

# “KhepOnTheWeb” : An Experimental Demonstrator in Telerobotics and Virtual Reality

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## Abstract

*Research in mobile robotics often requires heavy investments in time and money. Mobile robots are still quite expensive and complex. Moreover, experimental set-ups need important preparations. Despite the fact that the number of researchers using real robots is growing, a good robot is still an important investment that many research groups cannot afford. For those groups that can afford a such equipment, the comparison of the results with other researchers is quite impossible due to the impact of the environment and the type of robot on the results. The goal of our work is to make complex mobile robots and environments available from a computer network, like Internet or ATM, for instance. This remote access could help in doing less expensive experiments and comparative benchmarks on a unique set-up. This paper presents a first set-up installed on Internet and used to demonstrate some possibilities of remote control of a Khepera mobile robot. Moreover, a virtual reality model of this experimental set-up has been developed in order to allow distant experimenters to get familiar with the system and to prepare experiments in virtual reality before accessing the real robot. The observation of the first users and the feedback on the development give important indications about the usability and the relevance of such a new tool for mobile robotics.*

## 1 Introduction

In the scientific community, researchers are used since years to remotely access, via standard communication networks, unique or expensive structures, like supercomputers, important databases, unique information resources or the World Wide Web (shortly, the Web), the email box or the ftp servers full of software.

Some experiments have been made to check the

possibility to remotely access to unique or expensive physical devices using actual information networks [1]. The final goal of a such development has been, for instance, the creation of virtual laboratories, physically distributed over several countries, but having communications facilities that make them very near each to each other [6]. Despite the growing number of such experiments, we are still in a phase where those environments are made to test the actual possibilities, without a real use as a working tool. We know some Swiss projects in this field that have failed to move to the operational phase, due to a large number of limitations, spanning from the network possibilities to the kind of user interface.

In a similar way, some experiments have been carried out to make physical devices available on the Web. A very famous example is the “Mercury project” [4]. This kind of experiment is also very useful in the sense that it gives important information about the reactions of the users, the kind of equipment needed and the constrains that both have to deal with.

Due to the recent advances in computer horsepower, especially applied to computer graphics, simulations in robotics are becoming more and more used. On one hand, robotics companies are getting more and more interested by the new technologies available in the fields of virtual reality and computer networking. For example, Robot Simulation Ltd. provides a robot library of VRML models for more than 150 industrial robots. This library is available for free on the Web [5]. On the other hand, some software companies are currently developing new tools for animating and controlling virtual reality environments, making use of the recently approved VRML2 standard [2]. A demonstration of a robot arm controlled by a Java applet is available on the Web site of VRUniverse [9].

## 2 Aims of the project

The goal of our project<sup>1</sup> is very similar to the first group of experiments described in the Introduction: our aim is to provide, through network communication facilities, one or more complex and unique mobile robotics set-up to the scientific community.

The main motivations are both economic and scientific. On one side, this kind of equipment is very expensive and could be shared between several research laboratories to reduce the expenses. On the other side, the comparison between different approaches in the field of mobile robotics can be made only on equipments where all conditions are perfectly identical. This does not only mean that the robot has to be exactly the same, but also that the environment has to be identical, in all details like light conditions or colour and type of floor.

The fact to have a common shared environment could be scientifically a great advantage for the understanding of the actual control approaches. Moreover, the availability of a virtual model of the experimental set-up provides an easy-to-use approach to the real set-up and can be used to prepare real experiments.

The goal and the motivation of this project fit very well with the activity of our lab, which is specialised in the development of mobile robots and tools for the research in control algorithms. The commercialisation of the miniature mobile robot Khepera, developed in our laboratory, is one of our major results in this direction. More than 170 universities and research centres in the world are equipped with this miniature mobile robot at the moment. The remote experimentation is the logical extension of this activity.

In a first exploratory phase, the goal of our work is to understand the possibilities available with the actual technology, the reaction of potential users and the requirement for the equipment used in this kind of set-up. For this reason we have chosen to make a first set-up available on the Web. In comparison with other similar projects, our set-up wants to have some additional features:

- The device controlled has to be a mobile robot equipped with an on-board camera. This is already the case of some other set-up that are partially available [8][3].
- Unlike all other mobile robots set-up, KhepOnTheWeb runs continuously, all the day and night, without the need of external support.

