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HAPTIC INTERFACES FOR REMOTE CONTROL OF MOBILE ROBOTS

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Abstract: Force feedback from a mobile robot to a remote control enlarges the sensoric capabilities of standard teleoperation approaches. In existing applications images and sensor data are displayed to the remote user. With additional force feedback, not only visual but also haptic interfaces are used to provide input to the teleoperator in order to improve remote control performances. This paper describes the hard- and software implementation for controlling a mobile robot over the Internet by the use of a force feedback joystick. *Copyright © 2002 IFAC*

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Remote Control, Mobile Robots, Force Feedback, Sensors, Distributed Control.

1. INTRODUCTION

Modern telepresence systems try to include auditory and haptic senses in addition to visual data to provide input information to a human teleoperator. This active area of research in remote control addresses integration of multimodals sensory inputs, time delay effects, and combination with autonomous control reactions. In such multimodal teleoperation systems the haptic interface comprises kinesthetic and tactile, possibly even temperature feed back. In this paper the realization of such a direct mechanical interaction to a human teleoperator for the example of remote control of a mobile robot is analyzed (Schilling, *et al.*, 2000).The remote control of mobile robots is very helpful for operation in dangerous environments (Schilling and Roth, 1999). Such applications are also used for the military and in the desert for exploration. Force feedback from the mobile robot to the operator provides feedback to the operator.

2. HAPTIC INTERFACES FOR REMOTE CONTROL OF MOBILE ROBOTS

The subject of this paper is an experiment to control a mini-rover over the Internet (Lederman, 2001; Overstreet, 1999). A force sensor is fixed on the front of the car. This enables force measurement if the car pushes against an obstacle. The control of the car is based on feedback and gets directed with a joystick. Sensors attached on the car are connected to the inputs of a micro controller. Pulse width modulation output is used to control the motors for the drive and steering angle.

The MERLIN-car (Mobile Experiment Robot for Locomotion and Intelligent Navigation) is a 50 cm long remote control car. For wireless control of the car, it is necessary to use a radio link for communication between the car and the appropriate workstation, which is connected to the Internet, Figure 1. For this radio link, a second micro controller is used to connect to a computer. The connection between the workstation and the micro controller was implemented by the RS232 interface (serial port).

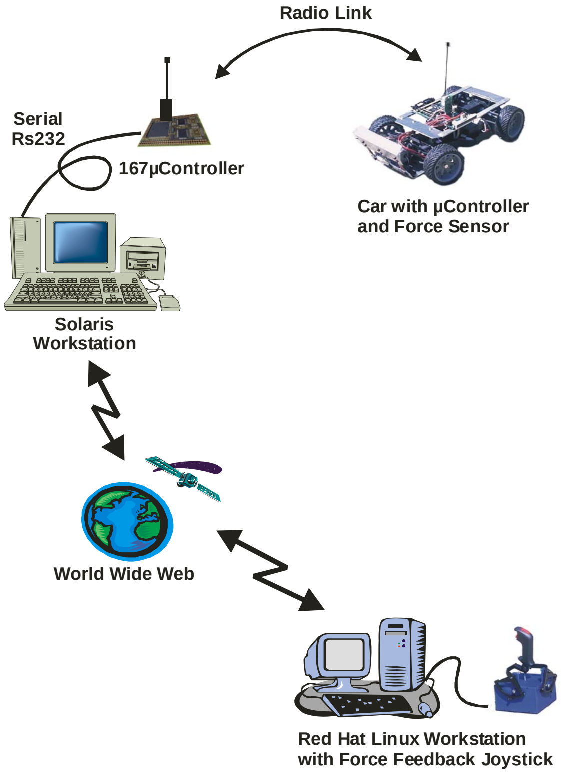

Fig. 1. Overview of the system

The data transfer over the Internet used the UDP Protocol. In contrast to the TCP/IP Protocol, no acknowledgement is given back of received data packages. This allows data to be transferred much faster. On the other side of the Internet, the operator receives tactile information through a force feedback joystick. Two built in motors apply torques in X- and Y-directions onto the joystick. A DSP board is included with the joystick to plug into a computer. As soon as the car hits an obstacle during forward motion, the force sensor output applies a torque to the motors in the joystick. The amount of force at the joystick is directly related to the force acting on the front of the car. If the car is standing on a steep hill and moves without applying current to the drive, a force is also given back, so that the operator can recognize the movement of the car.

