

# Realization of Virtual Master Manipulator Using Bilateral Control

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**Abstract**— Bilateral control has been widely used in many industries including medical surgery. Slave manipulator usually works in a remote site or in a hazardous environment. Master operator is sensing the environment through the slave manipulator. Usually doctors are very sensitive to the tactile sensation they feel through medical tools. If bilateral control is used in surgery, ideally doctor should feel the feeling of the body tissue and the reaction force from the specialized tool. In this paper specialized tool is replaced by a virtual model.

## I. INTRODUCTION

**M**OTION control is a wide area that came to light with the automation. Bilateral control is also coming under the broad subject of motion control. Sensing an environment remotely is the main idea of bilateral control.

### A Bilateral control

Bilateral control can be broadly categorized according to the scope of applications. First application is remote sensing. If the environment to be sensed is placed at a remote location, communication is usually done with the communication networks. Bilateral control is also used in hazardous environments where human operators are inaccessible. Third application area involves scaling the environment. Micro-Macro or Macro-Micro applications are examples for this.

### B Minimally Invasive Surgery

Minimally Invasive Surgery (MIS) is sometimes called minimal-access or "keyhole" surgery. MIS is one of the exciting recent developments in medicine. A minimally invasive procedure is performed via a small opening instead of a long incision. Usually a small camera called a laparoscope is inserted to guide the surgeon. A long surgical tool is inserted through the incision. This tool is remotely operated by the surgeon. Master slave systems "Da Vinci and Zeus" are examples for MIS. Main advantages include less healing time, less risks of infections and minimum blood loss.

However MIS has a major disadvantage. When the surgeon performs the operation through the surgical tool, he lacks the tactile information. To eliminate this problem bilateral control with tactile feedback has been proposed by several researchers. W. Iida *et al.*[1] has proposed a forceps robot which can transmit tactile sensation to the master operator.

When special surgical instruments like scissors, are used the feeling that the surgeon feels is the addition of

reaction force from the environment and the tool impedance itself.

$$\text{Surgeon feels} = \text{Reaction force from the body tissue} + \text{Operating tool reaction} \quad (1)$$

Skilled operators are very sensitive to the tools that they are used to. Surgeons are used to feel the tool reaction force as well. Following figure depicts such a specialized surgical tool. As for the construction, a spring has been used.



Fig. 1. Surgical tool

These specialized tools are often expensive. Therefore it is good if the expensive tool can be eliminated with a virtual tool. With the virtual tool, surgeon should be able to sense the actual tool feeling together with the reaction force from the body tissue. This idea is depicted in the following figure.

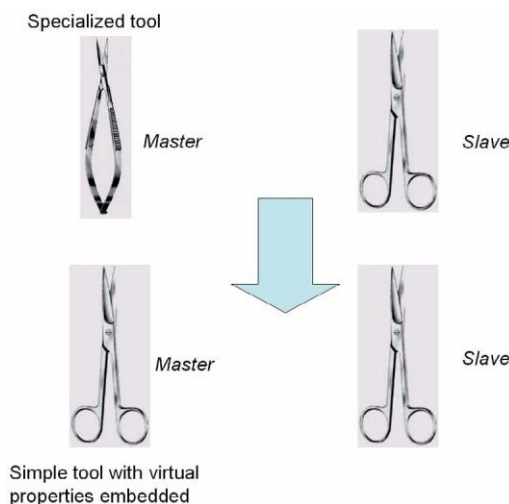
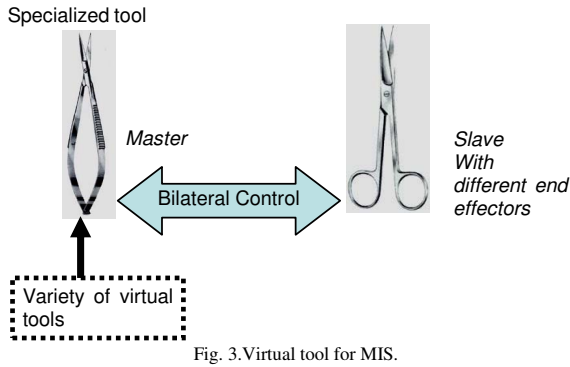


Fig. 2. Virtual Tool

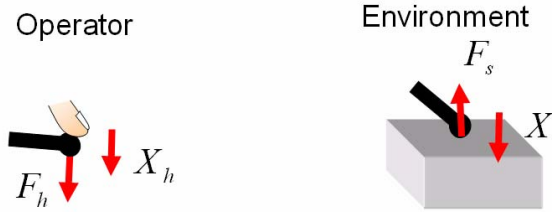
In MIS, surgeon often requires various surgical tools to be changed during the surgery. Therefore it is advantageous to have one simple master manipulator and have various virtual tool feeling on the master side.