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<sup>1</sup>This project, called "Sharing of Unique or Expensive Equipment for Research and Education: The Remote Manipulation Paradigm" is part of the Swiss Priority Programme SPP ICS of the Swiss National Foundation.

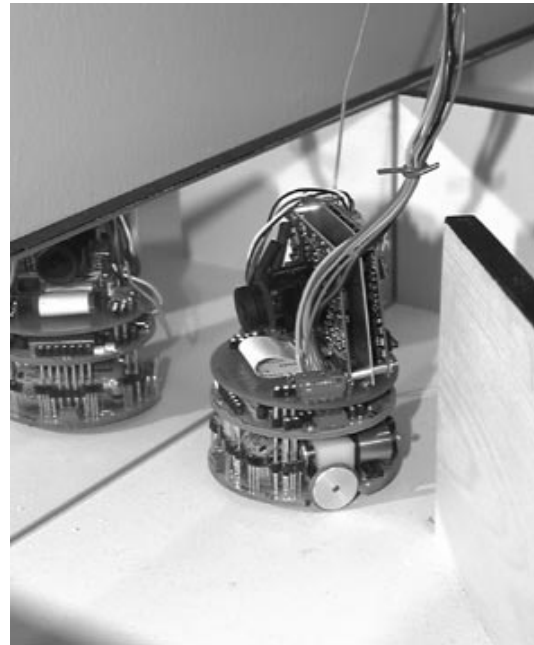


Figure 1: Khepera equipped with a video camera and looking into a mirror.

- The interface has to have a live video feedback and run in a standard Web environment.
- A virtual reality model of the experimental set-up is available, so that the user can get familiar with the user interface and the controls of the mobile robot.

## 3 KhepOnTheWeb Description

For this experiment, the choice has been made to use our miniature mobile robot Khepera equipped with an on-board CCD camera. The robot is placed in a maze and connected to a PC through a wired link. An additional camera is set on the ceiling, looking at the maze. The PC controlling the robot is equipped with a frame grabber for the image acquisition and is connected to Internet. A server provides "real-time" visual feedback to the user, who accesses the information from Netscape. The user can switch between the robot camera and the external camera using the user interface. The virtual model of the robot features the same user interface as the real one, and hence the user can select a view from one of the two cameras.

### 3.1 Khepera: a miniature mobile robot

Khepera is a cylindrical robot 55 mm in diameter and of variable height. This miniature mobile robot has been developed by E. Franzi, A. Guignard, and

F. Mondada [7]. The size of Khepera lets the experimenter to realize a large environment on a limited surface. For this robot, indeed, a normal table of 0.9 x 1.8 m represents the same relative working surface of a tennis court for a standard size robot (55 cm in diameter). The space available over the table corresponds to a 6-floor-high building for a standard robot, which lets us to employ a suspended cable for power supply without disturbing the robot movements; we can also place a camera observing the environment without need of large-angle lenses.

In its basic configuration (two lower layers of figure 1) Khepera is made up of two layers corresponding to two main boards: the sensory-motor board and the CPU board.

The motor system consists of two lateral wheels and two pivots in front and back. This configuration is very good for facing complex geometric obstacles because the robot can turn in place without displacement.

The sensor system of the basic robot, also placed in the lower board, is composed by 8 infrared proximity sensors. These sensors can also be used as simple passive infrared light sensors.

The CPU board encloses the robot's processor, a Motorola MC68331. An RS232 serial line make it possible to communicate with an host computer. On the same cable, a wire provides power supply from an external power supply.

In our configuration, the basic Khepera has been extended with a CCD video camera. The video signal is send, by two additional wires, to the host computer equipped with a frame grabber.

### 3.2 Physical set-up

The robot has been placed in the maze shown in figure 2. The maze is made in such a way that the visitor can see various effects. In a general way, the walls are higher than the robot, so that the visitor has to move around to visit the maze. Just some walls in the middle of figure 2 are lower than the others. The wall placed on the left in figure 2 is a mirror, so that the visitor can see the robot in it. On the top right in figure 2, a ramp allow to the visitor to look outside the maze.

For an user coming for the first time in the maze, it is quite difficult to understand the geography of the environment. For this reason, and also because of the general interest to have an external view of the experiments, we have added, on the top of the environment, a mobile camera that can look to the maze. The complete set-up is shown in figure 3.

