

3D MAPPING FOR MOBILE ROBOTS USING INTERACTIVE VIRTUAL WORLDS AND INTERNET TELEOPERATION

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Abstract: In this paper we intend to recreate an interactive 3D virtual version of the real environment of a mobile robot and to ensure a bi-directional interaction with all the components of this workplace. This IVW (interactive virtual world), automatically built using VRML combined with Java, is actualized on line with 3D models of the objects present in the real workplace. Internet interaction between any remote operator and the IVW is ensured by a Java based virtual interface and may be used, as well to teleoperate the robot. The presented approach is applied to PIONEER 2 and LABMATE mobile robots.
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1. INTRODUCTION

The experimental equipment that supports research or undergraduate and graduate programs in Robotics is quite expensive and scarce in Mexican institutions or in some other countries in the region. A way to use the available equipment more efficiently is to have access to a given real robotics laboratory through Internet, a powerful communication tool available everywhere capable to provide as many *virtual clones* as needed concurrently. So several users could be working inside the robotics laboratory at a given time. Is in this context that we are developing the Virtual Robotics Laboratory (ROVIR project).

1.1 Internet Robotics

Internet Robotics is a new developing area where a lot of works are appearing in specialized congresses and magazines. In this context, Internet teleoperation and VW for manipulators and mobile robots have a great interest. Chelali (2001) presents some virtual reality tools for Internet Robotics to perform robot teleoperation through Internet. Two different control interfaces to teleoperate one of two available robots are proposed. The first one permits to teleoperate the environment through a graphical web based interface, using mouse or keyboard. The second one uses a dataglove. The main problem solved in this work is that the Internet bandwidth is not enough to get TV images in real time. To avoid this problem, the real environment is monitoring through 3D virtual geometrical models, which parameters are calculated remotely from the TV images and they are sending to the user via Internet.

A navigation interface for mobile robots is presented by Newman and Leonard (2001), which allows to build maps from a large scale unknown environments while that map is used concurrently to navigate. With this interface the robot is teleoperated and can be moved into the map. Because the environment is always changing the map is actualized online. At the end of the teleoperated navigation, the robot has created a large-scale map of the environment as complex to be. Moreover, the followed path is memorized and, using the map, the robot can go anywhere, by example, it can come back to its initial position automatically. There is a problem when the robot comes back by the same path: if an object is blocking the way, the robot will collide with it.

1.2 Mapping for mobile robots

We call "mapping" to the problem of generating 2D or 3D geometrical models of a mobile robot's environment based on a stream of measurements from on-board sensors. The goal of mapping is to define the location of targets or obstacles in a global frame of reference. To generate consistent maps of large-scale environments, the robot also have to solve a concurrent localization problem, which arises because robot odometry is far to be error free. Mapping is a simple problem if the robot's location is known; localization is not a hard task if a map is readily available; but map-based positioning, the problem combining both, mapping and localization, is hard. Map-based positioning requires the existence of enough stationary and distinguishable features in the environment; accurate sensors and the availability of significant processing power (Thrun, 2000) (Iturbe, 2001).

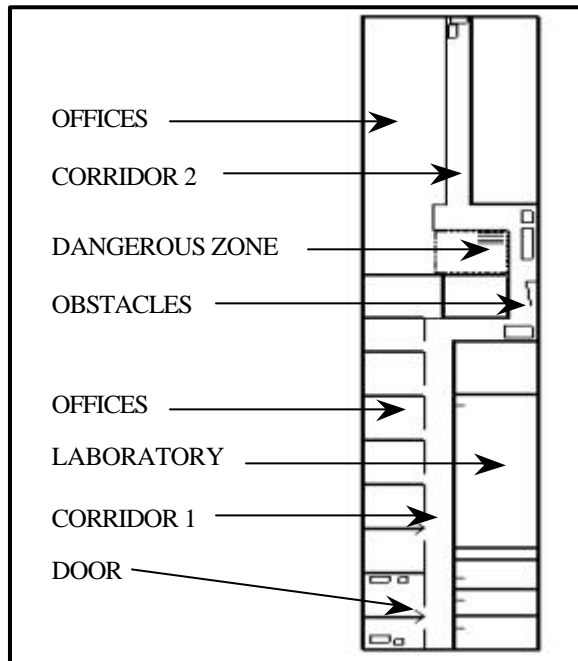


Fig. 1 Workspace of the PIONEER 2 at CINVESTAV.