The wheels of the car can spin on a slipping surface, therefore the velocity of the front wheels has to be measured and compared to the applied current to the drive. These measurements have to be used also to calculate the force feedback for the joystick. With all this measured sensor data, a sensor data fusion has to be done in order to calculate the force, which will be applied to the joystick.

3. VEHICLE DESIGN:

3.1 Chassis

The selection of a chassis for the mobile robot was an important task. The maximum payload which has to be carried is around 5 kg, which includes a micro controller, sensors, batteries and the radio link. A wide selection of chassis options is available through the huge offering of remote control cars in local stores. The selected chassis of the vehicle is made of ABS plastic; it is nearly unbreakable, very stiff and will not bend upon impact with an obstacle or when carrying a large payload. The stiffness of the suspension struts can be varied or different springs can be built into the suspension of the car, allowing even more load to be carried. The reason for such a high load is that the batteries are quite heavy and should last a long time. With a wheel diameter of 10 cm and a high ground clearance, the car can easily drive around outdoors with its differential drive. A picture of this car can be seen in Figure 3 (Salleh, *et al.*, 2000; Schilling, *et al.*, 2000).

3.2 Odometers

Hall sensors were chosen for distance measurement in the wheels. Infrared sensors experience too much interference from ambient light, especially in outdoor exploration. For this reason the hall sensors are a more reliable solution. They will be triggered by small magnets. The hall sensors that were used have a Schmidt trigger included, which is quite convenient, as shown in Figure 2.

Fig. 2. Wheel with odometers

Their signal can be connected directly to the digital input of the micro controller. Small magnets are glued into the rim of the wheel to measure the rotation speed of the tires. With 8 magnets per rim, the resolution is about 4 cm in the cars linear travel between magnets. Two hall sensors are fixed on each front wheel for detecting the robots direction.

3.3 Radio Link

Different radio links can be used for the data transfer between the workstation and the car. A trade study was performed between the following approaches:

Bluetooth is a technical innovation in the filed of wireless communication, but implementation issues make it unsuitable for this application. With the available development kit only a point to point connection was possible. For later interaction between different mobile robots, this system would not be applicable. The average current consumption is around 30mA and the range is only 10 meters. DECT devices that are mainly used in wireless telephones were also considered. Its range of about 300 meters is very good, but the current consumption is much higher than with the Bluetooth radio link.

A Radio Package Controller (RPC) was finally chosen. The average current consumption is only half that of Bluetooth. This RPC is an intelligent transceiver module, which enables a radio network/link to be simply implemented between multiple digital devices. It is a self-contained plug-in radio port, which requires only a simple antenna; 5V supply and a byte-wide I/O port on the C167 host micro controller. The module combines a UHF radio transceiver and a 40kbit/s packet. The reliable range indoors is around 30 m, and outside, 120 m. The module provides all the RF circuits and processor intensive low-level packet formatting and packet recovery functions required to interconnect a number of micro controllers in a radio network. A data packet of 1 to 27 bytes downloaded by the C167 micro controller into the RPC's packet buffer is transmitted by the RPC's transceiver and will "appear" in the receive buffer of the RPC. A data packet received by the RPC's transceiver is decoded and stored in a packet buffer. The host micro controller is then signaled with an interrupt that a valid packet is waiting to be uploaded. All the received bytes get transferred one by one to the microcontroller, for further processing.

3.4 The Haptic Control System

The haptic control system consists of different hardware components designed to provide feedback to a remote teleoperatic user (Lederman, 2001). The designed force sensor is a two-way full bridge strain gauge, glued on a 0.8 mm thick steel plate, which measures the deflection of the plate. The output voltage of the strain gauge is between 1 and 10 mV. An instrumentation amplifier is used to amplify the signal on to a range of 0 to 5 Volts. This signal experienced interference from both the robots radio link as well as the drive motor. Therefore a shielded box for the amplifier and shielded wires were placed close to the sensor to reduce the noise of the sensor signal.