A flexible cable fixed over the maze connects the

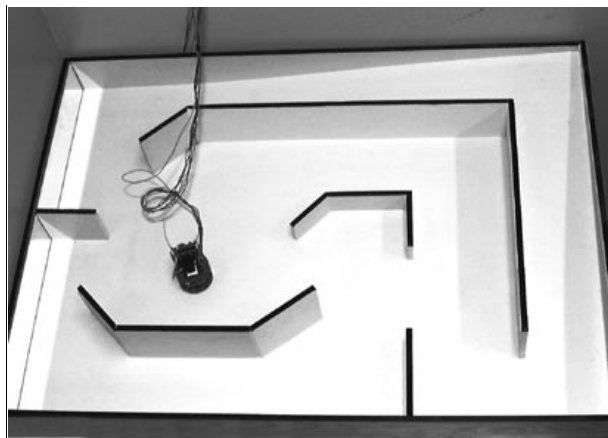


Figure 2: Maze where Khepera can move. The size of the maze is 65 x 90 cm.



Figure 3: The complete set-up is composed by the robot placed in the maze (bottom right) and connected to a PC through a wired link. On the top of the maze, an external camera (black) can give a global view to the visitor.

Khepera robot to a PC computer equipped with a frame grabber. The cable supports the RS232 serial line for the communication between robot and PC, the power supply for the robot and the video signal coming from the camera placed on the robot.

The external camera mounted on the top of the maze is also connected to the PC by an RS232 serial line for the control of the position and the zoom of the camera. The video signal coming from this second camera is also placed as input of the same frame grabber, using an analogue multiplexer. By switching this multiplexer, the user can choose between the robot view and the external view.

The PC runs a Web server and some software which performs the several tasks necessary for the control of the set-up:

- A program grabs continuously the images and put them in the memory of the PC in JPEG format.
- The Web server gives the access to all pages required by clients that connect to it.

As soon as a client access to the control page, the server starts a program that sends continuously the images stored in memory, using the server-push mode, supported by Netscape. The stream of JPEG images makes the video flow for the visual feedback of the visitor.

When the visitor clicks on a command, the server starts a program that analyses and executes the command. Three types of commands are available:

- Commands to control the movement of the robot. In this case the program called by the server just send the orders to the robot using the RS232 serial line connected to the robot.
  - Commands to control the movement of the external camera. Also in this case, the program called by the server just send the orders to the camera using the RS232 serial line connected to the camera.
  - Commands to switch the camera. In this case the program called by the server acts on the multiplexer present at the input of the frame grabber.
- A Java script running on the client sends some requests of information about the state of the robot. A program on the server answers to these requests and get the information, if needed, from the robot, using the RS232 serial line.

To allow only one user to control the robot, a mechanism of exclusion is implemented. A timeout disconnects the user after a given amount of time.

### 3.3 Graphical User Interface

The interface at the level of the client includes all possible operations that can be made on the robot, on the external camera and on the multiplexer. The complete window available under Netscape is shown in figure 4. The interface is composed by three columns, corresponding to the three types of commands that the user can perform: Video control and feedback, camera control (orientation and zoom) and robot control (position and speed).

The column in the middle includes the visual feedback, the control of the camera switch and the display of the status of the robot.

On the right column, two different control panels allow to send commands to the robot. The upper control panel allows to give displacement commands. By clicking on the graduation, it is possible to control the amplitude of the movement or of the rotation. The same type of interaction is used in the lower part, but to control the speed of the robot.

On the left column it is possible to control the orientation (pan and tilt) and the zoom of the external camera. Also in this case, the value is given by clicking on the graduation.

## 4 Virtual model

### 4.1 Overview

The virtual model of KhepOnTheWeb uses the same graphical user interface as the real KhepOnTheWeb. The images appearing in the camera view area look synthetic comparing to the ones coming from the real camera (see figures 4 and 5). The Khepera status is not reported since the interaction between the simulated robot and the user is very fast.

The HTML page contains a VRML scene (namely, `KhepOnTheWeb.wrl`) appearing on the center of the page and three Java applets: one on the left hand side (external camera control), one on the right hand side (robot control) and one in the middle below the VRML scene (switch between cameras). The applets display the same images as the ones displayed in the real KhepOnTheWeb, so that the user interface is very similar to the first one.

