ARGOS-ORPHEUS System for Remote Exploration of Hazardous Environment

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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. Orpheus robot contains multitude of sensors including cameras, 3D proximity scanners, thermometer, etc. The device is controlled through advanced user interface using ARGOS software with joystick and head mounted display with inertial head movement sensor. Since the control of the remote robot as well as the sensory data-flow is done in real-time, the communication subsystem forms vital part of the system. The communication is accomplished with Ethernet and both - wire or wireless connection may be used.

Key-words: communication, robot, robot control, telerobotics, user interfaces

1 Introduction

The Orpheus robotic system is intended as a practically usable rescue robot, pyrotechnical robot or a robot for firemen. It may operate in harsh environment, but it is also designed to work inside buildings – the robot is less than 60cm wide so it can pass through standard doors, it can also climb up standard steps.

The robot has been developed since January 2003 and Orpheus-X2 version represents second substantial modification including mechanical construction improvements, electronic subsystems and new user interface program for real-time control named ARGOS.

The robotic system consists of two main parts:

- Orpheus-X2 mobile robot,
- operator's station with ARGOS system.

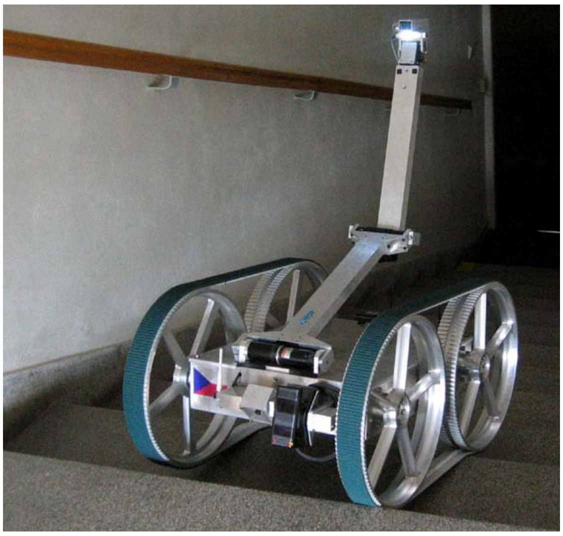

Fig. 1. Orpheus-X2 prototype

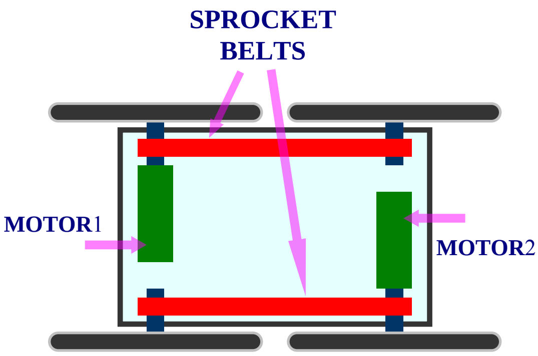

Fig. 2. Simplified scheme of the locomotor

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. The mechanical construction of the robot is made mostly by aluminium alloy.

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.

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.

Microcontroller System

The Orpheus microprocessor system consists of 8 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 ATMega8 - 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, onboard microcontrollers 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 Orpheus-X2 robot contains four cameras. The main cameras are on a sensory head. The head has two degrees of freedom, so the cameras may move left to right and up to down. The movement limits are similar to the ones of a human head. The cameras are sensitive, high resolution colour cameras 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.

