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FIELD VEHICLE TELEOPERATIONS SUPPORT BY VIRTUAL REALITY INTERFACES

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Abstract: Teleoperations of outdoor vehicles in hazardous environments is a traditional application area for tele-robotics. In this paper the application of Virtual Reality methods at the concrete application of the control of a remote mobile robot is addressed. The potential to provide a user friendly man-machine interface for the tele-operator by visualizing the sensor data obtained by the remote vehicle are investigated. Specific emphasis is here on navigation and control functionalities for mobile robots.

Keywords: Mobile robots, telematics, virtual reality, remote sensor data acquisition, computer simulation, path planning.

1. INTRODUCTION

Techniques for tele-operated robots have for more than 30 years played a major role in the context of space missions as well as in handling of hazardous materials. Unmanned, remotely controlled vehicles are often used for exploration and monitoring tasks in areas which are dangerous or unpleasant for humans, like deserts, deep sea, polluted or contaminated areas (T.B. Sheridan, 1992, M. Jamshidi and P. J. Eicker, 1993). With respect to control, concepts are to be developed to combine autonomous local control with telecommands from the remote operator (cf. Schilling and Roth (eds.), 2001 for an actual survey of such telematics applications). A crucial factor is in particular the bandwidth of the communication link. This paper addresses in this context the use of virtual reality methods to provide a user-friendly man-machine interface, visualizing the sensor data and using sensor data preprocessing to reduce the amount of data to be transferred.

Section 2 describes the outdoor vehicles used as the concrete example, the MERLIN rovers. The modelling of these vehicles in the virtual reality environment WorldToolKit is reviewn in section 3, while section 4 discusses the tele-operations of the MERLIN vehicles and the experiences from tests.

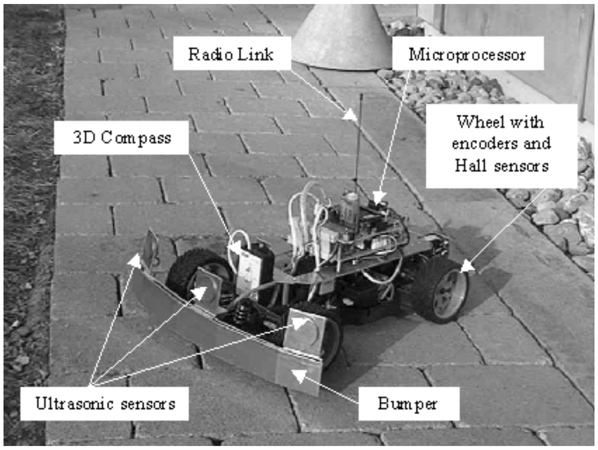

Fig. 1: The wheeled MERLIN vehicle equipped with standard sensors.

2. THE MERLIN ROVER

In the framework of the European Space Agency's Mars rover development effort MIDD (cf. Schilling et al., 1997), the MERLIN-vehicles (**M**obile **E**xperimental **R**obot for **L**ocomotion and **I**ntelligent **N**avigation) were initially developed as platform for outdoors sensor and navigation tests. There are tracked and wheeled versions of MERLIN.

MERLIN is based on a 40 cm long lightweight chassis and a suspension system, enabling to drive with speeds up to 50 km/h in outdoor environments (Schilling and Roth, 1999b). Due to its initial purpose, it can be easily equipped with different sensor configurations in order to characterize appropriately his working environment. Its standard sensor configuration includes

- odometry, to derive from hall sensors in the wheels by measurement of the wheel rotation and the steering angle an estimate of the current location and orientation,
- ultrasonic sensors, (3 in front, 1 in the rear) to measure distances to objects in the path,
- bumper in front, to initiate an emergency stop in case of contact.

Several other optional sensors have been integrated according to mission needs, such as

- gyros for orientation profiles,
- 3-D compass, consisting of a compass for the Earth's magnetic field and 2 inclinometers, to characterize the 3-dimensional orientation,
- GPS to determine the position in outdoor areas through the global positioning system,
- laser/camera active vision system for distance measurements to obstacles,
- camera to provide environment information to the teleoperator.

The on-board control algorithms are performed on a 16-bit microprocessor 80C167, which also coordinates the sensor data transfer via radio modem to a nearby PC. The aim in this project is to use these sensor data for tele-control purposes.

3. THE MODELLING OF THE MERLIN VEHICLE

From the sensor data position, location, and distances to obstacles are to be visualized to the teleoperator to allow him to assess the status of MERLIN in the working environment. For this purpose a model of MERLIN and the environment is to be generated. Among the various commercially available products to design virtual reality applications, WorldToolKit (WTK) was selected, due to its capabilities to overlay simulations with camera data (Franzen, et al., 1999).

