

# The Implementation of Bilateral Control Symmetrical Position, Force Reflection and Feedback Force on the Haptic Manipulator

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# The Implementation of Bilateral Control Symmetrical Position, Force Reflection and Feedback Force on the Haptic Manipulator

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**Abstract.** Humans often encounter obstacles in doing their work. Especially if the work is related to an emergency situation that concerns the safety of human life, it needs quick and appropriate handling. Telerobotic technology that has a haptic function is one solution to these problems. In this study a system of 1 DOF haptic manipulator with slave master configuration was developed using bilateral haptic manipulator control. In bilateral control the position and information are transmitted in two directions between two manipulators. Position information is obtained using a potentiometer and force information is obtained by representing the force with the current using the WCS2702 sensor. There are three control methods used, namely bilateral symmetrical position control, bilateral reflection force control and force feedback bilateral control. The best method of control is the bilateral feedback force control. In the force feedback bilateral control system, the slave can move following the master movement with a  $\pm 2^0$  position error. When the slave arm is held by a hard object, the master arm is also restrained with  $\pm 11^0$  position error. Whereas when the slave arm is held by a soft object, the reflection of the object is felt by the master arm with  $\pm 10^0$  position error. Movement of the master and slave arms is lighter than using bilateral control of symmetrical position.

## 1. Introduction

Humans often encounter various obstacles in doing their work. Especially if the work is related to an emergency situation that concerns the safety of human life, it needs quick and appropriate handling. Telerobotic technology was created as one solution to these problems. This technology generally consists of two manipulators, the master manipulator that is controlled by the slave operator and manipulator that touches the object (environment). The slave manipulator movement follows the operator-controlled master manipulator movement. This technology makes work can be completed quickly and precisely by the operator without having to go to the location of the object (environment) or touch objects directly.

Telerobotics only provide visual information on the object's condition (visual feedback) to the operator. So the operator's decision is only based on visual information. Touch sensation is very important for various activities Telerobotic systems that do not have haptic function have many risks [1]. Haptic technology allows operators to feel sensations as if touching objects directly so that decisions are more precise and accurate. With haptic technology, telerobotic development becomes wider. Examples of applications in the medical field are surgical robots, medical training robots, and blind assisted robots. One method for realizing haptic robots is bilateral control. The results of this study are expected to be able to realize a manipulator system that can feel touch.

## 2. Literature Review



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Literature review that will be used for this research are

2.1 Haptic

Haptics, a term derived from the Greek word "haptesthai" which means "of or relating to the sense of touch," refers to manual sensing (exploration for information extraction) and manipulation (to modify the environment) through touch. Touching objects can be done by humans, machines, or a combination of both, with a real, false, or environment

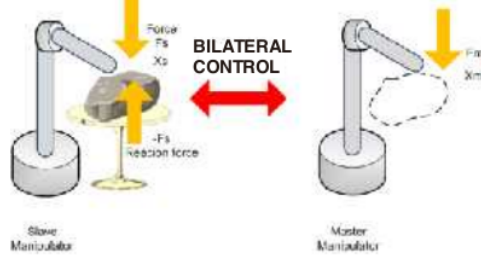


Fig. 1. Chart of Bilateral Control Blocks for Symmetrical Position

combination of both. These interactions can be accompanied by other sensory modalities such as vision or audio. Various disciplines, such as biomechanics, psychology, neurophysiology, engineering, and computer science, use this term refers to the study of human touch and force feedback with the external environment [2].

2.2 Bilateral Control

The bilateral control system is a control system for teleoperation with haptic feedback. In bilateral control, position and master and slave force information is transmitted to two robots in two directions [3]. Bilateral control is represented by equation (1). Force information obtained according to Newton III law. This law states that if we give an action force to an object it will give a reaction force of the same magnitude and opposite direction.

$$\theta_m - \theta_s = 0 \tag{1}$$

$$F_m + F_s = 0 \tag{2}$$

$$\alpha + \beta = \chi. \tag{1}$$

Figure 1 shows the forces given by the operator to the master robot arm, representing the force that the slave arm gives to the object. and successively represent the position of the master robot arms and slave.