1.3 Problem treated in this work

Here we present the development of a prototype for the Internet teleoperation of mobile robots to automatically generate a 3D map of the unknown environment, using information provided by its exteroceptive sensors: ultrasound and 3D laser. The 3D map is built using the VRML language to obtain a fully interactive virtual world (VW). The VW is used to monitor the robot's behavior and to "see" the robot's environment from a web page accessible via Internet, avoiding the need of TV images, characterized by a big bandwidth. The Internet teleoperation cope also with the well known mapping-navigation problem of the mobile robots.

1.4 Paper description.

In section 2 we present the chosen alternative to built the VW to be used as maps of the mobile robot environment. Section 3 is devoted to the use of information provided by exteroceptive sensors in the construction of VW using VRML. Section 4 shows the experimental results of our approach using a LABMATE mobile robot. Finally, section 5 is devoted to present some final comments.

2. WORKSPACE MODELING

Using on board sensors to obtain the 3D map of the mobile robot environment like an interactive VW is designed here as Workspace Modeling. The workspace modeling involves not only the considered environment but also the mobile robot it self. To model, to program and to teleoperate both, the virtual mobile robot and the real one, different languages to model virtual worlds in 3D can be used: Java3D, OpenGL and VRML.

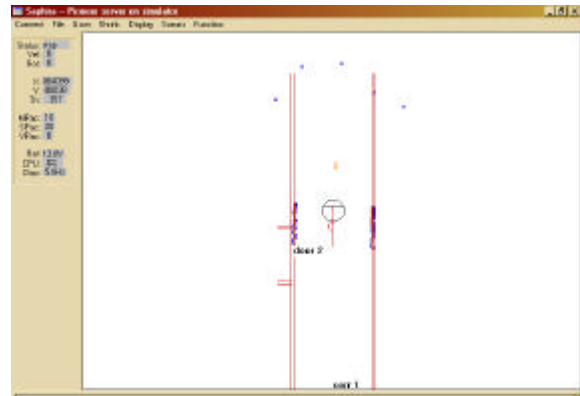


Fig. 2 Workspace reconstruction using ultrasound sensors to interpolate wall segments

VRML is a tool of very great help to create 3D VW, and very powerful to create all kind of virtual robots under WEB platforms, it generates small size codes easily that is quickly transmitted via Internet. Moreover, its great accessibility to manage an extensive variety of data types and linking with other programming languages (Java, Java *script*) allows us to enlarge the language and to manipulate the VW. Proof of this it is the great quantity of robots that can be found in the WWW, besides worlds that allow make the manipulation and teleoperation of real spaces through VW. The structure of VRML and its main characteristics can be found in several web pages (Sun, 1999; VRML, 1997).

2.1 Virtual Worlds using VRML

To create a virtual world (vw), first the real word elements to be represented must be defined, then put them into the computer represented by an appropriate graphical model. The representation of the mechanical parts using VRML is not too complicated: following the really simple language rules is enough. The interaction between the operator and the virtual objects is not a big problem, since VRML offers different kinds of logical sensors that allows the manipulation on the screen of the objects present in the workplace. To give some physical properties to vw like cinematic relationships or dynamical behavior of moving objects is more complex, specially to implement some interaction between the virtual world and teleoperation programs.

