VIRTUAL REALITY INTERFACE IN MATLAB/SIMULINK FOR 2DOF JOYSTICK CONTROL

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Abstract. *Estimation of the most important functional and non functional features during design process of the human-machine interfaces can be tedious. This particularly stands for a haptic device. Therefore, there is a need for a development and validation environment to be used for extensive tests during the design process. It will enable the designer to fine tune the device to different application environments. One solution is to make virtual reality world of simulated physics and force feedback interaction within Matlab environment. In this paper, the implementation of such virtual world with MATLAB Virtual Reality toolbox and Simulink 3D animation product is presented, discussed and evaluated.*

Key words: *component; haptics; telepresence; robotics; virtual reality*

1. INTRODUCTION

Modern intelligent robots are considered to be an invaluable extension to the human sensory-motor abilities, skills and power. Increased reliability enables machines to be involved in very sensitive fields such as medicine while processing power paves the ground for almost autonomous work under wide sensor feedbacks enabling better understanding of the robot-environment interaction. Even though we witness remarkable improvement in video and audio processors, tactile sensors and sensor fusion, still there is no sensor system able to see, hear, feel and understand the forms, shapes and meaning of interaction. This disables robots to prevail over skilled human operators thus requiring the human telepresence necessary if we want to achieve maximum from modern technology applied in challenging fields. Telepresence embodies compatible technologies which

allow operators to feel the effects of physical interaction on a remote site as if they were present. It requires sensor systems on physical site, along with processing and communication technology to transfer the information about interaction to the remote site where a mechanical device designed to closely match the interaction problem produces stimuli to human operator [1]. This force-information flow can be also established in an inverse way, thus enabling the operator to characterize the interaction. Typical bilaterally transmitted information is: position, velocity, force or voice. One of the most popular applications of telepresence is haptics involved in telerobotics medicine paradigm [2]. The design and functional demands of the physical interface enabling remote manipulation and telepresence can be considered twofold. The interface can be organized through master-slave manipulation where both the interface and the robot are of the same functionality with possibly the interface a bit scaled down in size. Another solution starts from 2 DOF or 3 DOF mechanical devices with software suited to mimic actual manipulation task and interaction. In more demanding tasks such interface can have up to 6 DOF [3].

In this paper we will address 2 d.o.f. joystick with parallelogram mechanism able to swing the handle of the joystick over two horizontal and perpendicular axes. The simple design enables low cost development while the main focus should be on the modeling and integration in the virtual control interface developed in MATLAB/Simulink.

Such solution to medical applications can be applied in many different tasks such as manipulator end-tip control in 2D, rehabilitation, wheel chair control, surgery, surgical training, etc [4, 5]. The stimuli that can be fed back to the operator can be, besides forces or torques of mechanical interaction with environment, also internal properties of the robot such as inertia, vibration, etc.

In the case of robotic surgery, the system made of surgeon, surgical robot and tools quite often can impress with precision, agility and repeatability in preprogrammed tasks but cannot be very useful in the cases when surgery comes out of preoperative plan. In such case, the surgeon takes charge and the robot is usually steered to follow commands from the joystick. Although it might be a complete solution, still there is evidence that robot-supported surgeries achieve similar success as standard surgeries, measured by the postoperative evaluation. The lack of touch stimuli at the surgeons' side is a crucial problem to be solved if we want to improve the robotics surgery today. Such stimuli can be achieved by the actuators attached to the mechanical interface, controlled to produce torque and force thus enabling the force and torque projected at the handle. If motors-drivers system is high performance one can expect wide range of forces starting from vibrations, via periodic, to impact forces. Shaping the interaction requires advanced algorithms along with fast computation. Standard algorithm prototyping tool is MATLAB with its Simulink environment. Therefore, designing a controller for joystick that will include interface for MATLAB/Simulink is one of the keystones in developing useful algorithmic tools for robotic telepresence.

In the following chapters, the emphasis will be on explaining the importance of development of such a haptic device. Mechanical and electrical design will be explained, as well as, sensing, control. Particular attention will be focused on the software needed to establish a chain of tools for haptic joystick modeling and control.

