Proceedings of EuroHaptics 2004, Munich Germany, June 5-7, 2004.

Bimanual Haptic Telepresence Technology Employed to Demining Operations

A. Kron and G. Schmidt

Institute of Automatic Control Engineering
Technische Universität München, Germany
Interactive Systems and Control Group
alexander.kron@ei.tum.de

1 Introduction

At present, more than 100 million undetonated landmines left over from wars are buried worldwide. Each year approximately 3000 individuals (most of them civilians) are maimed or injured by these mines. At least for every 5000 mines causes an expert's injury during its removal. For purpose of reducing the need for deminers to directly operate under these life-threatening conditions, application of telerobotic technology experiences a growing interest in recent years [1, 2]. Corresponding technology should comprise the following key components: reliable sensory detection of mines, mobility over rough terrain, and advanced manipulation capabilities. While the former requirements are research focus in many studies, e.g. [1, 2], the latter is only reported in [3, 4].

Typical task operations in demining are saving the mine for detonation, pulling the saved mine out of the ground, unscrewing and excluding the detonator from the explosive. Most of these actions require the use of both hands or in case of a telerobotic system a *bimanual manipulator*. Moreover, it is well-known that in addition to vision onto the object under consideration, experts need feedback of several other sensory modalities, especially *touch* and *force*, for improved sensitiveness. As consequence, we propose the development of a bimanual haptic telepresence system employed to demining as depicted in Fig. 1.

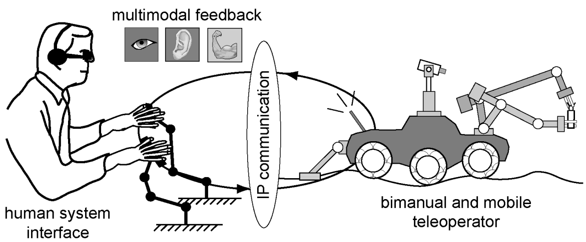

Fig. 1. Demining by use of a telepresence system.

This type of telepresence system enables an expert to perform the required task execution from a central control station located in safe environment. It uses in addition to visual display some sort of haptic display for inputting control commands over an IP communication link to the remote teleoperator. The teleoperator is equipped with multisensory components for sending *multimodal data* back to the expert as well as bimanual manipulators for more complex task execution. Thus complete handling of the mine from safe distance is assumed.

2 Hardware Setup

The desired advanced manipulation capabilities are achieved by means of a developed bimanual Master-Slave Arm System. The components could be transferred into a real demining robot by mounting the bimanual telemanipulators on a suitable mobile platform. The design of the haptic display rests upon a Wrist/Finger Haptic Display for generation of combined force feedback at wrist and fingers [5]. The system comprises a non-portable high performance **De**sktop **Ki**nesthetic **Fe**edback **D**evice (DeKiFeD4) coupled with the commercial hand force exoskeleton CyberGrasp from Immersion Corp. (see Fig. 2). The robotic arm enables proprioceptive inputs with 4 active DoF (3 translations, 1 rotation) in the Cartesian space and perception of forces/torques for each DoF with a capability up to 120 N and 20 Nm. The available force range is already sufficient for providing a human operator (HO) with kinesthetic stimuli enabling perception of object contact, stiffness, friction, and weight. 6 DoF force/torque sensors are mounted behind the coupling with the operator's wrist. The haptic glove produces finger forces up to 10 N for each finger. This type of finger force feedback proved to be adquate for perceiving fingertip to object contacts. Fig. 2 indicates, that the HO's forearms are fixed at the DeKiFeD4s behind the wrist by means of a strap. By this type of coupling a HO keeps all passive DoF of wrist motion, ensuring intuitive and natural hand motion.

