# Study on Computer Assistance for Telepresent Reaching Movements

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**Abstract.** A new computer assistance concept for bilateral telepresence is introduced which increases telepresent task performance without being explicitly perceived by the operator. Therefore, no training related to the assistance functions is needed, and intuitive telepresence is maintained. In the presented study, we analyze how an intelligent teleoperator can correct the inputs of the operator most efficiently without degrading the feeling of presence. It is expected that there is a tradeoff between maximizing task performance and maintaining feeling of presence. However, our experiments show that appropriate computer assistance methods can increase task performance and feeling of presence at the same time.

## 1 INTRODUCTION

Despite all technical progresses in telepresence systems, which have led to increased levels of performance and transparency, a telepresence system which conveys a truly natural sensation of the remote environment is still a distant vision. The sensation and performance is affected by inaccurate vision, tracking errors in position and force signals, and missing tactile sensation. These losses finally result in increased task execution times, increased failure rates, and increased stress levels for the operator. Furthermore, a single, well defined action can be performed better by an autonomous robot than by the human himself. It is, therefore, desirable to find a cooperation scheme which leaves the overall task strategy to the human operator, but makes the robot assist in the execution of single actions.

The three essential components of this assistance concept are illustrated in Fig. 1. The intelligent teleoperator must

1. infer the intended action of the operator from his motions (cf. [1])
2. develop a more accurate plan for this action, using additional sensor data, e.g. from an eye-in-hand camera
3. gently compensate small errors in the operator signals (cf. [2])

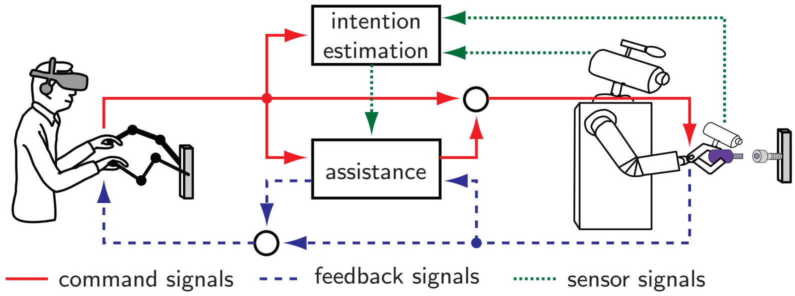


**Fig. 1.** Concept of intelligent, assistive teleoperator

In the ideal case, the task is completed more easily, although the human operator does not explicitly notice the assistance, so that his feeling of presence is not deteriorated.

### Contribution

We present a study of a virtual peg-in-hole task with different haptic assistance methods applied. In this study, the intended action is known beforehand, and the action plan is trivial. The analysis is targeted on the effects of the automatic error compensation. As assistance is supposed to be not perceived by the user, subjects are not informed about the presence of any assistance functions before the trials. It is investigated how the assistance methods affect the task performance and the feeling of presence. As a result, we conclude that an unobtrusive assistance function increases the task performance and also the feeling of presence, because the task execution better meets his expectations.

## 2 Assistance Modes

We assume a bilateral telepresence system with position-force architecture, i.e. master positions are sent to the teleoperator, and interaction forces at the slave site are sent back to the operator. Ideally, the teleoperator exactly replicates the positions of the operator, and the haptic interface exactly reproduces the interaction forces:

$$^{T}\boldsymbol{x} \stackrel{!}{=} {}^{O}\boldsymbol{x}, \quad {}^{O}\boldsymbol{F} \stackrel{!}{=} {}^{T}\boldsymbol{F} \tag{1}$$

However, technical limitations impede the realization of these equality conditions. Due to sensor noise, internal dynamics, and delays in the communication channel, the signals are overlaid by significant disturbances. Furthermore, the sight is also delayed and disturbed, which leads to inaccurate command signals by the operator himself. To lessen the negative effects of these position and force errors, an intelligent telepresence system can apply compensative corrections to the original signals:

$$^{T}\boldsymbol{x}' = f_x({}^{T}\boldsymbol{x}, {}^{O}\boldsymbol{x}), \quad {}^{O}\boldsymbol{F}' = f_F({}^{O}\boldsymbol{F}, {}^{T}\boldsymbol{F}) \tag{2}$$

These corrections depend on additional sensor data and on knowledge about the performed task. The assistance functions are, therefore, task dependent. For reasons of simplicity, we restrict ourselves to a peg-in-hole task which is part of tightening a screw, where only translational movements are considered.

