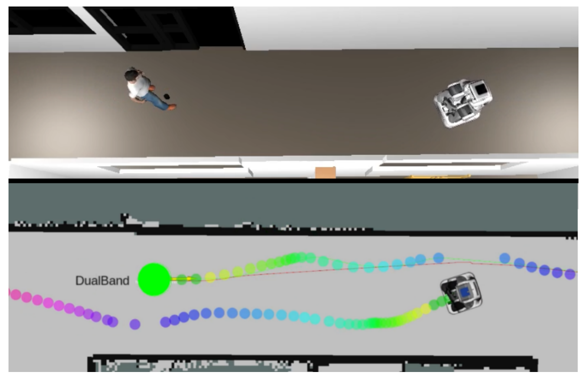

Fig. 1. MORSE simulator (top) and Rviz visualization (bottom) during the Wide corridor scenario with extended InHuS and CoHAN.

I. Introduction

Simulation in robotics tends to be more and more useful and even mandatory to have an effective system development [2]. However, simulation reaches some limitations in the scope of Human-Robot Interaction (HRI) due to the complexity of emulating rational human behaviors. Testing the HRI systems with real humans can be cumbersome and time-consuming, and in some situations, they can be hazardous to the participating humans. Specifically, in the field of social robot navigation, testing a new navigation scheme with real humans can be dangerous. Hence, researchers rely on human or crowd simulators like PedSim ROS[1], Menge ROS [3], SEAN [4] etc., to test their social navigation systems. However, the human agents simulated by the current simulators are simple reactive agents without any intelligence of their own. These agents, therefore, may not be ideal for testing complex human-robot navigation scenarios that occur in real life. For example, a child may try to disrupt the navigation by continuously blocking the robot's way. Sometimes this kind of playful behavior of a human needs to be tested in a simulation before letting the robot run in the wild. Therefore, simulating intelligent human agents with multiple behaviors is highly necessary for testing social robot navigation. In this paper, we present one such simulator capable of simulating an intelligent human agent with multiple behaviors and the ability to navigate or mitigate intricate social navigation scenarios.

Intelligent human navigation agents are simulated by combing our work [1], InHuS, with a modified version of the Cooperative Human Aware Navigation (CoHAN) planning system presented in [5]. The combined system enriches the human agent's navigation and bestows it with different navigation behaviors, thanks to the highly tunable CoHAN system. Our main contribution is the extended InHuS system with improved human agents for testing and debugging social robot navigation. A variety of human-robot navigation settings are presented in the results to show the advantages of this system.

The rest of the paper is organised as follows. Section II presents a brief description of various components of then combined system and discusses the advantages. In Section III, the simulated experiments and their results are presented. Finally, conclusions are presented in Section IV.

II. Intelligent Human Agent Navigation

Simulating intelligent human agents requires various components, each communicating with each other synchronously and evaluating the situation to take various decisions. In this section, we briefly present these components, InHuS and CoHAN, and how the combined system is advantageous.

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[1]https://github.com/srl-freiburg/pedsim_ros

A. InHuS

InHuS is a generic architecture able to provide an autonomous reactive and rational simulated human agent. Inspired by common architectures from autonomous robotics, many usual components are part of InHuS like a supervisor or a task and geometric planner. However, its core component, the Human Behavior Model module, defines goal decisions, reactions regarding other agents and builds the perception of the agent from data retrieved from the simulator.

This generic architecture has been first implemented in the scope of social navigation. Combined with the in-build Stage [6] simulator, it provides an environment to debug, experiment and tune human-aware robot navigation. It can also be used with the MORSE [7] simulator but it needs to be separately installed. One of the unique features of this implementation tailored to navigation is the ability to detect and act over the path blockage by the robot. Instead of taking a detour in such situation, the Navigation Conflict Manager makes the human agent to approach close to the blocking spot and wait for the robot to clear the way. This gives some persistence to goals and makes the agent show its intentions to other agents for the purpose of making them react. The other unique feature is the ability to set Attitudes. Attitudes are modes that affect goal decisions and reactions regarding the environment. Such modes can create unusual yet pertinent situations. For example, it can mimic the playing behavior of a child always going in front of the robot.