3.1 Virtual Reality Modeling with WTK

WTK is an object-oriented development environment, designed to be used in *real-time* applications with frame rates ranging from 5 to 30 frames per second. There exists a library of classes and objects, which support the integration of the specific application.

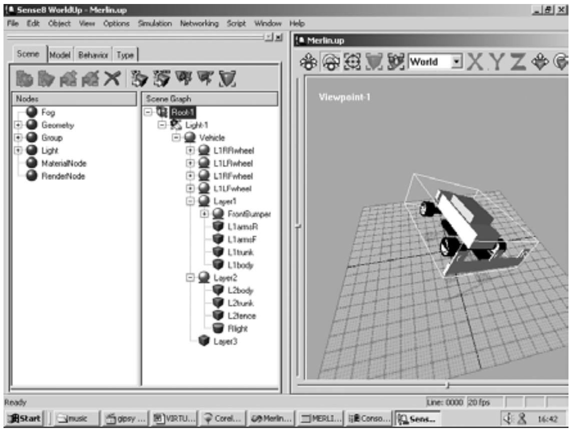

Fig. 2: The WTK virtual reality model of the MERLIN vehicle. On the left class components and their hierarchy are displayed.

In the context of this moving rover application are classes of particular interest, such as

Geometries. Predefined graphical objects such as blocks, spheres, cylinders, 3D text, etc.

Sensors. Manipulate object motion through connections to transform nodes, viewpoints, and movables nodes.

Paths. Allow geometries or viewpoints to follow predefined paths, these paths can be dynamically created, edited, interpolated, recorded, and played back in a variety of ways. A path is stored as a series of position and orientation records in absolute world coordinates. The more elements a path is composed of, the slower is the algorithm performance.

Tasks. Used to assign behaviors to individual objects, such as movement, change on appearance, testing for intersections, triggering other behavior, attaching sensors, etc.

Motion Links. Connect a source of position and orientation information with a target that moves to correspond with the changing information. Once a motion link is created, position and orientation records from the motion link source automatically cause corresponding translation and rotation of the motion link's target. If the target has more than one motion link associated with it, each of these motion links contributes to the motion of the target. WTK lets the user add control to a motion link so that the position and/or orientation of the motion link's target is constrained. This constraint can be added along any degree of freedom (DOF) or any combination of DOFs. The motion link source can be a path or a sensor. Motion link targets include: viewpoint, transform node, node path, and movable node.

User Interface (UI). Objects such as: toolbars, bitmaps, menus, message boxes, text boxes, file-request dialogs, are provided. When recompiled on another platform, the UI objects automatically change to match with the new operating system.

The simulation loop is the heart of a WTK application, the loop is played once every frame updating the events in the following order: Sensors are read, the universe's action function is called, objects are updated with sensor input, objects perform tasks, paths are performed in steps, the universe is rendered. The user can alter this order. WTK does not provide automatic means for terrain following, but provide the basic functions with which the user can write costume algorithms for this purpose.

3.2 Path Planning and Following

All the data from the MERLIN sensors, addressed in chapter 2, are collected in real time and sent to a PC through a radio link. There are algorithms to plan a path, which MERLIN will try to follow. In a second step, the path Merlin really follows is to be derived from the sensor measurements and is displayed to the teleoperator.

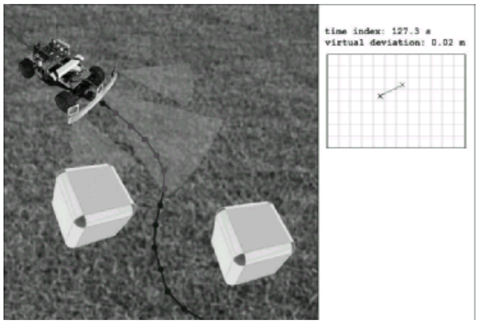

Fig. 3: Visualization of the planned path, MERLIN should follow, the beams of the ultrasonic sensors and the position of already detected obstacles on the teleoperator screen.

The user can by definition of via-points in a graphic user interface define a *theoretical path*. This is to be compared to the *real path,* the path that the Merlin hardware finally performs. In a virtual reality application it is straightforward to embedded a virtual model of MERLIN made with a VRML modeler in a virtual world, and display both types of paths to the teleoperator to assess the deviations (cf. Fig.3).