Equation (2) indicates that the position error between master and slave must be zero. This means that the master and slave movements must be the same, so that the master and slave positions are always the same. and Equation (3) shows the sum between the force of action and the reaction force must be equal to zero. This is in accordance with Newton's laws of action.

2.3 Literature Review

Research related to bilateral control systems has been carried out in various applications including mine cleaning [4] and Steer by wire system [5]. To detect external forces, there are various methods, including using strain gage sensors [6] and using a modified observer as a reaction force observer to estimate the reaction force without force sensor [7]

Research in Indonesia regarding bilateral control, among others, was carried out by Abdul Muis [8] who implemented bilateral controls using microcontrollers in two ways. First the microcontroller as the acquisition interface, both microcontrollers as control units. Both produce good responses but are unable to realize the touch sensation due to small actuator torque.

Wicaksono [9] implemented the 1 DOF robot control using a potentiometer to obtain position information and current sensors to obtain force information. When touching objects, the position error when the bilateral control is position to position reaches  $\pm 30^0$

Deniprasetyo [10] designs a position-force hybrid control on a real-time master-slave system via the Matlab / Simulink program with Arduino as the Dynamixel AX-12 + Interface and Servomotor as its actuator. When touching objects, the position error reaches  $\pm 20^0$

This research will implement a bilateral control of DOF manipulator using the WCS2702 current sensor to obtain force information and potentiometer to obtain position information.

**3. Working Methodology**

In the process of this research there are several steps taken, including the design of a bilateral symmetrical position control algorithm, the design of a bilateral reflection force control algorithm, a force feedback bilateral control algorithm. From each algorithm, the position and force information is obtained through 16 x 2 character LCD.

*A. Bilateral Control of Symmetrical Position*

The symmetrical position control system controls the master and slave motors using the difference in position between master and slave. This method does not require force information. This method is shown in Figure 2.

*B. Bilateral Control Force Reflection*

The force reflection control system controls the slave motor using the difference in position between master and slave. As for controlling the master motor using the force measured on the slave. Current sensors are mounted on the slave motor to represent the force on the slave. This method is shown in Figure 3.

*C. Kontrol Bilateral Umpan Balik Gaya*

The force feedback control system controls the slave motor using the difference in position between master and slave. Whereas to control the master motor using the difference between the master and slave forces. Current sensors are installed on the master and slave motors to represent the force. This method is shown in Figure 4.

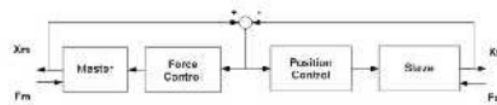


Fig. 2. Diagram of Bilateral Control Blocks of Symmetrical Position

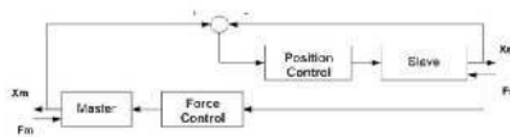


Fig. 3. Diagram of the Bilateral Force Reflection Control Block

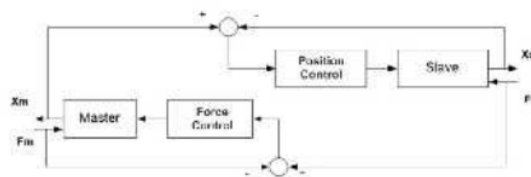


Fig. 4. Block Force Bilateral Control Block Diagram

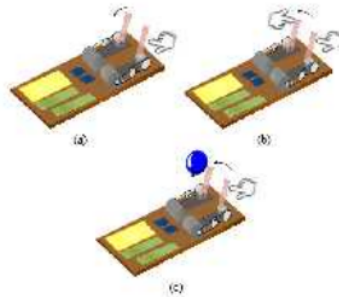


Fig. 5. Mechanism of Bilateral Control Testing when (a) Free Moving Slave Arm, (b) Slave Arm Detained by Hard Object, (c) Slave Arm is Held by Soft Object