There is no standard yet for metrics or benchmarks in social navigation. Some studies discuss this lack and propose some metrics [8, 9]. Inspired by these works, InHuS can record navigation data and compute a set of metrics relevant for the analysis of social robot navigation. All these features are implemented in the core module of Human Behavior Model.

B. CoHAN

The CoHAN system consists of various modules developed as a plugins for standard ROS navigation stack. The main components of this planning system are the Human Aware Timed Elastic Band (HATEB) local planner [10] and Human Path Prediction module that allow us to plan and predict the probable trajectories of humans along with the planning of the robot. This kind of planning not only results in proactive navigation of the robot, but also elicits a possible navigation solution for resolving conflicts in complex scenarios. Furthermore, the parameters of the system are tunable and the human aware constraints can be adjusted as needed, which allows us to tune the system to exhibit various navigation behaviors like co-operative, non co-operative, early intention show etc. CoHAN also presents various goal prediction methods for humans and different planning modes for the robot. The planning modes of the robot can shift in the run time based on the assessment of human-robot scenario. The architecture of our CoHAN system and its modules along with detailed explanation of the functionalities are presented in [5].

In order to use CoHAN system for the human agent, we modified the exiting HATEB local planner and Human (or Agent) Path Prediction modules to accommodate other humans and robot into the human trajectory planning. We also use special costmap layers for other humans and robot to plan an agent aware path for the human agent. This modified system treats the robot and human agent differently, specifically, it disables the mode shifting functionality [5] for the human agent to avoid conflicts with InHuS. This differentiation of agents is extended to costmap layers as well.

C. Why combine InHuS and CoHAN?

The implemented version of InHuS performs well, but its geometric planner is the standard ROS navigation stack. Despite the high-level decisions taken by InHuS at runtime to make the human agent reactive and rational, its local navigation behavior is poor. Since CoHAN enhanced the ROS navigation stack with human-aware properties, we decided to combine these systems and use CoHAN inside InHuS. Thus, we benefit from both the high-level decisions of InHuS about global navigation and the more natural human-aware local navigation of CoHAN.

Moreover, since CoHAN is highly tunable, the human agent's behavior in the other agent's vicinity can be tuned to be more or less cooperative. Indeed, by tightening the elastic band of HATEB, the human avatar will deviate less from its initial trajectory and then forces the robot to adapt and move away. Alternatively, loosening the band a lot can make the agent very cooperative and move away from the robot's trajectory to not disturb it. As mentioned previously, the Attitudes in InHuS can also create interesting situations. Two of the existing Attitudes in InHus are the StopAndLook and Harass. StopAndLook stops the agent and temporarily suspends its goal to look at the robot for a few seconds. And with the Harass Attitude, the agent always tries to go in front of the robot to disturb it.

Combining these two systems creates a smarter and more natural human agent with a lot of different possible behaviors. Indeed, considering the different more or less cooperative tuning of CoHAN and the several Attitudes that can be set in InHuS along with their own parameters, there are a lot of possibilities, and thus, a lot of different human agents to challenge the interacting robot.

III. Experiments

We present three scenarios[2] to expose the benefits of combining our systems. Each scenario is detailed below. The robot was controlled using two different navigation systems. First, by a simple move base from the ROS Navigation Stack. It is referred to as the SMB system. This system is not human-aware and poorly reactive. The second is the CoHAN system which was presented above. Note that the CoHAN controlling the robot and its version combined with InHuS are running completely independently from each other. On the other hand, the human was controlled either with the previous version of InHuS, referred to as InHuS, or by its extended version referred to as Combined. We show the traversed paths of

[2]https://youtu.be/YZdY9N-R0EU

the agents in different scenarios as coloured paths. The same colour of the path indicates the same time instant in both the robot's and human agent's path. These paths are labelled with arrows showing the direction of movement and R, H representing the robot and human respectively.

A. Wide corridor

This first scenario consists of making the human agent and the robot to cross each other in a wide corridor. Four configurations have been tested: InHuS alone, and then the Combined system has to cross a robot, controlled first by SMB and then by CoHAN.