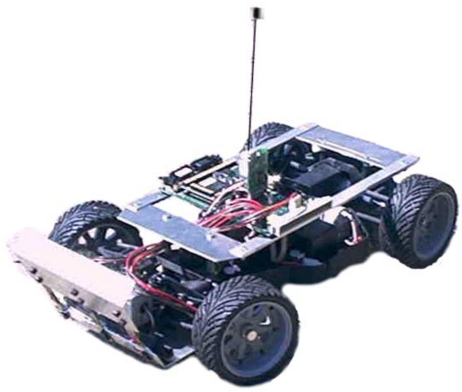

Fig. 3. Mobile robot with the force sensor

3.5 Telematics Software

Three distributed programs are used for the force feedback control of this mini rover. The client program controls the joystick and is in communication with the server, which is responsible for the data-transfer between the joystick and the robot, Figure 4. For local control of the robot, the onboard micro controller runs proprietary C code (Salleh, et al., 2000; Schilling, 1997).

The joystick is equipped with a PCI interface board for a high data-rate transfer between the client computer and the joystick. A C++ interface was developed to give fast and easy access to the board.

On the server side a radio link handles the communication between the server (Solaris workstation) and the mini-rover. The data transfer from the workstation to the radio link is handled by the serial port. The maximum reliable data transfer rate with this radio is around 8 Kbit/s. The bottleneck is mainly the Internet and not local limitations on data transfer rate, especially since in this application the amount of data is very small.

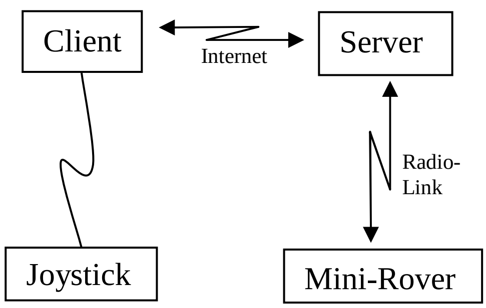

Fig. 4. Telematics software

Platform independence was not important, because the joystick on one side as well as the robot on the other are unique devices. Therefore installation of a program should pose no problems. For the micro controller, the comfortable ANSI C language was chosen instead of assembly.

Data transfer over the Internet between the Solaris workstation and the client PC is done by socket communication over the Internet with the usage of the "User Datagram Protocol". Two threads in the main program handle the transfer of data packages independently over the Internet.

A cross-compiler was used to create hex files for the C167 micro controller. Interrupt service routines are used for receiving and sending data packages over the radio link and also to calculate the speed of the car by the hall-sensors. The X- and Y-coordinate values from the joystick are transmitted directly to the car. After a conversion, they are assigned to the pulse width modulated output of the micro controller. The force value, current of the motor, velocity of the car and driving direction are sent back to the Solaris workstation. From there the force for the X- and Y-direction of the joystick are calculated and transferred over the Internet to the joystick.

3.6 Force Feedback Calculation

The force for the joystick has to be calculated from the values of the strain gauge force sensor, the velocity of the car and the motor current from the drive (Buss and Schmidt, 1999; Preusch, *et al.*, 2001; Rösch, 2000). For this task, rules are used which can be found in fuzzy controllers. These rules include the movement of the car when no current is applied or when the car is slipping on a wet surface. Also, if the speed of the car is very high, the user can feel a stronger resistance due to air-resistant and friction, than at a low speed.

4. CONTROL ASPECTS

Since control signals are transmitted over the Internet, the problem of variable time delays has to be taken into account. Direct steering gets very difficult, especially if the camera image-stream has a different delay than the force feedback. If the delay is too big, a move and wait strategy is best at the moment. By adding more sensors onto the robot (distance measurement) it would be possible to make it more intelligent. For example the robot could sense obstacles and avoid collisions with them.

