Presenting states and functions of objects under assembling operation with force display device

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Abstract

Assembling is one of the important factors in our daily life. The aim of assemble is to obtain a particular function from the subassembly which is generated by putting some parts together. This fact shows that assembling machne parts is possibly the most appropriate example to exeute. If we assemble some machine parts, we decide the positions by their shapes, and then, make sure both the state of parts by reaction force fed back to the hand when a part touches other parts and the behavior of the subassembly. In addition, it is advisable to use both hands for assembly. In this research, we constructed a virtual work space using a force display which gives us haptic sensation returned from not only assembling operation but collaboration with both hands.

1. Introduction

Assembling something is the elementary work which can be never separated from our daily life. We have the experience in assembling a shelf or enjoining a toy of blocks. It can be considered that putting a key in a key hole or corking a bathtub of a bath are a kind of assembly from a point of view that they are putting two parts together. In this way we usually do assembly operation unconsciously. The purpose of assembly can be considered to be the generation of a particular function specified by putting two thing together in the constant relation. Therefore, when the position relation between each part includes wrong one, then the assembledobject become useless. The typical example is the relation between machine parts and the object assembled from them (we call it a subassembly). In real assembly work, combination between parts decides the function based on their primitive shapes. And we confirm whether the parts are put at the right position or not by the feel of click obtained in assembling. So it's necessary to give an operator both visual and haptic information to have him/her mate two parts by recognizing the states of them when an assembly work is realized in virtual space. At the same time, it's essential to express a function of a subassembly as a result of assembly operation. Based on the above-mentioned reason, we attempt to construct virtual work space which gives an operator both visual and haptic feel under condition that he/she make up machine parts by his/her both hands.

2. Basic operation of assembly work

"insert an axis in a gear", "put a screw in a tapped hole", "fit a board in a ditch". Seemingly we can think these works to be different at all. But the difference is only in the constraint relation between parts after aseembling operation, and it is common in the point of inserting a convex shape into a concave one. From this point of view, the most basic action in assembly work is considered to have a part insert into a hollow object or a hole. In this paper we will describe the method for realizing the insertion operation using two 3D models of a peg and a block with a hole. Under the assumption that user's hand is located on the center point of the peg, movement of the peg is controlled by the haptic feedback display which will be mentioned later. And the block can be moved when it is grasped by user's hand shown at the bottom of the figure 2.1. A hand model is linked to the data glove which will also be mentioned later. Therefore when they collide each other, the operator can feel the force acting on only the peg through the haptic display. Because there is no haptic feeling in the data glove grasping the block, no force can be returned to the hand, but it can represent the fine movement of finger in garasping operation.

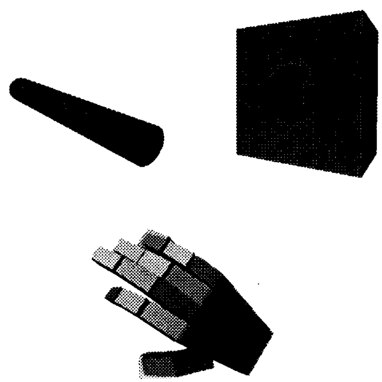


Figure 2.1: The peg, block and hand model

3. System organization

We show in the following the organization of the system which builds the virtual work space.