## 4. Experiment and Result

### 4.1 Testing of Flow Sensitivity to Force

The purpose of this test is to determine the force value for each current generated by the current sensor. This test is done by moving the motor with a variety of voltage values. The voltage variation value is proportional to the DAC value given by the microcontroller. Then hold the arm using a spring balance so that the motor cannot rotate. After that, increase the voltage slowly and record the force measured by the spring balance and the current measured by the current sensor for each voltage increase. From the calculation, the value of the force is:

$$F = 2.9679 \times i - 0.7366 \quad (3)$$

TABLE I. TESTING OF SENSITIVITY FLOWS ON FORCES

Direction	DAC	Ampere	Force (N)	Testing Equation Force
Right	0	0.61	1.1	1.07
	10	0.61	1.1	1.07
	20	0.61	1	1.07
	30	0.61	1	1.07
	40	0.55	0.8	0.89
	50	0.47	0.7	0.66
	60	0.43	0.5	0.54
	70	0.33	0.1	0.25
	195	-0.45	0.6	0.6
	205	-0.55	0.8	0.89
	215	-0.64	1.15	1.18
	225	-0.78	1.62	1.59
	235	-0.82	1.8	1.71
	245	-0.88	1.9	1.88
	255	-0.94	2	2.05

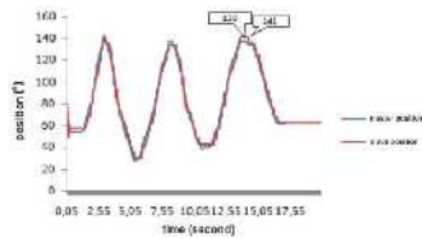


Fig. 6. Master and Slave Position Chart Using Bilateral Position of Symmetrical Position when the Slave Arm is Free

Bilateral control testing was carried out in 3 ways, namely the condition when the slave arm moved freely and when the slave arm was held by a hard object and when the slave arm was held by a soft object to find out the reaction of the slave object to the master [11]

4.2 Bilateral Control Symmetrical Position

1) Conditions when the Slave Arm is Free

The test is done by moving the master arm using the hand while the automatic slave arm moves freely following the master arm. The testing mechanism is shown in Figure 5 (a). Figure 6 shows the test results that slave is able to follow the master with a position error of  $\pm 3^{\circ}$ . This is due to the delay effect between master and slave. In addition, the movement of the master and slave arms feels heavy.

2) Conditions when the Slave Arm is Withheld by a Hard Object

The test is done by moving the master arm using the hand while the automatic slave arm moves freely following the master arm. But at certain times, the slave arm is held using an object

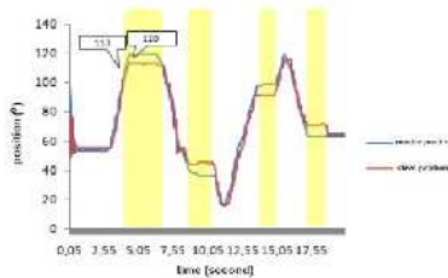


Fig. 7. Master and Slave Position Chart Using Bilateral Control Symmetrical Position when the Slave Arm is Held by a Hard Object

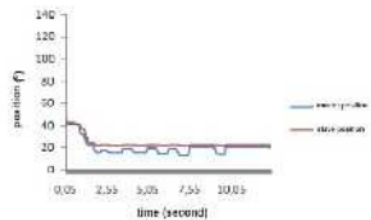


Fig. 8. Position of Master and Slave Position Using Bilateral Control of Symmetrical Position when Slave Arm is Held by Soft Object

in the opposite direction. The testing mechanism is shown in Figure 5 (b). Figure 7 shows the results of the test that the slave is able to follow the master movement. In this test, the slave arm touches the object four times, namely the yellow area. When the slave arm touches the object the operator feels the master

arm is also stuck. But the master's position when it stops is not the same when the slave touches the object. There is a position error of  $\pm 7^0$ . This is due to the delay effect between master and slave. The greater the delay, the bigger the position error when the master and slave arms. The movement of the slave master is heavy.

