HuBeRo – A Framework to Simulate Human Behaviour in Robot Research

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Abstract:

Social robots' software is commonly tested in a simulation due to the safety and convenience reasons as well as an environment configuration repeatability assurance. An interaction between a robot and a human requires taking a person presence and his movement abilities into consideration. The purpose of the article is to present the HuBeRo framework, which can be used to simulate human motion behaviour. The framework allows independent control of each individual's activity, which distinguishes the presented approach from state-of-the-art, open-source solutions from the robotics domain. The article presents the framework assumptions, architecture, and an exemplary application with respect to presented scenarios.

Keywords: *human simulation, HRI, social robotics, robot control*

1. Introduction

The society of the modern world is ageing. This phenomenon applies not only to countries of the old continent but also those with such a large population as China. Therefore, the number of young people who would be able to support the elderly decreases. Social robotics concerns this problem by creating solutions that can support people in carrying out their daily activities [3, 8, 18].

One of the problems that must be solved when designing a social robot is a navigation in a dynamically changing environment. The challenge, which researchers must face, is to evolve algorithms that provide robot collision avoidance concomitantly with a movement pattern that is convenient for surrounding people [9, 17]. To be able to determine if the robot meets this requirement, many tests must be performed.

Modern robotic systems are essayed in simulation environments [23]. Such an approach for evaluation allows creating the entire robot system more effectively and safely. The simulator should take into account the kinematics and dynamics of the robot as well as the existence of static and dynamic elements of the environment. One particular example of such a dynamic element is a simulated human, which should be considered not only as an object that is able to change its position, but also behaves in a certain way [20, 24].

The problem of human behaviour modelling is not trivial due to the enormous complexity of the imperative that guides people while moving. Since its description in a strictly mathematical way is impossible [5], a qualitative evaluation is straitened. Moreover, a human movement manner may differ among different ethnic and age groups. To the best of the authors' knowledge, there is no comprehensive solution to this problem.

The purpose of this article is to present HuBeRo framework that allows a control of simulated individuals on a simple movement tasks level. Commanding of a simulated human is executed according to a specific scenario, designed concerning an environment structure. Both scenario and environment, related to a specific application, are designed by an end user.

The aim of the HuBeRo is to assist robots' software designer during the control system development process. Our work proposes an architecture of the system and presents test scenarios taking advantage of a novel, socially compatible local navigation algorithm. Although the path calculation is performed with a use of the custom method, it is out of the scope of this paper as its description is complex. Moreover, we do not evaluate the paths quantitatively in this work, because our objective is to point out the framework itself.

The main signatures, which distinguish HuBeRo from other frameworks for human behaviour simulation, are: possibility to create application–specific scenarios using the predefined functions, ability to control individuals – instead of a whole collective, and software modularity.

The paper structure is as follows. First, state of the art solutions are depicted (sec. 2). Next, the HuBeRo framework assumptions (sec. 3) and architecture (sec. 4) are described. Then, the test scenarios are presented (sec. 5). The paper ends up with conclusions (sec. 6).

2. Related Work

State-of-the-art works considering human motion behaviour simulation frameworks focus on different aspects. Pan et. al [16] proposed the MASSEgress computational framework that incorporates a pattern–based model in which agents are allowed to select the appropriate type of behaviour based on e.g., the surrounding environment and experience. Since it is derived from pattern–based model – it does not allow to control individuals separately. Berg et. al [25] presented an approach for interactive navigation of multiple agents in crowded scenes. The formulation employs a pre-computed roadmap - providing macroscopic connectivity, aggregated with a navigation for each agent. Agents' environment perception allows them to compute a collision-free path based on i.a. extended Velocity Obstacles. Schmitz et. al [22] proposed a novel framework intended for various types of robots – SimVis3D. The authors focused on the introduction of an animated human character into the software. The movement of the person is planned using splines. The tool verification is performed via an exemplary scenario. Koh et. al [10] introduced an agent–based system, which replicates pedestrian behaviours taking a pedestrian's sensory, attention, memory, and navigational behaviors into consideration. They designed a two-level navigation model in order to generate such behaviours as: overtaking, waiting, sidestepping, and lane-forming in a crowded area. Reed et. al [21] designed a framework that was comprehensively validated, e.g., [28], and is widely used in the research conducted by the SAE[1]. The software allows to simulate physical posture and motion. The framework's architecture concerns from low-level joint manipulation to a complex tasks execution. It was achieved via a coordination of individual modules (creating a single agent) that communicate with each other. However, the software is available only for the commercial use.