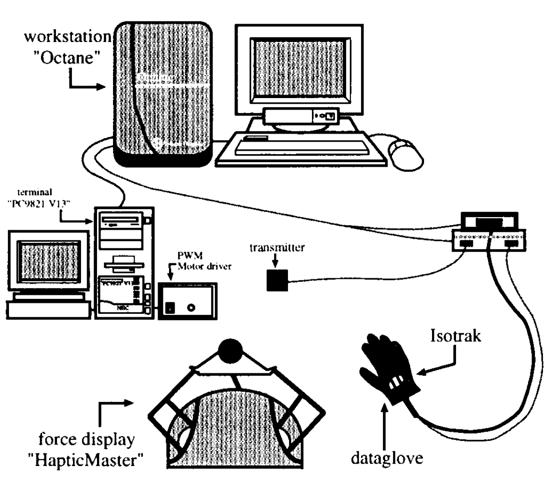


Figure 3.1: Figure of the system organization

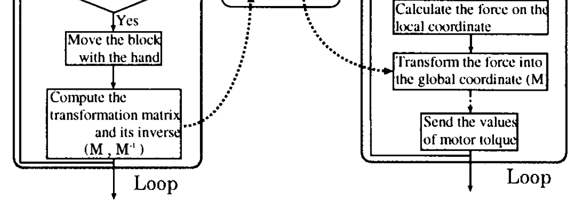
To present the reaction force returned when parts contact each other, the force feedback device HapticMaster is used in this research. The data glove for the right hand is used in order to detect the movement of the right hand, then an operator grasps a block with his right hand and a peg with his left hand when executing assembly operation.

4. Creation of task space

The task environment constructed consists of the part which calculates the reaction force and the one which draws three-dimensional graphic. These processing parts always run in parallel, and they share the coordinate of the center position of the peg and the coordinate transformation matrix of the block, with which they make it possible to make correspondence between the movement of models and their reaction force. (figure 4.1)

4.1 The drawing part

Movement of a 3 dimensional model is managed with the drawing process side. Grasping operation of the block is also treated in the same process. The block model and the hand model have their own Boundin Boxes, one of whichis located over the block and the others are attached to each first joint of the thumb and the little finger. And when the Bounding Box of the block and two Bounding Box of the fingers intersect, it is judged that the grasping is occured.



4.2 Reaction power in contact

When two objects come in contact, it is important what kind of force acts on which position of the partner. If an object collides with other one and each of them has its own shape, naturally, the force should be returned. Part models used in this system which are shown in figure 2.1 are the block having the hole in the center and the peg of cylindrical shape with smaller diameter than that of the hole. So, assuming that the block is fixed at some position and that a peg is inserted into a hole from roughly vertical direction against the plane with a hole, the area is classified into the ones shown in figure 4.1.

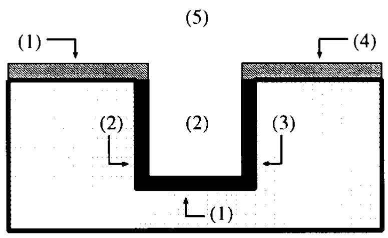


Figure 4.1: Devision of the block surface

Setting up the position of the grip of HapticMaster into the *So*, which is the coordinate of the center point of the peg as shown in figure 4.2, the system let an operator move the peg, but so far the data such as the lengthand the radius of the peg are not given. To exprss the length of the peg, we adopt the following method using the center point *So* and that of ots base *Sbo*. If *Sbo* is in area of the figure 4.1, the peg is determined to come in contact with the block. And the force which is returned to *Sbo* at the touched point on the block is calculated. Then we can obtain a necessary value by regarding the force as one acting on the whole peg. Using the two points *So* and *Sbo*, the length of the peg is represented as a line whose length is a half of *Sl*. By using only these two points, it may be possible to represent a peg with length which is extremely thin thing like a needle, but inpossible to express a thick one.
For the purpose of finding a feature in insertion operation, we had a small experiment as following.
Using a real block and a peg, when having persons of around 10 operate to put the peg in the hole on the block in the following two cases, (1) when the block faces on the front of the operator, (2) when it faces on his side, 90 percent or more of them keep the peg in the state which is deifferent by the gap of 3-5 degrees from a normal vector of the face till the insertion time from the initial point. It can't be always concluded that this result is right as it is a simple examination, but the fact that 90 percent or more of them took the same action can't be ignored. So considering this fact, the following methods are used to express the force acting on the peg. When a peg enters in a hole, we have narrowed the radius of the hole by the radius of the peg. Figure 4.2 shows the difference between part models used to visualization and that used to calculate reaction force.

