INTEGRATION OF 3D PROXIMITY SCANNER TO ORPHEUS ROBOTIC SYSTEM

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Abstract: Orpheus mobile robot is a teleoperated device primarily designed for remote exploration of hazardous places and rescue missions. The robot is able to operate both indoors and outdoors, is made to be durable and reliable. The device is controlled through advanced user interface with joystick and head mounted display with inertial head movement sensor. To increase the system's operability in difficult conditions (fog, smoke, dark), 3D proximity scanner controlled by on-board processor through Ethernet connection was integrated to it. The scanner also represents a step towards semi-autonomous mode of the robot.

Keywords: communication, robot, robot control, telerobotics, user interfaces

1. INTRODUCTION

The Orpheus robotic system has been developed in our department from the beginning of year 2003. The project is a natural continuation of "mainly research" U.T.A.R. project (Zalud, 2001), (Zalud, *et al.*, 2002), (Neuzil, *et al.*, 2002) and is intended as a practically usable tool for rescue teams, pyrotechnists and firemen.

The Orpheus robotic system consists of two main parts:

- Orpheus mobile robot,
- operator's station.

Fig. 1. Orpheus

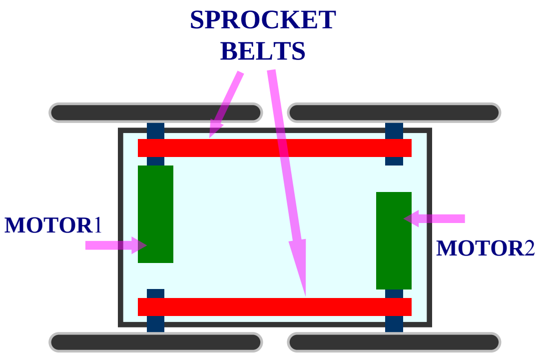

Fig. 2. Simplified scheme of the locomotor

2. MOBILE ROBOT DESCRIPTION

The robot itself (see Fig. 1) is formed by a box with 430x540x112mm dimensions and four wheels with 420 mm diameter.

The maximum outer dimensions of the robot are 550x830x410mm. The weight of the fully equipped robot with batteries is 42.5Kg.

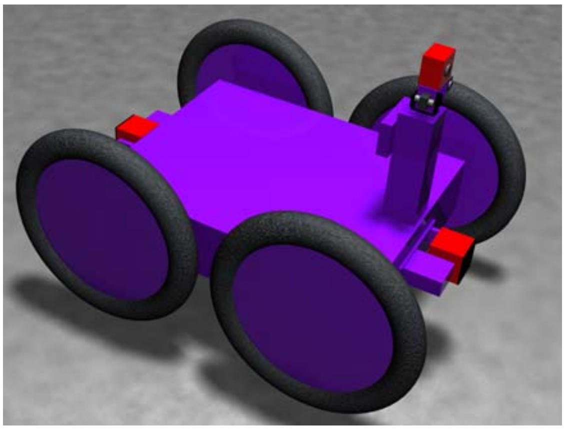

Fig. 3. Spatial placement of cameras

2.1 Locomotion Subsystem

Our department has developed a new Skid-steered Mobile Platform (SSMP) for the Orpheus mobile robot. The SSMP is intended to be both indoor and outdoor device, so its design was set up for this purpose. Another our important goal was to design the device easy-to-construct because of our limited machinery and equipment.

Finally we decided to make the platform like shown in Fig 2. The base frame of SSMP is a rectangular aluminium construction. Two banks of two drive wheels are each linked to an electrical motor via sprocket belt. The two drive assemblies for the left and right banks are identical, and they operate independently to steer the vehicle. The motors can be driven in both directions, thus causing the vehicle to move forward, backward, right or left. Motors are equipped with incremental encoders and are controlled in velocity loop. Two 24V DC motors with integrated incremental encoders and three-stage planetary gearboxes are used.

2.2 Electronics

The electronics of the Orpheus robot consists of two main parts:

- Atmel AVR based microcontroller subsystem,
- NEXCOM processor board for on-board calculations and Ethernet communication.

Microcontroller System

The Orpheus microprocessor system consists of 11 microcontrollers. The processors communicate by RS-232 serial interface using TTL levels.