All these works are similar in regards to a conceptual design of a framework – implement systems based on agents that are aware of interactions and environment structure. However, inputs and outputs of computation blocks for human behaviour calculation and level of knowledge about the environment usually differ. Our approach is designed from the perspective of individuals. It provides pedestrian heterogeneity and hence can be categorized as a microscopic simulation model. The HuBeRo framework has built-in interface to a popular robotic framework, which makes it ready-to-use in a robotics research domain.

3. Framework Assumptions

The framework requirements are defined so as to allow the introduction of virtual people into a simulation and controlling them in such a way to re-enact typical scenarios for social robotics research. Moreover, the framework should support the end user in qualitative grading of a system operation and allow to adjust execution manner for a specific case.

As the HuBeRo framework is not a standalone software, two groups of requirements were demarcated. The first group is related to the HuBeRo itself ((a)-(e)), whereas the second one – to the system incorporating the HuBeRo ((f)). The requirements are as follows:

(a) provides an API allowing an individual Human control in a simulation,

(b) allows the creation of scenarios that incorporate Human movement activities [4],

(c) allows the simulation parameters modification e.g., a shape of a personal space [6], motivation to reach the goal, maitaining appetible speed or desire to avoid collisions [7],

(d) allows the collection of the human path points (for analysis of human paths, depending on the simulation parameters),

(e) asserts the integration with various simulation software and motion controllers or planners,

(f) provides a graphical representation of the environment entities.

4. Framework Architecture

The HuBeRo framework description is based on the simple Environment ontology (Fig. 1) that is used as a dictionary of basic concepts. The basic entity is the Spatial Object, with its geometrical attributes, e.g., a shape and pose – expressed in the Environment coordinate system. Considering Object's movement ability, Movable Spatial Object was distinguished. The very special Movable Spatial Object is a Human that owns two values: $poseCurrent$ and $poseGoal$, standing for operational parameters for the Human action. Four operations were defined – each of them is associated with one of the basic Human movement controlling functions of the HuBeRo framework.

