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Teleoperation System Control Based on The Method for Supervisory Control With Variable Time Delay

***Abstract* —Teleoperation is the technique of controlling system from a remote location, which consists of a master and slave system. Master system usually represents the model of the slave system controlled by an operator. The slave system is usually dislocated in relation to the master system and is controlled by commands sent from the master system over communication a channel. The concept of Supervisory management is generally used up to indicate that one or more human operators set the initial conditions for the control, monitoring and alternately adjusting and receiving information from the computer that is closing the control loop by itself, via external sensors. The mobile robot performs certain tasks using IR sensors, the operator monitors his work and makes some changes in the way the mobile robot works, if necessary.**

***Keywords* — Teleoperation, Supervisory control, Mobile robot, Time delay**

I. INTRODUCTION

REMOTE control is a technique of keeping the system remotely in situations where immediate (close) control is not feasible, because it is dangerous and / or unavailable, [1]. It is commonly in environments that are inaccessible (deep seas, space, etc.) or dangerous (military, radioactive environment, etc.) for human.

The distance in this control system can be from a few centimeters (microspaces) to several million kilometers (Spacecraft). The teleoperator is a remotely operated vehicle or system, and the person who supervises the controlled system and takes the necessary control action is called the operator. Teleoperation is a technique which is used to control a vehicle or an system from an remote location [2].

One of the pioneers in robotics and technology for remote control, Thomas B. Sheridan defines supervisory control as follows: "In the strictest sense, supervisory control means that one or more human operators are intermittently programming and continually receiving information from a computer that itself closes an autonomous control loop through artificial effectors to the controlled process or task environment.". This concept was incorporated in the earliest machines which sought to extend the physical capabilities of man. In contrast, with automatic control, the machine adapts to changing circumstances and makes decisions in pursuit of some goal which can be as simple as switching a heating system on and off to maintain a room temperature within a specified range [3].

Supervised control [4], [5] is commonly described in one of two ways: first, the control system or process works independently, the operator controls the work and occasionally from time to time when it considers it necessary, intervenes by changing the control algorithm to some way; in the second, the system requires instructions from the operator, autonomously performing tasks, returns results and awaits further instructions.

There are several types of mobile robots, which are used in various applications. The most common types are used in space applications, military applications, protection of property, deep sea applications, mining and forestry.

II. BASIC CONCEPTS

A hierarchical diagram of the system for supervised control in teleoperation systems proposed by Jin-Shyan and Pau-Lo is shown in Fig. 1, [6].

The system uses three layers of architecture. The command layer, an abstract model is a simplified representation of the control system and the operator uses it to make decisions about changes in the control system.
The operator by doing the virtual control over the abstract model, at the same time sends requests for specific assignments, the local regulator who actually regulates the detailed operation of the assignments on the basis of feedback about the events at the control level.

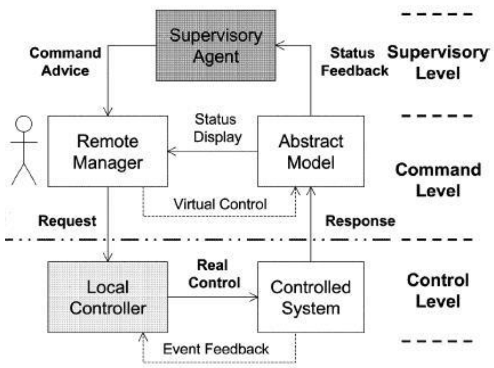

Fig. 1. Supervisory control in teleoperation systems

Possible changes in the system will be transmitted in the total form of the abstract model via the channel response. In this way, the operator has restrictions to the activities. There are two major features in an supervisory control system, semi-autonomous actions and complexity. Accordingly to this, the operator can not be aware of all events that occur in the system.

Therefore, it is important for the operators work, that the system is designed in a way to provide all informations for decision making, that the system is designed in a reasonable form and warn the operator for conditions that require special attention.