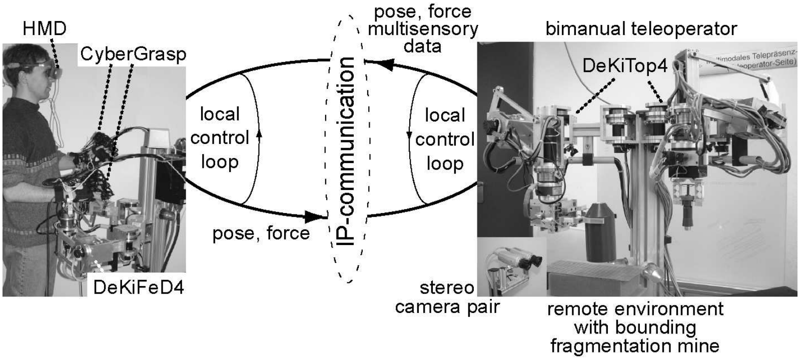

Fig. 2. Bimanual haptic telepresence system employed to demining task execution.

Object manipulation in remote environment (RE) is achieved by means of a bimanual teleoperator (see Fig. 2). By duplicating both DeKiFeD4s and mounting two-jaw grippers as end-effectors, we built a left- and right-sided **De**sktop **Ki**nesthetic **Te**leoperator (DeKiTop4), with respectively 4 active DoFs positioning the gripper, and 1 active DoF performing a grasp. Typically, bimanual coordinated tasks are accomplished with asymmetric roles for both hands, referring to the well-known classification into a non-dominant (NDH) and dominant (DH) hand [6]. For that purpose, we designed one gripper with horizontally, the other with vertically arranged jaws. The first gripper is used for NDH's operation such as maintaining an object in a stable position for manipulation by the DH. The second gripper ensures accomplishment of more dextrous and manipulatory actions. Both grippers are equipped with force sensors measuring grasp forces.

In addition, 6 DoF force/torque sensors are located behind the gripping devices. The gripper configurations ensure a sufficient workspace overlap.

3 Bilateral Control of Kinesthetic Master-Slave-System

Bilateral control of kinesthetic Master-Slave-Systems (MSS) aims at ensuring stable teleoperation and transparent perception of the RE. Up to now, several control architectures are developed. A short survey is given in [7]. The proposed architectures are classified by the number of information channels used for data transfer between master and slave. Typically, force and pose or velocity information is transmitted. In this work a bilateral control architecture extending the concept of *dual hybrid teleoperation* [8] is implemented for left and right-sided MSS, respectively. The idea underlying dual hybrid teleoperation is that for low environmental impedance[1] Z_e (free motion) the master should act as a force source/position sensor, whereas the slave should behave as a positions source/force sensor. If Z_e is large (hard contact) the master should act as a force sensor/position source, whereas the slave behaves as a force source exerting forces on the environment the operator inputs at the master and sending measured slave positions back. The varying operating behavior of master and slave is enabled by changing local control algorithms depending on online identification of Z_e. Fig. 3 illustrates the implemented control scheme.

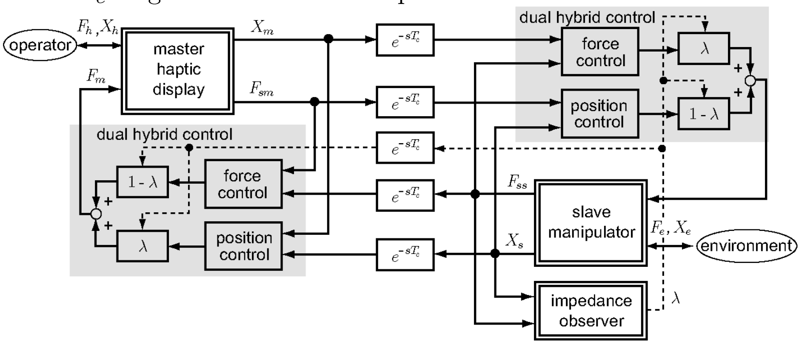

Fig. 3. Bilateral control scheme of the kinesthetic Master-Slave-System.