### 4.2 VRML scene

The VRML scene was written in VRML2 using a simple text editor and the specification manual of VRML2. It includes the mobile robot Khepera defined as a VRML `Transform` and the maze featuring textured shapes like the logo plates set on its walls

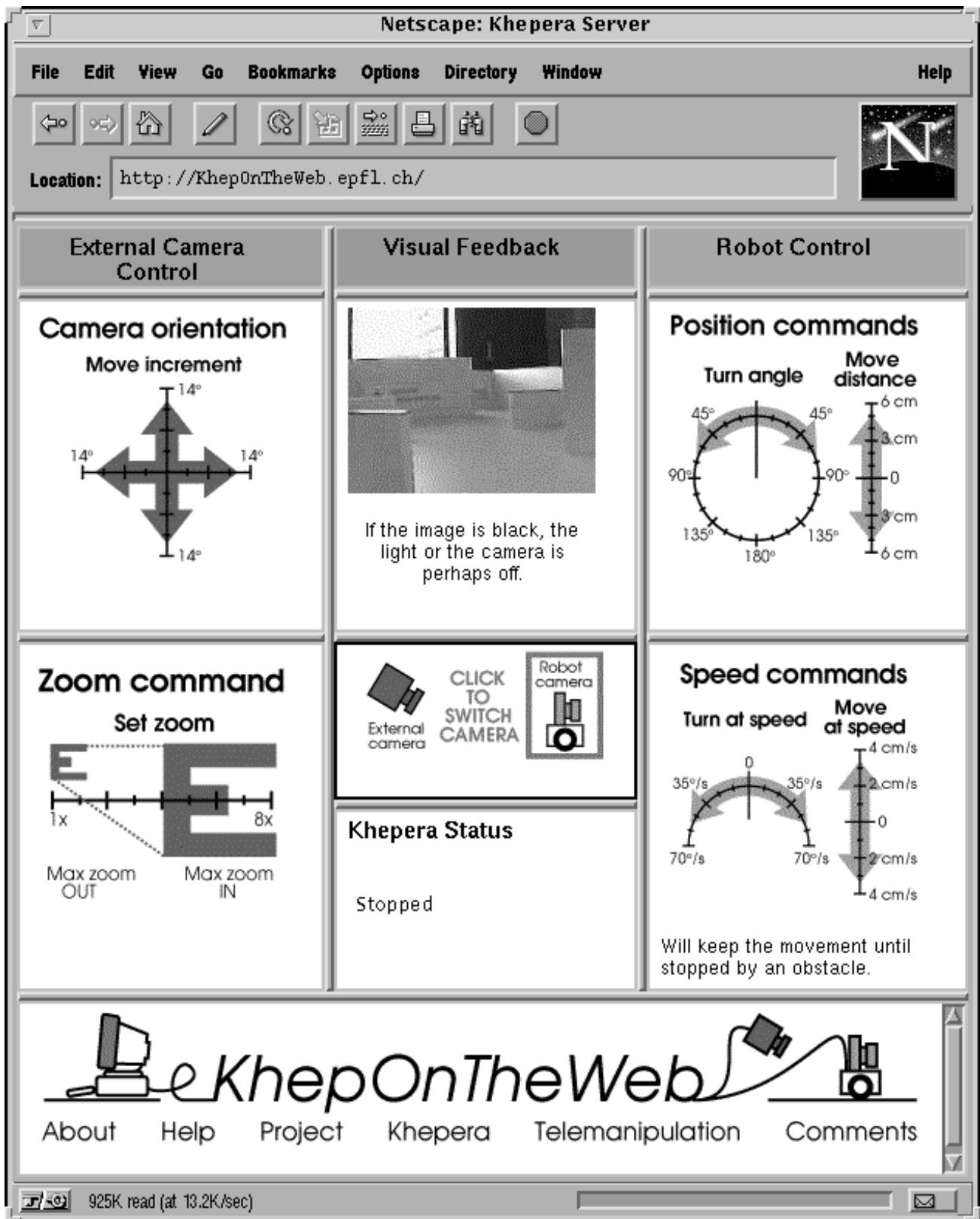


Figure 4: The remote control interface for the real robot under Netscape Navigator.