It has been shown that humans approach an unobstructed target point on a straight line [3]. Therefore, it is reasonable, to decompose the approach into the alignment motion $\boldsymbol{x}_\perp$, which is perpendicular to the axis of the screw, and the insertion motion $\boldsymbol{x}_\parallel$, which is directed along the axis of the screw. For a successful task execution, the alignment motion needs to be corrected, while the insertion motion has no effect on the task execution. Fig. 2 shows the orthogonal decomposition of the displacement vector between screw head and screwdriver.

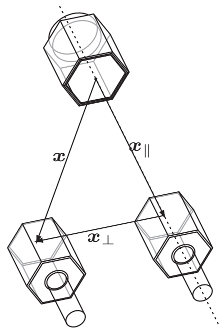


**Fig. 2.** Coordinate system definitions for the peg-in-hole task assistance

## 2.1 Position Based Assistance

For a correct insertion of the screwdriver into the screw head, the lateral displacement must be zero just before the screwdriver enters the head:

$$\|\boldsymbol{x}_\perp\| = 0 \quad \text{when } \|\boldsymbol{x}_\parallel\| \leq 0 \tag{3}$$

A simple mapping from operator to teleoperator positions which ensures this condition is described by:

$$^T\boldsymbol{x}_\perp = \frac{\|^T\boldsymbol{x}_\parallel\|}{x_0}\, ^O\boldsymbol{x}_\perp \tag{4}$$

However, this mapping proved to be very obtrusive in the pilot study which compromises the intuitiveness of the assistance. Therefore, an alternative mapping based on the lateral velocity was implemented:

$$^T\dot{\boldsymbol{x}}_\perp = f(^T\boldsymbol{x}, ^O\dot{\boldsymbol{x}})\, ^O\dot{\boldsymbol{x}}_\perp \tag{5}$$

The mapping function $f$ can be constructed as *unidirectional damping (UD)*, which damps lateral motions only in directions pointing away from the center line, or as *bidirectional damping (BD)*, where motions away from the center line are damped, and motions back are amplified:

| *unidirectional damping (UD)* | *bidirectional damping (BD)* |
|---|---|
| $f(\boldsymbol{x},\dot{\boldsymbol{x}}) = \begin{cases} g(\boldsymbol{x}) & \boldsymbol{x}_\perp \dot{\boldsymbol{x}}_\perp > 0 \\ 1 & \text{otherwise} \end{cases}$ | $f(\boldsymbol{x},\dot{\boldsymbol{x}}) = \begin{cases} g(\boldsymbol{x}) & \boldsymbol{x}_\perp \dot{\boldsymbol{x}}_\perp > 0 \\ (g(\boldsymbol{x}))^{-1} & \text{otherwise} \end{cases}$ |

The actual damping factor $g$ can either implement a *constant damping (CD)* or a *position dependent damping (PD)*, which allows to increase the strength of the assistance the lower the distance between tool and workpiece:

| *constant damping (CD)* | *position dependent damping (PD)* |
|---|---|
| $g(\boldsymbol{x}) = d$ | $g(\boldsymbol{x}) = d\,\frac{\|\boldsymbol{x}_\parallel\|}{x_0}$ |

According to a pre-study, the velocity mappings are suitable to reduce the lateral error at the point of insertion. However, they can lead to unbounded differences between operator and teleoperator positions ${}^{T}\boldsymbol{x}$ and ${}^{O}\boldsymbol{x}$. In order to limit the difference, an appropriate velocity mapping must be activated when no target is approached.

Although alignment errors can be significantly reduced by the described velocity mapping, the alignment error cannot be guaranteed to be zero at the point of insertion. Therefore, a *position correction (PC)* can be applied to the tool position just before the tool enters the workpiece.

### 2.2 Force Based Assistance

In the force based assistance mode, forces are applied to the operator handle to guide the operator on the optimal trajectory to the target. Consequently, there is no deviation between master and slave position, but instead the forces on both sides do not match. As with position assistance, different methods of force assistance can be employed.