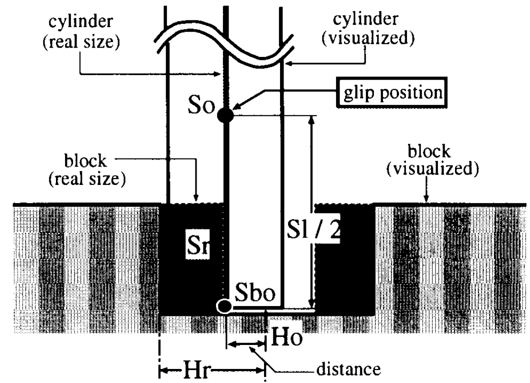


Figure 4.2: expression of length and thickness of the peg

5. Cooperation by both hands

5.1 Realization of cooperation work

The method for caliculating the reaction force described in section 4.2 is based on the premise that the block is fixed and that the position is known. If an object of operation is a big machine, the operation is done in a fixed state. But when a man works, he will usually have parts in both hands and move or assemble them. Even if he treats a part which is too largee to pick up, he keeps his hand putting on it and assemble another part with his another hand. Advantage in doing assemble work by both hands is that the efficiency of work will increase because we can arrange parts in the specified position more exactrily. Based on this idea, we attempt to realize bi-manual operation in virtual space. Recently, in the field of both drawings and haptics, the studies to realize cooperation work with both hands are advanced. [2] [3] [4] [5] The absolute position and posture of a block change in assembly by both hands, but the relative position between the block and the peg and that of force acting them do not change. So at first, in the state that the block is fixed the force itself is calculated, and then by converting the value according to the posture of the block, the real reaction force returned from the block after the movement is calculated. Merits of this method are (1) calculation of the force is easy because the peg is fixed on the local coordinate of the block, which is equivalent to calculating the force based on the condition that the block is fixed at the particular position. (2) the position of the given 3 dimensional models are usable without any changes. The method is described below.

5.2 Coordinate transformation

Each 3 dimensional model is usually generated based on its original local coordinate system. Relation between each vertex on a model is described based on this local coordinate, it is converted into a global coordinate system in case used in the virtual sapace (figure 5.1).
If the transformation matrix which represents relation between 2 coordinate systems is found, even if whichever is selected as a base ,the same result is to be provided by converting another coordinate system. In this study, the force is caliculated in the following procedure.

[1] The matrix M to convert the coordinate of the block into the global coordinate and the inverse matrix M^{-1} are acquired from the drawing part.

[2] Each vertex on the cylinderical peg is converted into the coordinate system of the block using M^{-1} .

[3] The reaction force is calculated on a coordinate of the block.

[4] A value caliculated above is returned to the global coordinate system by M.

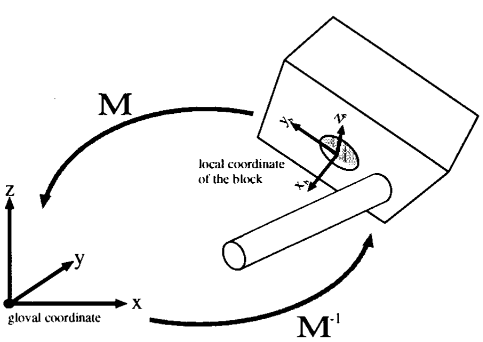


Figure 5.1: coordinate transformation

6. Generation of subassembly

A machine part realizes a specified movement when several parts and groups are put together. For example, when a shaft is put in a gear, if there isn't a gap between the shaft and the hole of the gear they will be united and move, but if gap is large they don't interfer in their behavior mutually. In this way, according to the type of the part to be put together, the state of the assembly will change. In this research, the difference among the states of assemblies is expressed by the both sides of the drawing part and the haptic part.