The purpose of this system is to perform low-level real-time tasks like motor control, sensory data pre-processing, etc.

The processors used:

ATMEL AT90S2313

- servo controller
- LCD display controller
- motor controllers

ATMEL AT90S8535

- camera switch and analogue measurement

ATMEL ATMega161

- main processor
- communication processor
- thermosensor controller

Nexcom processor board

The Orpheus robot is newly equipped with on-board NEXCOM processor board with 1GHz VIA processor and various communication capabilities like USB, FireWire, Ethernet, etc. The purpose of this processor board is to make a bridge among various communication standards, microcontroller and operator's station. The robot-to-operator station communication is based on Ethernet.

The board is also intended as a computational machine for AI-based algorithms for the future development.

2.3 Sensory Subsystem

The robot contains three cameras. Their spatial placement is shown on Fig. 3. The main camera is on a sensory head. It has two degrees of freedom – may move left to right and up to down. The movements limits are similar to the ones of a human head. The camera is a sensitive, high resolution colour camera with Sony chip. The other two cameras are black&white high-sensitive cameras with one degree of freedom. The front camera has IR light to work in complete darkness.

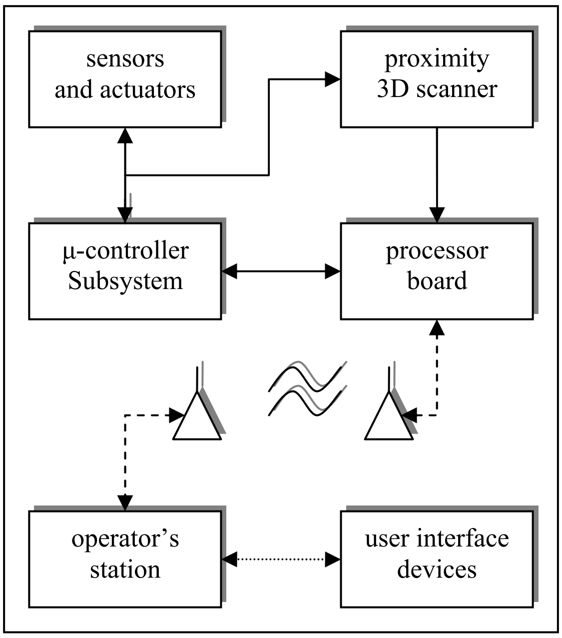

Fig. 4. Communication scheme of Orpheus robotic system; continuous line – RS232 serial communication, dashed line – Ethernet

connection, dotted line – other communication (USB, etc.)

An infrared thermosensor is used for object temperature measurement. The sensor provides three independent temperatures – the object temperature measured by infrared (IR) radiance objects, the sensory head temperature (the sensor measures the difference between temperatures in principle, so the derivation of this temperature is crucial to know if the measurement is precise), and the temperature of the electronics box, which is also used to measure the temperature inside the robot. The thermosensor is placed beside the main camera and rotates with it. It causes the temperature of the object in the centre of the camera picture is measured.

Standard walkie-talkie is used for one-directional audio transmission. One of two microphones displaced on the robot may be used during a mission. The first one is integrated in the sensory head and is directional. Since it moves with the main camera, the operator can hear the sounds from the direction he/she is looking to. The operator also may use the second – omnidirectional – microphone placed on the body of the robot.

2.3 Communication

Communication over the Orpheus robotic system is divided into several parts (see Fig. 4).

Communication on the microcontroller level is done via RS-232 serial line. The microcontrollers talk to each other by TTL level RS-232 line with validatory protocol, while the communication with smart sensors is done by standard RS-232.

The processor board is equipped with two serial lines. One of them is used for communication with the microcontroller subsystem, the other communicates with the 3D proximity sensor because of its need for quite high communication bandwidth.

The communication between the Nexcom processor board and operator's station computer is newly done through Ethernet. The advantage is that the connection may be accomplished through Ethernet cable or wirelessly using wi-fi.

The video transmission from robot cameras is nowadays made through 2.4GHz analogue modules. Nonetheless this video transfer is very unreliable and of poor quality, so it will be substituted by transmission over Ethernet in near future.

The last communication is between the operator's station computer and other devices forming the user interface (namely joysticks and head movement sensor). This is done through standard communication channels (USB, etc.) and is not solved in this project.