### 3) The condition when the Slave Arm is Withheld by a Soft Object

The test is done by moving the master arm using the hand while the automatic slave arm moves following the master arm. But at certain times, the slave's arm touches the balloon. The testing mechanism is shown in Figure 5 (c). Figure 8 shows the results of the test, when the slave arm touches the balloon, the operator can feel the reflection quite well. But there is a  $\pm 10^0$  position error. Error occurs due to delay between master and slave. This causes the operator to not be able to feel the reflection of objects directly. When the slave arm touches a soft object to a depth of several cm which causes the arm to move as far as  $n^0$  from the surface of the object, the position of the master arm becomes an error  $+n^0$ . The error is generally greater than the slave displacement. And if the pressure on the master arm is released, the arm will move until the position is the same as the slave arm's position. So that the transfer of the master arm is greater than the displacement of the slave arm. Not all soft objects can be detected as soft objects. This is because force control is not adaptive to object impedance.

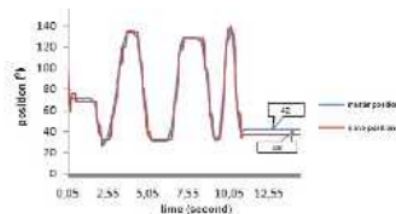
### 4.3 Bilateral Control Force Reflection

This test is done in 3 ways, namely:

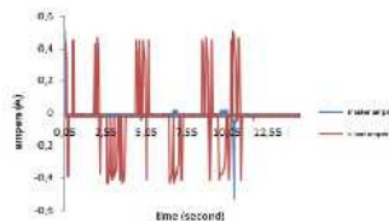
#### 1) Conditions when the Slave Arm is Free

The testing mechanism is shown in Figure 5 (a).

Figure 9 shows the test results that slave is able to follow the master with a position error of  $\pm 4^0$ . This is due to the delay effect between master and slave. The movement of the master and slave arms is lighter than the bilateral symmetrical position control method. Figure 10 shows a flow graph where a current surge occurs when the master and slave change position from rest to move. So that the spikes occur every master and the slave changes direction. This surge of current only happens for a moment. The current value is the opposite of the position value. When the arm turns toward a more positive angle, the current is negative, whereas when the arm turns toward a more negative angle, the current is positive. This is due to the entry into force of Newton's law 3. Where an object tends to maintain its original state. When one time moves in one direction there are several surges of current. This is due to errors that hinder the master movement. The movement of the master arm feels lighter than using a bilateral control symmetrical position



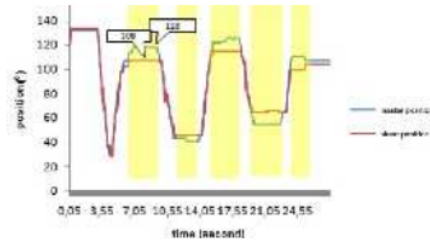
8 Fig. 9. Master and Slave Position Charts Using Bilateral Force Reflection Control when the Slave Arm is Free





8

Fig. 10. Master and Slave Position Charts Using Bilateral Force Reflection Control when the Slave Arm is Free



8

Fig. 11. Master and Slave Position Chart Using Bilateral Control Reflection Force when the Slave Arm is Held by a Hard Object