The force which is applied to the operator in order to correct deviations from the ideal target path is always directed towards the center line. Its magnitude depends on the tool position $x = x_T = x_O$. It takes the general form:

$$ {}^{O}\boldsymbol{F} = -f({}^{T}\boldsymbol{x})\frac{{}^{T}\boldsymbol{x}_\perp}{\|{}^{T}\boldsymbol{x}_\perp\|} + {}^{T}\boldsymbol{F} \qquad (6) $$

Analogously to the position based assistance, it can be distinguished between *unidirectional (UD)* and *bidirectional damping (BD)*:

| *unidirectional damping (UD)* | *bidirectional damping (BD)* |
|---|---|
| $f(\boldsymbol{x},\dot{\boldsymbol{x}}) = \begin{cases} g(\boldsymbol{x}) & \boldsymbol{x}_\perp \dot{\boldsymbol{x}}_\perp > 0 \\ 0 & \text{otherwise} \end{cases}$ | $f(\boldsymbol{x},\dot{\boldsymbol{x}}) = g(\boldsymbol{x})$ |

In the simplest method, a *constant force (CF)* $F_c$ is applied in direction of the center line when the orthogonal distance $||\boldsymbol{x}_\perp||$ exceeds a threshold $r_c$. However, the definition of an appropriate force magnitude is difficult, because the same force is applied for small and large errors $||\boldsymbol{x}_\perp||$ and independently from the distance to the target $\|\boldsymbol{x}_\parallel\|$. A more sophisticated *position dependent force (PF)* method takes both into account:

| *constant force (CF)* | *position dependent force (PF)* |
|---|---|
| $g(\boldsymbol{x}) = \begin{cases} F_c & ||\boldsymbol{x}_\perp|| > r_c \\ 0 & \text{otherwise} \end{cases}$ | $g(\boldsymbol{x}) = \begin{cases} F_c \, ||\boldsymbol{x}_\perp|| \left( \frac{x_0 - \|\boldsymbol{x}_\parallel\|}{x_0} \right) & ||\boldsymbol{x}_\perp|| > r_c \\ 0 & \text{otherwise} \end{cases}$ |

An alternative approach to the position based force calculation is a *time dependent force (TF)* approach. In this approach the force increases linearly with time when the tool position is outside a cylinder of radius $r_c$ and is reset to zero when the tool reenters this cylinder.

## 3 Methods

The evaluation scenario was inspired by the evaluation of a telepresence system presented in [4]. The task consisted in inserting a hexagon screwdriver into the hexagon socket of a screw and turn it. For the purpose of this study, the experiment was simplified in order to make the psychophysical analysis more meaningful. Instead of using a physical teleoperator, a virtual environment was employed which ensures a better reproducibility and higher safety. Furthermore, the task was restricted to the three translational degrees of freedom. Only the approach phase was analyzed, i.e. no interaction forces occurred.

The experiments were designed to evaluate the effects of the different assistance methods on presence ratings and performance. The following four questions were addressed:

1. Does damping, direction and scaling within the position based assistance mode influence presence ratings and performance?
2. Does additional position correction in the final phase influence presence ratings?
3. Do force calculation methods affect both presence and performance measures?
4. Is there a difference between force vs. position based assistance mode?

### 3.1 Participants

Experiments were conducted with 21 students from the Technische Universität München. 11 participants with an average age of 24 years(4 woman, 7 men) experienced different position based assistance modes (group A), 10 participants (5 woman, 5 men) were randomly assigned to the force assistance mode group B (average age: 23 years). All test persons were right-handed and had normal or corrected to normal vision.

