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Remote Controlled Robotic Arm with Visual Feedback

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Abstract
This paper presents a robotic arm equipped with a visual feedback channel that acquires data from the space where it operates in order to have a precise remote control. The prototype is an anthropomorphic model (i.e. constructed in similarity with the human hand - regarding the movement abilities and degrees of freedom) and has both haptic and visual feedback in order to ensure better control and high precision operation. The main contribution and novelty of the robotic system is the architecture that combines robotic technical solutions with virtual reality devices, the algorithms for data processing (for the replication of movements and processing the sensorial data) and the practical solutions for the implementation. The paper is focused on the visual feedback channel, that allows the operator to visually explore the site of the operation, in addition to gathering visual data of the operation. Our experiments confirmed the validity of the architecture and the improvements in training and operating capacity.

Keywords: *robotic hand, robotic arm, visual feedback.*

1. Introduction

The paper we present the visual feedback channel of a tele- operated robotic arm that, according to experimental tests, improves the performances of a robotic arm equipped with haptic feedback. The robotic arm was designed and built for handling as effectively as possible objects of different size and weight. Both commands and feedback data acquisition systems are based on virtual reality devices (data gloves and gloves) and on replication of movements (of the hand and head of the operator).
The robotic arm is tele-operated (i.e., not autonomous), the remote control allowing interventions in hazardous environments - a good example is space exploration, but also terrestrial applications as repairs to equipments that is for different reasons not accessible directly to human operators.
Many of the programs of space exploration have used and still use different devices to have a visual feedback form the remote sites that are explored, and we will use this domain to illustrate the utility of the application mostly because it is appealing. The visual feedback is used not only for main motion control of a vehicle, but also for operating several devices, including robotic extensions.
One of the most popular and also the earliest examples are those of space programs Russian Lunokhod-1 (1970) and Lunokhod-2 (1973) in which various operations of a vehicle on the moon were controlled in real time by a human operator who was in the control room on the Earth. The human operators controlled the vehicles using joysticks and received information from cameras that were mounted on these vehicles.[1]

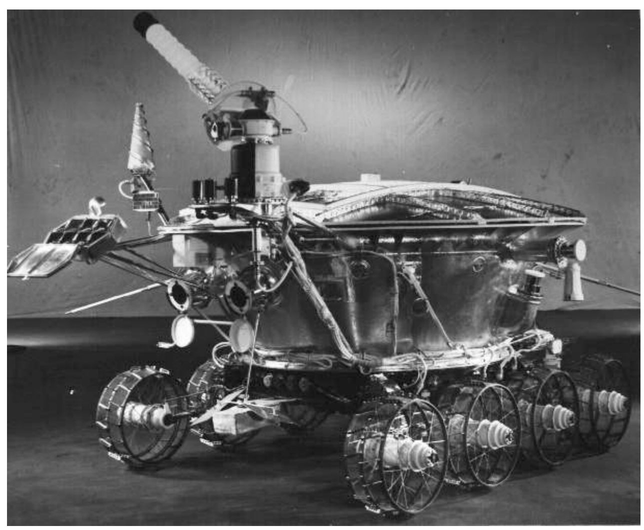

Fig. 1 Lunokhod-1 lunar vehicle [1]

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Both vehicles Lunokhod remained on the Moon surface after completing their missions - in the case of Lunokhod-2 the termination of activity went as planned and its coordinates were known, but for Lunokhod-1 the transmission was abruptly interrupted and the researchers did not know the place and position where it remained. [1] The position of the Lunokhod-1 lunar vehicle on the moon remained a mystery until 2010 when its coordinates were identified using high-resolution cameras on Lunar Reconnaissance Orbiter (LRO).

Fig. 2. Lunokhod control room, where from operators monitor and control the movements and operations of the vehicles with the help of visual feed-back [1]

Among other robots used in space missions most interesting in connection to our applications are the robotic rover Curiosity and robotic vehicle Opportunity launched by NASA. Both of them can perform certain tasks autonomously, but are still partly dependent to the commands received from operators in Mission control centers on Earth.

