Abstract

The telemanipulation control approach is widely used in micro/nano manipulation where complex handling tasks are to be completed in very small spaces unnatural for humans. Visual, tactile, position or force feedbacks are used assisting the operator to see, sense and control the manipulation process. Without any of these feedbacks it is very difficult to work into the unknown micro/nano world. It is possible to create virtual working environment using the impedance parameters spring, damping and inertia to follow its dynamics. To improve operator’s skills for handling the micro/nano operations, an impedance scaling approach is used herein. The development of a telemanipulation approach for mechatronic handling devices employed for micro/nano operations with three degrees of freedom (DoF) is presented. A virtual environment is created and sensed accounting for spring and damping virtual force effects. The effectiveness of the teleoperation control is experimentally investigated on a 3 DoF robot for scanning operation and a mechatronic handling device for biological investigations, using an inverted microscope and digital cameras.

Keywords: telemanipulation control, impedance scaling, micro/nano handling operations.

1. Introduction.

In any robotic system, the interface between human and machine plays an enormous role in the effectiveness of the system. However, in some applications where humans continuously interact with robots the interface is much more complicated because the processes developing in the environment either changes very fast or are unknown for the operator. These changes characterise the working spaces as dynamic environments that require a more effective approach for perception of the working environment dynamics. Typically, this problem is approached either via teleoperation with a joystick or by means of another suitable input device [1-4], and a graphical user interface is usually developed and submitted together with the input device.

Telemanipulation is a capability of performing remote manipulation of objects or operations into various dynamic environments [5-6]. If the reaction of the environment is of great importance or the robot can cause damage in the far environment, force feedback is needed to improve operator’s efficiency.

Operator’s skills are improved developing different virtual environments, which simulate remote working spaces or dangerous tasks performance such as handling radioactive materials or explosives.

In micro/nano teleoperation, a haptic interface provides the operator with the feeling that he touches the expanded micro/nano objects with his fingers. Force and position scaling is an important issue in the micro/nano remote environment, and there are basically two scaling approaches: linear and nonlinear scaling.

The performance of a dynamically scaled telemanipulation in the nano space using virtual impedance is also an object of study [7]. Here, the force applied by the operator is compared to the scaled nano force and the force difference is the input of the virtual impedance. The output of the virtual impedance is the reference position both of the master and the slave system.

Different approaches are designed to improve operator’s telemicromanipulation skills [1-5]. The micro-manipulators used are equipped with tactile, force or audio feedback. Since contact forces are very small (almost zero), they are scaled up for operator’s convenience, and information data can not be collected without any kind of feedback mentioned before. The general task of the present paper is to realize an approach for modeling and sensing micro/nano surfaces with unknown properties, using any kind of feedback.

Some software applications have been developed [8], modeling virtual surfaces needed for operator’s training, but a universal micro teleoperation training approach does not exist yet. The used dynamic parameters for environment modeling are fixed and the operator needs much time to master some specific micro/nano operations.

The aim of this paper is to develop a telemanipulation control approach for mechatronic handling devices for micro/nano operations, designing a virtual working environment dynamics appropriate for any operator. The approach is based on a procedure for impedance scaling parameter identification needed for operator’s self-training. The robot-operator link will be realized by means of a joystick and its force feedback effects.

2. Telemanipulation robot control for micro/ nano surface scanning operations and mechatronic handling device for bioresearch.

The teleoperated system - a subject of the present paper, consists of the following parts (Fig.1.): operator, joystick and micro-manipulator. The hand of the operator applies a force (Fₒ) to the joystick which reads this signal and transfers it to the micro-manipulator causing joystick displacement (xₒ). Each joystick displacement (xₒ) is scaled down and corresponds to micro-manipulator displacement (xₒ).
An inverted microscope Carl Zeiss Jena is used as a visual feedback. The real working space is presented to the operator by means of a digital camera equipped with specialized software. The joystick used is with force feedback that enables one to generate force effects. In our task, the knot mechanical impedance [9] is prevailing while the non-knot one is disregarded, i.e. it is worked with stiffness and damping forces, disregarding inertia forces. The joystick reads micro-manipulator coordinates \( x_i \) in the virtual working surface, and the force feedback models this virtual surface denoting it by \( F_i \). The operator can sense the surface boundaries and he can control the working tool motion speed.

A nonlinear scaling is utilized in the present paper, reading as follows [6]:

\[
\begin{align*}
(1) \quad & x_j = \alpha x_i (t) \\
(2) \quad & F_j = \alpha^2 M_j \ddot{x}_i + \alpha^2 B_j \dot{x}_i + \alpha^2 K_j x_i,
\end{align*}
\]

where \( x_j \) and \( F_j \) are scaled values of the (slave) robot position and force; \( \alpha \) is the scale position constant; \( M_j, B_j, K_j \) are virtual mass, viscosity constant and stiffness, respectively; \( \ddot{x}_i, \dot{x}_i, x_i \) are robot acceleration, velocity and position.