Therefore this paper proposes a novel method to embed virtual tool properties to a bilateral forceps robot. Proposed bilateral forceps system should behave with the virtual model properties as if the specialized tool is used.

## II. BILATERAL CONTROL

In this section bilateral control is introduced. Fig 4. shows the basic structure.



Position and force information is transmitted from the slave side to the master side and master side to the slave side as well. Environment reaction is recreated in the master side. Masters operating intension is also transmitted to the slave side so that slave starts to move according to the master. If human operator exerts  $F_h$  force at the master side, and the manipulator moves by  $X_h$ , then the impedance of the master side is  $Z_m$ . This can be shown by the following equation.

$$X_h = \frac{1}{Z_m} F_h \quad (2)$$

Similarly, slave side reaction can also be shown by the following equation.

$$F_s = -Z_e X_s \quad (3)$$

Ideally, position of master and slave should be equal. Addition of forces at master and slave manipulators should be zero.

$$X_h - X_s = 0 \quad (4)$$

$$F_h + F_s = 0 \quad (5)$$

However, in applications where master and slave are

different, position and force scaling may be used. Following figure depicts the basic block diagram of bilateral control. Function of the disturbance observer and the reaction force observer will be discussed in the next section. For this diagram it is assumed master and slave are driven by identical linear motors.

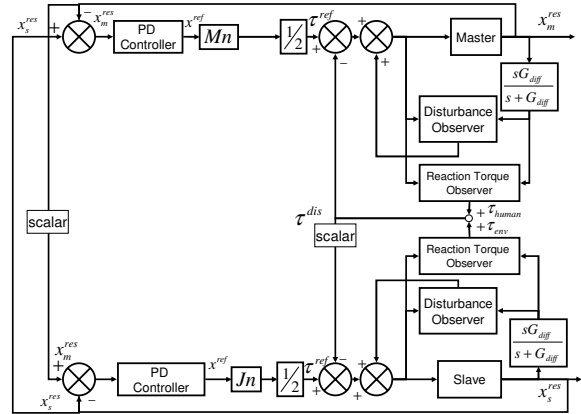


Fig. 5. Bilateral Model

If one to one response is expected from master and slave, scales are set to 1.

## III. DISTURBANCE OBSERVER

Disturbance observer will be used to record the torque of the linear motor. This method is cost effective than having a torque recorder and it produces more reliable results. Fig. 6 shows the typical arrangement of the disturbance observer.  $F_{dis}$  is the estimated disturbance. Disturbance observer can be extended to calculate the operating torque.

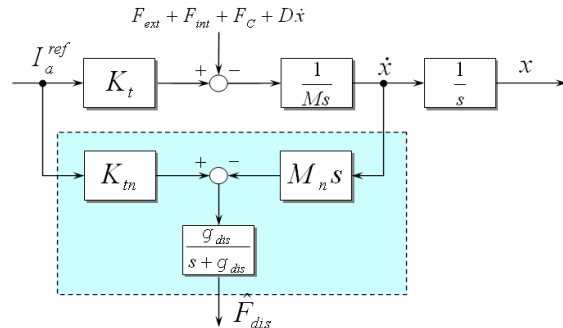


Fig. 6. Disturbance Observer

Reaction Force Observer is an extension to the disturbance observer. Reaction force observer estimates the environment reaction force without a force sensor. Usually force sensors produce noisy response. In the conventional force measurement, strain gauges are used. However they have very narrow bandwidth. Reaction torque observer is capable of producing accurate force information in a cost effective manner.

#### IV. MODELLING

Following figure depicts a master manipulator. A virtual spring is expected to be inserted in between the jaws.