In all forms of supervisory control there is a typical five-step cycle in the human supervisor's behavior: (1) planning, including the setting of subgoals relative to the given task goals, (2) instructing the computer, (3) monitoring its execution of instructions and making minor adjustments, (4) intervening to circumvent the automatic controller as necessary, and (5) learning from the experience in order to plan better [7].

In this paper the supervisory control method is proposed in order to control a mobile robot. The mobile robot performs certain tasks using IR sensors, the operator monitors his work and makes some changes in the way the mobile robot works if necessary.

III. Mobile Robot

To be able to apply the method of supervised control it is necessary to create a special mobile robot. This robot must operate autonomously, but must also have the option of remote control (total or partial). For this we use Arduino MEGA2560 microcontroller board, (see Fig. 2.) that contains a microcontroller ATmega2560. The programming and management part of the components is also placed on the board.

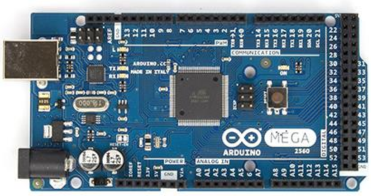

Fig. 2. The Arduino Mega 2560 microcontroller board

Servo motors provide the option of setting the position of the engine in exactly the right spot in which you want the engine to be lead. Each servo motor has three paths presented by unique colors, red is connected to the power supply, black or brown is connected to ground, and orange or yellow is connected to the PWM pin of the microcontroller. On Fig. 3 are shown the servomotors used by the mobile robot.

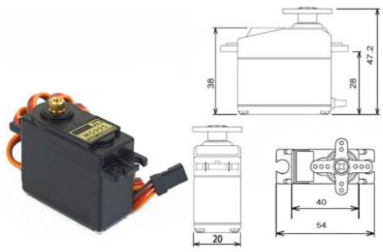

Fig. 3. Servo motor

In order to achive communication between the mobile robot and the computer, a Bluetooth module is used which is connected to the microcontroller. HC-05 module, see Fig. 4, is an easy to use Bluetooth SPP (Serial Port Protocol) module, designed for transparent wireless serial connection setup [8].

There are few things to pay attention when connecting the Bluetooth module with the microcontroller, like the different voltage needed to power up the module and the voltage needed by the logic pins of the module. The Bluetooth module pins are: Vcc – power supply, GND – eaurthing/grid leak, Rx - pin through which the module receives data, Tx - pin through which the module sends data.

Fig. 4. Bluetooth module

Furthermore, to achive a higher level of mobile robot incependence, there are IR sensors installed on the mobile robot for stripe path following. This kind of sensor may be used in multiple purposes, like determining the distance to an obstacle or for stripe path following presented in this paper. The Infrared consists of two types of diodes, IR LED (Infrared Light Emitting Diode) and a Photodiode. IR diodes emit infrared light reflected from the surface. The reflected light is detected by photodiodes. The level of the reflected light depends on the color background. The highest level of the reflected light is if the background color is white and the lowest if the background color is black, shown on Fig. 5. The amount of current passed through the photodiode is directly proportional to amount of IR rays falls on it [9].

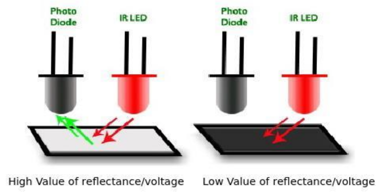

Fig. 5. The principle of sending and receiving light

The sensors work on the white background with black stripe path principle, due to reflection of light and for better sensor values on the microcontroller. The sensors follow the black stripe and depending of the values the sensors read, certain motions of the servos are activated, and the mobile robot continues to follow the black stripe, shown on Fig 6.

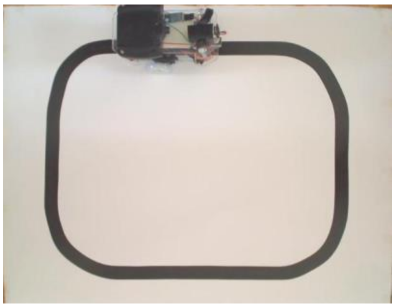

Fig. 6. Stripe following course

In order to better understand all connections between the ATMega2560 and the other parts, a scheme of the mobile robot is shown on Fig. 7 from which it can be seen how its components are connected.

