A General Concept of the Internet-based Telemanipulation

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Abstract

This paper presents a general approach to telemanipulation. The concept is divided into layers. This paper introduces these layers as well as their functionality. The constraints of this model are discussed and different guiding styles for an autonomous robot are presented. The robot can learn the guiding style of the operator and can follow the learned style during the period when the command is delayed because of the latency caused by Internet communication.

1. Introduction

Telemanipulation has been a research topic for decades. The efficiency of telemanipulation has been grown in the last few years. The application of the Internet gives new possibilities to the researcher [1].

This section gives a general approach to telemanipulation. The second section contains a detailed description of the general approach. The third section summarizes the constraints of telemanipulation. The fourth section gives some examples to the approach. Several types of Master Device are introduced.

1.1. General approach to telemanipulation

Figure 1 shows the general concept of telemanipulation. The "world" is divided into two sets: the Master Site and the Slave Site. The main aim of telemanipulation: the operator has some task to do at the remote site where he/she cannot be physically. The telemanipulation system extends the operator's capability to be able to work at the Remote Workplace. This extension is achieved by a master-slave system. The master-slave system is realized as two information channels: Action and Reaction channel. The Action channel transports the information from the operator to the Remote Workplace. The Reaction channel transports the information to the opposite direction: from the Remote Workplace to the Operator.

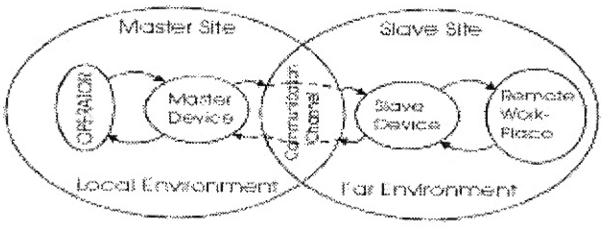

Figure 1. General concept of the telemanipulation.

There is another approach for the telemanipulation. The process of the telemanipulation can be partitioned into two coupled sub-processes. One sub-process is running in the Local Environment: Local Process. The other sub-process is running in the Far Environment: Remote Process. The Local Process is the information circulation between the Operator and the Master Device. The Far Process is the information circulation between the Slave Device and the Far Environment. If telemanipulation is idealistic, the two processes are the same. In case of ideal telemanipulation, the Master Device represents the Remote Workplace in the Local Environment and the Slave Device represents the Operator in the Far Environment. The Communication Channel is the coupler between the two sub-processes. The main task of the Communication Channel is to cover total transparency in case of ideal telemanipulation.

1.2. Definitions

After short description of generalized telemanipulation, we consider some cases. The telemanipulation can be observed also as a Human Robot System, where a human and a machine work simultaneously together to achieve a task. The Slave Device can be a Multi Robot System, where more than one robots are working together to achieve a task.

The Internet, as a worldwide information set, can be a good artificial environment to distribute the information between the Local and Far Environment. Next step from the simple configuration is the Internet-based Tele-cooperation, where Master and Slave Systems are connected to the Internet. The Internet-based Tele-cooperation can be classified into multi slave site, multi master site or multi slave and master site tele-cooperation.

In the distributed systems one of the main challenge is the distribution of the intelligence. If two or more systems are working together, it can be separated into two main groups. First, if the intelligence is not balanced between the systems, the cooperative scheme called Server-Client cooperation. In this situation the Server has more intelligence than the Slave does. The Client sends the sensed data to the Server and the Server generates the reaction against to the sensed data. If the intelligence is balanced, it is called Peer to Peer cooperation. The communication language can be more symbolical in the Peer to Peer cooperation. The advantage of the symbolical language is the expressions, which can describe difficult commands. A lower bandwidth is necessary for the symbolical language, than for the low-level language.