Fig. 5. Orpheus operator's station for telepresence control

3. OPERATOR'S STATION

The operator's station for remote control of the mobile robot consists of several main parts:

- computer,
- video grabber,
- joystick,
- head mounted display,
- headtracker.

The operator's station needs 230V AC to supply the devices.

3.1 User Interface

The robot is controlled by operator with help of so called visual telepresence (see Fig. 5). The operator has a head mounted display with inertial head movement sensor. His/her movements are measured, transformed and transmitted to Orpheus. The camera makes almost the same movements like the operator's head and since the operator can see the picture from it, he/she feels to be in the place where the robot is. The movements of the whole robot are controlled by joystick.

The user interface of Orpheus mobile robot system is programmed in C++ language under Microsoft Windows XP system. It uses DirectX functions. 2D drawing graphics library was developed to draw 2D objects to surfaces.

The main principle of the Orpheus user interface is that the digital data may be easily displayed over the video, so the operator does not need to switch among displays. The idea is that the added data are painted to small dark windows and these windows are inserted to the video image. The windows are semi-transparent, so the objects in video can be seen through the windows. In the following text the small windows with additional data are called as displays.

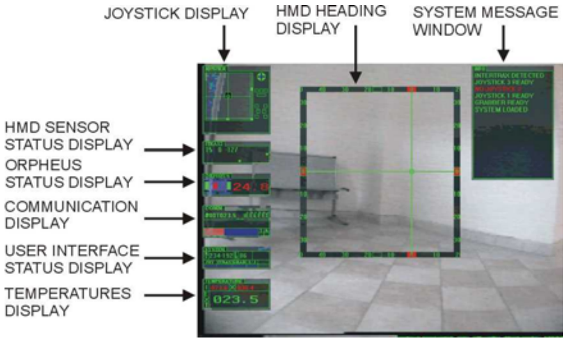

Fig. 7. Full view

The used scheme of the user interface is very variable, and allow virtually any type of 2D or 3D data to be displayed over the video from the cameras. One of the important features of the interface is, that since Direct3D blending is used, transparency of the included data may be defined – and every object (including 2D objects) on the screen may have its own transparency value.

The typical configuration of the user interface is shown in Fig. 7.

In the centre part there is a **Head Mounted Display Heading Display**. This display shows the relative rotation difference between the camera and the body of the robot. This difference is derived from the operator's head movements. The display seems to be a very important tool for the operator, since in many situations there is no other evidence of the head-to-body relative rotation. It has to be considered the angle-of-view of the cameras onboard the robot have significantly smaller angle of view comparing to the one of humans. It causes the operator often cannot see the body of the robot, which normally serves as his/her "navigation" point. The cross in the centre of this display shows the rotation roughly, the exact position may be read from the numbers around it.

System Message Window represents the system messages like overall system status, list of devices currently connected to the system (joysticks, grabber, etc.). This is a tool to show events that happen once rather than continuous display (as against all of the other displays). The data are expressed as a text messages that roll on an "infinite paper roll". Different colours are used for different message significance level.

The series of small displays on the left side of the screen are described now (from the upper to the lower):

- *joystick display* – shows the status of the main joystick. It shows the actual position of the joystick, the pressed buttons, hat and throttle position. It may also display the pre-computed motor speeds. If the joystick is not connected or is not working properly, the red warning message is displayed,
- *hmd sensor status display* – this display shows the Intertrax head position sensor status and measurements. The data are displayed in the form of numbers, graphical representation of the data is also provided. If the Intertrax is disconnected, red warning message is displayed. If this happen, the camera movements may be controlled by the joystick (the joystick, in general, may control all of the accessible functions of Orpheus),
- *communication display* – shows the status of the Ethernet communication.
- *user interface status display* – shows the current status of the user interface. The video resolution and actual framerate are displayed in the form of numbers. In the lower part of the display there are three LED-like displays showing if the joystick, HMD-sensor, and grabber are connected to the operator's station. The last LED shows the type of control (joystick only, or head mounted display with joystick),
- *temperatures display* – in the central part there is an object temperature measured by the infrared sensor. In the upper part there is an ambient temperature (more exactly the temperature of the sensory head) and the temperature inside the robot.