All these applications have to solve the problems specific to remote control in the situation of very large communication delays due to the long distance and the limited speed of propagation of radio waves. The most recent vehicle of this type used in space missions is Yutu Moon launched during Chang'e lunar exploration March implemented by China National Space Administration. [2]

Fig. 3. The lunar vehicle Yutu Moon on mission on the Moon surface is commanded by human operators at the China National Space Administration [2]

Vehicles are not the only type of systems that make use of remote control with visual feed-back, for space applications. In the space operations a new concept was developed - the Robonaut (from Robot and Astronaut) which is a robot that is remotely controlled by a human operator [3]. The human operator acts through a Robonaut, he receives real-time feedback of many types (visual, auditory, haptic, thermal, etc.) from the sensorial interfaces of the Robonaut, depending on the environments in which it operates and the specific task. The feedback data are processed and calibrated by the human operator so that he can act through the Robonaut with high efficiency and precision in performing the different operations.

Fig. 4. The Robonaut designed NASA Johnson Space Center in Houston, Texas. [3]

2. The Anthropomorphic Robotic Arm with Haptic and Visual Feedback

The robotic arm presented in this paper was developed with several applications as target, including space operations, i.e. implying high precision teleoperation (remote control based on adequate feedback). Other fields of applications imply the operation in dangerous or remote sites, not directly accessible to the human operator. The efficient remote control is based on the status of the robotic arm, the environment and sensorial feed-back.

From the mechanical point of view, the robotic arm (the prototype is presented in figures 5 and 9) is an anthropomorphic model, with an arm and a hand having 5 fingers with similar number of degrees of freedom as the human arm/hand/fingers. The robotic arm has two channels of feedback (haptic and visual) that provides information to the human operator in order to increase accuracy in handling objects (in the experiments done so far).

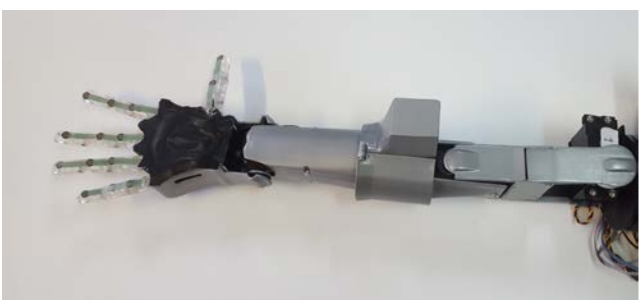

Fig. 5. Remotely operated robotic arm with pressure sensors on the fingers

The movements of all mechanical segments are commanded through replication of the operator's arm and hand movements, using a data glove (for the hand) and additional sensors for the arm (see it mounted on the arm in figure 9).

Recently there is a large interest in the industry and academic research for design of intelligent robotic systems, including various types of anthropomorphic robotic hands [4]. Some of them are based on replication of human movements and use data gloves for data acquisition. Recent scientific papers present the variety of solutions available on the market or reported in scientific literature [5], [6].

Comparing the prototype presented in this paper with different models available on the market, one should notice the originality of our solution. Although it makes use of available products (data glove, stereo camera, virtual reality glasses), the concept is original both in architecture and computational algorithms. For instance, although many recent project use data gloves for the command of a robotic hand, or bending sensors for the movements of the arms and feet of a robot [7], the combination of both has not been yet implemented by other authors. Other solutions use cameras for recognition of the gestures [8], but in our architecture the cameras substitute the "eyes" of the operator.

The integration of the visual feedback and sensorial perceptions as a whole virtual reality environments is also new in this field.

The haptic feedback channel is presented in [9] and does not require the image data from the visual feedback channel. However, this offers o consistent improvement of the performances and allows flexibility in operation and training.

3. Implementation of Visual feedback channel for teleoperation of the robotic arm

In order to use the robotic arm at a certain distance from the operator, as designed to, visual information of any sort is necessary. The simplest solution uses one ore many video camera, placed in the vicinity of the robotic arm - not always as a part of the robotic system. Our solution implements the video channel in an integrated virtual reality environment, in order to obtain a better correlation of the operator with the robotic arm he/she controls. The human operator will process the video information as a visual feedback of the efficiency of the operation. The visual feedback channel gives visual information at 1: 1 from the place where the robotic arm acts and thus contributes to a better precision in achieving different missions.