2. Layer Definitions

The Master Site and the Slave Site are partitioned to three main layers. The layers can communicate vertically with the local layers as well as horizontally with the remote layers via the Internet. The Sensor Layer contains the necessary sensors to observe the Remote Environment, and the Remote Workplace. In general, these sensors are non-contact sensors. The Manipulator Layer makes the effective work in the Remote Workplace. This layer involves the Slave Device typically. This layer may contain contact sensors. The Transporter Layer includes such a system, a Transporter, which can carry the realization of the sensor and manipulator layer.

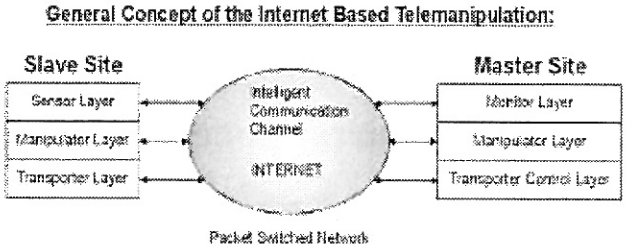

Figure 2. Layer definition for the general concept of the Internet-based Telemanipulation.

The Monitor Layer at the Master Site shows the processed data of the Sensor Layer. These monitors are usually non-contact displays or indicators. The Manipulator Layer has a real contact with the Operator. This layer involves the Master Device typically. This layer, included with the Master Device, may contain contact sensors, and contact actuators. The contact actuators relay the sensed data of the contact sensors of the Manipulator Layer. The Transporter Control Layer controls the Transporter at the Slave Site. This layer may contain services that can help to the navigation of the Transporter Layer at the Slave Site.

2.1. Sensor layer

The configuration of the Sensor Layer can be seen on Figure 3. The non-contact sensors on the Slave Site are observing the Far Environment. The Intelligent Sensed Data Computing System at the Slave Site is a preprocessor for the sensed data. The purpose of this device is filtering, correction and compression. The audio and video compression formats are widely used on the Internet, to decrease the necessary bandwidth. The Computing System may contain a pattern recognition module to improve the efficiency and intelligence of the Slave Site.

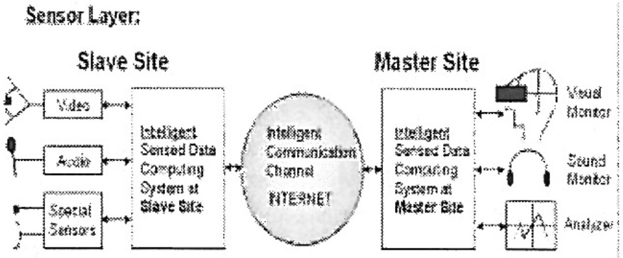

Figure 3. Sensor Layer definition for the general concept of the Internet-based Telemanipulation.

The purpose of the Intelligent Sensed Data Computing System at the Master Side is data decompression and recovery of lost data.

2.2. Manipulator layer

The configuration of the Manipulator Layer can be seen on Figure 4. Typically, this layer includes the Slave and the Master device, as it is mentioned above.

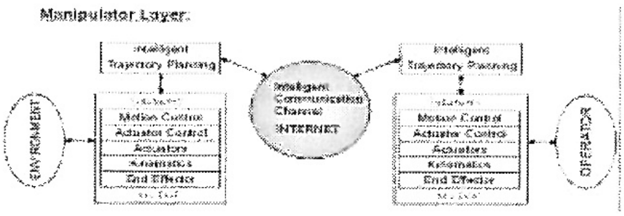

Figure 4. Manipulator Layer definition for the general concept of the Internet-based Telemanipulation.

The main purpose of this layer is the force-feedback. The force-feedback is an information flow between the layers and between the Master and Slave Site. The force-feedback is a typical action-reaction process. The exact realization of the force-feedback depends on the specific approach. The configuration of the Master Device is not equal to the configuration of the Slave Device in a general case. The main purpose of the Intelligent Path Planning is to couple the master and the slave in position and force.