2. Hardware for Haptic-Enabled 2 DOF Joystick

The design framework as integrated development tool for rapid prototyping of control algorithms in the task of arm manipulation through 2D joystick is based on the mechanism, electrical and sensor system. Mechanical system is a combination of gimbal and pantograph-like linkage mechanism. A parallelogram mechanism with one degree of freedom is hung on the top plate of the joystick housing. The mechanism, with its support, can freely swing around horizontal axis. Both degrees of freedom are actuated with two high performance DC motors. The mechanics of the joystick basically transforms two internal coordinates, motor angles q_{1m}, and q_{2m} into handle angles ρ, and θ.

A solid model of the 2D joystick is given in Fig. 1. The motor drivers are custom designed and adapted to fit this application. The drivers are implemented and tested in several human-machine interfaces of which the most advanced ones are described in [5]. Sensing system of the 2D joystick is customized to provide internal coordinates measurements, force sensing, as well as safety sensors that will detect presence of human arm, locking function, etc. The control system is designed around Humusoft MF624 data acquisition board that enables 8 AI, 8AO, 8DI, 8DO, four counters for incremental encoders, driver for MATLAB Real-Time Toolbox, driver for xPC target, driver for Real-Time Windows target, and driver for 32-bit Windows applications. The resources of the MF624 are sufficient to make truly useful interface system for further integration in robotic telepresence applications.
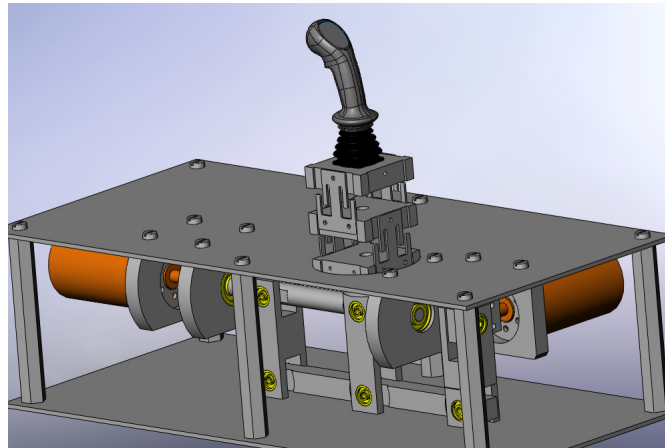

Fig. 1. Complete solid model of the 2D joystick with the stick attached on top of the force sensing unit.

Such a mechatronic device is not available on the market as a system open for further research. It must be customized according to specific needs. Assuming it is machined, assembled, and validated, the next step is to make it operational within MATLAB/Simulink environment. Such environment is a powerful tool that can handle many problems related to this problem. Therefore, it is important to consider and evaluate all possible functionalities of the MATLAB to be used later in Joystick control as a haptic device. Validating different application environments, designed in MATLAB and projected onto Joystick interface to produce adequate stimuli on the operator, are another

research problem in this paper. A common approach is virtualization of the world the joystick will communicate with. This virtualization starts from the simulation of mechanics of interaction directly in MATLAB. Using MATLAB it is possible to design and engage any environment of interest for development and testing haptic interfaces. This approach will considerably simplify and reduce the cost of the development process.

3. SOFTWARE FOR HAPTICS AND TELEPRESENCE

Today's teleoperation robotic surgical systems (like Zeus and the daVinci systems) provide versatile tools and methods that augment surgical operation process, listed in [7], but so far they do not provide the feedback or tactile/force (haptic) sensations crucial for better surgery. The significance of haptic feedback in master-slave operation is discussed below.

To provide a surgeon with force perception during teleoperation, the system must contain two components, one on the patient and one on the surgeon side:

1. A sensorized surgical instrument (like endoscope with force sensors attached to its tip, or clamps with force sensing unit in its joint or at the grasping tips)
2. A force-reflective human-machine interface that mediates between the surgeon and the robot, transferring hand movement commands to the robot and instrument/tissue interaction measurements to the surgeon's hands.