### 3.2 Experimental Design and Independent Variables

1. *Position based assistance mode: Influence of damping, direction and scaling.* Participants of group A experienced 12 different position based assistance modes and additionally had to fulfill the task without any assistance. The factors of interest were: damping (constant vs. position dependent), direction (uni-, bidirectional) and scaling factors (0.75, 0.50, 0.10). All 12 combinations (and the control condition) were presented 5 times.
2. *Position based assistance mode: Influence of position correction in final phase.* In order to answer the question regarding the influence of correction in the final approach phase, participants of group A also experienced four additional schemes with final phase correction: Damping (constant vs. position dependent) and direction (uni-, bidirectional) with the scaling factor 0.5 were varied (each of the 4 additional combinations were repeated 5 times each).
3. *Force based assistance mode.* Participants of group B fulfilled their task under 5 different force calculation methods (time dependent force, constant unidirectional force, constant bidirectional force, position dependent unidirectional force, position dependent bidirectional force) with three scaling factors (0.75, 0.50, 0.10). Additionally, they experienced the control condition with no assistance mode. Each combination was again presented 5 times.
4. *Force vs. position based assistance mode.* To test this research question some data from group A (combinations from 1.) and group B (combinations from 3. without the time dependent force method) entered the analysis.

### 3.3 Dependent Variables

Two dependent variables were considered:

1. *Presence Measure.* To measure the influence of different assistance mode schemes on the presence feeling, two items of the presence questionnaire of [5] were selected (translated into German by [6]): "How natural did your interactions with the environment seem?" and "How compelling was your sense of moving around inside the virtual environment?" Each question was rated on a 7-point rating scale. A sum score of presence rating $P$ was computed by summing both items.
2. *Performance Measure.* As a performance measure for each of the above described analyses except analysis 2, the inverse of the lateral position deviation between screwdriver and screw head $\|\boldsymbol{x}_\perp\|^{-1}$ was chosen.

### 3.4 Apparatus

The virtual reality is visually rendered using a head-mounted display (HMD) with SXGA resolution and a frame rate of 30 Hz. The virtual camera orientation is determined by tracking the head orientation of the test person. Haptic interaction is achieved through the large scale haptic display ViSHaRD10 (also used in [4]), which fully covers the workspace of a human arm and can display forces up to 120 N. ViSHaRD10 is controlled in admittance mode with a virtual mass of 10 kg and a virtual damping of 2 kg/s.

### 3.5 Experimental Procedure

Participants were trained to become familiar with the test environment and the task. As soon as the they could successfully complete the task in three consecutive trials with a maximum deviation in task execution time of one second, the preparation period was finished. Afterwards, they completed their trials depending on their group membership without being informed about the variation of the assistance modes. Each of the above described combinations was presented five times in fully randomized order to avoid learning effects. After each trial, the participant answered both questions regarding his subjective feeling of presence.

## 4 Results

Presence and performance measure of each combination were averaged across the 5 repetitions. The averaged baseline measure (no assistance mode) was subtracted from each experimental manipulation to derive information about improvement of applying the assistance modes. Influence of the assistance mode characteristics on both dependent variables were first tested with multivariate analyses of variance (*MANOVA*) with the test statistics Pillai Spur. Significant effects (as well as question 2) were tested with univariate analyses of variance (*ANOVA*). Partial $\eta^2$ was chosen as effect size; if necessary, violations of assumed sphericity were corrected by the Greenhouse-Geisser correction. The significance level was set to 1%.

### 4.1 Position Based Assistance Mode: Influence of Damping, Direction and Scaling

The *MANOVA* reveals significant effects of damping ($F(2, 9) = 35.6$, $p < 0.01$; $\eta^2 = 0.89$) and scaling ($F(4, 40) = 5.2$, $p < 0.01$; $\eta^2 = 0.34$). Additionally, the interaction between both factors was statistically significant at the 5%-significance level ($F(4, 40) = 3.1$, $p < 0.05$; $\eta^2 = 0.23$). No other effect was statistically significant and therefore not considered further.

1. *Presence Measure.* Damping influenced the presence rating ($F(1, 10) = 13.1$, $p < 0.01$; $\eta^2 = 0.57$): Position based damping was rated to result in a greater feeling of presence (cf. Fig. 3a). Additionally, scaling factor affected the presence feeling indicating a greater increase of the rating with increasing scaling factor (corrected by Greenhouse Geisser: $F(1.2, 12.5) = 10.3$, $p < 0.01$; $\eta^2 = 0.51$). However, as can be seen from Fig. 3a, this is only true with the constant damping assistance scheme (significant interaction: $F(2, 20) = 8.3$, $p < 0.01$; $\eta^2 = 0.45$).