2.3. Transporter layer

The configuration of the Transporter Layer can be seen on Figure 5. The configuration of the Slave Site of Transporter Layer is very similar to one side of the Manipulator layer. The Transporter Layer has connection with the Far Environment. The Transporter Layer carries the Slave Device and the necessary sensors.

The Task Oriented Path Planning System controls the transporter on the Slave Side. This device may use advanced services for navigation such as Global Positioning System (GPS), Geographic Information System (GIS) and Intelligent Transport System (ITS).

2.4. Intelligent Communication Channel

This section summarizes the basic properties of the Intelligent Communication Channel (ICC). The Internet is discussed as an example of the ICC.

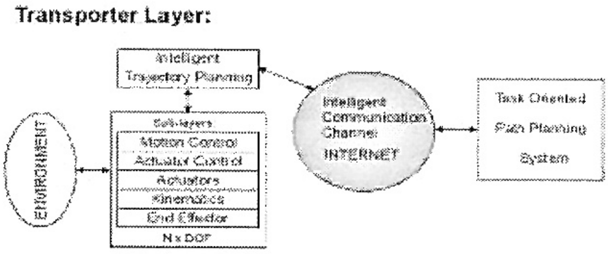

Figure 5. Layer definition for the general concept of the Internet-based Telemanipulation.

In this section some basic features are mentioned from the viewpoint of the telemanipulation system. The basic protocol of the Internet is TCP/IP. TCP/IP is a packet switched protocol. This means that the driver divides the data into packets, and sends the packets individually. The receiver tries to collect all the packets and rebuild the original data from the packets. The packet loosing is a common problem on a packet switched network. When a packet is lost there are two ways to recover the information. One, the protocol on the receiver side asks the driver to send the lost packet again. The TCP/IP does in this way. Second, a module tries to recover the lost information from the received packets.

The time delay is another basic problem in the packet switched network. The time delay always occurs when the signal extend from point A to point B, which is not the same as point A. The question is the magnitude of the delay. The magnitude of time delay alters the packet switched network. Variable time delay has two main reasons. One, the route of the packets is different on the network. Second, the traffic changes on the network. There are routers on the packet switched network. The routers control the traffic on the network, so the path of the current packet mainly depends on the routers.

3. General Constraints

After the introduction of the layers, a summary is given about the constraints of this configuration of telemanipulation.

3.1. Delays

Delays in telemanipulation system are the one of the biggest constraints. There are several kinds of delay in the configuration. The most significant is the delay between the Master and Slave Site. The greatest part of this delay comes from the data transmission latency. The magnitude of the delay is changing, as it was discussed above. The second significant delay is the computational delay. The blocks with intelligence are represented as a computational engine. This computational engine needs time to calculate the output from the input. Other type of delay is the actuator delay. The real actuator has parasitic dynamics, which causes delay in the system.

3.2. Noises

Noise is a signal that is not necessary for operation. It is needed to separate the necessary and not necessary signals for the proper operation. Noises are generated in many places. The source of noises can be divided into two main parts. One: the noise that comes from the Local or from the Far Environment. Second: the noise that is generated inside the master-slave system.

3.3. Signals and packets

This section discusses the signals and packets in a telemanipulation system. This section summarizes the common properties of the signals and packets. The signals are in the Local and Far processes. The packets are in the Intelligent Communication Channel.

The calculation of the signal or packet dropout likelihood is important for the continuous operation. In the packet switched network the packet dropout is very common phenomena. For the continuous operation, signal or packet dropout recovery is necessary. There are two main sets of method for recovery. One is data redundancy. This method is widely used in many applications. One disadvantage of this method that wider bandwidth is necessary. The second set of recovery methods is the interpolation or extrapolation methods. If a data is lost, the system tries to calculate it from the neighbors of the lost data.

Many types of communication channels exist in the master-slave system. Every communication channel has its own applied area. The robust and fast transfer methods between these channels are important. A simple example is the continuous to discrete and discrete to continuous converters.