The focus of this paper is not just to create different models for haptic-enabled user interface. To avoid expensive physical prototyping, one should exploit the virtual reality world, with real physical models of objects being controlled. The forces are then generated as the interaction between simulated environment and physical tool. Virtual Reality toolbox from Matlab is used as a general framework for development of such an application. Programming of main functionalities, design process and interfacing with mechatronic 2 d.o.f. joystick should be added up. In the design process and implementation of such a user interface the energy and information flow must be discussed first. The diagram in Figure 2 shows the flow of forces and information.
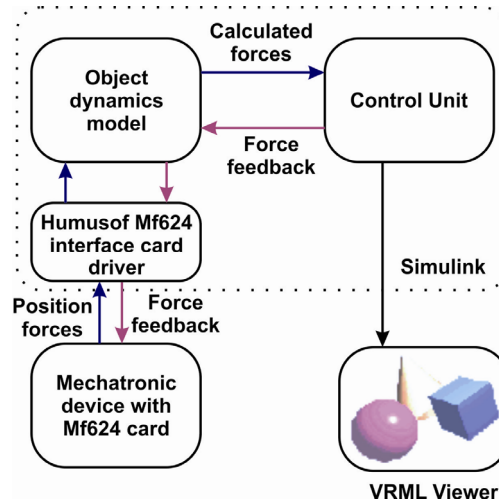

Fig. 2. Forces and information flow in haptic-enabled mechatronic 2 d.o.f. joystick

The application paradigm is as follows. By moving the handle bar of the joystick, the human operator gives the information on the desired position of the object in virtual world. This is fed in the Simulink model of virtual world and here is the place where possible virtual interactions between virtual tool and virtual environment are calculated. Computed interactions are fed back to the hardware able to project interaction forces directly to the operator's hand. The forces generated on four force sensors attached to the base of the handle bar are fed into the control unit, which will be described shortly. At the same time computed interactions are fed to VRML Viewer to augment physical stimuli by visualization.

The forces, generated in the virtual world, are fed back to the joystick control unit. The control unit embodies different models and algorithms that are used to produce signals that control forces generated by drivers on joystick handle. This control unit, together with mechatronic device acts like a mechanical filter of forces, where a complex set of forces, interacting with the object being controlled in virtual world, is transformed into just two different force vectors placed along two axes of the joystick. Choosing the right model and/or algorithm that will be the core of the control unit is a subject of an entire new research based on this mechatronic model, so it will not be further discussed in this paper.

3.1. Virtual world in Virtual Reality toolbox

The Simulink 3D Animation product [8] is a solution for interacting with virtual reality models of time-varying dynamic systems. It extends the capabilities of MATLAB and Simulink software into the world of virtual reality graphics. It provides a complete authoring, development, and working environment for carrying out 3-D visual simulations. The main features that this product enables are:

- Virtual worlds – For creating virtual worlds or three-dimensional scenes using standard Virtual Reality Modeling Language (VRML) technology.
- Dynamic systems – For creating and defining dynamic systems with the MATLAB and Simulink products.
- Animation – For viewing moving three-dimensional scenes driven by signals from the Simulink environment.
- Manipulation – For changing the positions and properties of objects in a virtual world while running a simulation.
- Interaction – For interacting with dynamical models from the virtual environment and by using input devices.

Object dynamics model block (Figure 2) is responsible for simulation of the environment, controlled object and interaction between those two. In this case, the object being controlled is non-deformable ball (with given diameter and mass) and a hard surface with walls. The surface plane is orthogonal to force of gravity, and appropriate friction between the ball and the surface is added. The walls are not hard and interaction between the ball and the walls is modeled like if there is spring, with given spring coefficient, between the hard wall and the ball. The user has a task of positioning the ball in a given position. If that position is inside the walls then a user should overcome just friction between the surface and the ball. If the given position is outside the walls then the user will have to overcome the force with witch the wall acts on the ball. All calculated forces of interaction between the walls and the surface are forwarded to The control unit. The control unit with its interaction models and algorithms generates and feeds back infor-

mation of desired momentum on actuator's shafts. Through joystick handle's mechanical construction, that momentum is transformed into forces that generate sensation of real interaction with simulated ball on user's hand.

3.2. Telepresence in Virtual Reality

Along with the development of fast telecommunication services, the characteristics of telepresence systems are improved significantly. In recent years, telepresence systems have often been combined with teleaction systems that allow users to remotely interact with the environments. Here, remote environments include possibly distant and/or scaled physical environments, virtual environments (as in our case) – VEs and augmented realities [6].

