An Interactive Test Environment for Autonomous Robots

M. Finke[1], J. Strassner[2], J. Speier[2], L. Peters[1], M. Pauly[1], M. Göbel[1], H. Surmann[1]

GMD - German National Research Center for Information Technology,
1 Institute for Autonomous intelligent Systems (AiS), D-53754 Sankt Augustin, Germany
2 Institute for Media Communication (IMK), D-53754 Sankt Augustin, Germany
Marion.Finke@gmd.de

Abstract

Systems involving autonomous components are much more flexible and powerful than conventional ones. But building them bears lots of difficulties since complexity in design and control increases with the number, and the skills of the autonomous systems. For interacting with the environment, each autonomous component must react on data given by sensors - sensors which perceive information in a completely different way than humans. Virtual environments provide facilities to make processes of autonomous systems alive by giving them a visual existence. This paper presents how a virtual environment is employed to help building, verifying, and enhancing an autonomous mobile system.

Keywords: mobile robotics, virtual reality, human computer interaction, sensors, tele-operation

1 Introduction

In recent years, mobile robots gained more and more autonomy. Technology is moving away from toy-like robots towards big machines doing service tasks in human populated environments like factories or offices [1]. Most of these service robots are not fully autonomous. Although their jobs usually are simple transportation tasks, they still have to rely on human aid or can not move freely but are bound to tracks. Examples for partially autonomous robots are Helpmate [2] serving in hospitals, Mortimer [4], responsible for room-service in a hotel, and MOPS [11], a system for mail distribution. Tele-operated robots have a low degree of autonomy, but can execute more complex tasks than just transporting, but also manipulating objects. Typical application areas are work in hazardous environments like nuclear waste handling [5], in underwater robotics [7] or in space robotics [3].

Fully autonomous systems are still rare, since their development is highly complex. We are developing a team of autonomous service robots for indoor tasks like transportation, surveillance, and monitoring [9]. A virtual environment is connected to one of the robots. Virtual environments are frequently employed for robot tele-operation, as described in [10] and [7], where simple commands can be sent to remote robots which are in turn visualized in the virtual scene. Our scenario extends these facilities by providing interaction mechanisms that are more than simple commands: Virtual obstacles can be placed in the virtual model of the building and influence the real robot's behavior. Visualization of the robot's sensor data in the virtual environment as well as the information deduced from it by the robot gives additional information of the robot's view and reasoning. A view of the scene as humans perceive it is available via the 3D-virtual model and by displaying the stereo image data given by a camera mounted on board of the robot. Thus, the robot´s reasoning can be compared to the human view and can be validated easily.

In this paper, we will first introduce the scenario featuring our mobile robot in the virtual environment. We describe in detail how the user can observe the robot scene, can interact with the robot from the virtual environment, and can compare his view of the world with the robot's view. Section three presents the virtual environment used. A technical description of our robot team and their working environment follows. We conclude with a comprehension and possible extensions to our system.

2 Scenario

Our mobile robots carry out transportation tasks in an office environment. They work in two buildings with several floors equipped with additional sensors and actuators for enabling the robots to open doors etc. One of the robots is connected via radio Ethernet to the virtual environment where the user can assign tasks to the robot, and watch the robot plan and execute its job. During execution, the user can influence the robot's behavior. In the virtual world, we are not confined to see what is happening in the real world. In addition, sensor information can be visualized, and conclusions drawn from this data are displayed for the user. The original plan can be compared with the results during execution.

2.1 Observation

Figure 1 shows an initial scene in our robot's lab. On the table a model of the whole building can be seen. The user can zoom into this model to perceive the scenario at any required detail.

Behind the table a model of the robot can be seen. It carries a virtual screen which enables the user to either have a bird's-eye view on the scene or to take a look into the real world from viewpoint of the moving robot. The bird's-eye view is a copy of the virtual scenario. The look into the real world corresponds to the view of a camera mounted on the robot. Camera data is sent from the robot and displayed on the screen on top of the virtual robot. Thus, the user can have a virtual ride on the robot having a human view on the environment while looking from the robot's position. The user can switch between the look into the real world and the look into the virtual scene by head movements. Figure 2 shows the virtual robot with a look into the real world.

Figure 3 shows a typical, detailed scene during execution. On the left a view into the virtual environment: The robot moves in a corridor with offices to the right and left. On the right, a photo of the real building can be seen.