2. *Performance Measure.* Variation in damping also affected position accuracy ($F(1, 10) = 76.2$, $p < 0.01$, $\eta^2 = 0.88$): When inserting the screwdriver using the position based damping scheme, performance was significantly better (cf. Fig. 3b). Scaling did not statistically influence accuracy on the 1%-significance level, but on the 5%-significance level ($F(2, 20) = 15.3$, $p < 0.05$; $\eta^2 = 0.60$) indicating best performance with highest scaling; Bonferroni test showed significant improvement with the highest scaling compared to both other ones (again on the 5%-significance level). The interaction between damping and scaling was not statistically significant ($F(2, 20) = 0.1$, $p < 0.01$).

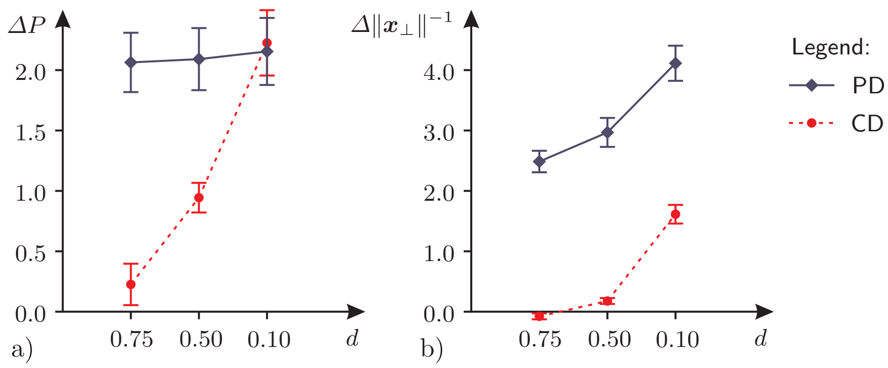


**Fig. 3.** Enhancements of position based assistance modes compared to unassisted trials on a) presence and b) performance

### 4.2 Position Based Assistance Mode: Influence of Position Correction in Final Phase

Whether adding position correction in the final phase affected rating of presence was tested with an univariate *ANOVA* and revealed a significant influence ($F(1, 10) = 11.3$, $p < 0.01$; $\eta^2 = 0.53$): Position correction was rated to improve the presence feeling. Additionally, an interaction between position correction and damping could also be observed at the 5% significance level ($F(1, 10) = 5.7$, $p < 0.05$; $\eta^2 = 0.36$) indicating greater differences in presence ratings without position correction in the final phase just as described before (cf. Fig. 4a).

### 4.3 Force Based Assistance Mode.

The influence of the five different force based assistance schemes (cf. Sec. 3.2) was tested with a *MANOVA* and affect the dependent variables ($F(8, 72) = 4.5$, $p < 0.01$; $\eta^2 = 0.33$). Additionally, the interaction between method and scaling factor reached statistical significance ($F(16, 144) = 5.0$, $p < 0.01$; $\eta^2 = 0.36$).

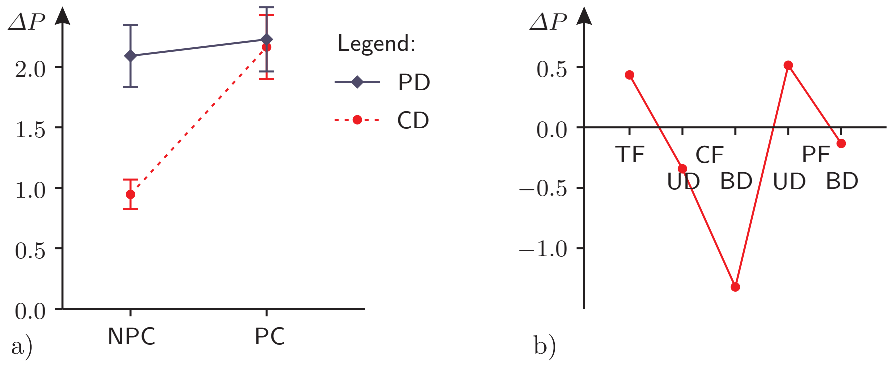


**Fig. 4.** a) Influence of position correction in final phase and damping on presence rating (position based assistance mode); b) Influence of different force based assistance modes on presence ratings

Scaling factor was significant at the 5%-significane level ($F(4, 36) = 3.3$, $p < 0.05$; $\eta^2 = 0.23$). Results of the separate analyses for each dependent variables are described below.