Figure 6 gives the block diagram of the visual feedback channel that includes a 3D stereo color camera (in our prototype we used a 3D Stereo Sony XDCAM HD), a processing block and the video interconnection interface. The operator video interface consists of virtual reality 3D glasses (we used Sony HMZ-3TW model) and a unit for detecting and processing the head position, with its controller (DPP). DPP uses a gyroscope (L3G4200D) which provides position data in 3 axes and a 16-bit I2C interface type / SPI.

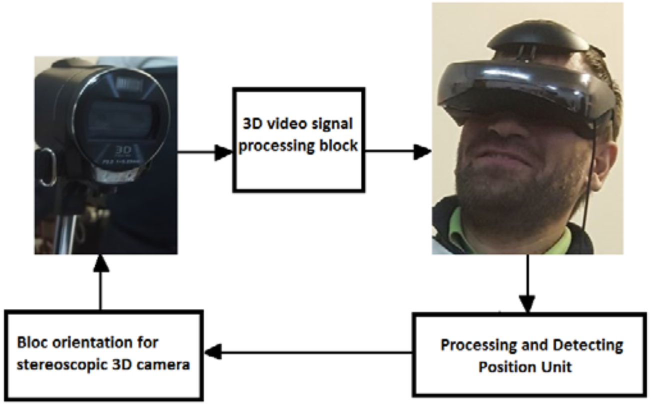

Fig. 6. The visual feedback channel

The gyroscope signal is processed with 3D video processor (Arduino was used), and further commands the guidance system for the stereo HD camcorder. For the guidance system of the camcorder it was used the Motorized Pan / Tilt Head for Camcorder.
The DPP was therefore designed in order to control the movements of the camera: it detects the movements of the operator's head and the data are transmitted to the control unit of the stereo camcorder (BCVS) for synchronous orientation of the camcorder. This way the operator can explore the environment in order to collect information from remote space where robotic arm has to achieve different missions. All movements and sequence of movements of the head are duplicated synchronously by the stereo camera. Feedback channels implemented on the robotic arm provides telepresence human operator function and allows it to be implemented in the real environment in which remote robotic arm is placed through it and act upon that environment.
It is a kind of virtual reality integration system, but the remote control allows action in real world. The algorithms for data processing and commands were developed by the authors.
The figure below shows the functional diagram of the visual feedback channel. The image is captured by a video camera stereo (3D) and transmitted through an HDMI link to the 3D glasses Sony HMZ-T3W type what OLED display HD stereo projection on the retina. The OLED display provides a contrast, brightness, color and sharpness very good suitable for two independent images that are simultaneously coordinated for each eye (3D).

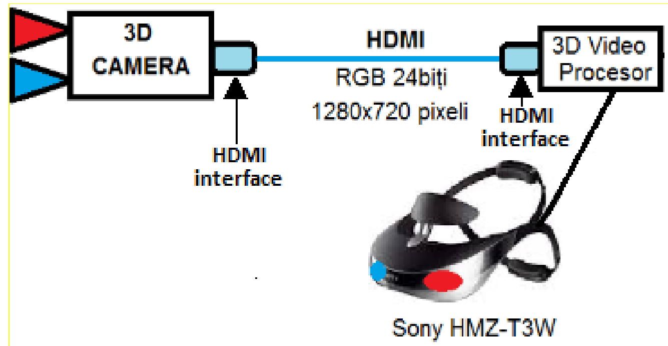

Fig. 7. Functional diagram of the visual feedback channel

The features of the Sony HMZ-T3W glasses that were selected for the implementation include:
- Resolution: 1280 x 720
- Control: brightness, sharpness, color
- Opening: 45 degrees
- Signal: RGB 24 bit
- Virtual image size: 750 inches (19m)