A view from one corridor through doors leading to the central section of the floor to the next corridor can be seen in figure 4. When the robot opens or closes the doors, the corresponding status information is sent to the virtual environment, where the virtual doors of the building are updated.

2.2 User-Robot Interaction

The scenario starts with the view shown in figure 1. The user can now assign tasks to the robot, for example to go and fetch an object. Tasks are defined by pointing, e. g. to the destination room in the building. Once a task is completely specified, it is sent to the robot which starts execution.

Another way to interact with the robot is provided by virtual obstacles. The soda can on the table in figure 1 can be used as such an obstacle. When grabbed and drawn into the robot's way, its coordinates are sent to the robot which will behave as if confronted with a real obstacle. This corresponds to adding a virtual sensor to the real robot to perceive virtual objects. The Behavior of the robot is based on sensor fusion of this virtual sensor and the real ones.

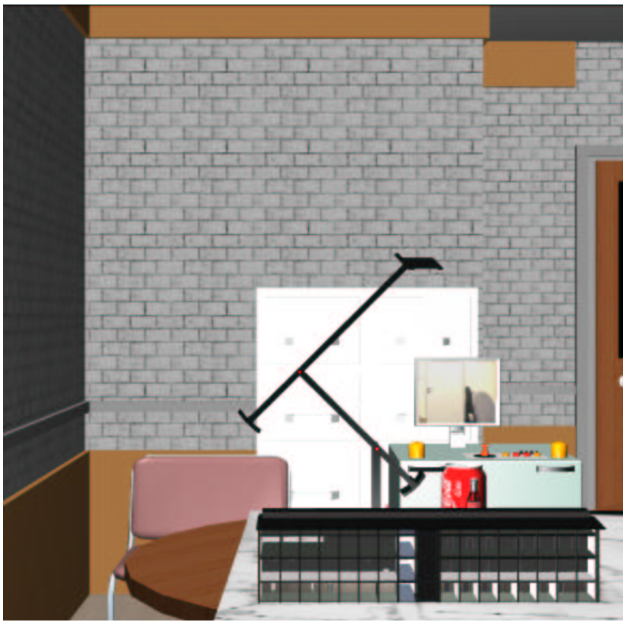

Figure 1: The initial scene.

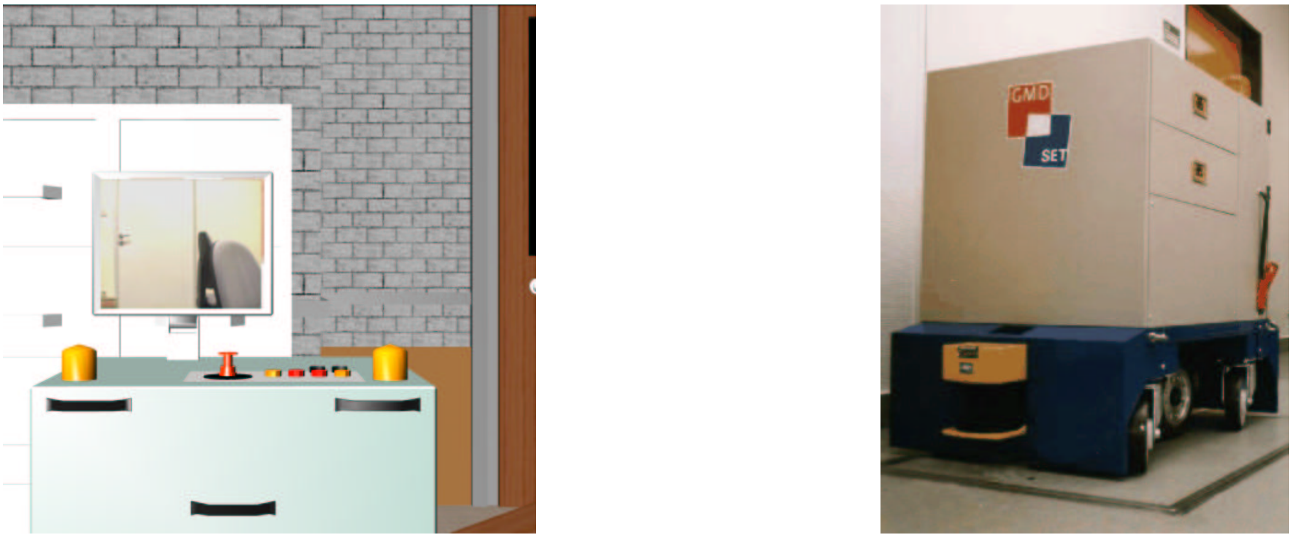

Figure 2: The virtual and the real robot.