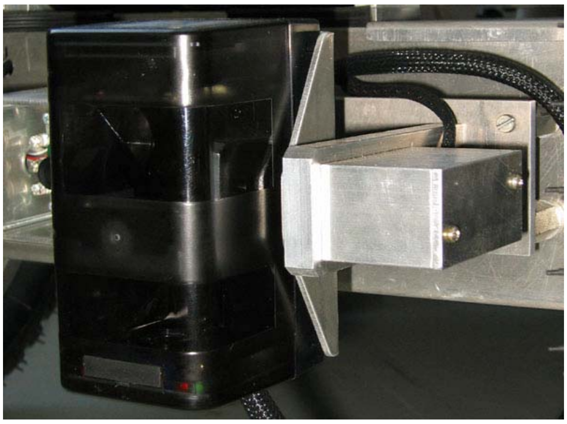

Fig. 3. Detail of 3D proximity scanner mounted on Orpheus robot

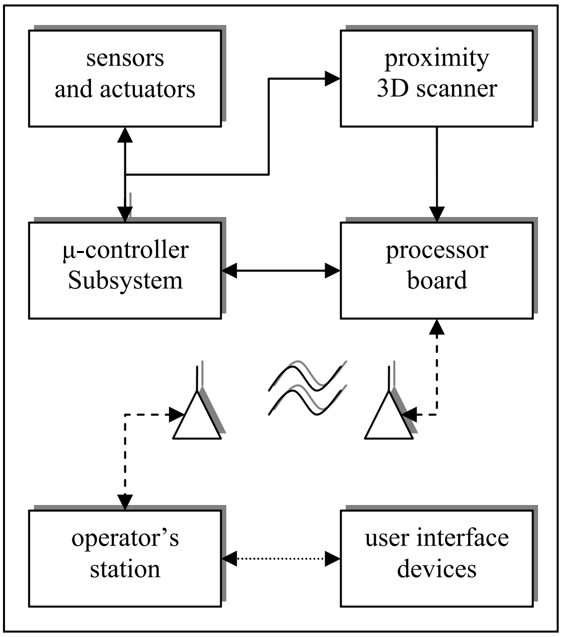

Fig. 4. Communication scheme of Orpheus robotic system; continuous line – RS232 serial communication, dashed line – Ethernet connection, dotted line – other communication (USB, etc.)

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.

The MEMS based ADXL202 accelerometer made by Analog Devices in inclinometer mode is used to measure the robot body inclination. The sensor's pulse-width outputs are measured by Atmel AVR Mega8 microcontroller which is connected to the robot's internal communication system. The disturbance caused by the horizontal movement of the robot is not significant in this case because the maximum robot speed is approx. 2km/h and the most of the strong robot inclinations happen in substantially lower speed.

The novel 3D proximity scanner constructed by our team consists of a triangulation 2D scanner and one rotational degree-of-freedom positioning device (see Fig. 3). 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. The 2D proximity scanner is rotated sequentially and appropriate angle is added to the measured data. It means the data are in polar coordinates primarily. For the transfer to Cartesian coordinates, equations (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.

2.4 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 with respect to its protocol.

The processor board is equipped with a couple of serial lines. The primary serial communication line is used for communication with the microcontroller subsystem, the others communicate with 3D proximity scanners because of heir need for quite high communication bandwidth.