The remote control of the robot can be seen as a closed loop control, where a velocity and direction is given to the robot, and force/velocity is feedback to the control unit (operator). If the user is not touching the joystick, a controller keeps the joystick in the centre. Due to unbalanced links and a permanent change in the sliding friction on the joystick, two different control parameters are used, depending on the position of the stick. Figure 5 shows the output of the step controller; there the asymmetric force applied onto the motors of the joystick can be seen very well.

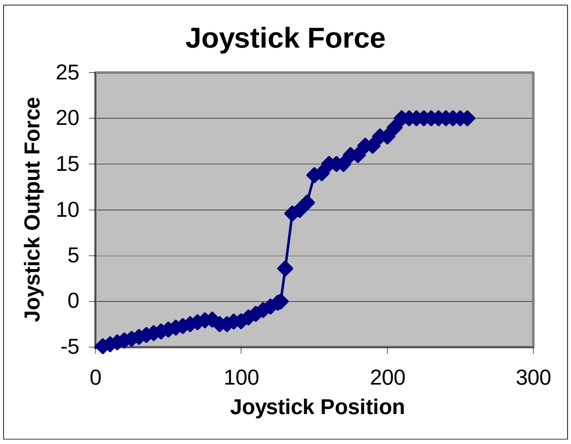

Fig. 5. Position control of the joystick

5. RESULTS

The system described has been implemented for use in haptic control experiments over the Internet. The feedback force on the joystick, allows the operator to sense the robots movement. This is accomplished by accounting for the values of the force sensor, velocity of the car and the current applied to the motor (Everett).

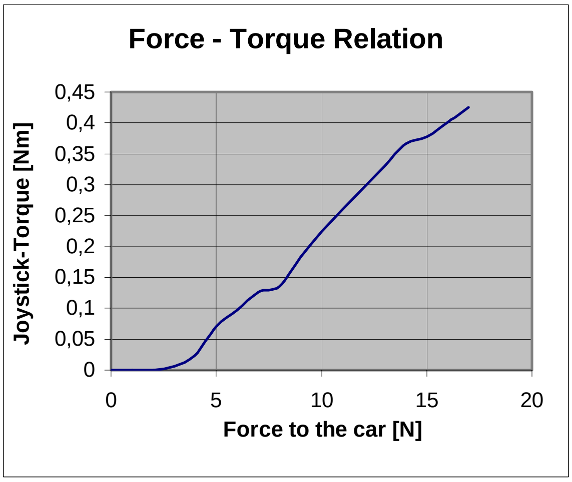

Fig. 6. Force - torque relation between the car and the joystick

The force of the car, when it hits an obstacle, is measurable with the designed strain gauge force sensor. The relationship between the measured force on the car, compared to the applied torque on the joystick can be seen in Figure 6. Two force sensors have been fixed on the car, which enable measurement if the car doesn't hit an obstacle at a 90° angle, Figure 7.

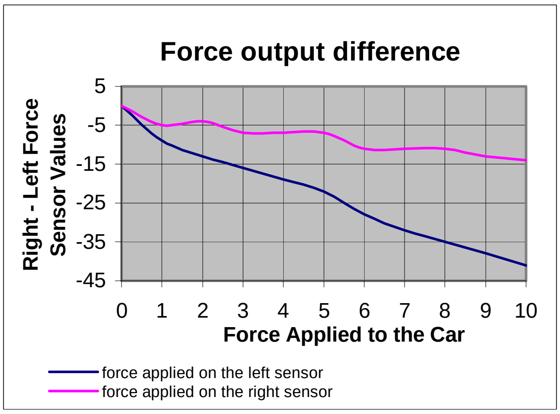

Fig. 7. Force output difference of the two strain gauge sensors

In order to convey a sense of the velocity of the car, Figure 8 shows the force applied on the joystick in relation to the velocity of the car. When a backward torque is applied to the joystick, the output values range from 127 when no torque is applied to 255 when the maximum torque is applied.