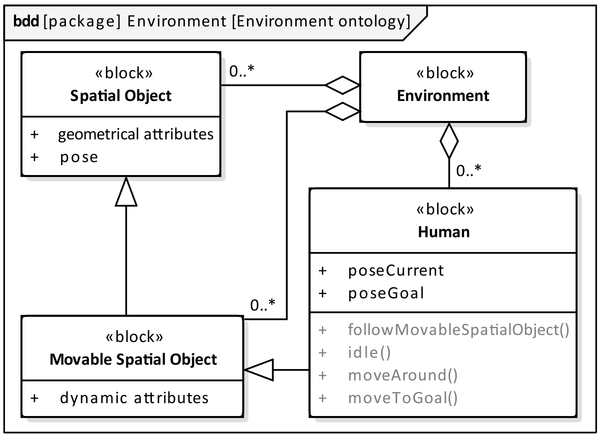

Fig. 1. Environment ontology

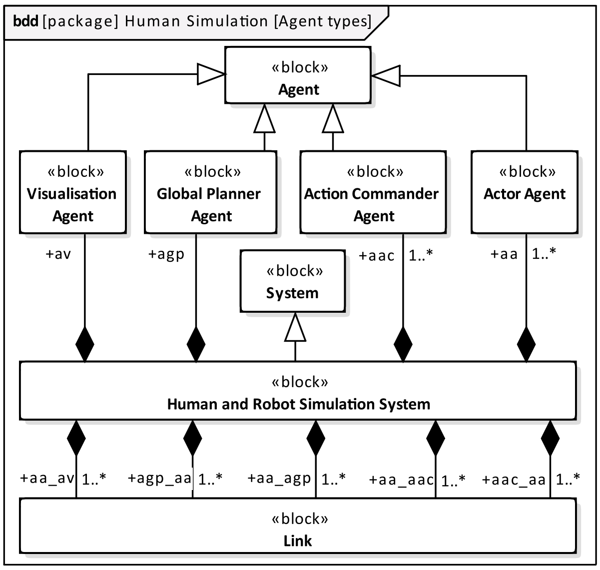

Fig. 2. The composition of HuBeRo Simulation System

A specification of the HuBeRo framework uses the EARL language (version 1.1) [1, 27] that basis on the

Embodied Agent approach [12, 29–31]. In our approach, the *Human and Robot Simulation System* can be composed of multiple Human and Robot agents that coexist in the shared Environment.

The framework defines a group of CERT-type Agents *aa* and inter Agent communication Links that are used for transferring data between *aa* and other Agents (Figs.2 and 3). Each *aa* corresponds to a Human in the Environment.

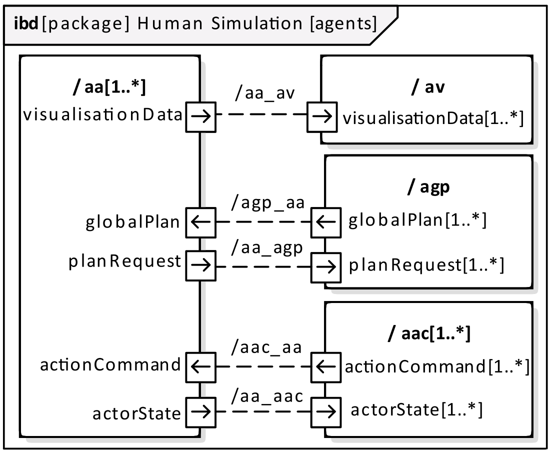

Fig. 3. General structure and communication of the HuBeRo framework with associated Agents

The framework provides communication of *aa* with following Agents:

- *aac* (CT-type) – defines a set of tasks in a specific order (scenario) to be performed by a Human,
- *av* (CET-type) – provides a graphical representation of the Human cognition – related to, e.g., its state and attributes like position or personal zone,
- *agp* (CT-type) – performs a global path calculation on a *aa* request.

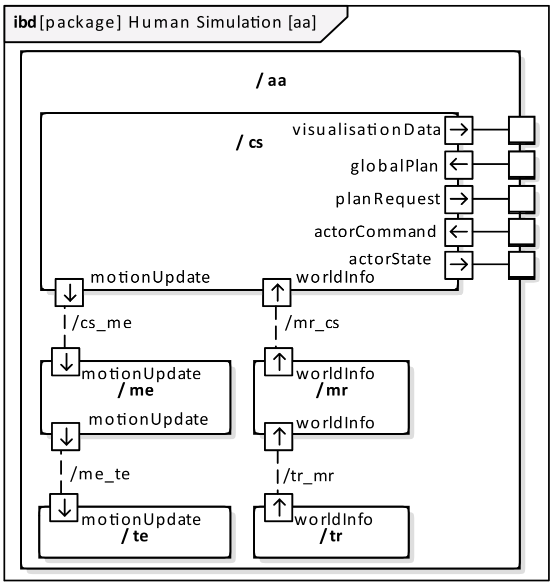

Fig. 4. aa internal structure definition

The *aac* can also be interfaced with Robot's *cs* [26]. A System structured in that way allows to synchronise Agents operation, utilizing an action status feedback from both types of Agents.

Currently, $|aac| \leq |aa|$ is required due to the inability of a single Human to schedule commands coming from more than one source. On the other hand, a single *aac* can send commands to more than one *aa*. The number of *aac* Agents in the System must be determined by the end user at the scenario design stage. The $|aac|$ depends on the requirement, whether the scenario control is to be centrally located or distributed.