An actual problem of public networks is security. Robust but fast encoding-decoding algorithms are needed to keep the communication channel under cover.

3.4. Remote control modes

The remote control modes of robotic systems can be divided into four types [1]:

Direct Control Mode. We can control the mobile robot by sending the primitive command and necessary parameters. The robot will execute the command without any intelligence; that is, what the user had sent leads to the action of the robot directly. The robot behaves as a puppet in this mode, and is operated only by the user who understands the robot's characteristics. Direct control via the Internet with inherent high latency and low bandwidth is not suitable for robotic systems.

Behavior Programming Mode. The primitive intelligence of mobile robots such as collision avoidance, path planning, self-referencing, and object recognition are regarded as basic functions for multiple motion behaviors of the system. The operator can control the robot to accomplish a task by remote programming the behavior through a high-level computer language. Therefore, the control system can reduce the load of the communication network so that the program can handle the complex task.

Supervisory Mode. The robot is envisioned to work as the service man that provides the web users with specific service for supervisory control. The web users only need to send a high-level command to the server, and then the robot will perform the task by built-in mechanisms and local intelligence. Much current research on constructing the local intelligence of mobile robots, such as collision avoidance, path planning, self-referencing and object recognition, can be used to enhance the robot's capability. Because of the latency of the Internet and the safety of a mobile robot, the supervisory control is essential for Internet applications. With enough local intelligence of the robot, the control system can avoid too many communication details through the Internet.

Learning Mode. Dependent on how long the learned knowledge is valid, two types of the remote learning modes are classified as follows: Long-term Learning and Short-term Learning. In the next chapter a learning type control method will be presented. The robot can learn the operator guiding style and can follow the learned style during the period when the command is delayed because of the latency caused by Internet communication.

4. Application Example

4.1. Definition of the basic robot guiding

The main objective of mobile robots is to reach their destination, while avoiding any obstacles that appear [7]. Autonomous robots need to gather information of the surrounding area in order to define proper guiding strategy [2]. Such robots can detect objects in their scanned area (Figure 6a).

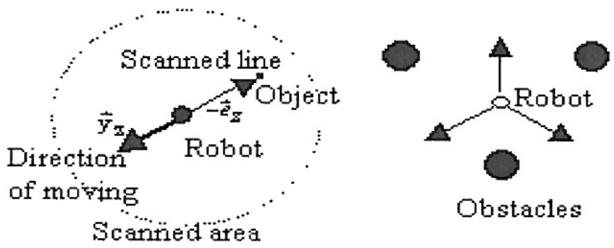

Figure 6. a. Rule of PBG model. b. Stuck position.

The main point of guiding is to define the moving direction according to the style and the scanned area. Let us consider two extreme styles. The main guiding rule of an aircraft carrying dangerous material is to keep "as far from the mountains as possible". Remaining in secret while seeking a mouse leads to the opposite behavior for a cat, namely, "get as close to the object as possible". A simple combination of these can characterize the main rule of a traffic system: "keep close to right side". However, the basic robot guiding control has no intelligent task for problem solving. For example, finding a path in a labyrinth needs additional intelligence. The next section briefly introduces a widely adopted guiding model.

4.2. Potential Based Guiding model (PBG)

The main guiding rule of PBG (*Potential Based Guiding*) is to repulse the robot from the objects [3]. The process is divided into two blocks (Figure 7). One defines the possible moving directions and the other evaluates them.

This means that the first block defines a moving vector $\bar{y}_z = y_z \bar{e}_z$, $z = 1..o = n$ (n is the number of scanned lines, and o is the number of evaluated directions) from the measured distances x_i to each scanned lines. These vectors

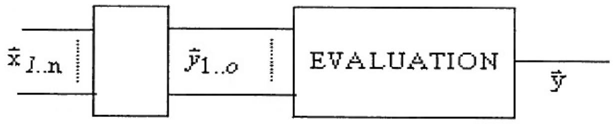

Figure 7. Guiding control.

are pointed into the opposite of the scanned direction (key idea of PBG), and their absolute values depending on the detected distances are:

$$\bar{y}_z = \bar{e}_z w_z(x_z) \quad (1)$$

This means that the potential function of the robot is sliced in the scanned directions (Figure 8).