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

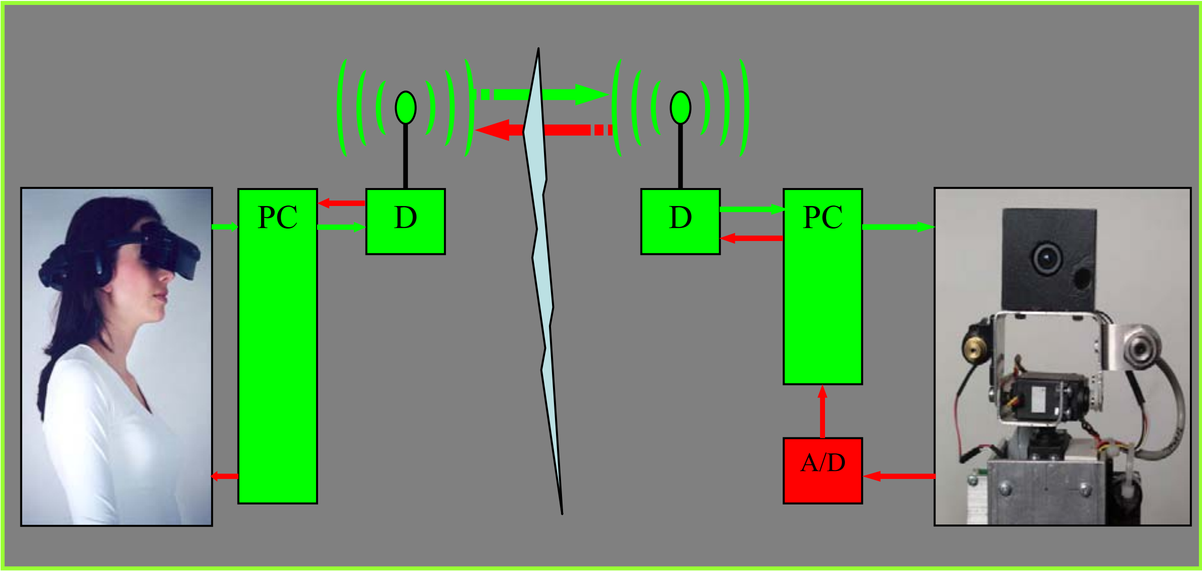

Fig. 6. ARGOS-Orpheus-X2 visual telepresence scheme

The communication between the Nexcom processor board and operator's station computer (and its ARGOS system) is done through Ethernet. The advantage is that the connection may be accomplished through Ethernet cable or wirelessly using wi-fi. The connection is programmed with help of Socket SDK and is made as a series of independent virtual communication lines. Each physical RS-232 line on the processor board has its own virtual communication line and the low level functions are programmed to be compatible with standard serial line functions, so the higher levels of the ARGOS system may cope with the data in exactly the same way as if they were read/written from/to physical serial communication line.

The video transmission from robot cameras is firstly digitized by standard DirectShow device (USB2.0 or FireWire), encoded and transferred through another virtual line. The data may be compressed by several algorithms depending on required output video quality and required data-rate. Since the data may be also transmitted wirelessly – what means unpredictable dynamic changes of actual available data-rates, the system is also able to dynamically change the video data-rate.

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.

3 Operator's Station

The operator's station (see Fig. 5) 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. 6). 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.

Since the robot is teleoperated in real time, the operator's program forms vital part of Orpheus system. Since our team works also on other remote controlled mobile robotic systems and since most features of these robots are similar, we decided to develop a unified system for their control. The system is named ARGOS (according to guardian with hundred eyes from Greek mythology), is still under development and is currently deployed on two of our robotic systems (Orpheus-X2 and U.T.A.R.).

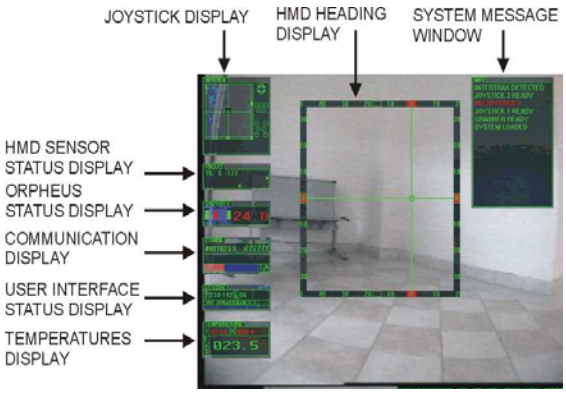

Fig. 7. Typical view configuration of ARGOS system

The ARGOS system is programmed in C++ language under Microsoft Windows XP system. It uses Win32 and DirectX 9.0c SDK. 2D drawing graphics library was developed to draw 2D objects to surfaces. The 3D objects are programmed on vertex level, advanced texturing methods are used. The ARGOS system uses also progressive techniques like point sprites to substantially reduce the amount of vertex data to be displayed. The consequence of this is that the ARGOS system may be applied only on newer graphical processing units and runs under Microsoft Windows XP only.

The main principle of the ARGOS 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.

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 and 3D objects) on the screen may have its own transparency value.

One of the typical configurations 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. Advanced joystick system with throttle stick is used and id it is necessary, the joystick may control all functions of the robotic system – HOTAS (hands on throttle and stick) principle is used – the operator does not need to waste time by using of any other control devices,
- *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 fully controlled by the joystick,
- *communication display* – shows the status of the Ethernet communication – it displays actual datarate. Different colors are used for instant operator information of the communication status between Orpheus and ARGOS,

Fig. 8. Orpheus-X2 in action

- *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, mouse with joystick, etc.),
- *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.

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. 8), like hard terrain, dim light conditions, smoke, etc.
Since the robot is remotely controlled by the operator in real time, the communication between the robot itself and operator's station must be both fast and reliable. The Ethernet connection proved to be a good choice for the task because of its versatility and high data-rate. At the current state the robot may be controlled via Ethernet cable or wirelessly through hi-speed Wi-fi modules. The system is prepared for other possibilities, like optical cable or other wireless technologies.

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