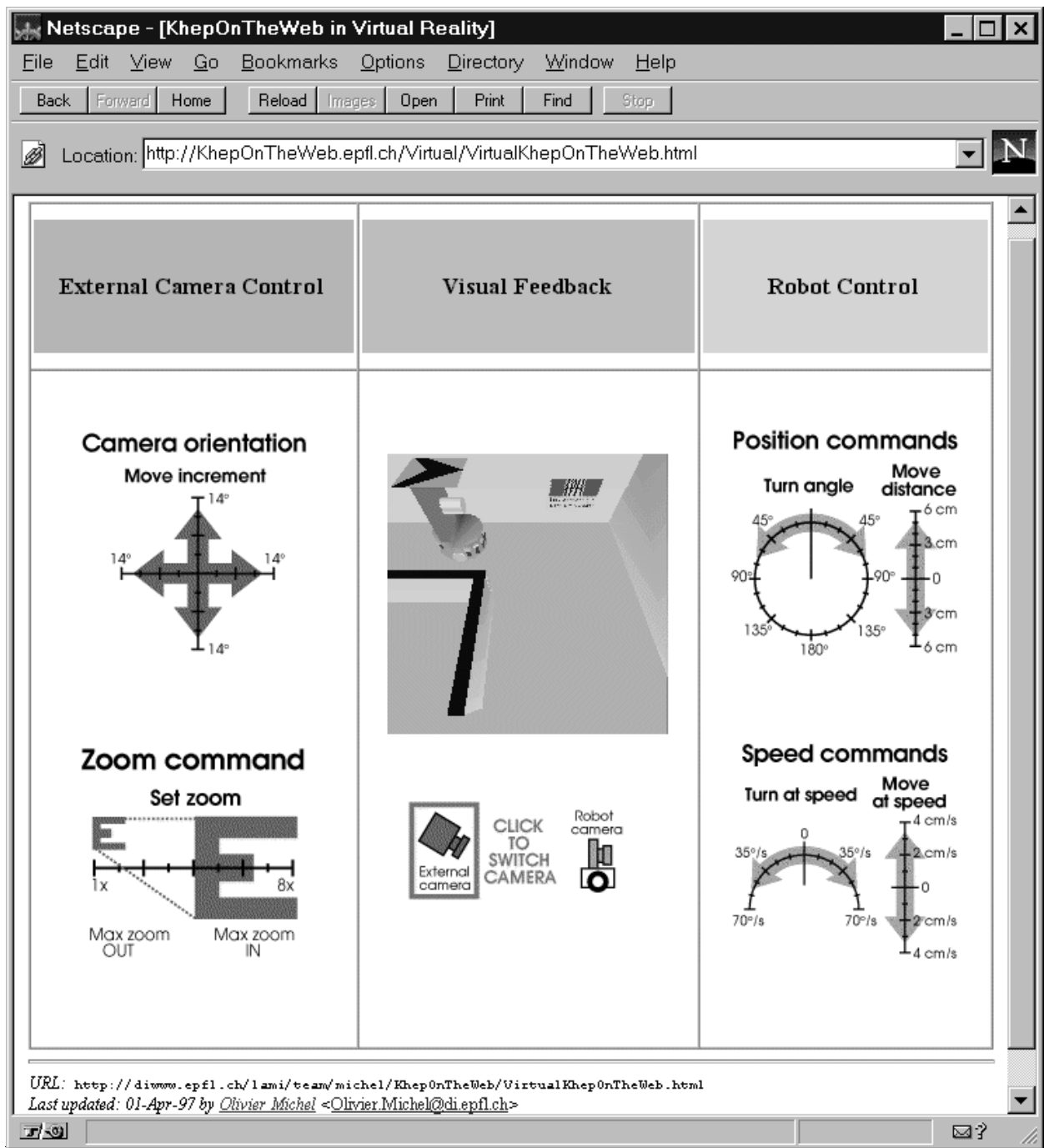


Figure 5: The remote control interface for the virtual robot under Netscape Navigator on a PC with Windows'95.

(LAMI, EPFL, IA and Khepera logos) as well as red arrows lying on the ground and indicating the inclination. Two view points are defined: one on the top of the scene corresponding to the camera above the maze and the other inside the robot itself, corresponding to the robot's onboard camera.