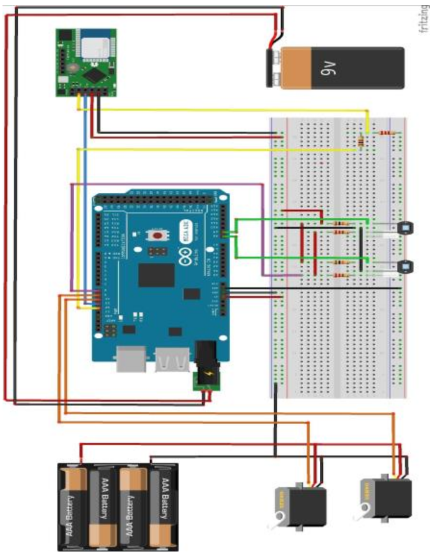

Fig. 7. Mobile robot scheme

After connecting all parts together and checking all control operations, an mobile robot is designed, shown on Fig. 8. The next step is to program the microcontroller ATMega2560. Programming is needed to enable autonomous operation of the mobile robot when the operator only supervises his work, but also the possibility that the operator affects the operation of the mobile robot.

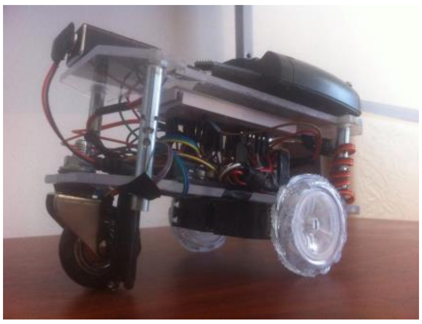

Fig. 8. Mobile robot

The program is written in the Arduino IDE environment, which has two basic functions, function *setup()* and function *loop()*. The program for the presented mobile robot needs two libraries defined in Arduino IDE, #include<Servo.h>, to control the motors, and #include <SoftwareSerial.h> , for serial communication.

IV. Remote Communication

Communication between the mobile robot and the operator is performed using Bluetooth and a global network of Internet. Bluetooth wireless data is used for communication between the mobile robot and the host computer, see Fig. 10. In this way it is possible that the mobile robot has no connection cables. This increases its maneuverability.

Host computer to a remote computer, which can be at any location, communicate using a global network Internet, (see Fig. 9.). The first connection that is established is the connection between the mobile robot and the computer using Bluetooth. This is accomplished using a Terminal, which is installed on the computer that is used to establish a Bluetooth connection between these two devices. The Terminal sends data via Bluetooth to the mobile robot, ie. to his Bluetooth modul, which recives the data and sends it to the microcontroller. The microcontroller activates an operation based on the recived data, eg. Change the path of movement, activate IR sensor mode, and other operations. This allows the operator to control the mobile robot with an computer. The computer which is located in the evironment of the mobile robot is called a Host computer.The complete communication between the remote computer and the mobile robot is shown on Fig. 9.

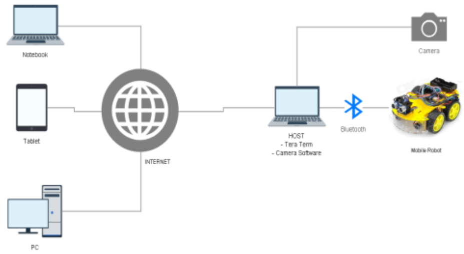

Fig. 9. Remote communication scheme

The mobile robot remote communication and control using Internet can be established in several ways. Since the connection between the mobile robot and the Host computer is established, it is necessary to access the Host computer from any location using Internet, in order to control the mobile robot.

In this paper, a software that allows computer remote control called Chrome Remote Desktop is used.
The characteristics of this software are high speed and establishing a secure access to communication, since the user is logging in with his google account.

A camera which performs a visual projection of the mobile robot is used to ensure that the operator knows the position and the state of the mobile robot. The camera sends visual feedback information to the operator, and the operator can perform actions based on the feedback informations.

