Scaling Issues for Teleoperation

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Abstract

In many teleoperation tasks scaling of positions is needed due to different workspaces of the master and the slave robot. Two examples, where the PHANToM T-Model is used for teleoperation with force feedback in our institute, are telesurgery and teleassembly. In both cases the teleoperation task can be divided in an approach phase and a manipulation phase. In the approach phase the PHANToM's movement has to be enlarged, whereas in the manipulation phase the scaling is 1:1 or even zoomed to allow easy manipulation (telesurgery).

In the proposed paper the effects of the position scaling on the forces and/or the control parameters are addressed. As force feedback can give the human operator much aid to fulfill the task, it should not be perturbed due to wrong scaling. Our results show that the human reacts on changes in the stiffness of his environment. So, if scaling is done, the resulting stiffness, that can be detected by the human arm at the PHANToM needs to be the same as without scaling.

1 Introduction

In the field of robotic applications teleoperation plays an important role, due to the still limited autonomous capabilities of robots. Robots equipped with sensors can perform certain tasks in an autonomous way, but their reaction on situations that are not foreseen is limited. Teleoperation is a possibility to enhance the use cases for robots in unknown environments.

Teleoperation has often only visual and acoustic feedback for the operator. Additional sensor information, e.g. forces, can be displayed optionally [HBDH93]. So the operator can not use all his senses to fulfill the task, especially his sensomotoric skills are neglected. Using force feedback will overcome this limitation, so recently a lot of research is done in this field. The PHANToM device [MS94] is one of the first commercial products, that gave a push to these developments.

Introducing a generic haptic device brings up the problem that the master and the slave devices have a different kinematic structure and different workspaces. The problem of different kinematics can be solved by introducing a generic interface, e.g. Cartesian control [OH00]. If the workspace sizes of the master device and the slave robot differ, indexing or scaling has to be done.

To analyze the scaling effects we have two scenarios with different needs and different dimensions. One is the telesurgery, where the PHANToM is coupled with a ZEUS robot arm from ComputerMotion for minimal invasive surgery. Here the interesting space for the surgery lies in a cubic with about 2 cm edge length, but the instrument has to travel through the body about 20 cm. The other case is the teleassembly with an industrial robot from Kuka. The task is to insert a piston into a motorblock, where in the approach phase the piston has to be moved about 1 m and in the put-in phase there is a maximal tolerance of 1/10 mm in the positioning the slave robot. Fig 1 shows the principle setup for the scenarios.

The problem of micro assembly will not be ad-

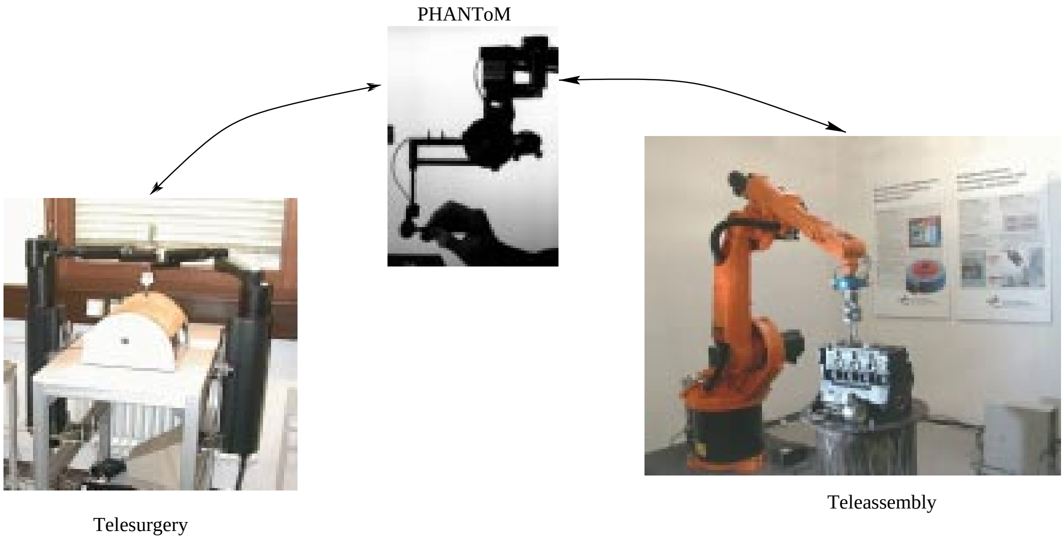

Figure 1: Scenarios for different scaling parameters

dressed. In a micro assembly teleoperation scaling is more difficult, because the sources of the dominant forces, e.g. gravity in the macro world, change [YHUY94].

2 Control Structure

In both scenarios the slave robot is position controlled and the master device has direct force feedback with additional position error feedback. Latter is to stabilize the system due to different dynamic properties of the master and the slave robot. The control structure can be seen in Fig 2.