The *aa* structure is presented in Fig. 4. A Human perception (*tr* and *mr* Subsystems) is comprehensive in terms of geometrical attributes of Spatial Objects (e.g. position) and dynamic attributes of Movable Objects (e.g., position and velocity). The *cs* Subsystem executes a local navigation algorithm necessary to perform the Human movements in the Environment. The control loop ends up with the act of *me* and *te* Subsystems that update the Human pose value in a simulated world.

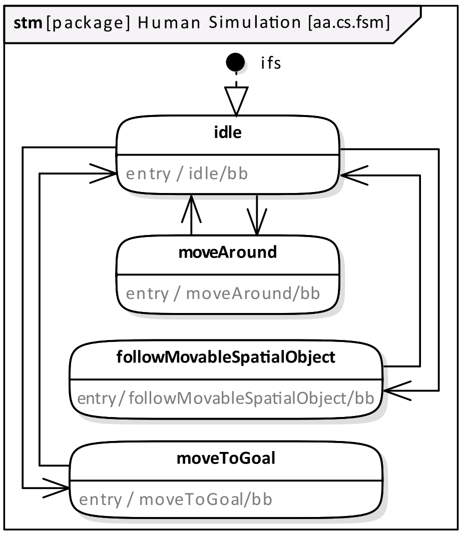

Fig. 5. $aa.cs.fsm$ definition

The operation of $aa.cs$ is presented in Fig. 5 by a Finite State Machine. In the *idle/bb* state the Human maintains its pose and waits for a new motion command arrival. The *moveToGoal/s* state realises the behaviour of reaching a certain goal (movement from $poseCurrent$ to $poseGoal$). The HuBeRo framework does not name any specific algorithm of this behaviour transition function execution, as many different navigation algorithms can be adopted. The act of the behaviour associated with *moveAround/s* is similar to the previous one, but after reaching a certain goal, a new $poseGoal$ is drawn randomly. The point is selected within the predefined Environment bounds. As the Control Subsystem operates in *followMovableSpatialObject/s* state, the Human follows another Movable Spatial Object. What distinguishes this state from previously mentioned ones is that a predicted path to the Object must be updated periodically. The second difference is that after the Human has moved close enough to the Movable Spatial Object, the behaviour is not terminated, but the Human waits until the Object moves away.

The HuBeRo framework is equipped with a wide range of parameters defined in $aa.cs$, e.g., a shape of the personal space or a degree of desire to avoid collisions. We state that for a fixed Environment configuration, the paths taken by a Human differ depending on the parameters' values.

5. Test Scenarios

The structure of the exemplary HuBeRo application is shown in Fig. 6. Description of the application is supplemented with requirements references (sec. 3) in the $R - (requirement\ label)$ form.

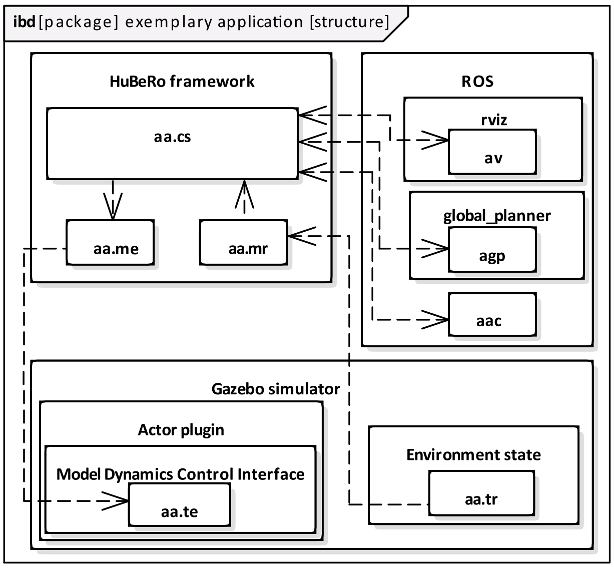

Fig. 6. An exemplary application of the HuBeRo framework with its dependencies

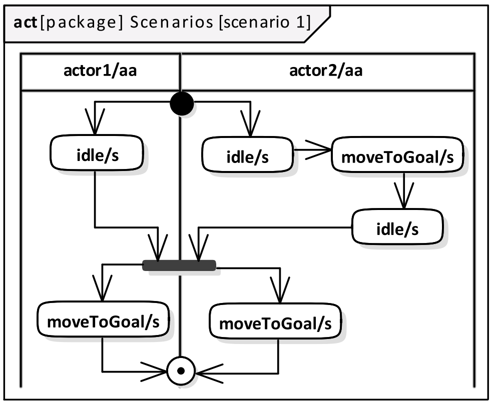

Fig. 7. Sequence of $aa.cs.fsm$ FSM States transitions in the living room scenario