A telemanipulation impedance scaling approach is developed as outlined above, using the knot impedance, only, i.e. the damping and spring coefficients. The equation modeling the force feedback \( F_j \), which calibrates the joystick and improves the operator’s skills by providing him with appropriate interaction dynamics, is as follows:

\[
(3) \quad B_j \ddot{x}_j + K_j x_j = F_j
\]

To define an appropriate force scale factor consisting of damping and spring coefficients, a technique for dynamic formulation of personal impedance parameters is developed (Fig.2.). It differs from the methods [10-11] used before, since the working space can be modeled not using the real force feedback sensor. Moreover, operator’s skills can be dynamically improved, aiding him in sensing the force feedback signal coming from the joystick used. The algorithm starts with a registration, i.e. generation of a file with user’s name and password. Thus, any operator can save his own individual impedance parameters appropriate for the operation of a real telemanipulation process.

Virtual two dimensional space for testing and improving the operator’s skills is modeled. Tracks are used as surfaces, thus introducing different trajectories. Track boundaries with spring effect are modeled as a danger zone (the zone near to the boundary of the track, 5 or 10 pixels large). The working tool is modeled in the virtual environment and it is defined as a mobile object. Control of the mobile object is performed by means of the joystick input device, connected to the computer via USB port.

Damping and spring effects with low amplitudes are introduced prior to the track test start. If a mobile object enters the danger zone during the test, the spring effect is actuated. If a mobile object passes half of the danger zone, the test is terminated and starts again. If a mobile object comes out from the danger zone, the spring effect is blocked and the track test continues till the end of the last lap. The results are analyzed after the test end, and if operator’s time exceeds that previously specified, the damping effect is blocked and the test starts again.

If operator’s time is smaller than the specified one, the test is considered to be successful, and the impedance coefficients found can be considered as appropriate. These dynamic parameters can be used in a real working space. Hence, the operator thus skilled can protect from damage tool handling in a micro/nano environment. Time reading is necessary, since many micro-operations are time-dependent and processes developing in some chemical or biological environment change very rapidly. Many operators are not able to position or orientate the working tool with high precision or high speed. The dynamic approach developed herein makes possible the improvement of operator’s skills in tool positioning and orientation, using a teleoperation input device in a micro/nano working environment.

Operator’s self-training is useful, since there are a number of complex micro/nano operations that humans can hardly realize for a restricted time and with high precision. This implies damage of objects, such as biological cells, and failure of micro-biological experiments. It is very difficult to find skilful specialists who will perform those interventions. It is also very inconvenient to train each operator in handling a teleoperated system. It is easier and faster to provide him with a possibility of self-training,
applying the approach developed and including the impedance scaling method.

3. Software applications for telemanipulation and virtual operator self-training

To verify the functionality of the developed approach, software application based on the method of the operator self-training is realized. A Logitech WingMan 3D Force Feedback joystick is used with DirectX 9.00 SDK package from Microsoft. It is suitable for initializing all parameters of different peripheral devices, such as mouse, keyboard and joystick. Modeling and shaping of the virtual impedance is also possible, generating spring and damping force effects.

The virtual environment together with the mobile object, as realized by applying the software developed, is presented in Fig. 3. Track boundaries are modeled by spring effect. Velocity is controlled by a damping effect that depends of time and operator’s movements. The number of laps and time are visualised as monitoring parameters. Thus, coefficients of operator’s personal impedance can be found and saved in a file, being ready for use in a real process.

4. Experimental set-ups and results.

The proposed approach of telemanipulation control, designing a virtual working environment dynamics appropriate for any individual operator, has been implemented in the control of: (i) two mechatronic handling devices (MHD) for micro/nano surface scanning operations [12] and (ii) mechatronic handling device for bioresearch [13]. The micro-manipulator developed for surface quality investigation (Fig. 4) consists of three DoF necessary for:

(i) one translation in Z direction for fine probe positioning in a range of 8 µm and
(ii) two scanning motions along X, Y directions of the measurement surface in a range of 40 µm.

The piezo ceramic elements used are stack piezo actuators with maximal range of 8µm and resolution open loop of 0,01 nm. The PA series of actuators are internally pre-loaded by a mechanical spring, making them ideal for dynamic applications [14]. Actuator motion is controlled by a three-channel high voltage card till 150V. A control resolution of 14 bits makes it possible to operate in the nm-range. An inverted microscope and connected digital cameras are used to visualize the scanning probe position and orientation.

The experiments performed with 5 studdents show significant improvement of their skills for manipulation and handling operations to be performed in regard to time reduction about 5 times.
Fig. 7. Photo of the experimental set up.

5. Conclusion and future work

Using the impedance scaling technique, it is possible to sense a working micro/nano environment which is unknown and unnatural for humans. The technique provides the operator with appropriate perceptions. Thus, he can sense the working space boundaries and control the end-effector velocity.

Approach verification is made, developing two mechatronic handling devices with 3 degrees of freedom. They are used for micro/nano surface scanning operations and for bioresearch. The experimental tests performed for the utilization of the approach developed show that the efficiency of the two robotized micro/nano manipulations has been significantly increased, improving operator's skills and operating with appropriate environment dynamics.

The future work is related to the study of approach functionality, planning experiments with different persons with rather different dynamics. Integration of a real force feedback sensor is also planned.

Acknowledgements

The authors gratefully acknowledge the support of DFG by the Project-Nr. KA 1186/11-1 MeCHaPiCS/2005 "Mechatronic handling devices based on piezo-ceramic structures for micro- and nano-applications". Moreover, this work was carried out within the framework of the EC Network of Excellence "Multi material micro manufacture: Technology and Applications (4M)" under the NoE No. 500274 of NMP2-CT-2004.

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