Usually the evaluation is based on the sum operator that results in [4]:

$$\bar{y} = \sum_{z=1}^{n=o} \bar{e}_z \cdot w_z(x_z) \quad (2)$$

In many cases this kind of evaluation is not effective. For example, let the potential function on each scanned line be the same. Applying (2) to symmetrically located obstacles, will result in a zero vector (Figure 6b). Choosing one of the $\bar{y}_z$ in the evaluation would lead to a better solution.

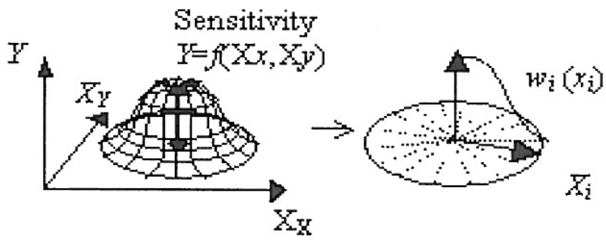

Figure 8. Structure of the potential function.

Despite the advantages of PBG, its use is restricted by the fact that its guiding strongly alternates in some cases [5]. For instance, this problem arises when the robot has to run parallel with a wall that is a basic case in a corridor. [6] [8] proposes an extension to a Vector Field Based model (VFB) that eliminates this disadvantage.

In order to show the effectiveness of the specialized fuzzy logic technique proposed for PBG we implemented various PBG-based techniques chosen from the literature and used it as a "teacher" robot. The proposed technique was implemented in a "student" robot. We concluded that the trained "student" robot showed the same guiding style and found the path with small difference as the "teacher" did, even in case of a new set of obstacles.

In order to save the computational complexity we used simplified triangular fuzzy sets defined in Ruspini-partition [9]. We set 7 sets at each dimension that implies rough approximation, however, the guiding style of the "teacher" and the "student" robots have no remarkable difference. The rule base can be reduced by the method published in [10]. As another example, we controlled the "teacher" robot manually. Let us present only three extremes of the results. Figure 9 shows three cases. The basic guiding styles of the manual control were: 1.) Keep on left side. 2.) Keep on right side. 3.) Get as far from the objects as necessary. Figure 9 shows the guiding of the three trained "student" robots among the new set of objects.

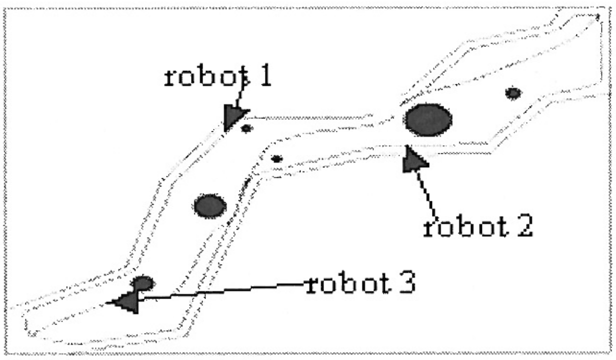

Figure 9. Guiding styles learned from humans.

5. Conclusion

This paper presented a general approach to telemanipulation. Some constraints were discussed and different guiding styles for an autonomous robot were presented. This paper also presented an overview of remote control, various control methods and discussed the Potential Based Guiding model. These techniques will be useful during the implementation of different control modes into our software. The next step will be to modify the "Virtual Wall" application in order to be able to establish connection with a server in Gifu (Japan) for remote controlling a 3D robot model implemented in OpenGL. After successful direct control tests, behavior control mode can be implemented and various guiding models can be examined.

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