2.2 Interactive Virtual Worlds

We are able to manipulate the robot by means of both, Java *scripts* and Java applets. In Java *scripts*, we just program some kinematics restrictions, but the use of the Java applets allows the robust programming of the robot, besides we can program sockets to communicate the client user with the server. Sockets communication between the client and the server allows us to teleoperate the real robot, which is connected to the server computer. We can achieve also the VW update with the objects present in the real space, because the artificial vision system is also connected to the server.

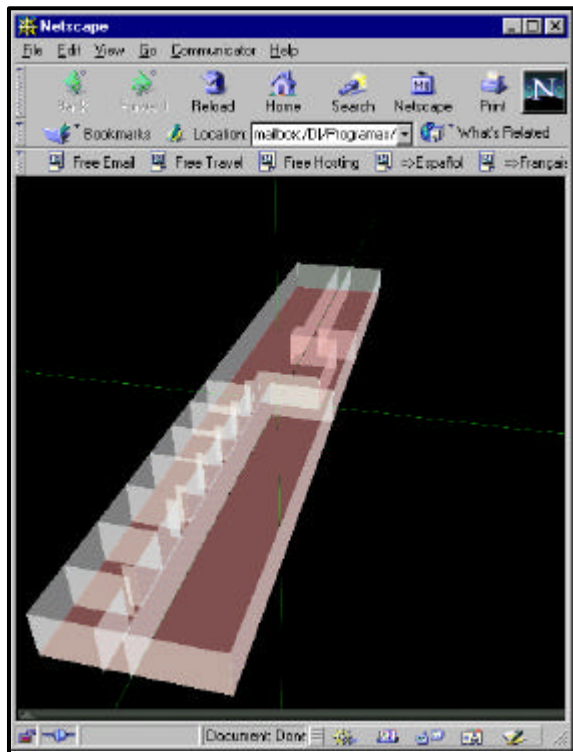


Fig. 3 Workspace reconstruction using VRML to represent interpolated wall segments

VRML allows the efficient creation of VW with good geometric representation, animation and even some one way interaction with an operator through computer monitor and mouse, based on VRML sensors. However, interactive VW needs a more complex communication functions for what VRML in its native form is so limited.

The VRML limitation is found when the VW must be manipulated with accurate values produced by other programs, or when object data is coming from the real world, as well as when we try to use in the real world data generated in the virtual one. In spite of its limitations, VRML allows to include Java *script* code in a program, which gives more flexibility to make some manipulations in the VW (Rohrmeier, 1999). To cope with the communication problem, a special Java *script* based interface called External Communication Interface (ECI) was implemented. The ECI allows the manipulation of the virtual world with real and precise data from another programs performing special robotic functions as teleoperation, monitoring and simulation systems (Zaldivar, 2001).

This VRML communication system was developed in Java in order to guarantee access to the virtual laboratory from anywhere using almost any computer platform. Internet access is made possible through Java applets.

A VRML virtual world is basically a tree, whose main node or *Browser* contains all geometrical and movement information. In this tree, each *children node* is a Java class modifiable from an external program, allowing behavioral online control of the VW elements. To reach the full two ways

manipulation of the VW from Java, the following steps must be performed:

- Get the VRML world in a Browser class object from Java program.
- Read, in a node class object, the object or object set containing node to be manipulated, wherever to be in the tree.
- Read the event to allow make the desired manipulation. This reading must be made in an EventIn/EventOut class object.

The proposed ECI system allows gather Java and VRML to get full interactive and bi-directional virtual worlds. In this way, several operations and programming interfaces of the virtual robot were developed. (Ibarra-Zannatha, et al., 2001b)

3. WORKSPACE CREATION

The corridors, some rooms and some labs of the Automatic Control Department building compose the considered workspace (fig. 1). Workspace's geometrical information is captured through the exteroceptive sensors of the mobile robot and used to reconstruct a 3D virtual version using VRML. These sensors may be used alone or in an integrated way based on some sensor fusion technique.