4. Training and Experiments

The testing of the correct functioning of visual feedback channel was first made separately from the robotic arm as shown in the figure below. Indeed, there is no interaction between the different functions of the robotic arm and sensorial interface.
The operator executed several movements (up-down, turnings, rotations) with the head, in order to visually explore the environment and tune the stereo camera. A second person (the observer) had filmed the training session. The operator get used to explore the environment with small, continuos movements.
We did not define and measure the precision and delay of the replication of the movements of the head to camera - there are obvious limitations in the speed of movements, changing of directions etc., that will be significant parameters of the final product, especially if intended to use in hazardous environments. So far, the observer and the footage confirmed the replication of the movements of the head.
After the first training session for the visual feedback, a second training session tested the ability of the operator to command the robotic arm with only virtual visual contact with it, and the capability of the robotic arm to perform

basic tasks like gestures and grasping of various objects.

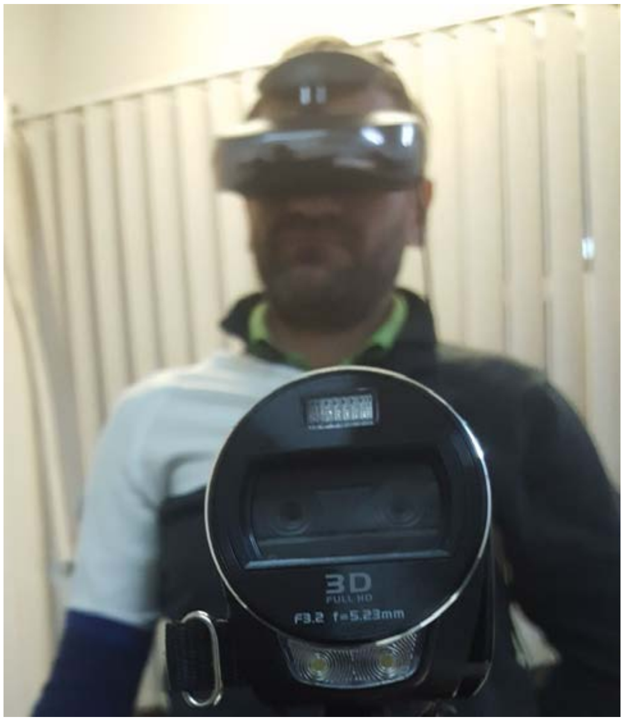

Fig. 8 Testing of visual feedback channel functioning, with the camera of the robotic arm in the front

The human operator managed to command the robotic arm to manipulate objects as shown in the figure below, although additional training was needed in order to coordinate the movements.
Since the operator had no direct visual contact with the robotic arm and the objects used in experiments, it would be the same if the robotic arm would be at a certain distance or in a different room. Objects of different sizes, density and weight were grasped, lifted and moved in order to establish the capabilities and limitations and identify further developments and improvement of the prototype.
The operator reported in first experiments a certain difficulty and unease in operating the robotic system (that he previously commanded having direct visual contact), but also reported the benefits of the virtual reality integration of the system, that makes training and operating more "natural" and easy to learn and adjust. In the end, due to direct visual feed-back, the operator was able to perform simple tasks like moving on a fix distance or doing some gestures much more accurate than in the absence of the feedback.

Fig. 9. Testing functioning robotic arm equipped with visual and haptic feedback channels

4. Conclusions

The paper presents the visual feedback channel of a anthropomorphic robotic system (consisting of a robotic arm and hand) with haptic feedback. The visual feedback channel is more than just a camera in the operation space - it gives a virtual reality 3D image and is able to explore the environment according to the necessity of the task performed. The robotic arm replicates the movement of the operator's hand and arm, while the 3D camera follows the movement of the head. The architecture and the processing algorithms are the original contribution of the authors. The main novelty of this robotic arm is

given by the combination of robotics and virtual reality in order to tele-operate the system.
Our experiments confirmed the validity of the architecture and processing algorithms, since the operator was able to perform simple tasks with the robotic hand using only the visual feed-back channel, as if the robotic system would be in a remote space. Further developments will need to solve the problems given by long distance delays of signals and the improvements of the mechanical structure.

Acknowledgments

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