3.3 Behavior Characterization

Every sensor in Merlin has been separately calibrated before it is being integrated, and deviations from ideal performance are recorded for each individual sensor. The accumulated effect of deviations determine the vehicle's behavior which can be characterized in two ways:

- analytically/numerically based on characteristics of sensor errors and types of obstacles/environments, which is a difficult approach with real-time processing requirement;
- experimentally, through the construction of a behavior library by a virtual reality application.

For generation of such a library it is necessary to decompose or classify all the possible valid environment elements. Environment elements can be further classified into path elements, and obstacle elements. A valid element should show a single geometrical feature that it is not contained in any of the other elements; therefore it constitutes a building unit to produce complex elements. This brings the advantage that only the behavior correlated to unit elements has to be characterized, since the reaction to more complicate environments can be obtained out of the composition of the behaviors attached to the single constituent elements, due to the linearity of the problem.

Once the environment elements are defined, they can be implemented in a virtual world, and a virtual application can be tailored to automatically construct the behavior library. This application can successively download an environment element into the virtual world, and through the *path processing*, *Path Planning and Following*, it can determine experimentally the behavior of MERLIN in order to generate the *final path*. This two pieces of data (*theoretical element environment*, *deviation*) form the content of the entry for the specified element. The behavior library will consist then in a table with as much entries as the number of different environment elements defined, with the two values per entry described.

3.4 Behavior Prediction

Once the behavior of the vehicle is completely characterized, then it is possible to predict by simulation how it will behave in a given environment. Thus the teleoperator can anticipate from the simulation what kind of effects could occur during operations in unknown environments.

To do this, first it is necessary to generate an environment where Merlin will be placed, this environment can be built with a 3D geometry modeler, possibly based on data obtained from real environments, for example, out of topographic data used in cartography, data from RADARSAT, etc.

In the new environment, the user can define a theoretical path, and the virtual reality application can decompose this path in a concatenation of successive environment elements, as defined in the previous section, *Behavior Characterization*. Then it is straightforward to set up the behavior of the virtual Merlin in accordance with the *Behavior Library*, thus every environment element traversed will define the behavior Merlin displays during the simulation.

4. THE TELE-OPERATIONS SCENARIO

In the overall tele-operations scenario, as displayed in Fig. 4, the virtual reality approach described before is introduced at two areas

- as a comfortable user-interface to the human teleoperator, supporting planning by predictive simulations and by visualization of deviations between planned and measured activities.
- by reducing the data transfer rates on the telecommunication link, when preprocessed virtual reality inputs are transferred, and not sensor raw data.

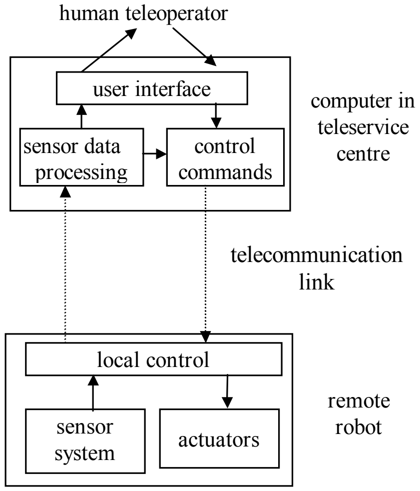

Fig. 4: The information flow between teleoperator and remote robot.

While the first point concerns the quality of the data presentation to the tele-operator, the second point can reduce through data compression the requirements for the telecommunication link.

This tele-operations scenario is currently intensively applied in tele-education, where students tele-operate via internet experiments with real hardware in laboratories of the world-wide partner universities (cf. http://www.ars.fh-weingarten.de/team , http://www.ars.fh-weingarten.de/iecat , Schilling and Roth, 1999,).

The software has been realized by JAVA servlets and applets (Schilling, Roth and Rösch, 2001). Thus on the client's side, the site of remote teleoperator, only a standard web browser needs to be available. The server is implemented on a UNIX-computer, a standby server is available, if continuous service is required. The video streaming and chat facilities can be run on separate machines for safety and performance reasons.

5. CONCLUSIONS

The integration of virtual reality techniques in the design of a teleoperator user interface is supporting the interpretation and visualisation of remote sensor data. Simulations to predict future events can be integrated, and deviations between planned and measured characteristics can be graphically displayed. This system was applied in the concrete application for tele-operations of the mobile robot for outdoor environments MERLIN. Nevertheless the application range for supporting the provision of services at remote locations is much wider. The progress in telecommunication and information processing technologies offers now an infrastructure for provision of telemaintenance and telediagnosis services with an enormous economic potential in the area of automation technology.

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