Master and Slave local control algorithms add force and position control commands weighted by a normalized factor $\lambda \in [0, 1]$, which differs with varying Z_e. For free motion ($Z_e \downarrow$) λ is set to zero, leading to a force controlled master and a position controlled slave. A hard contact ($Z_e \uparrow$) results in λ=1 which corresponds to a position controlled master and a force controlled slave. The control algorithms are based on explicit force control with force feedforward and position state control. The computation of λ is performed by an environmental impedance observer. A recursive least square method is employed to identify Z_e using the measured force F_{ss} and position X_s at the manipulator. This control architecture demonstrated in simulation and experimental results stable teleoperation as well as realistic impression of free motion and hard contact which

[1] Z_e represents the relation between force F_e and velocity V_e or position X_e. Z_e is expressed using the mechanical parameters mass m_e, damping b_e, and stiffness k_e by: $Z_e(s) = F_e(s)/V_e(s) = F_e(s)/X_e(s)s = m_e s^2 + b_e s + k_e$.

frequently change during demining operations. Note, that data transmission was accomplished within a LAN with a delay time $T_c \leq 10\,\text{ms}$.

4 Results

The proposed bimanual telepresence system is employed and evaluated in cooperation with demining experts from the German Armed Forces in München on disposal of a remote bounding fragmentation mine (see Fig. 2). The evaluation results are shortly summarized by the following findings: Using force feedback in comparison to no force feedback increases system performance significantly and enables a more delicated operating behavior. This was proved by measuring the contact forces in the RE which decrease significantly if the deminer was supported by force feedback. Subjects stated, that the system allows accomplishment of hand motions, which are typical for demining operations. While the task under consideration is done by experts at a real physical mine within 60 sec, average task completion time[2] of 8 demining experts with training intervals $<$ 30 min on the system were 800 sec. The experts stated that developed haptic feedback technologies are highly useful and that they already enable realistic demining operations in RE. They recommended the proposed approach of bimanual haptic telepresence technology for an integration into future telerobotic systems supporting deminer's work in real terrain.

Acknowledgments:
This work was supported in part by the German Research Foundation (DFG) within the Collaborative Research Centre SFB 453 on "High-Fidelity Telepresence and Teleaction".

References

1. Nicoud, J.: Vehicles and Robots for Humanitarian Demining. The Industrial Robot **24** (1997) 164–168
2. Habib, M.: Service Robots in Humanitarian Landmine Clearance. In: Proc. of the Int. Symposium on Robots (ISR 2001), Seoul (2001)
3. Hirose, S., Kato, K.: Development of Quadruped Walking Robot with the Mission of Mine Detection and Removal - Proposal of Shape-Feedback Master-Slave Arm. In: Proc. of the IEEE Int. Conf. on Robotics and Automation, Leuven, Belgium (1998) 1713–1718
4. Kron, A., Schmidt, G., Petzold, B., Zh, M., Steinbach, E., Hinterseer, P.: Disposal of explosive ordnances by use of a bimanual haptic telepresence system. In: Proc. of the IEEE Int. Conf. on Robotics and Automation, ICRA, New Orleans, LA (2004)
5. Kron, A., Schmidt, G.: A Bimanual Haptic Telepresence System - Design Issues and Experimental Results. In: Proc. of the Int. Workshop on High-Fidelity Telepresence and Teleaction. CD Proceedings, jointly with the conference HUMANOIDS, München, Germany (2003)
6. Guiard, Y.: Asymmetric Division of Labor in Human Skilled Bimanual Action: The Kinematic Chain as a Model. Journal of Motor Behavior **19** (1987) 486–517
7. Salcudean, S.E. Number 230 in Control for Teleoperation and Haptic Interfaces, Lecture Notes. In: Control Problems in Robotics and Automation. Springer Verlag, Berlin (1998) 51–66
8. Reboulet, C., Plihon, Y., Briere, Y. Experimental Robotics IV. The 4th Int. Symposium on Eperimental Robotics. In: Interest of the dual hybrid control scheme for teleoperation with time delays. Springer Verlag (1996) 498–506

[2] In general, telepresence systems are assessed to provide high-fidelity performance if teleoperated task execution lasts about 10 times longer in comparison to similar manual operation in a real physical environment.