As a base simulation software the Gazebo is used (R- (e)). The Gazebo provides all necessary Environment–related input data, along with a 3D representation of the Environment (R- (f)). The HuBeRo framework itself introduces a novel local planning algorithm, which is supported by the external global planner module [13]. Moreover, the Rviz was selected as a visualisation tool, which stands for another dependency of the HuBeRo framework. The Rviz is used for grading the framework qualitatively. Commanding of the simulated Humans is accomplished via the custom ROS [19] framework applications with a use of the HuBeRo-ROS interface (R- (a)).

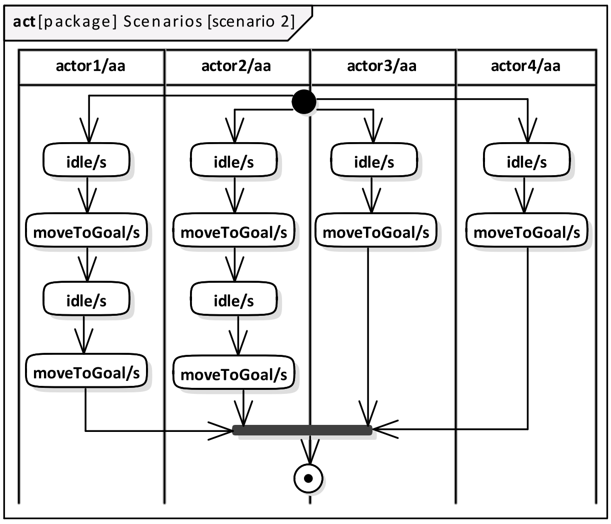

Fig. 8. Sequence of $aa.cs.fsm$ FSM States transitions in the parking scenario

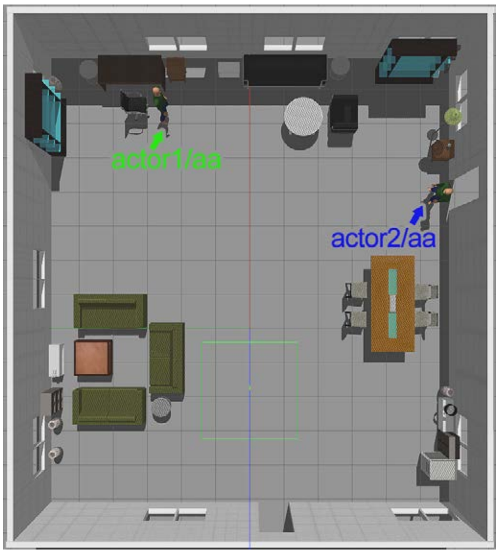

Fig. 9. Representation of the living room Environment used in the test scenario. Screenshot obtained with a use of the Gazebo simulator

To evaluate the proposed simulation framework the two specific scenarios were designed (R- (b)). SysML activity diagrams were used to indicate the sequence of *aa.cs.fsm* state changes for the simulated actors. The Environment configuration (at the end of the scenario) along with paths executed during the operation (R- (d)) and the personal space shapes are presented in the screenshots. The desired speed of pedestrians in all cases was set to 1.29 m/s [15], whereas speed limits arise from object's dynamics.