6.1 Combination of two parts

If a peg is inserted inot a hole to certain depth, it is united with the block, and they must be moved together. The state where they are put together must be represented both sides of the drawing part and the haptic part. To realize the state,when a peg is inserted into a hole to the certain depth, in the drawing part each vertex of the peg is converted into that on the local coordinate of the block to move them together(figure 5.1), and in the haptic part the reaction force from the block acts at the center point of the peg when it's moved. When a gap between a hole and a peg is extremely small, by calculationg the force acting on the peg using a dampar model, difficulty in inserting/extracting the peg into/from the hole is represented.

6.2 Peg insertion with both hands

In the figure 6.1, when the parts are mated ,the weight of the block acting on peg should be reduced because the right hand supports it during assembling. On the other side, if the block is constrainted not to be moved with the right hand, it is possible not to move the block even if the peg is put in a hole. But as the data glove attached to the right hand cannot give the haptic feeling to the hand, it is difficult to judge whether the block is constrainted or not. But if the holding down action is equivarently regarded as the quantity of change, the action can be realized even if no haptic information is available. So the state in which the hand is attached to the block is classified into the next two cases, the method to caliculate the force acting on the peg is changed according to each case.

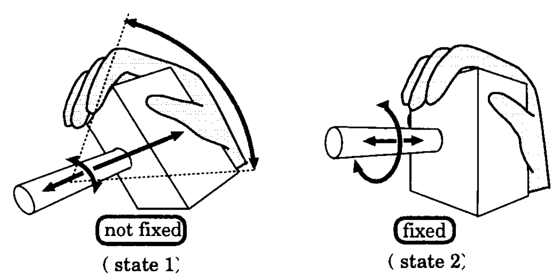


Figure 6.1: state1 and state2

[State 1] the block is supported. As the block is not constrained, the right hand also moves with the block after the mating operation is finished. (The left of figure 6.1.)

[state 2] the block is held down. As the block is fixed, neither the block nor the peg move even if the peg is moved after the mating operation. (The right of figure 6.1.)

Then if the following conditions are satisfied at the same time, it's judged that the state2 occurs.

[condition 1] the tip of the peg contacts with the inside of the hole.

[condition 2] Amount of force acting on the peg from the inside of the hole exceeds a fixed quantity.

We attach a small Bounding Box to the top of the middle finger to support the two previous conditions.

[condition 3] The Bunding Box at the middle finger and that of the block intersect.

At first,the peg is need to be inserted in the hole. When the block isn't fixed,the reaction force acting on the peg doesn't become larger than a certain value because the block is moved by this force. On the other hand when it is fixed, it can be considered that the value of the force should be larger.

7. Contents of execution

In the virtual workspace created based on the previous method, we prepare 4 tasks mentioned below. In the experiment, we select an assembly consisting of a block and a peg. Two kinds of blocks are used, one has a hole with a larger radius than and another the same radiua as that of a peg.

task1 Make the peg touch on the surface of the block.

task2 Make the peg inserted into the hole on condition the block is fixed.

task3 Make the peg inserted into the hole on condition the block is not fixed.

task4 Take the right hand off from the block after two parts are put together.

These tasks are executed for each of two block models. The size of each model is below:
[peg] length:200mm, radius(the base):15mm
[block (with a large hole)]
length/width:80mm, thickness:60mm
rasius(hole):20mm, depth(hole):50mm
[block (with a small hole)]
rasius(hole):15mm
Others are the same as the block with a large hole.

8. Experimental result

Results when the block with large holeis used only shown in following pictures.