The described view represents only an example of data arrangement showing the abilities of the engine. It has to be pointed out that such configuration may be too complex for an operator in most standard situations and the operator may become flooded by the amount of not-so-significant data.

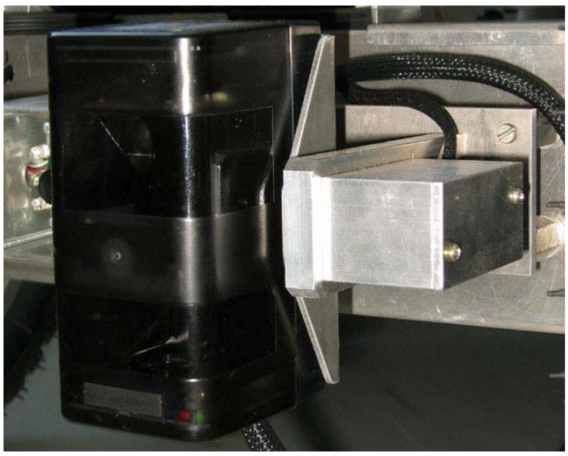

Fig. 8. Detail of 3D proximity scanner mounted on Orpheus robot

Fig. 9. Proximity data integration to the user interface

4. 3D PROXIMITY SCANNER

The novel 3D proximity scanner consists of a triangulation 2D scanner and one rotational degree-of-freedom positioning device. The mechanical construction is clearly visible on Fig. 8. The 2D scanner is fastened on aluminium holder and rotated by servo. The movement limits are ±90˚, which means the scanner may "look" directly up or down. The positioning precision is better than 1˚.

The principle of operation of the scanner is easy. 2D proximity scanner is rotated sequentially and appropriate angle is added to measured data. It means data are in polar coordinates primarily. For the transfer to Cartesian coordinates, (1-3) are used.

$$x_{i,j} = r*\cos(\alpha) \quad (1)$$
$$y_{i,j} = r*\sin(\alpha)*\cos(\beta) \quad (2)$$
$$zi,j = r*\sin(\alpha)*\sin(\beta) \quad (3)$$

where
α - horizontal angle of measurement
β - vertical angle of measurement (rotation of the whole 2D scanner)
r - measured distance

Note the *rα* plane is related to the 2D scanner and rotates with it vertically with *β* angle.

5. PROXIMITY DATA INTEGRATION TO USER INTERFACE

The main purpose for the 3D scanner on Orpheus robot is to provide the operator proximity measurements in poor light conditions like fog, smoke, night, too high contrast in the scene, etc. This means the data have to be suitably expressed to the operator to provide him the important environmental information. For this reason the user interface engine based on Microsoft DirectX was developed.

The data from actual 2D measurement may be easily displayed to the user interface display in the form of small circular nets representing the polar distances from the sensor (see the central upper and lower parts of the user interface display on Fig 9). Although this display is very informative, it only shows one 2D scan from the scanner at a time. To increase the information value, 3D representation of the proximity data is suitable – see Fig. 10 (one complete 3D scan processed by robot evidence grids algorithm). The data here are recalculated from the original coordinates by (1-3) and rendered to a surface by Direct3D, while each distance measurement (or each cell of robot evidence grids – see below) is represented by a box snapped to a grid. Since the whole scene is on a Direct3D surface, it may be easily integrated to the operator's view. Whilst for the instant navigation of the teleoperated machine, the actual 3D scan is the most needed, for longer-term navigation, map building is necessary.

To combine the data with older measurements and to build 3D maps autonomously, approach known as robot evidence grids introduced in 1983 at the CMU Mobile Robot Laboratory (Martin, *et al.*, 1998), extended to 3D space is used. Approach based on Bayesian probability was chosen – see more details (Stepan, 2001).

