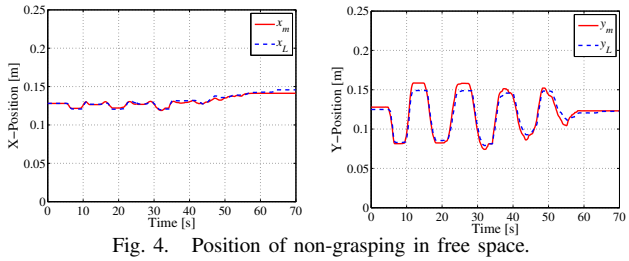
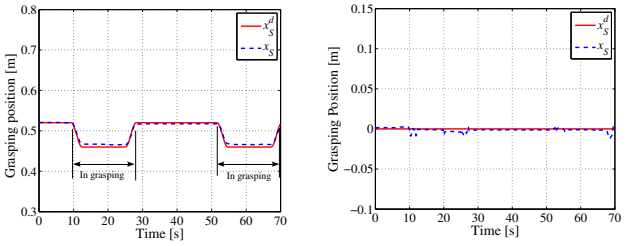


Fig. 4. Position of non-grasping in free space.



(a) X-Position (b) Y-Position

Fig. 5. Position of Shape-System and x_S^d.

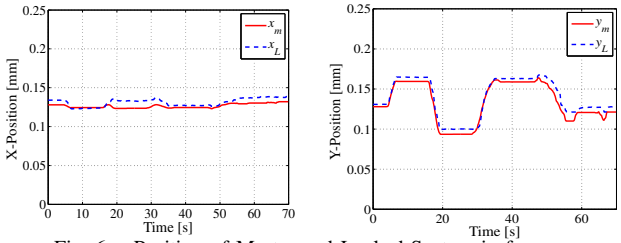


Fig. 6. Position of Master and Locked-System in free space.

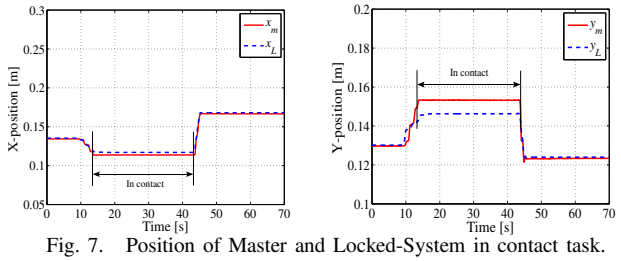


Fig. 7. Position of Master and Locked-System in contact task.

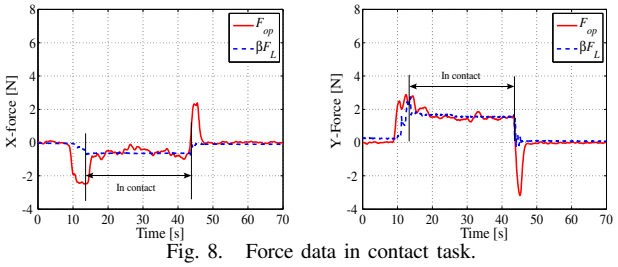


Fig. 8. Force data in contact task.

in the free space. We can see the positions of both side are achieved. The Fig. 5 shows the time responses of the end-effector position of slave of the Shape-System, In this figure, we can conclude that the relative position between two slaves following the target trajectory with grasping object is achieved. In the Fig. 6, the grasping object at the center position between two end-effectors of the slaves is able to transported following the end-effector of the master robot. The object is presumed to mix with closed links of the slaves. When grasping, the distance between the slaves is narrowed.

The experimental results in case of contact with the environment is shown in Figs. 7, 8. The objected is grasped and come to contact with the environment following vertical Y axis. Fig. 7 shows the time responses of the end-effector position of the Locked-System with the master. The Fig. 8 shows the reflection forces when the object contacts with the environment. We can see that the reflecting force from the environment and the scaling force of the human are same values.

VI. Conclusions

In this paper, we proposed a new control law with four-channel force-flection (FR) algorithm for a Single Master-Multiple Slave (SMMS) teleoperation system based on ISS small gain theorem. This proposal resolves the dynamics of multiple slaves system such as the Shape-System dynamic and the Locked-System dynamic of the control law. Moreover, the proposal control law can be used to achieve an autonomous grasping object by multiple slave and the transportation of the object by the control experiment. In this work, the slaves are possible to hold even if unknown objects or the width extendable of object if it can be held by the force control. The force information on the grasping object is necessary for the position control law to keep the object to be held. To analyze stability, the input-to-state stability (ISS) small gain approach was used to show the overall FR teleoperation system to be input-to-state stable. Finally, several experimental results show the effectiveness of our proposal control method.

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