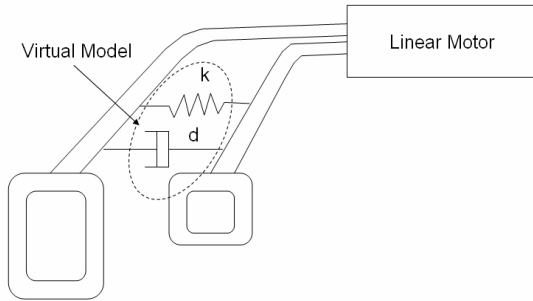


Fig 7. Master Manipulator with Virtual Model

Therefore master operator should feel the spring as well as the reaction force from the environment. Spring is modelled with a spring damper model depicted in Fig 8.

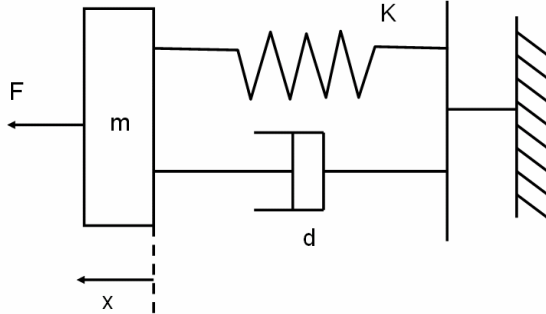


Fig.8. Virtual Spring Damper Model

Dynamics

$$F = m\ddot{x} + d\dot{x} + kx \quad (6)$$

Where,

- m : Normal mass
- d : Damping coefficient
- k : Spring constant

In lapse domain

$$X(s)[ms^2 + ds + k] = F(s) \quad (7)$$

Equation 7 is exerted to the bilateral control system is represented by Fig. 9. In Fig. 9 “model” represents the transfer function represented by equation 7. Action of the model is fed before the disturbance observer. Therefore this model acts as a reference to the master side.

Operator is interacting with the master side gripper. Slave side forceps, is interacting with the environment which will be a human tissue in MIS.

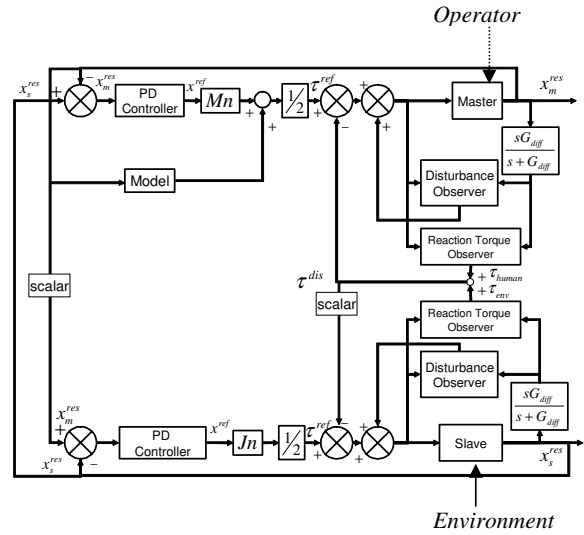


Fig. 9. Master model with Bilateral Control

#### V. CONSTRUCTION

##### A. Linear motor

Linear motor is similar to the conventional rotary motor with one exception. Here the response is in the linear direction.

Dynamic equation for the linear motor can be described by the following equation.

$$f = m\ddot{x} + d\dot{x} \quad (8)$$

Where,

- f: force
- m: nominal mass
- d: viscous friction

of the linear motor.

$$k_i i^{ref} = f \quad (9)$$

Where  $k_i$  is the force constant of the linear motor.

TABLE I  
Specifications of linear motor assembly.

Maximum force	30N
Current	0.5A
Resolution	1 $\mu$ m
Physical weight	340g

##### B Forceps Robot

Forceps robot is used for this experiment. Following figure 10, 11 depicts the experimental setup of the forceps robot.