2.3 Observing the World with the Robot's Eyes

The virtual world enables us to see not only the robot acting in the real world, but see the world with the eyes of the robot at the same time and thus validating the robot's perception and reasoning process.

As soon as the robot receives a task, it starts planning a coarse path to the destination. The path is described using points of interest like doors. The planned path is sent to the virtual environment, visualized, and remains visible during execution. Therefore, if the robot deviates from the plan this becomes obvious in the virtual world. This feature serves for validating the robot's path planning strategy.

Figure 4: The view through a fire-door shows the robot moving along the corridor.

During execution our robot moves in a structured environment containing dynamic objects that might have not been there the day before, e. g. a huge parcel or a table, and even moving objects like humans. Sensors must be employed to keep track with the robot´s actual position and to recognize static and moving obstacles to avoid collisions.

In contrary to the human observer, the robot has a 2D-perception of the world. The camera on board serves as feedback for the human observer. The camera data is displayed in the virtual environment without being evaluated on board of the robot. The robot ”sees“ using two laser scanners, one looking forward and one looking backward. They measure 361 distance values for a range of 180 degrees, giving a two-dimensional view with a radius of 10 m.

Navigation is based on a map of the static environment containing natural landmarks like doors or changing width of corridors. Constantly evaluating the wheel position gives an estimation for the current position, relative to a known starting position. This estimation is done until the next landmark is found using the laser scanners.

The scans are evaluated to find certain patterns re-

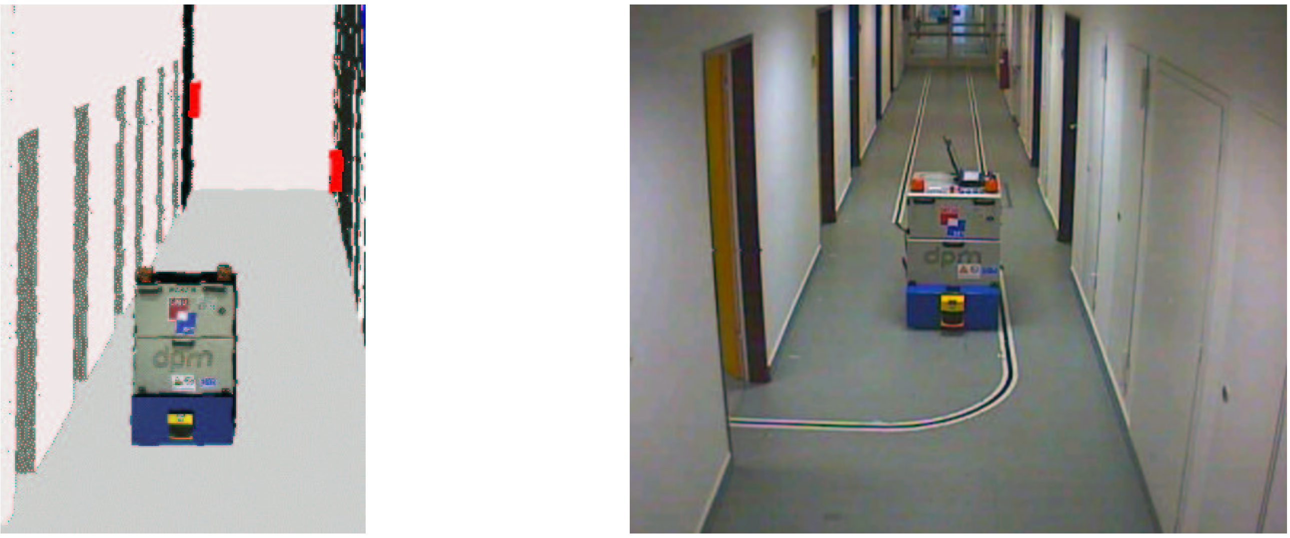

Figure 3: View from top with the robot moving along a corridor having offices to the right and left.

lated to humans, a fellow robot, or known natural landmarks like doors. Usually, at least three or four landmarks in either direction are visible. The actual position estimation is then updated using the relative position to known landmarks. A detailed description of sensor data evaluation for our robots is given in [8]. Figure 5 shows an example of sensor data evaluation. On the left hand side, a typical 2D-scan is displayed for the robot moving in the corridor. Changes in width of the corridors are recognized by the robot and checked against known landmarks contained in its world model. In the scan on the right hand side (5), recognized features are marked.