### 4.3 Java applets

Each applet receives click events from the user and sends VRML events to the VRML scene. Such an interaction between VRML and Java was made possible by using a special Java package (vrml external interface) available from the Silicon Graphics since January 21, 1997 at <http://vrml.sgi.com/moving-worlds/spec/ExternalInterface.html>. This package allows Java applets to send events to VRML nodes and also to receive events from VRML nodes. It works only with VRML2. Hence, to move the robot on the scene, the Java applet needs to send a `set_translation` event to the Group node corresponding to the mobile robot. Rotation is achieved by sending `set_rotation` events to the robot. Camera choices were made possible by sending a `set_bind` event to the View node corresponding to the camera the user wants to select.

Moreover, the use of a VRML2 time sensor allowed the simulated robot to run in real time. Such a time sensor is included in the VRML scene and sends events each simulation tick to the applet controlling the robot movement. Each event passes the current time with a high precision to the applet so that the applet can compute the new position of the mobile robot according to this time value. This approach provides an interesting advantage: the mobile robot runs on real time. In other words, a speed of 4 cm/s chosen by the user makes the robot actually move at four centimeters per second in its simulated environment, independently from the horsepower of the host computer. Of course powerful computer will provide a better image quality mainly due to a better frame rate. Some tests performed on a Pentium 166 showed a very nice fluidity in the animation.

In order to prevent the mobile robot from running through the walls of the maze, it was necessary to implement a series of tests. These tests check continuously whether the coordinates of the robot enter the forbidden areas corresponding to the neighborhood of the walls. Although VRML2 provide a number of sensors for the navigation into VRML scenes, we could not use them because they are relative to the current view: if the onboard camera is selected, the robot can detect collisions but if the external camera is selected, collision detection becomes impossible.

### 4.4 Implementation

Since VRML2 specifications were approved recently, very few VRML2 plugins and browsers are available at the time we developed the virtual KhepOnTheWeb. We used a beta version of the Silicon Graphics CosmoPlayer available for WindowsNT and Windows95. The vrml external interface package (also very recent) is only supported by Netscape Navigator. Hence, the only systems on which the virtual KhepOnTheWeb can be experienced are WindowsNT and Windows95 (and possibly Silicon Graphics Irix, but we didn't test it) running Netscape Navigator with the CosmoPlayer plugin. Since all components are available for free and Windows systems are widely used, a large public can access the virtual KhepOnTheWeb. Anyway, it is expected in the near future that the new technologies we used are going to be supported by an increasing number of systems.

### 5 Early feedback

This interface and this set-up are not really the first we have tried. We have started in 1995 developing a control interface based on a videoconferencing software. This first attempt gave interesting results, but the software was running only on Macintosh, and this was a major disadvantage. We tried some other solutions before coming to a pure Web interface, and this last solution seems to have many advantages:

- Netscape is a very standard software available on many machines. At the moment of writing this article, Explorer do not support the push server necessary to send the video feedback.
- The graphic possibilities and the interactivity on an HTML page are good, and the use of Java remove all limitations.
- Despite the heavy approach of continuously sending complete images to the client, the performances are interesting.
- The availability of a virtual reality model makes the set-up easier to understand by novice users and allows experiments to be prepared in virtual reality before accessing the real robot.

Once decided to have a pure Web interface we have started to program and build the environment. The first results were interesting at the technical level, but the reactions of the first users have been very bad, due to the interface available in this first prototype. Many experiments on new users have been made at this stage to understand their needs and to define a better interface. The result of this definition, merged