Let *s(a)=o* means a cell *a* is occupied, and *s(a)=u* means a cell *a* is unoccupied. Let *M* represent a measurement. Let *p(A/M)* represent our best estimate of the probability of event *A* given measurement *M*. By definition the likehood

$$p(A/M) = \frac{p(A \wedge M)}{p(M)}, \quad (4)$$

where *p(M)* is the estimate of *M* given no additional information. From here we can write Equation (5.2).

$$\frac{p(s(a)=o/M)}{p(s(a)=u/M)} = \frac{p(M/s(a)=o)p(s(a)=o)}{p(M/s(a)=u)p(s(a)=u)}, \quad (5)$$

for a cell *a*. Now suppose the information *I* is already in the map and new measurement *M* should be integrated to the map to find *p(s(a)=o/I^M)*, provided the new measurement is independent to all previous information. The probability cannot be computed simply by *p(I^M)=p(I)p(M)*, since if *I* indicates that the cell is occupied then we would hope *M* to be more likely to indicate the same thing. The probabilities may be calculated by Eq. (6).

$$p(I \wedge M/s(a)=o) = \\ = p(I/s(a)=o)p(M/s(a)=o) \quad (6a)$$
$$p(I \wedge M/s(a)=u) = \\ = p(I/s(a)=u)p(M/s(a)=u) \quad (6b)$$

If we combine (5) and (6), we can write the resulting Eq. (7).

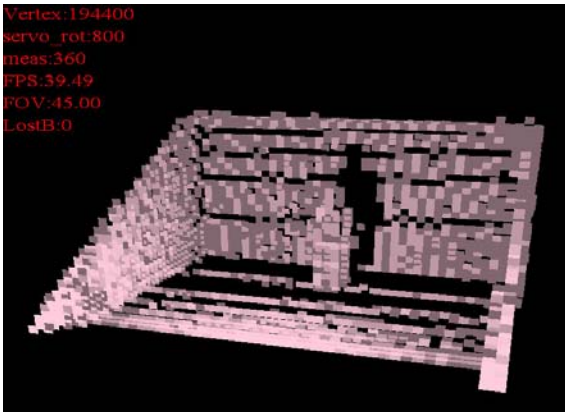

Fig. 10. 3D-proximity data measured by the scanner

$$\frac{p(s(a)=o/I\wedge M)}{p(s(a)=u/I\wedge M)}= \\ =\frac{p(s(a)=o/I)p(M/s(a)=o)}{p(s(a)=u/I)p(M/s(a)=o)} \quad (7)$$

If no prior map is defined (i.e. the map is not known or added to the system from some external source), all the cells are filled with the same value 0.5, so we can write Eq. (8).

$$\forall a : p(s(a)=o)=p(s(a)=u)=0.5 \quad (8)$$

For the robot evidence grids the position of the robot must be known every-time a new scan is being added to the map. The author plans to combine Proximity Laser Scanner Cross-Correlation Based Method for Cooperative Self-Localization and Map Building (Zalud, 2001) with odometry data from incremental encoders and geomagnetic sensor data to acquire the translational and rotational position of the Orpheus robot. The other possibility is to use other 2D or 3D scan matching methods, like HAYAI or 6D SLAM (Surmann, 2004). The self-localization of the robot represents the future work of the author and is not presented in this paper.

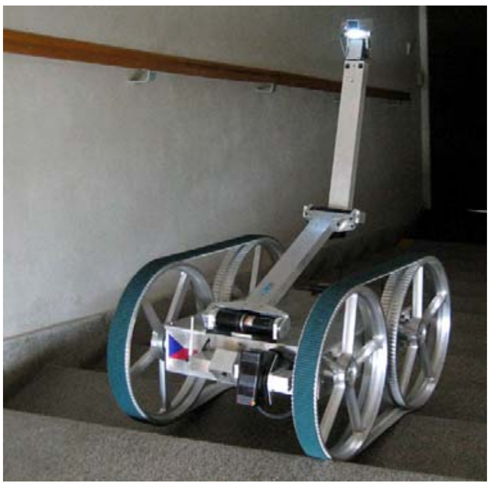

Fig. 11. Orpheus with 3D scanner climbing up stairs

6. CONCLUSIONS AND PERSPECTIVES

One of the most important features of the Orpheus robotic system is its ability to work under difficult conditions (see Fig. 11), like hard terrain, dim light conditions, smoke, etc. The 3D laser scanner adds the possibility to see most of the obstacles even in the situations when video is not usable. The appropriate display of the 3D data through innovated user interface makes the measurements well usable in real time during missions and extends the its usability.

The biggest drawbacks of the present solution of 3D scanner with Hokuyo 2D scanner are the long scanning time (one 2D scan takes about 330ms) and low precision in comparison with e.g. SICK PLS.

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