The haptics seen as a force feedback with tactile sensation is basic technology in the telepresence systems and also the key element that distinguishes modern telepresence systems from the classic ones. Establishing the feedback system of a user and tele-operated machine raises new research issues, especially when this loop is closed over unreliable communication network, like the Internet. To overcome this kind of problems, new telecommunication protocols for this purpose need to be developed, as well as new control algorithms that can minimize this kind of error in the system.

Also, the interface between teleoperated mechatronic device and the control unit, and the control unit and communication network must be suited to meet these specific needs. The same stands for the user's side where the haptic device is. If we were making prototypes for each change and problem that needs to be solved, the development process could be very tedious. Therefore, the teleoperated system in this research is based on Virtual Reality system. In that way, the control unit, interfaces development and communication error reduction can be done in simulated test environment. After thorough testing and validation in a simulated environment, the real teleoperated mechatronic device with haptic feedback can be designed and implemented.

4. TAXONOMY OF VR INTERFACE

It is observed that robotized applications require considerable amount of training and the operator should reach the level of skill needed for successful completion of robot guidance. Otherwise no benefit of robot application can be expected. The role of haptic joystick is crucial not only in the final application paradigm but also during the training process.

True functionality of the haptic device such as the one described in this paper will be further evaluated against taxonomy of tasks where human interacts with it. Such device is a powerful tool in:

- transferring of human hand movement to a remote device, or to a virtual object,
- estimating the level of skill a human operator has reached,
- guiding of the operator's training process,
- establishing intelligence framework in haptic control,
- understanding of human hand movements by recognizing intention within a specific context of the task.

All of these applications might enhance telepresence during applications such as robotized surgery. One of such examples will be discussed briefly.

At first, an operator or a subject will be given a task of moving an object in virtual reality to a predefined position with haptics turned off. In this case the subject has only visual feedback. After that other subjects will be given the same task but with haptics turned on where both feedbacks, visual and force, will be established. Thorough examination on trial-by-trial performance improvement can show how the chosen haptics algorithm improves, if at all, the process of motor learning. Achieved elementary skills can be further upgraded in a comprehensive motor repertoire needed for successful completion of the telepresence. If the designed models in virtual reality are made with tolerable approximation this transfer should go seamlessly. With the real device, the control unit algorithms can be truly tested and adjusted. The knowledge gained in this future research should give us a new awareness and better understanding of human sensory-motor system to make teleoperated systems with performances equal to those when the operator is on the actual site.

Considering the amount of experiments and its variety within a general telepresence paradigm it is very important to establish a comprehensive tool chain for virtual reality support of a haptic joystick. This will greatly reduce the cost of establishing better human-robot interaction and speed up the training process.

5. CONCLUSION

This paper presents the concept of Virtual Reality enabled mechatronic system for haptic research. Besides the already known advantages of such a mechatronic device, now we can speed up the process of experimenting and algorithms design for force-feedback and tactile sensation generation and transfer to a human operator on a remote site. Also, we emphasized the need for this system as a tool that will allow us to make taxonomy of tasks for further evaluation of human interaction, and to determine if haptics algorithm improves the learning of motor skills. In future, this system will be used as a tool for conducting experiments that will lead to a better understanding of human sensory-motor system, particularly when it comes to understanding how humans learn motor skills.

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VIRTUAL REALITY INTERFEJS U MATLAB/SIMULINK OKRUŽENJU ZA KONTROLU 2 DOF DŽOJSTIKA

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Izbor najbitnijih funkcionalnih i nefunkcionlnih parametara u toku procesa dizajniranja interfejsa čovek-mašina može biti veoma zahtevno. Ovo naročito važi za haptički uređaj. Stoga, postoji potreba kako za razvojnim okruženjem, tako i za okruženjem za validaciju koje će omogućiti opsežne testove u toku procesa razvoja. Ovo okruženje će omogućiti dizajneru da precizno podesi uređaj za različite aplikacije. Jedno rešenje se ogleda u kreiranju virtuelnog sveta sa simuliranom fizikom i force-feedback interkacijom u okviru Matlab okruženja. U ovom radu je opisana, diskutovana i evaluirana implementacija takvog virtuelnog sveta sa Matlab Virtual Reality alatima i Simulink 3D animation proizvodom.

Ključne reči: *komponenta; haptika; teleprisustvo; robotika; virtuelna realnost*