This process is bound to be error prone. One reason is sensor noise which may not only result in small errors, but may lead to finding a landmark where none exists, which can result in more substantial error. Errors are even more likely when the environment is crowded, for example by humans standing in front of a door and therefore making the recognition of this landmark impossible. Thus displaying information deduced from sensors is relevant for making the robot's reasoning accessible to the developer.

In our virtual scene the user can choose which information is displayed. Information available consists of

- the robot's estimation about its position
- the robot's real position
- sensor data from the laser scanners
- recognized natural landmarks

In the virtual world, the bird's-eye view displays the robot in the model of its environment. The position of the robot corresponds to the position the real robot inferred from sensor data. This estimated position can be matched with the real position by comparing the virtual view with the real world provided by the stereo camera on board of the robot. To display sensor data, laser scans are sent from the robot to the virtual scene. They are mapped on the virtual model of the building and displayed accordingly. Additionally, information like landmarks, humans, and robots that have been recognized are visualized in the virtual scene.

The following information can be displayed in the virtual environment all at the same time:

- 3D virtual model of the world
- 3D human view of the real world using the stereo camera
- 2D robot view of the world using the laser scanner and information extracted from the scan data

This gives the possibility to see the informations related to each other such as deviations are made clear. The development of robot hard- and software can therefore be validated in answering the following questions:

- Does the information given by the sensors suffice?

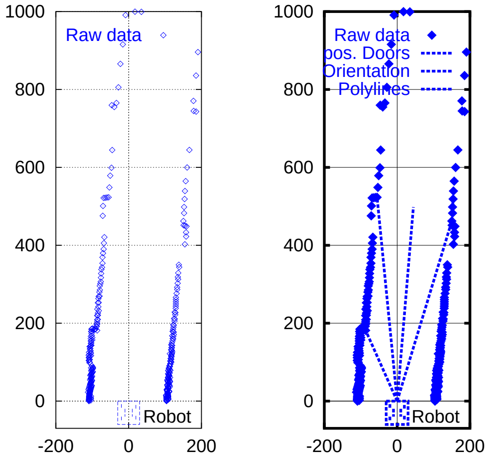

Figure 5: A 2D-representation of original scan data is shown on the left. The scan on the right contains recognized features like doors.

- Does the object recognition process work correctly?
- Is the navigation strategy sensible?

3 The Virtual Environment

Our requested task is fulfilled best by focusing on object interaction rather than entering the virtual world. Therefore, a stereoscopic, non-immersive two-sided Responsive Workbench is used which consists of a table-top-display extended by a projection wall.

The Responsive Workbench concept as described in [6] and [12] is an alternative to the multimedia and virtual reality models of the past decade. In this new concept, the user no longer experiences simulations of the world in the computer, but the computer is ubiquitously integrated into the user's world.

Virtual objects and control tools are located on a real workbench. The objects, displayed as computer-generated stereoscopic images are projected onto the surface of a table. The computer screen is changed to a horizontal, enlarged work top version and replaces the two-dimensional flat screen. A guide uses the virtual working environment while several observers can watch events through shutter glasses. The guide operates within a non-immersive virtual reality environment. Responsive Environments, consisting of tracking devices, cameras, and projectors replace the traditional computer and are adapted to human needs.

3.1 Interaction Facilities

The control tools implement complex actions like transitions, rotations, and zooming, that can be easily achieved by intuitive movements of the user's hand. Each control instrument is represented as a small virtual object that can be activated by grabbing it with the hand and moving it onto an object, which is to be manipulated. Rotations of objects then can be done just by turning the hand. The zoom operation is accomplished by simple up and down movements of a small virtual magnifier, which has been grabbed by the hand. In our scenario, main tools for interaction and navigation are a Polhemus Stylus and a Space-mouse.