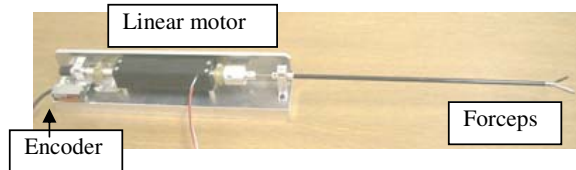


Fig. 10. Forceps connected to the Slave

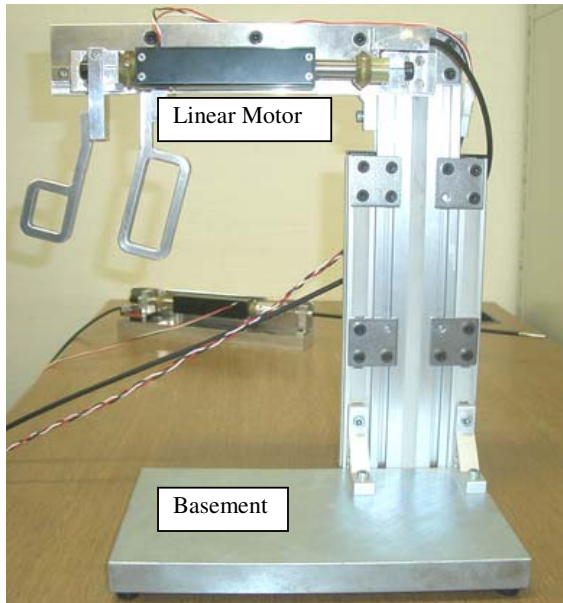


Fig. 11. Master Manipulator

## VI. EXPERIMENT

The forceps robot depicted in Fig.11 was used for the experiment. Human operator directly manipulates the master system. At the end of the forceps, small rubber balloon is kept for measurements. Initially, readings were taken without the virtual spring model. Then experiment is carried out with the virtual spring model. Same rubber balloon is sensed through the embedded virtual master model.

Following parameters were used for the experiment.

Table II

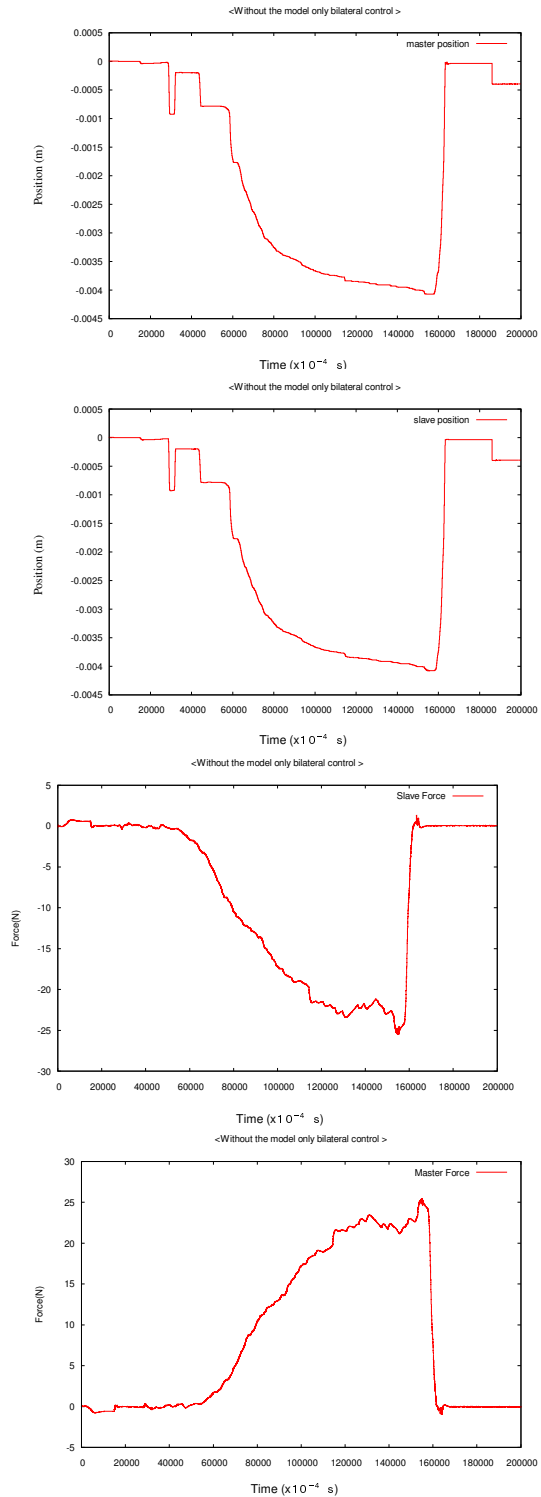
Experiment parameters

$K_p$	Position gain	9000
$K_v$	Velocity gain	200
$K_f$	Force gain	1
$K_{in}$	Force coefficient	22
$k$	Spring constant	1000
$b$	Damping coefficient	0.01
$M_n$	Nominal mass	0.16
$St$	Sampling time (s)	0.0001

## VII. EXPERIMENTAL RESULTS

Initially experiment was carried out without the embedded model. Fig. 12 depicts the results when bilateral control is in action. A soft rubber balloon is kept in between the slave forceps. The force is sensed through the master manipulator. Master manipulator is pressed once and then released. As for the results, master and slave position responses are almost the same. Force responses are also the same except the sign. Force-Position response depicts the properties of the environment. Curve implies the nonlinear properties of the rubber balloon.