1. *Presence Measure.* Assistance scheme affected significantly the presence rating (corrected by Greenhouse Geisser: $F(1.9, 16.7) = 15.9$, $p < 0.01$; $\eta^2 = 0.64$). Bonferroni tests revealed a significant difference between the constant and the position dependent bidirectional force scheme ($p < 0.01$) indicating a decrease of the presence feeling with the constant force mode. A marginally significant difference between the time dependent force and the constant bidirectional force assistance scheme ($p = 0.01$) was due to a greater decrease in presence ratings with the constant bidirectional force assistance mode (cf. Fig. 4b).
   The interaction between method and scaling reached also statistical significance ($F(8, 72) = 7.9$, $p < 0.01$; $\eta^2 = 0.47$): The greatest decrease in presence rating could be observed with the constant bidirectional force assistance and the higher force scaling ($F(2, 18) = 7.0$, $p < 0.01$; $\eta^2 = 0.44$).
2. *Performance Measure.* Neither method of force assistance mode ($F(4, 36) = 0.3$, $p = 0.89$) nor scaling factor ($F(2, 18) = 0.62$, $p = 0.54$) nor the interaction between both (corrected by Greenhouse Geisser: $F(2.7, 24.5) = 2.9$, $p = 0.06$) did influence performance in a statistically significant way.

### 4.4 Force vs. Position Based Assistance Mode

Lastly, both assistance modes were compared according to their effect on presence feeling and positioning accuracy. There was statistically significant influence on presence rating ($F(1, 19) = 11.4$, $p < 0.01$; $\eta^2 = 0.38$) as well as on performance ($F(1, 19) = 54.1$, $p < 0.01$; $\eta^2 = 0.74$). Working with the position based control scheme resulted not only in an improved presence feeling compared to experiencing the force control scheme ($\overline{\Delta P} = 1.6$, $\sigma = 1.6$ vs. $\overline{\Delta P} = -0.2$, $\sigma = 1.1$) but also in increased positioning accuracy.

## 5 Discussion

Different assistance methods for supporting a human operator in telepresent reaching movements were presented. They can be grouped into position-based, force-based, and hybrid approaches. In position assistance mode, the position of the teleoperator is altered in such a way that a reaching movement towards the target is shifted in the direction of this target. In force assistance mode, a force is applied on operator site to push the operator on the ideal target trajectory.

The experimental results revealed that position based assistance modes for the analyzed free-space motions showed best accuracy as well as high presence feeling with position based damping and even improved with higher scaling factors. In contrast, the force based assistance modes led to a decrease in performance and perceived presence. When directly comparing both assistance schemes the position based one resulted not only in an improvement of presence feeling but also in an increase of positioning accuracy.

The next study will be dedicated to the analysis of a scenario which involves stiff contacts or requires a contact force to be held constant, e.g. carrying or grasping objects. It is hypothesized that these task can be favorably assisted by using force assistance mode.

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## References

1. D. K. E. Aarno, “Intention recognition in human machine collaborative systems,” Ph.D. dissertation, KTH School of Computer Science and Communication, Stockholm, Sweden, March 2007.
2. W. B. Griffin, “Shared control for dexterous telemanipulation with haptic feedback,” Ph.D. dissertation, Stanford University, Palo Alto, USA, June 2003.
3. T. Flash and N. Hogan, “The coordination of arm movements: an experimentally confirmed mathematical model,” *Journal of Neuroscience*, vol. 5, pp. 1688 – 1703, January 1985.
4. A. Peer, B. Stanczyk, and M. Buss, “Haptic Telemanipulation with Dissimilar Kinematics,” in *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems*, Edmonton, Canada, 2005, pp. 2483–2487.
5. B. G. Witmer and M. J. Singer, “Measuring presence in virtual environments: A presence questionnaire,” *Presence: Teleoperators and Virtual Environments*, vol. 7(3), pp. 225–240, 1998.
6. R. Scheuchenpflug, “Measuring presence in virtual environments,” in *Proceedings of the 9th International Conference on Human-Computer Interaction*, M. J. Smith, G. Salvendey, and M. R. Kasdorf, Eds., 2001, pp. 56–58.