4 A Team of Autonomous Service Robots

Our team of mobile robots consists of three identical vehicles (see figure 2) as far as sensors and actuators are concerned. Each one is about 80 cm × 60 cm large and 90 cm high. The mobile platform can carry a payload of 200 kg at speeds of up to 0.8 m/s. Being equipped with different accessory, they can cover a large variety of tasks like express mail delivery, food catering, surveillance and monitoring, etc.

They are moving within two buildings of our research lab that have been enhanced with additional infrastructure to create a "robot friendly" environment. This environment provides sensors and actuators that can be operated via a wireless link by the robots. Each floor is divided into three parts connected through fire doors that can be operated by the robot. The central part connects the buildings through a corridor. It also provides access to the elevator that can again be used by the robots.

An additional facility, this time mainly for the humans, is the service request and monitoring of the robots via web-browser. Each person having access to the web can send service requests to the robots. These continously deliver information about their current status to the user and thus continously provide feedback.

5 Conclusion

We presented autonomous robots connected to a virtual environment. The interaction between the virtual environment and the robots is more than pure teleoperation. The user can not only send simple commands to the robot, but can influence its behavior by virtual obstacles. One of the major advantages of the interacting between real and virtual world is the information displayed in the virtual environment. Here, computed models of the scenes can be overlayed with actual camera data from the robot. Information perceived and computed by the robot can be displayed at the same time with the information perceived by humans.

Several extensions to the existing system are planned. Interaction can be intensified by extending the scenario by a number of pure virtual robots and virtual actors. Even the building can be purely virtual. Therefore, it is possible to simulate environments and/or robots before they exist. To enhance the robot's capabilities, a manipulator will be added. Control and feedback from and to the virtual world will be possible using a haptic device.

Useful applications for this interactive test environment include assistance in planning environments, training of users in operating systems like robots, and optimizing robot control by visualizing the processing of sensor data and thus making the robot's reasoning more transparent for the developer.

References

[1] Rodney A. Brooks. From earwigs to humans. In *IIAS The Third Brain and Mind International Symposium "Concept Formation, Thinking and their Development"*, 1996. Kyoto, Japan.

[2] Joseph F. Engelberger. Health care robotics goes commercial - the helpmate experience. *Robotica*, VII:517–523, 1993.

[3] J. Fröhlich and R. Dillmann. Sensorsimulation-based interactive telerobot control system. In *Advanced Space Technologies for Robot Applications (ASTRA '94)*, 1994. Noordwijk, The Netherlands.

[4] René Graf and Peter Weckesser. Roomservice in a hotel. In *3rd IFAC Symposium on Intelligent Autonomous Vehicles - IAV 98*, volume 2, pages 641–647, 1998. Madrid, Spain.

[5] K. Kim, M. W. Vannette, Jerry L. Hall, and Donald R. Flugrad. Remote manipulator and its teleoperated guide vehicle for hazardous waste sampling operations. In *Proceedings of the International Conference on Robotics and Automation. Volume 3*, pages 2620–2626, Los Alamitos, CA, USA, May 1994.

[6] Wolfgang Krüger, Christian-A. Bohn, Bernd Fröhlich, Heinrich Schuth, Wolfgang Strauß, and Gerold Wesche. The responsive workbench: A virtual work environment. *Computer*, 28(7):42–48, July 1995.

[7] Qingping Lin and Chengi Kuo. Virtual teleoperation of underwater robots. In *Proceedings IEEE International Conference on Robotics and Automation*, 1997. Albuquerque, New Mexico.

[8] Michael Pauly, Hartmut Surmann, Marion Finke, and Nan Liang. Real-time object detection for autonomous robots. In *AMS-98*, pages 57–64. Springer Verlag, 1998. Karlsruhe, Germany.

[9] Liliane Peters, Hartmut Surmann, Michael Pauly, and Nan Liang. Ariadne – a service robot team. *ERCIM News*, pages 39–40, 1998.

[10] Kristian T. Simsarian, Lennart E. Fahlén, and Emmanuel Frécon. Virtually telling robots what to do. In *Interface to Real and Virtual Worlds*, 1995. Montpellier.

[11] Nadine Tschichhold-Guerman Sjur J. Vestli. Mops - a system for mail distribution in office-type buildings. *Service Robot: An International Journal*, 2:29–35, 1996.

[12] Gerold Wesche, Jürgen Wind, and Martin Göbel. Projects in VR: Visualization on the Responsive Workbench. *IEEE Computer Graphics and Applications*, 17(4):10–12, July/August 1997.