V. Experimental Results

In this part of the paper the experimental verification of the created Teleoperation system is carried out. The biggest problem with Teleoperation over Internet is the variable communication delay. It depends on the distance between the two locations, the number of users, the quality of the network between the two locations, the number of routers etc. It can cause loss of stability of the teleoperation system, temporary cessation of communication or simply interfere with the operator to properly render its decisions.For the created Teleoperation system, the operator has at all times data on how many the current time delay is.

Analysis of the created Teleoperation system is made when the system works in the same network, within a town and two towns in Bosnia and Herzegowina.

For time delay data collection in the experiment, three locations were used. The system contains the mobile robot, a computer which is used to control the mobile robot, and a camera, to send visual feedback informations to the operator, as shown on Fig. 10.

Fig. 10. Designed Teleoperation system

On each of these locations some parameters are tested, like system access, time delays and stability of the system. For each of the three locations, five time delay measurements were made. During each measurement the minimum, maximum and average time delay was measured. After data collection for an location, the average values for all minimum, maximum and average values for time delay were used. The results for each location where the measurements were done are presented on Fig 11.

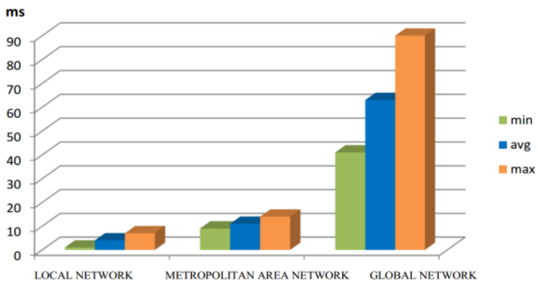

Fig. 11. Results for each location where the measurements were done

The first tested location is a network where the system and the device for remote control are located in the same network. This is the closest communication which is possible for system parameters tests. The Internet speed used in this network is 6144/512 kbps. The second tested location is located few kilometers away from the system. The system can be accessed via the Internet, and the tested parameters are the same like in the first test. The Internet speed used in this case is 6144/512 kbps. The third location used for the experiment and data collection for time delays is the farthest location, between two cities in Bosnia and Herzegowina. The system is accessed via the Internet, and the Internet speed on which the remote control is tested 8192/768 kbps. The Table 1. shows the measured time delay values for the three different locations where the parameters were measured.

Table 1: Measured Time Delays

Location	Time delay
1. Local network	min = 1 ms
	max = 7 ms
	avg = 4 ms
2. Metropolitan Area Network.	min = 9 ms
	max = 14 ms
	avg = 11 ms
3. Global network	min = 41 ms
	max = 90 ms
	avg = 63 ms

The results presented in Table 1, show that there are differences in time delays measured on different locations.

The system was stable during all measurements and there were no unexpected situations in the system. Establishing the communication with the system and with remote control was fast, efficiently and stable in all cases.Regardless to the measured values, an important factor is the operator who controlled the system. In the first case the operator did not notice any difficulties during his work with the system. The system was fast and effective without any visible time delays. In the second case the operator noticed a minimum number of visible time delays, reflected on the video signal of the camera, during his work with the system, but it has not affected the stability and the effectiveness of the system. The third tested location for the mobile robot remote control was the farthest used in the experiment. The operator did not notice any visible time delay. The system worked stable and effective. Because of the minimum time delays and relatively low speed of the mobile robot, controlling a system like the one presented in this paper is easy. On the basis of these analyzes it can be generalized that this system can be accessed and controlled from any location in the world, with minimum time delays.

VI. Conclusion

On the basis of the experimental results it can be concluded that the designed system works well regardless of the distance between the operator and the system. The mobile robot works independently and executes received operations. The operator supervises the mobile robot and if necessary, changes the condition of the mobile robot.

Because of the one-way communication the system is stable. The operator can operate the system at all times, add new motion paths and change the direction and speed of the mobile robot. Because of the built-in camera the operator can see the status of the mobile robot. After the operator is done with his work, the mobile robot returns to his autonomous working mode, following the stripes.

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