Despite of the sensor used, mobile robot's perception system produces geometrical information about the environment that must be transformed into a 3D VW using VRML. For example, in fig. 2 we show the geometrical information produced by the ultrasound sensors of the PIONEER 2 when it navigates along the corridors shown in fig. 1. Which is a constellation of points (x, y) representing the distances to present obstacles taken from the center of the mobile robot along the different axes corresponding to the ultrasound sensors of the PIONEER 2. Interpolating these points it is easy to locate corridor walls.

To rebuild the environment as a 3D virtual world based on VRML, we tried two methods. The first method places a unit cylinder in each one of the points belonging to the interpolated line representing a segment of the corridor wall. It is a very simple solution, it does not require complex algorithms nor long calculations; but displaying and navigating in this kind of VW requires the generation of an enormous quantity of VRML objects which reduce the speed.

In the second, the virtual world is built using entire walls calculated from the interpolated lines representing wall segments. Here, the effort involved in obtaining wall segments is bigger, because, instead of using the rough points obtained by sensors (ultrasound, laser, vision), one has to compute the size and position of the wall segment corresponding to the cluster of points under consideration. Fig. 3 show the VW based on wall segments corresponding to the geometrical information displayed in fig. 2, while fig. 8 shows a virtual world built using unit cylinders.



Fig. 4 Corridor image obtained by the tilt-and-pan camera mounted on mobile robot.

3.1 Realistic render

One can go further using the second method by applying the well know Kanatani geometrical transformations to produce three rectified images, one for each orthogonal projection through the correction of the perspective deformation of the objects present in the image. In the transformed projections all the objects appear without any perspective deformation, specially the walls and the floor of the considered corridors and rooms. Fig. 4 shows the original image of the corridor taken by the TV camera mounted on the mobile robot, while figure 5 shows the rectified right wall. This rectified image will be used as render in the virtual 3D reconstructed workspace of the PIONEER 2 (Iturbe, 2001)



Fig. 5 Rectified image of the right wall obtained by Kanatani geometrical restoration.

4. EXPERIMENTAL RESULTS

The reported results were obtained at the Robotics Laboratory of the University of Zaragoza, Spain, through a joint project with the Robotics Laboratory of the CINVESTAV, Mexico. The aim of this joint project, based on the LABMATE mobile robot, was to develop an interactive 3D virtual world working in real time, that let us represent maps generated by the exteroceptive sensors of the robot, in this case, a 3D

laser. The interaction between operators and the LABMATE mobile robot is ensured by a friendly Internet interface. The aim of the application is the VRML representation of the robot operation, to avoid the use of ambience TV cameras monitoring the robot behavior in its workspace, that would require a broad band great to those need in our approach, and that introduce undesirables delays. Another important motivation is the Internet control of the robot along its trajectory that facilitates its operation.

4.1 Platform description

The 3D-laser sensor gathers information of the environment, even when a program is executed on the robot. The operator sends movement commands to the robot, as well as requests of odometric information that informs of the position and current direction of the robot. This information is transmitted quickly because a great broad of band is not required because the data are represented by a few bytes. With this information the robot can be represented in the virtual world with real data. Actually, there is a problem, the information produced by the laser is very large and it can not be obtained in real time, except if we use a communication channel with a great broad of band. The system has been tested in the LABMATE mobile robot and it has shown a great efficiency in its operation.

The on board PC uses Solaris, a Unix like Operating System with TCP/IP access. Here, the main program running waits for the client connection and receives information from the environment, captured by the exteroceptive robot sensors, to command the robot movements.

The server is a SunSparc workstation, accessible through Internet, using Solaris as operating system. The access to this server is done via a web page that sends the Java applets to the remote client as Java applets. The overall computational architecture is known as client/server. This workstation operates as server to attend the remote client, and as client to be connected with the on board server, when sending or requesting the information that requires the client.