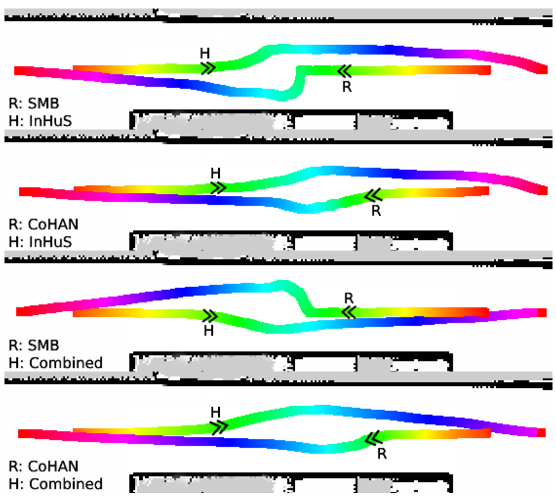

Fig. 2. Traversed paths of the agents generated by InHuS during the Wide corridor scenario. From top to bottom the configurations are respectively : InHuS-SMB, InHuS-CoHAN, Combined-SMB, Combined-CoHAN.

From the traversed paths generated by InHuS in Fig. 2, we can see the influence of using CoHAN. In the first run, the agent and the robot are close to colliding, but InHuS begins to go on one side while SMB makes the robot suddenly stop and move aside. The crossing isn't smooth at all. The second run with InHuS and CoHAN shows that CoHAN anticipates the human and adapts to make the human's path smoother even though the human does not anticipate the robot's movements. In the third run, we use the combined system to control the human, and the robot is controlled by using SMB. The paths clearly show the human going early on one side to let room for the robot. SMB still waits for the last moment to change its path, but the human's trajectory is smooth. Finally, the Combined system and CoHAN together find a more agreeable solution. They cross each other smoothly, and the robot reacts first to disturb the human as little as possible.

Thanks to these runs, we can conclude that CoHAN's navigation is more socially friendly and that combining it with InHuS enhances the human avatar's behavior.

B. Narrow corridor

In this scenario, the corridor is just large enough to accommodate only two agents to cross each other. Thus, if an agent is in the middle of the corridor, it blocks the other's way. The only natural solution is that both agents proactively move close to a wall to clear the other's path.

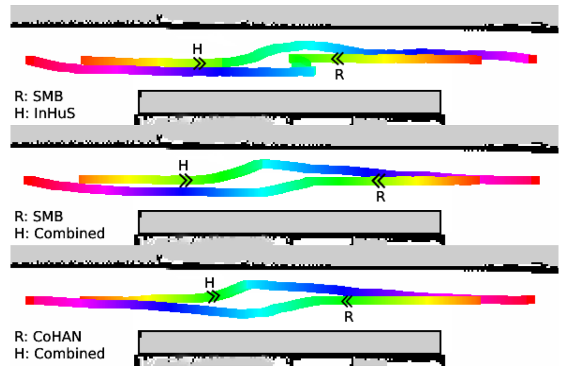

Fig. 3. Traversed paths generated by InHuS during the Narrow corridor scenario. From top to bottom the configurations are respectively : InHuS-SMB, Combined-SMB, Combined-CoHAN.

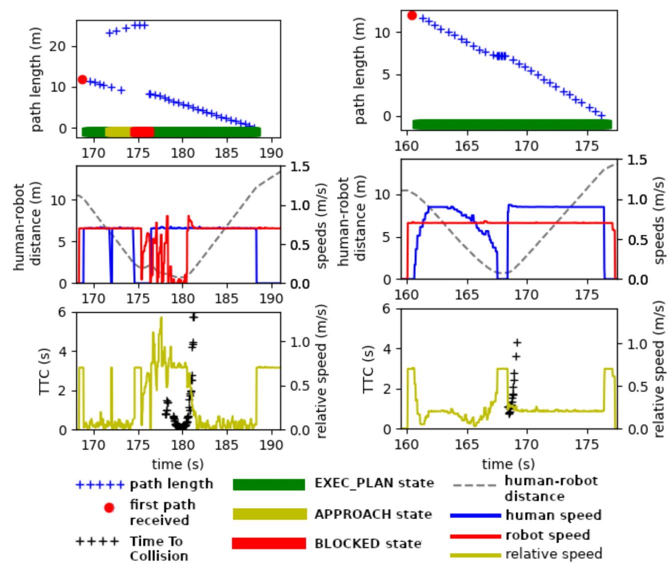

Fig. 4. Graphs of all relevant metrics recorded or computed by InHuS during the Narrow corridor scenario. The three graphs on the left are from the InHuS-SMB run and the three on the right are from the Combined-SMB run.