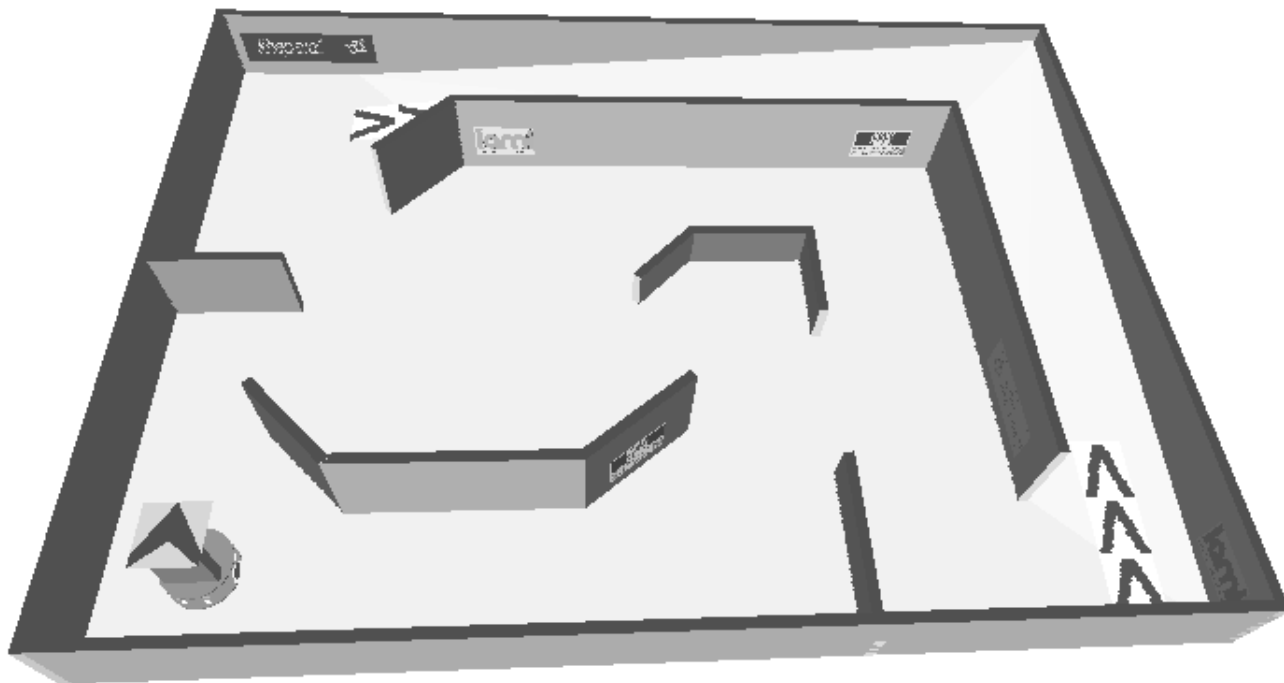


Figure 6: A view of the VRML scene including the robot and the maze.

with some technical limitations, has given the interface presented in figure 4. The use of colours, not visible in this paper, helps also to associate the right control panel with the right operation. Finally we have spent more time on the design of the interface than in all other engineering parts. In order to simplify the understanding of the system, the same user interface was chosen to develop the virtual reality model of KhepOnTheWeb.

Although the virtual implementation of KhepOnTheWeb could never replace the real experimentation, it turned out to be much more interactive than the real one. This property comes from the fact that every component of the virtual KhepOnTheWeb is downloaded and executed on the local host. Hence, once everything is downloaded (i.e., Web page, Java applets and VRML scene), the user gets a very high execution speed depending only upon its computer horsepower and not upon the network performance. This very high interactivity makes it easier for novice users to discover the features of KhepOnTheWeb. Moreover, it also provides a powerful tool for preparing real experiments.

## 6 Conclusion

The server is open to public access on the Web at the following address: <http://KhepOnTheWeb.epfl.ch/>. Both the real and the virtual set-ups are available from this site.

The experience accumulated in our first tests shown some important aspects. Such a physical environment is technically feasible with commercial parts. Everything, from the robot to the camera, from the server to the frame grabber, are very standard commercial products. Moreover, it is very likely that the virtual reality technology used here is going to become increasingly widespread on the Web and hence very accessible. The real problem comes from the fact that Web surfers often prefer to “click and wait” than to “read and click” ; hence, it is very difficult to introduce a complex set-up. A great effort has to be made to build a user friendly interface, very intuitive and without the need of complex explanations. Nowadays, the software engineers must be able to create good quality control panels and visualisation tool, but also to provide simple interfaces and strong interactivities in order to make their softwares appreciated by the end users and finally used! The Web is going to be more and more used by industrial designers looking



for productivity and demanding more and more interactivity. This is an important aspect that we will take into account in our further developments.

In addition to the features presented here, the next set-up will allow to program and monitor every action of the robot. Moreover new simulation tools allowing an easy circulation of robot controllers over the Internet could serve as a basis for designing a standard protocol for networked mobile robotics.

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