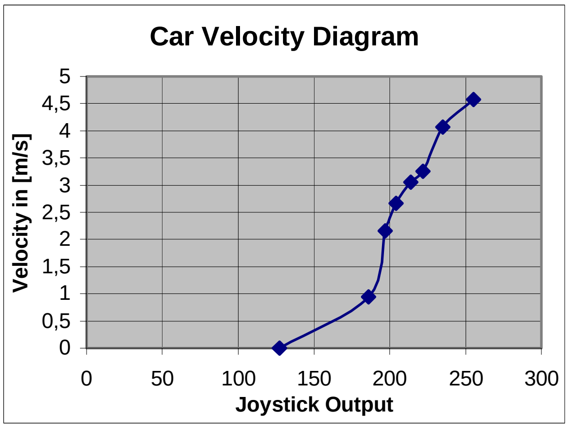

Fig. 8. Velocity of the car related to the joystick output

The chosen radio transceiver is a small, energy saving device. The data transfer-rate and large reliable range, even indoors, make this radio link a very suitable device.

The results from a test run of the system are shown in Figure 9. In this test, the robot was pushing a box placed on the floor. The robot was placed in contact with the box and began from rest. The force increased until the box began to move at which time the force decreased. When the car stopped, the force went to zero.

A cycle for one data package from the server to the car and back takes approximately 35 ms. If the server and the client are in the same subnet of the LAN, then no time delay is noticeable when the robot is controlled with the joystick. The measured time delay was between 80 and 110 ms from locations on different continents.

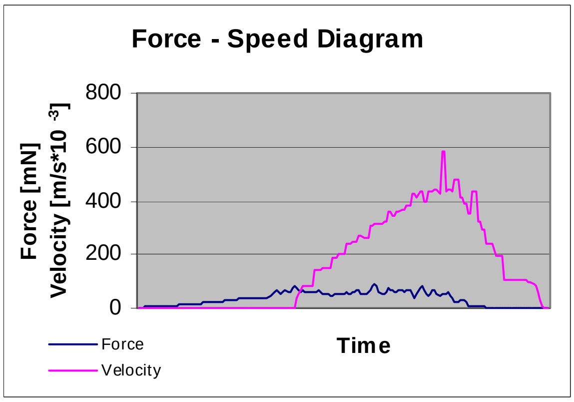

Fig. 9. Force – speed diagram

Mathematical descriptions of the rover as well as simulation models are in progress. Preliminary results can be seen in Figure 10.

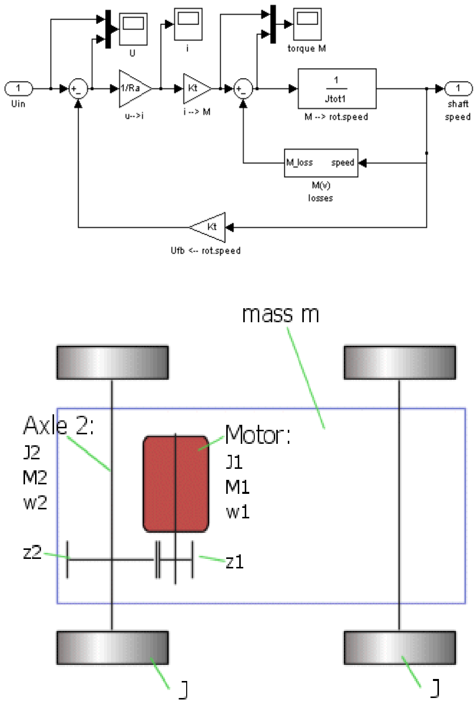

Fig. 10. Math model and simulation of the rover

Related experiments are being performed in conjunction with several international university partners in Europe, USA and Canada.

6. CONCLUSIONS

Mobile robots can be controlled with the use of haptic interfaces. With the mini rover, subjects can be pushed over the floor. The force given back to the joystick depends on the friction and the weight of the obstacle. The basic system is now in place and further research, such as a delay in the control loop, is in progress.

There is a wide range of applications for such a teleoperation system. It is useful of course when operating in remote locations. Other areas might be in dangerous environments and when handling dangerous materials. Teleoperation can also be used in remote medicine. For space and underwater exploration, a remote force feedback control is imaginable.

7. ACKNOWLEDGEMENTS

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