Position and force responses of master and slave sides are almost identical. Therefore this method is capable enough to transmit vivid sensation to the operator. Force and position responses can be changed by changing the values of  $K_p$ ,  $K_v$  of the PD controller and disturbance observer gains.



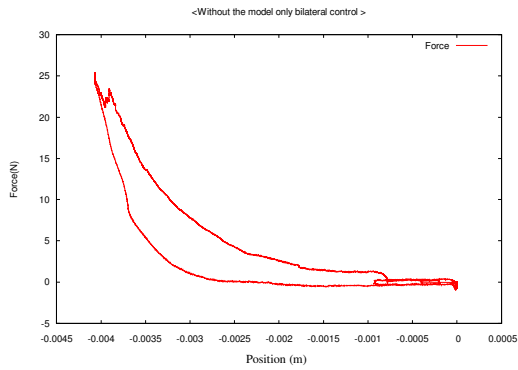


Fig. 12. Responses without the Model

In the second part, virtual spring model is inserted. Response is measured without a slave load. Master manipulator is pressed three times and released. Master and slave have returned to their original position indicating the virtual spring properties. Master force response is little bigger than the slave response. That is due to the virtual spring acting in the master side.

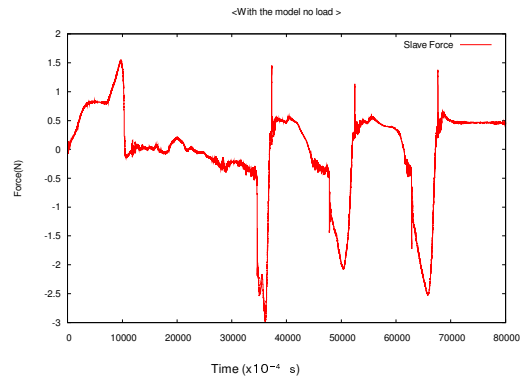
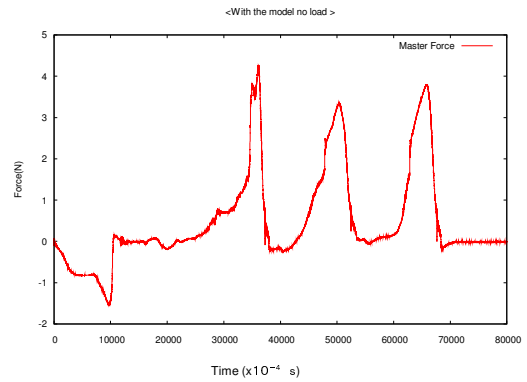
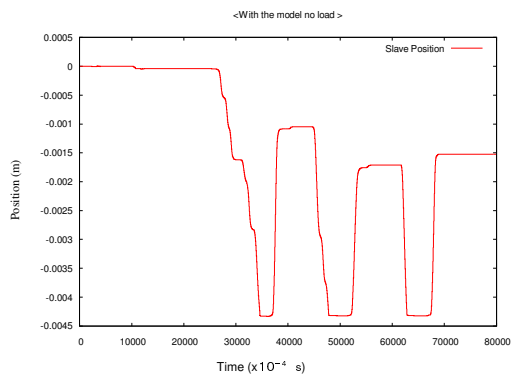
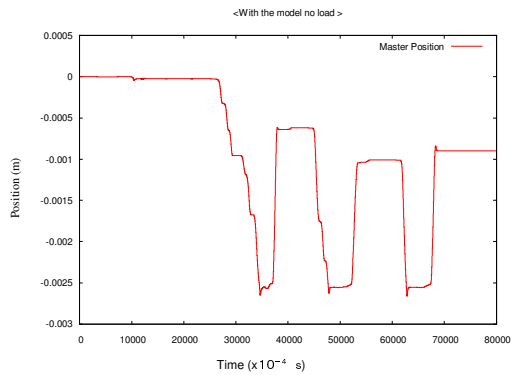
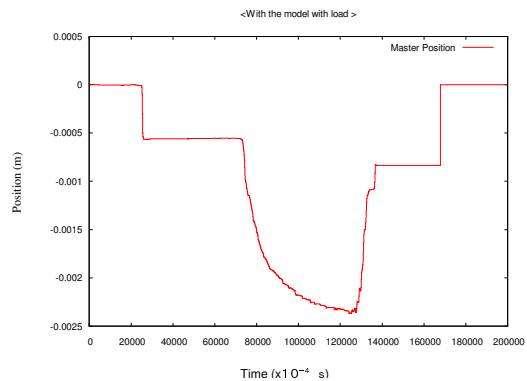