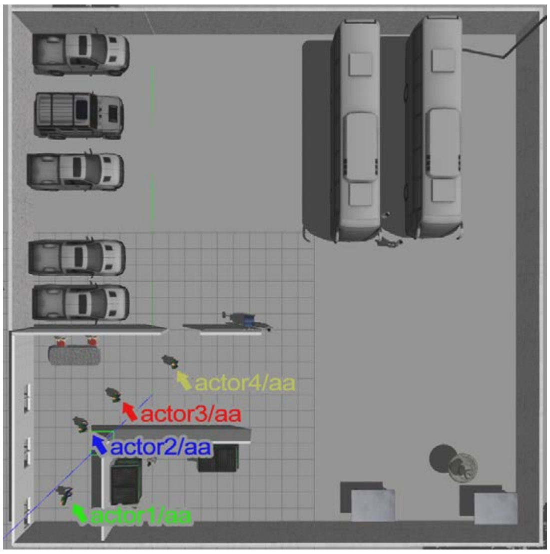

Fig. 10. Representation of the parking Environment used in the test scenario. Screenshot obtained with a use of the Gazebo simulator

The first scenario (Fig. 7) is realised in the living room with 2 Humans – *actor1/aa* and *actor2/aa*. The initial Environment configuration is shown in Fig. 9. At first, *actor2/aa* walks over to *actor1/aa* and invites him to eat a dinner. Later on, both *actor1/aa* and *actor2/aa* go to the table surroundings. The same scenario was executed 2 times: for the first time Humans had a personal space modelled as a circle (Fig. 11) with a radius of $0.20\,m$, whereas in the second case it was an ellipse with semi–axes of $1.10\ m$ and $0.80\ m$ (Fig. 12). This experiment shows that the requirement (c)) has been met.

The second scenario (Fig. 8) is realised in the parking Environment containing 4 Humans – *actor1/aa*, ..., *actor4/aa* (Fig. 10). Each Human starts his walk around the table and tries to get to his car. However, only 2 Humans go straight ahead to the destination, others decide to interrupt their trip. The reason behind is that *actor1/aa* must throw away rubbish and *actor2/aa* meets a friend standing around the corner. In this case, during the first simulation, Humans had a personal space modelled as an axis-aligned square with side lengths of $0.25\ m$ (Fig. 13), whereas in the second run the personal space shape was a circle with a radius of $0.70\ m$ (Fig. 14). A video presentation of both scenarios performance is available online [2].

The differences in paths executed by Humans are noticeable in both scenarios. More visible differences occurred in the parking, where the enlargement of personal space size disallowed Human to pass through the small aisle (Fig. 10).

The only parameter that was changed during the execution of the scenarios was the conformations of the Humans' personal spaces. Alternative outcomes can be achieved by the rearrangement of other local planner parameters. The results described above show that a wide class of scenarios can be mapped into a simulation.

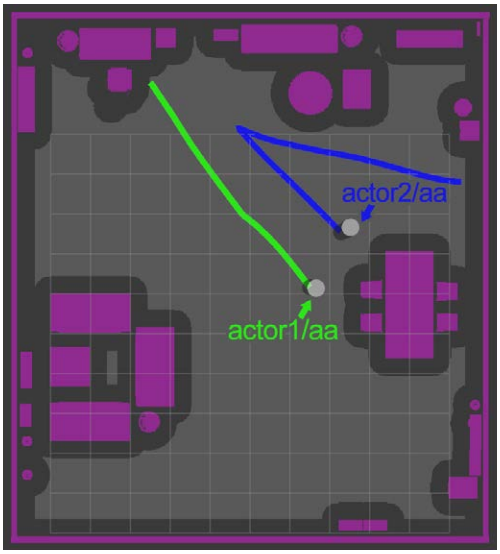

Fig. 11. Humans paths executed in the living room scenario – circular personal zone. Screenshot obtained with a use of the Rviz visualisation tool

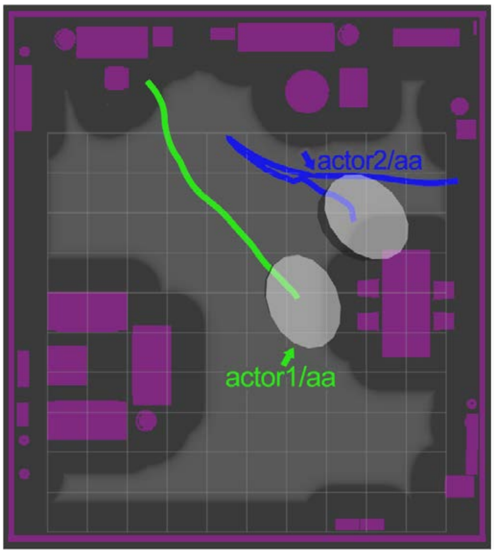

Fig. 12. Humans paths executed in the living room scenario – elliptical personal zone. Screenshot obtained with a use of the Rviz visualisation tool