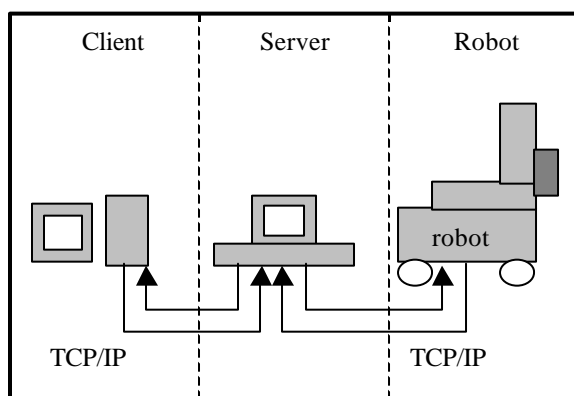


Fig. 6 Scheme of the three layer client/server structure used in the prototype

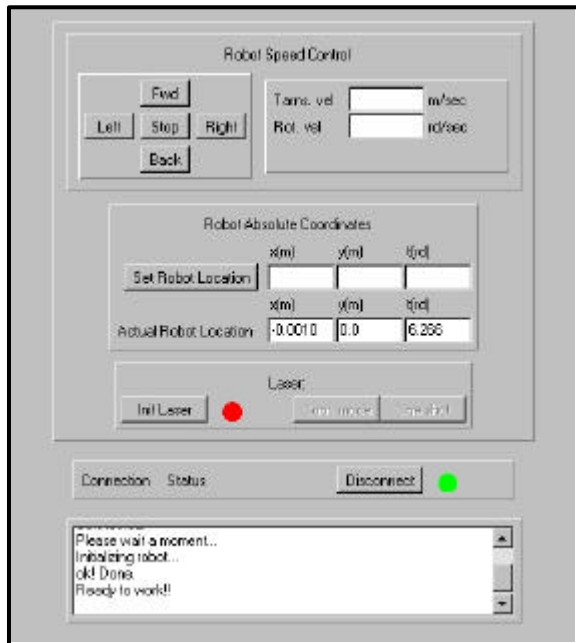


Fig. 7 User Interface for Internet Teleoperation.

4.2 Communication flow

The communication between the LABMATE and the operator is ensured by an interface programmed in Java based on the ECI (External Communication Interface) and published in a web page using html language. Fig. 7 shows the communication interface. The ECI was developed at CINVESTAV to cope with the problem of having a full bi-directional communication between a VRML virtual world and a Java (or C, C++, etc.) program. The access to this interface is made via Internet from any remote PC.

The SunSparc server considers the connection request of a remote operator (client) when the connection button is clicked. The acceptance of this request is sent by the server and displayed in the status window of the interface. Simultaneously, the SunSparc server is connected with the server program running in the on board computer. The LABMATE mobile robot is ready to be teleoperated.

The user interface allows the full robot operation. The client sends to the LABMATE movement commands on line, he can also, request odometric information to locate the mobile robot or to request environment geometric data acquisition, using the exteroceptive robot sensors (3D laser, ultrasound, vision), for the 3D workspace recreation.

When the operator sends a movement command from the user interface, a request is sent to the SunSparc server. Then, the server sends the movement commands to the LABMATE producing the corresponding movement. In the inverse sense, the robot sends the sensor information to the user interface through a *thread*. With this information, the interface automatically up-dates the virtual world.

When the operator request new geometrical data from the environment, the server activates the 3D

laser to generate 480 new points through a 240° scanning of the workspace. We can choose a single scanning or a continuous scanning. A package with 480 points (angle and distance) is sent by the robot to the user interface to actualize the virtual world corresponding to the reconstructed workspace.

4.3 3D Virtual World

The interactive virtual world (VW) corresponding to the LABMATE mobile robot and its environment is easily programmed. The robot must be at the position corresponding to the odometric information coming from the Java applet. The virtual robot was programmed as a main *node* with some fixed *children* and some variable children created in real time. The last nodes corresponding to the 3D-environment model obtained by the 3D laser, that generates 480 different points in each scanning.