Fig. 13. Responses with the Model

Finally, rubber balloon is kept at the slave forceps when the virtual spring model is in action. Master manipulator is pressed once and released. Master and slave have returned to their original position indicating the virtual spring properties. Master force response is little bigger than the slave response. That is due to the virtual spring acting in the master side. Operator at the master side could feel the virtual tool reaction force together with the environment reaction.



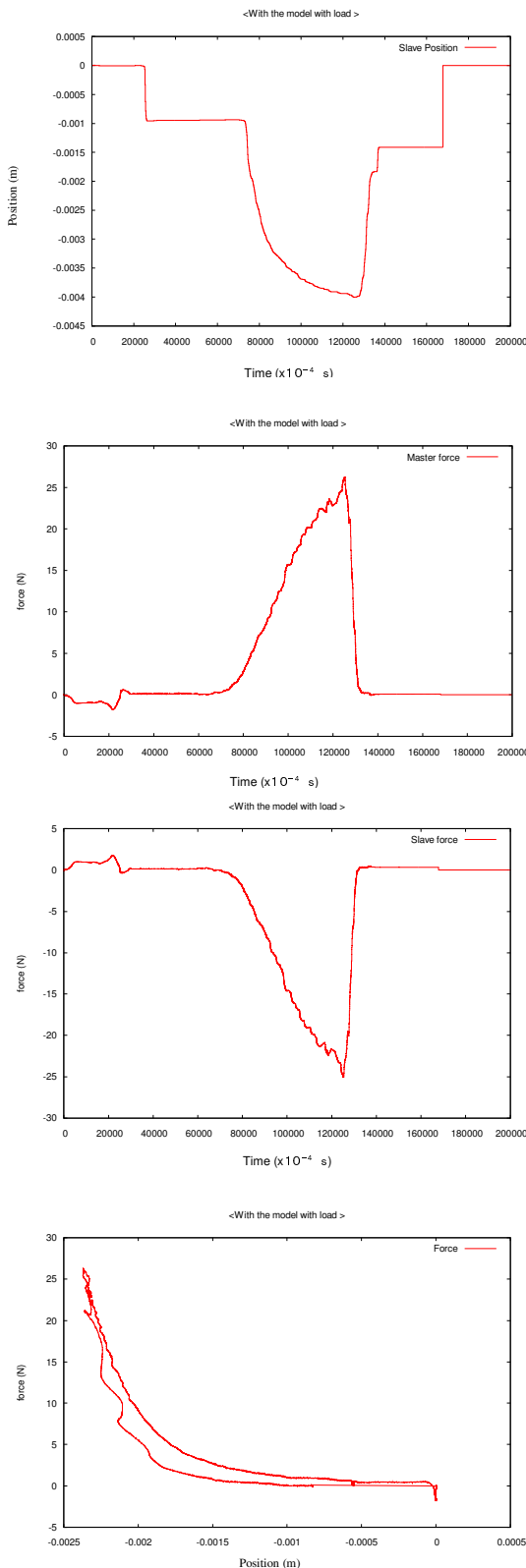


Fig. 14. Responses with the Model and Load

## VIII. CONCLUSION

In this paper, a novel method to embed virtual tool properties for a bilateral forceps robot was proposed. Virtual master tool model was proposed specially for Minimally Invasive Surgery. Proposed model works in place of a specialized tool. By changing the model, Surgeon can feel the sensation of the tool together with the reaction force. Experiment was carried out to validate the proposal. This concept can also be extended for other applications as well.

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