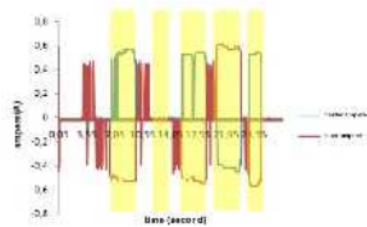


Fig. 12. Master and Slave Flow Charts Using Bilateral Control Force Reflection when the Slave Arm is Held by a Hard Object

2) Conditions when the Slave Arm is Withheld by a Hard Object

The testing mechanism is shown in Figure 5 (b). Figure 11 shows the results of the test that the slave is able to follow the master movement. In this test, the slave arm touches the object five times, namely the yellow area. When the slave arm touches the object the operator feels the master arm is also stuck. But the master's position when it stops is not the same when the slave touches the object. There is a position error of  $\pm 10^0$ . The current graph is shown in Figure 12.

3) The condition when the Slave Arm is Withheld by a Soft Object

The testing mechanism is shown in Figure 5 (c). Figure 13 shows the results of the test, namely when the slave arm touches the balloon, the operator can feel the reflection quite well. But there is a  $\pm 10^0$  position error.

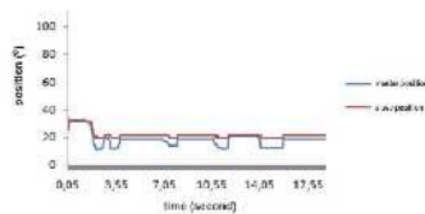


Fig. 13. Master and Slave Flow Charts Using Bilateral Control Force Reflection when the Slave Arm is Withheld by a Soft Object

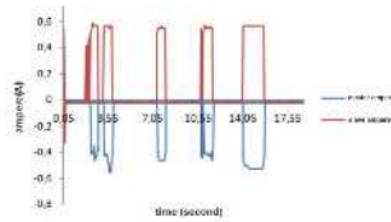


Fig. 14. Master and Slave Force Charts Using Bilateral Control Force Reflection when the Slave Arm is Withheld by a Soft Object

Error occurs due to delay between master and slave. This causes the operator to not be able to feel the reflection of objects directly. When the slave arm touches a soft object to a depth of several cm which causes the arm to move as far as  $n^\circ$  from the surface of the object, the position of the master arm becomes an error  $+n^\circ$ . The error is generally greater than the slave displacement. And if the pressure on the master arm is released, the arm will move until the position is the same as the slave arm's position. So that the transfer of the master arm is greater than the displacement of the slave arm. Not all soft objects can be detected as soft objects. This is because force control is not adaptive to object impedance. The current graph is shown in Figure 14.

4.4 Bilateral feedback on force feedback

This test is done in 3 ways, namely:

1) Conditions when the Slave Arm is Free

The testing mechanism is shown in Figure 5 (a). Figure 15 shows the test result that slave is able to follow the master with a position error of  $\pm 2^\circ$ . This is due to the delay effect between master and slave. The movement of the master and slave arms is lighter than the bilateral symmetrical position control method. Figure 16 shows the flow graph The movement of the master arm feels lighter than using bilateral control of symmetrical position and bilateral control

2) Conditions when the Slave Arm is Withheld by a Hard Object

The testing mechanism is shown in Figure 5 (b).

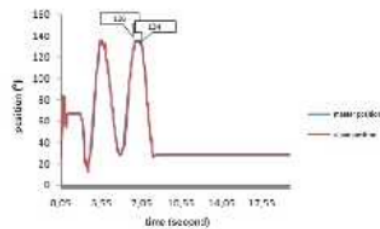


Fig. 15. Master and Slave Position Chart Using Bilateral Feedback Force Control when the Slave Arm is Free

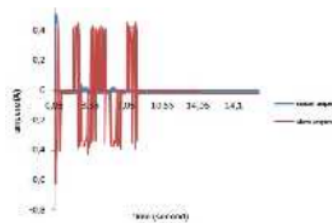


Fig. 16. Master and Slave Flow Charts Using Bilateral Feedback Force Control when the Slave Arm is Free