In our prototype we have two options to create the variable *nodes*. That the Java applet creates this *nodes* implies 480 communications between the teleoperation interface and the VRML virtual world. If this applet sends simultaneously the 480 points to VRML, the most time consuming process is optimized, but VRML must perform the dynamical creation of the variable *nodes* or *children*.

When the 3D laser information arrives to the user interface, for each of the 480 points a cylinder, whose radius and height was previously chosen, is added to the virtual world. Fig. 8 shows the reconstruction of a given environment.

5. FINAL COMMENTS

An Internet teleoperation system coupled to a system to create automatically 3D VW was presented. One of its main features is the use of the environment geometrical information acquired by exteroceptive sensors to build the VW. Moreover, the robot autonomy and the use of a vw to monitoring the robot behavior cope with the known effects of the Internet delays.

The VW is built with VRML and that ensures the bi-directional communication with any kind of Java or C++ program by the application of the ECI, specially developed to build fully interactive VW.

The presented solution copes with the mapping-navigation problem, because navigation was replaced by an Internet compatible teleoperation interface.

Real time generation of the 3D map as a VRML virtual world allows the on line monitoring of the robot to avoid collisions during its Internet teleoperation.

We can use any kind of exteroceptive sensor to obtain geometric information from the robot environment to recreate the virtual 3D map: ultrasound sensor (PIONEER 2) or 3D laser (LABMAT). Realistic render based on Kanatani geometric transformation is used in the reconstructed VW. It can

be used, also, for obstacle modeling to up-date the VW with the obstacles encountered by the LABMAT.

Actual works are performed to introduce Internet 2 to widen the available bandwidth in order to allow real time control and monitoring. In the actual prototype, the walls encountered in the robot environment are modeled with some geometrical distortions, because the laser measurements are made when the robot is moving. Then, we will need to perform some correction algorithm to compensate the effect on the laser measurements due to the robot movement.

Implementation of dynamical models and control algorithms using our ECI communication system will permit the use of the virtual laboratory to perform not only vision and programming practices but also control practices.

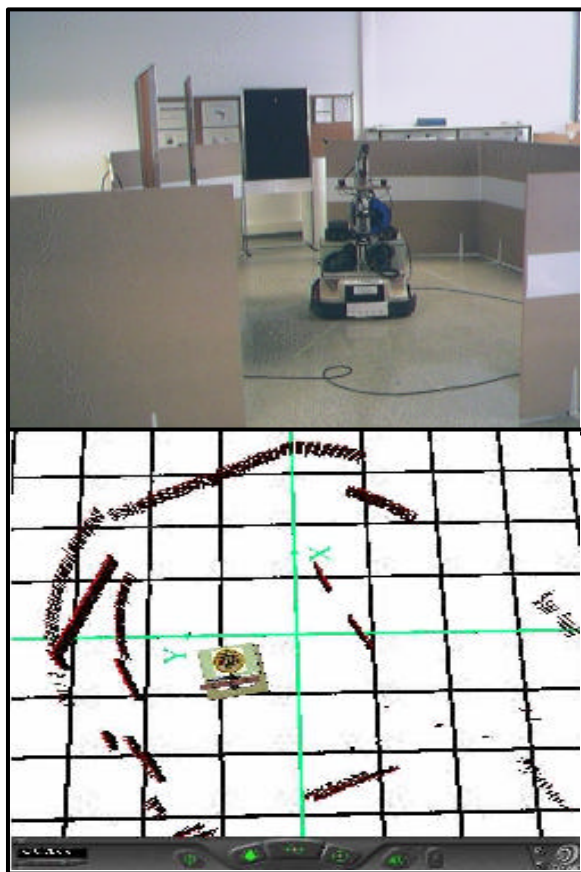


Fig. 8 VRML virtual world corresponding to the reconstructed workspace.

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