We first confronted InHuS and SMB in the narrow corridor. The human agent's path is blocked by the robot. So it switches to APPROACH state to get close anyway and finally switches to BLOCKED once it is very close as shown in the top left-hand corner graph in Fig. 4. As the SMB system gets close to the human, its path gets blocked as well, and so it starts backing off to take a detour. This reaction can be seen on the robot's path of the top part of Fig. 3. While doing so, the robot leaves some space for the human to move, but the human stops soon after since its path is blocked again. In the same way, the robot will stop backing off to go through the small space the human left while moving before being blocked again. After some such chaotic repetitions, they eventually both find themselves close to opposite walls, and they cross each other. However, they both had to stop several times.

In the second case, the robot is still with SMB, but this time the human is controlled by the Combined system. At first glance, we can see the improvements on the figure 3, the crossing is way smoother. The human starts moving aside early, which never blocks the robot. We can also notice this on the right part of Fig. 4, the middle graph shows the human speed slowing down as the human-robot distance gets smaller. Since the robot is late to move aside, the human has to stop, but the robot is able to cross without stopping. With less cooperative settings, the human could move aside and not stop. Finally, we tried the same scenario with the Combined system and CoHAN. This is the best run since both agents proactively move aside to clear the path of the other. Thus, the crossing happens very smoothly seen on the bottom part of Fig. 3.

This scenario showed once again the benefits of using CoHAN as a navigation planner. It can solve problems like the narrow corridor one, which requires anticipating other's movements in order to proactively move to one side of the corridor.

C. Pillar corridor

This last scenario aims to expose the ability to tune the combined system to create different behaviors in order to challenge the interacting robot. Two different settings are presented. The first one is a cooperative human, which tends to facilitate other's paths. The other is a non-cooperative one that deviates only as a last resort. In addition to the CoHAN non-cooperative setting, the second run also activates the StopAndLook Attitude of InHuS. The two presented runs are made with the Combined system controlling the human with different settings and CoHAN controlling the robot.

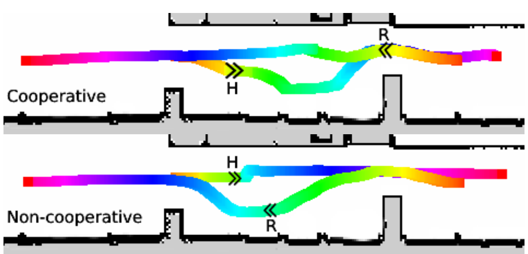

Fig. 5. Traversed paths generated by InHuS during the Pillar corridor scenario. The top part is with cooperative settings and the bottom part with non-cooperative settings along with the StopAndLook Attitude.

The top part of Fig. 5 shows how the combined system acts with cooperative settings. Just after the pillar, the robot slows down as it gets closer to the human, but the human already moved aside to clear the robot's way. They slowly cross each other to reach their goals. On the other hand, with non-cooperative settings and the StopAndLook Attitude, the human behaves completely differently. As shown on the bottom part of figure 5, the human's trajectory is almost a straight line. Since the path's color changes over time, we can notice on the human path that there is almost no green, and the cyan part is very small. It is because the human stopped to look at the robot for a few seconds. During this stop, the robot adapts and avoids the human by passing next to it.

These are just two examples of different behaviors, but they show the ability to tune human agent's behavior, thanks to both CoHAN and InHuS.

IV. Conclusion

The Intelligent Human Simulator (InHuS) provides autonomous, reactive and rational simulated human agents that can make high-level decisions to reach their goal. Our main contribution, which is, combining InHuS with a modified version of the Cooperative Human Aware Navigation (CoHAN) planning system greatly enhanced the navigation of the human agents. Associated with the in-build Stage simulator, this extended version of InHuS provides an environment to run repeatable scenarios, a highly tunable agent's behavior, and a way to easily visualize navigation and interaction data.

As future work, we aim to make a publicly available package of this environment to enable others to debug, experiment, and tune their social robot navigation system.

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