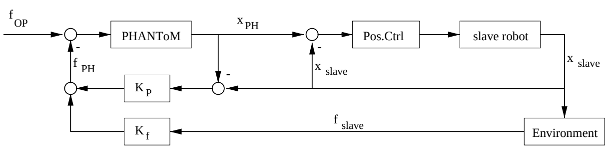

Figure 2: Control structure for teleoperation

The feedback control law is

$$f_{PH} = K_P(x_{PH} - x_{slave}) + K_f f_{Env}, \qquad (1)$$

where x_{PH} and x_{slave} are the positions of the PHANToM and the slave robot respectively, f_{PH} is the force displayed by the PHANToM and f_{Env} is measured at the remote side. K_P and K_f are the control parameters.

K_f is normally equal to one, but can be tuned down, if communication delay affects the stability. K_P represents a virtual coupling between the master and the slave system and depends on the dynamic properties, communication delays and/or the desired task.

3 Indexing

If the workspace of the master device is smaller than the one of the slave robot, only part of the latter workspace can be mapped to the master side, so that it is accessible to the operator. Indexing means, that the movement is not scaled, but that we have a variable offset (index) of the master's position within the slave's workspace, see Fig 3. In this case force feedback is not influenced by the different dimensions of the robots.

The problem of indexing is that it is not very comfortable to move the slave from one manipulation area to another, because e.g. in the teleassembly scenario indexing has to be done very often.

On the other hand, if the interesting area for the manipulation is smaller than the master's workspace (e.g. telesurgery), indexing does not

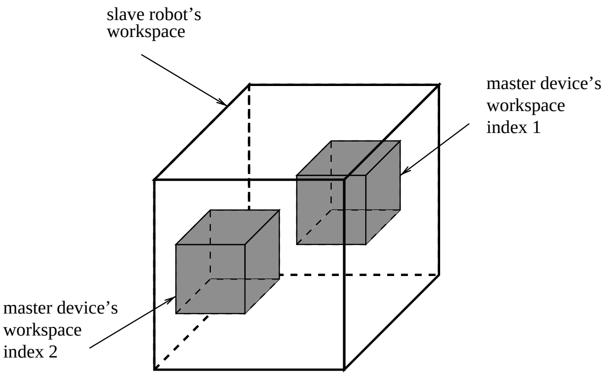

Figure 3: Indexing within slave robot's workspace

help to improve the task.

4 Scaling the movement

A solution to these problems is to scale the movement according to the desired task and task phase, i.e. in an approach phase the master's motion is magnified to the slave's workspace and in the manipulation phase it is kept constant or downsized. Now the effect of this scaling is analyzed. We define the scaling factor s as follows

$$x_{slave} = s \cdot x_{PH}. \tag{2}$$

If scaling is done to the position only, the forces felt by the human keep the same as measured at the remote side and so the appearing stiffness of the environment changes due to the scaling factor s.

$$K_u = \frac{f_{Env}}{\Delta x_{slave} \cdot \frac{1}{s}} = s \cdot K_{Env} \tag{3}$$

where K_u is the stiffness felt at the operator side (neglecting dynamic effects like damping or inertia) , f_{Env} is the force measured and Δx_{slave} is the displacement of the slave robot. K_{Env} is the stiffness of the environment, which is scaled by s to the operator.

If $s > 1$ the stiffness of the environment appears to the human higher as it is and so the system can become unstable. So we have to scale the force with the same factor to avoid this behavior and the resulting feedback law is

$$f_{PH} = K_P(x_{PH} - \frac{1}{s}x_{slave}) + K_f\frac{1}{s}f_{Env}. \tag{4}$$

This case occurs in the teleassembly scenario (Fig 5), because the dimensions of the work cell are much bigger than the workspace of the PHANToM. In the approach phase, when the piston is manoeuvred to the motorblock we use $s = 5$. With this factor still indexing is needed once. But bigger scaling factors resulted in an unstable teleoperation system, because the positional resolution of the human and the dynamic of the robot are limited. During the manipulation phase, i.e. inserting the piston we used the scaling factor $s = 1$ with good results.

If $s < 1$ the motion is scaled down. So the displacement of the slave robot is smaller than the one of the master device. This is equal to the optical zooming. Again as the human feels the properties of the environment like stiffness, these properties should maintain and so the same scaling has to be done to the measured forces.

Figure 4: Telesurgery experiment with German secretary of research Mrs. Bulmahn

In the telesurgery scenario the workspace of the PHANToM is nearly adequate for the approach phase, so scaling $s = 1$ is used. During the manipulation phase, e.g. cutting soft material with a scalpel, we used a scaling factor $s = 0.3$, which led to pleasing results. Even untrained persons are able to handle the teleoperated scalpel secure, as we presented during a visit of the German secretary for research Mrs. Bulmahn (Fig 4).

Approach phase

Manipulation phase

Figure 5: Teleassembly of piston into a motorblock

5 Conclusions

In several experiments with the two different scenarios it was seen that scaling the position and forces is a good way to match the different workspace sizes of master and slave. If it is done carefully the environment stiffness maintained at the master's side and so the human's sensomotoric skills can be used to fulfill the task. In the telesurgery scenario a down scaling was performed in the manipulation task, whereas in the teleassembly scenario the master's motion was scaled up during the approach phase.

Further work has to be done concerning a smooth zooming. This includes also the problem of scaling when the slave is in contact. Then the proposed force scaling will lead to an force step at the master side, which disturbs the feedback and can cause instability.

6 Acknowledgments

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