6. Conclusions

The HuBeRo framework introduces a detailed solution for a human behaviour simulation. It allows controlling individual humans during the execution of pre-defined motion scenarios. Although the HuBeRo was designed mainly for the execution of specific cases related to social robotics research, the API allows to create many sophisticated scenarios. Providing a metric map of an environment, the end user is able to flawlessly test custom scripts in different surroundings.

The main restriction of the framework is a limited set of commands, defining simple tasks for human locomotion. Moreover, the in-depth knowledge of para-

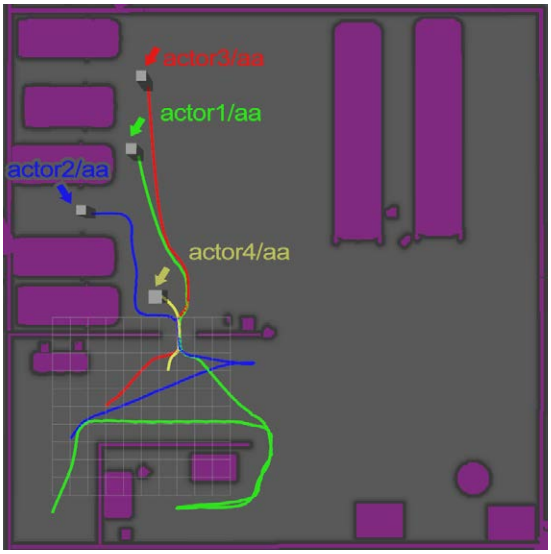

Fig. 13. Humans paths executed in the parking scenario – rectangular personal zone. Screenshot obtained with a use of the Rviz visualisation tool

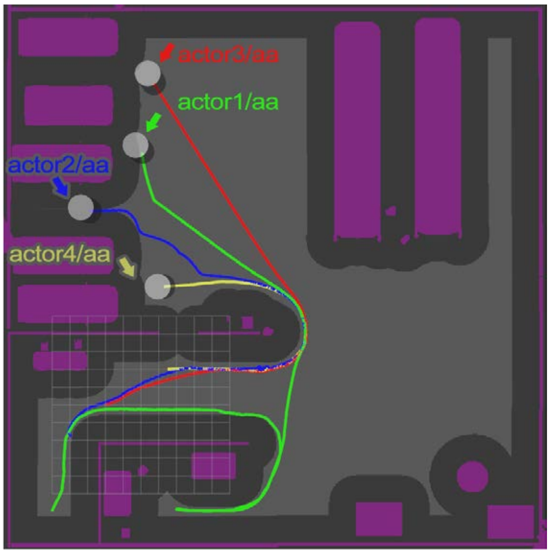

Fig. 14. Humans paths executed in the parking scenario – circular personal zone. Screenshot obtained with a use of the Rviz visualisation tool

meters is obligatory to achieve a certain human behaviour in a specific scenario.

The advantage of the HuBeRo framework is that its modules are interchangeable. The local planning algorithm, integrated with the motion controller, can be replaced with another state-of-the-art implementation.

The main goal of future work is to evaluate, how much the paths generated in a simulated world reflect the ones executed by people in a real life. For comparison purposes, human localization techniques would be useful [11]. Moreover, extensions of a motion controller that would take into account complex human behaviours can be created based on human activities recognition algorithms [14].

The HuBeRo framework is planned to be used in the INCARE project [2] as an environment for test scenarios including fall prevention, transportation attendance, hazard detection, and guarding.

Notes

[1] Society of Automotive Engineers `https://sae.org`

[2] Video presentation of the scenarios execution: https://vimeo.com/397552304

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