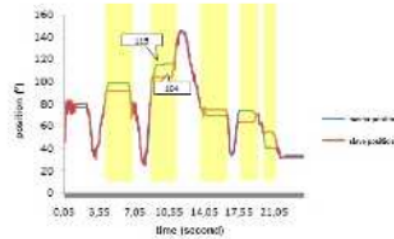


Fig. 17. Master and Slave Position Chart Using Force Feedback Bilateral Control when the Slave Arm Is Held by a Hard Object

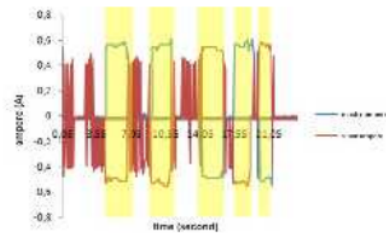


Fig. 18. Position of Master and Slave Position Using the Force Feedback Bilateral Control when the Slave Arm is Held by a Hard Object

Figure 17 shows the results of the test that the slave is able to follow the master movement. When the slave arm touches the object the operator feels the master arm is also stuck. But the master's position when it stops is not the same when the slave touches the object. There is a position error of  $\pm 11^{\circ}$ . The current graph is shown in Figure 18.

1) The condition when the Slave Arm is Withheld from a Soft Object

The testing mechanism is shown in Figure 5 (c). Figure 19 shows the results of the test, when the slave arm touches the balloon, the operator can feel the reflection quite well. But there is a  $\pm 10^0$  position error. Error occurs due to delay between master and slave. Not all soft objects can be detected as soft objects. This is because force control is not adaptive to object impedance. The current graph is shown in Figure 20.

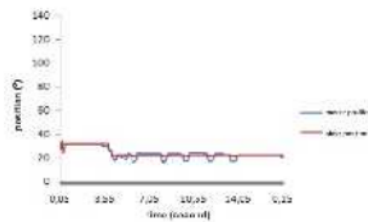


Fig. 19. Position of Master and Slave Chart Using Force Feedback Bilateral Control when the Slave Arm is Held by a Soft Object

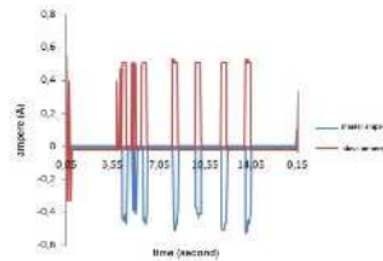


Fig. 20. Position of Master and Slave Position Using the Force Feedback Bilateral Control when the Slave Arm is Held by a Hard Object

## 5. Conclusion

In this study, it was concluded that the bilateral control is symmetrical, the slave can move following the master movement with a position error of  $\pm 3^0$ . When the slave arm is held by a hard object, the master arm is also restrained with a  $\pm 7^0$  position error. Whereas when the slave arm is held by a soft object, the reflection of the object is felt by the master arm with a  $\pm 10^0$  position error. Movement of heavy master and slave arms

In the bilateral control system reflection force, the slave can move following the master movement with a position error of  $\pm 4^0$ . When the slave arm is held by a hard object, the master arm is also restrained with a  $\pm 10^0$  position error. Whereas when the slave arm is held by a soft object, the reflection of the object is felt by the master arm with a  $\pm 10^0$  position error. The movement of the master and slave arms is lighter than using a bilateral control symmetrical position.

In the force feedback bilateral control system, the slave can move following the master movement with a  $\pm 2^0$  position error. When the slave arm is held by a hard object, the master arm is also restrained with a  $\pm 11^0$  position error. Whereas when the slave arm is held by a soft object, the reflection of the object is felt by the master arm with a  $\pm 10^0$  position error. Movement of the master and slave arms is lighter than using bilateral control of symmetrical position and bilateral control of reflection force.

The three methods have not been able to feel the touch of various soft objects so that it needs to add a force control that is adaptive to the object impedance.

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