[figure 8.1]
The peg in the left hand and the block is in the right one.
In real space an operator hangs the glip of a force feedback device, through which he/she(but representatively we use "he" below) can feel reaction force generated by collution in virtual space. A data glove and 3D magnetic sensor is put on the right hand to get behavior of it. By using this data, the right hand model attains the motion such as grasping.
[figure 8.2]
The peg touching the surface of the block.
Motion of the peg model is controlled by moving the glip grasped by the left hand.
In virtual space, when the peg collides with the block, reaction force along the normal of the surface acts on the glip. By moving the peg slowly, an operator can feel that he is touching a plane. Then if the peg is moved out of the surface, he can recognize that the peg fell down and whether the peg is on the block or not by the difference between the base(peg) and the surface(block). The reaction force is recognized exactly only in case both parts are moved slowly and softly touched each other. If they collide rapidly and strongly, vibration causes at the glip, which makes it impossible to represent a plane precisely. Espacially this problem is easy to occur when only the block is moved to be touched to the peg because the right hand has no haptic device then the movement changes extremely.
The purpose of this work is to insert a peg into a hole, so we don't consider reaction which acts on the side and the rear of the block.
[figure 8.3]
The peg inserted in the hole when the block is fixed.
As the hole is cylinder shaped, reaction force on inside of the hole makes an operator feel as if drawing circles when he moves the peg along the center axis of the hole. And when the base of the peg has reaches the bottom, the peg isn't allowed to move forward any more because of the force against the direction.
A hole of the block is large,so clearance between the

hole and the peg is comparatively large and it is easy to move the peg into or out of the hole. But if the clearance is quite small, inserting or extracting the peg is difficult because of friction acting between each cylindrical side of two parts.
In such case it is considered to be nesessary to fix the block because even if an operator tries to insert the peg into the hole,the block is merely pushed to move without putting together. And after the block is fixed, the peg is restricted not on its movement itself but on the range of movement by reaction force. This fact allows the peg to translate along and rotate around its axis alone. The state "fixed" is occured when three conditions in section6.2.

[figure 8.4]

The peg inserted in the hole when the block isn't fixed.
In case that the block isn't fixed, the right hand can be regarded as merely attatching to the block. So when two parts are assembled, the hand moves along with the subassembly.
In figure8.4, we can see the difference in position relation of both hands between in virtual space and in real space.
In the real work space both hands are located almost horizontal, on the other hand those in the virtual work space are located almost vertical. This means that the right hand model is no longer controlled by the sensors, but the movement of the block. If the clearance between the peg and the hole is small,the two parts are atatched and move together even if they are linked at the shallow point of the hole. Behavior of the block and the hand completely depends on that of the peg. But if the clearance is large, the peg have to be inserted by proper depth because they are easy to be disassembled as they're not so close.
The state "fixed" is canceled when the middle finger is taken off from the block.

[figure 8.5]

The right hand is removed after inserting the peg into the hole. Even if the right hand is removed in figure8.5, the block moves in thesame way as figure8.4.

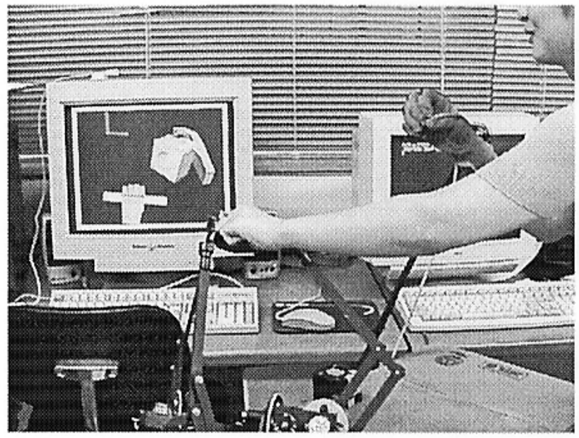


Figure 8.1: before assembling

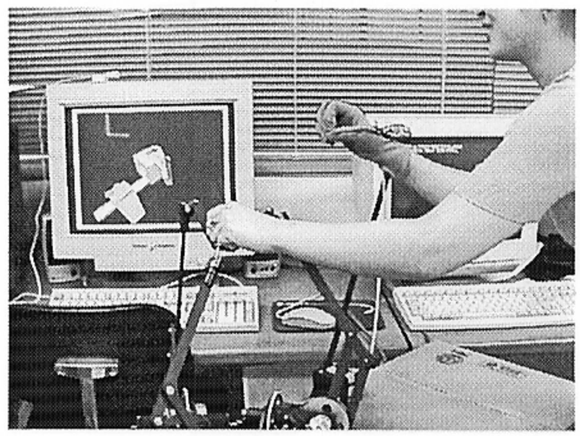


Figure 8.2: execution of task1

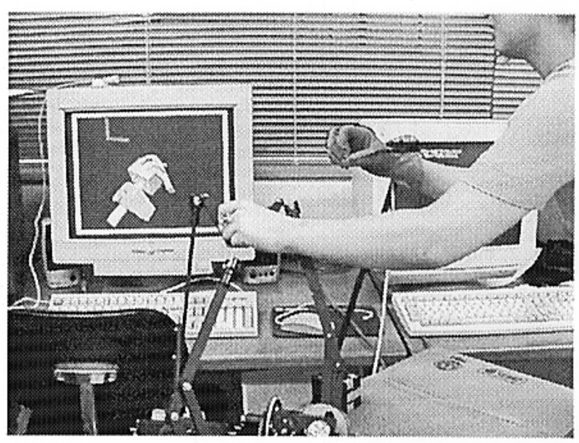


Figure 8.3: execution of task2

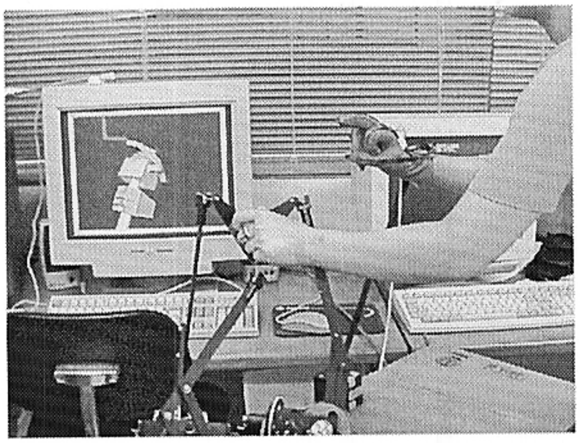


Figure 8.4: execution of task3

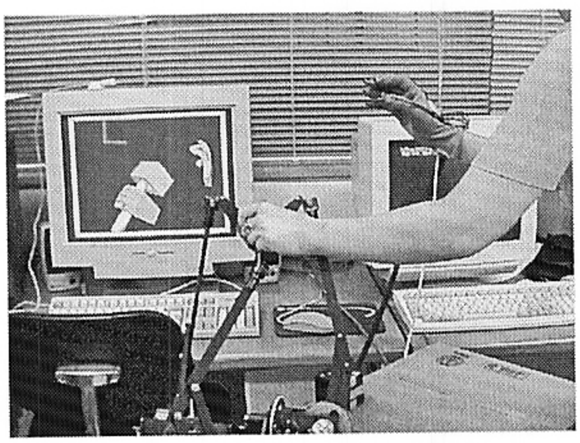


Figure 8.5: execution of task4

9. Consideration about execution result

In the experiment it was identified that the state of each part after assembly is different according to the difference of the radius of the hole. Dependent of the movement of the right hand, intense vibration has occurred with HapticMster during execution, an oprator cannot realize the force returned from the device precisely. As this cause, It is thought that he cannot adjust strength needed to push the block to the peg, because there is no haptic function on the right hand having the block. In order to solve this problem, The right hand need to have haptic feeling to dissolve the difference in haptic feeling between the right hand and left one. Using two force display devices, we would like to realize assembling operation by both hands.

10. Conclusion

In this study, the fundamental assembly operation which needs both hands in virtual space and the state of an assembly after assembly operation is finished are realized using a single haptic display device. We are going to realize the system in which reaction force occurring when two parts garasped with both hands contact can be sensed with both hands using two haptic displays. In this paper we treat the case in which two parts have a fixed relation after mating operation,but there are cases where the degree of freedom with respect to translation or rotation may remain. We would like to continue research to solve problems including the one mentioned above.

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