Improving operational feeling in using virtual tools by reproducing virtual behavior from real one captured in advance

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Abstract

As it is not easy for a user in virtual environment to use virtual tools, improving the feasibility of manipulating them is necessary to help him correctly achieve his intenstion. Tools are used to change the current state of an object into desirable one, so the several constraints are imposed on their movement, a grasping method and an object class to be manipulated. Consequently, it is possible for the system to predict user's intent by watching his behavior. We propose a method to measure the movement of real tools when they are exploited for a particular purpose and to store them so that they are retrieved according to their constraints. Inferring user's intention through the observation of his behavior, the system plays back one of the stored movements. This allows any users to exploit a virtual tool in virtual environment in the similar way to the real one.

1. INTRODUCTION

An artificial reality or a virtual reality have been attracted attention as techniques for having us intuitively understand problems which it is hard for us to experience in daily life. For making it easy for us to intuitively comprehend events occurring in virtual environments, a man machine interface plays an important role to secure fast and correct communication between us and a computer.

Displays, keyboards or mouses are well known as interface tool for bridging between a person and a computer, but a mouse does not allows a person with no experience in a virtual space to manipulate the 3 dimensional space at his own will. A number of purpose-built input/output devices have been developed in virtual reality studies to facilitate the 3 dimensional manipulation. Input devices such as a handle or an accelerator used in drive simulators are typical examples. These purpose-made devices generally make it difficult to generalize a system for controlling devices including problems of their sizes, costs and popularization into families. An approach of building a knowledge base of tools was proposed to divide input devices from a core system by restricting them to 3 dimensional position sensors and data gloves (Funahashi et al., 1997). Using the tool knowledge base, interaction between operator's hands and various tools is defined in this system. We think that an action of a tool is decided by the gesture with an operator's hand and that the tool works as the result. In this case, if the system does not move a tool simply but move the tool exploiting captured data, the tool operation with a sense of reality can be visualized. As a tool is grasped by recognizing the gesture of operator's hands and operated referring to the tool knowledge base, it is difficult to realize any operation which an operator does not intend. As providing the semantic model for each tool and classifying operation of tools by grasping method and the movement, the proposed method is flexible and makes it possible to realize extension of new operation in addition to reproduction of operation.

Tools are used to manipulate an object for attaining a particular purposive operation, this allows a system to anticipate an operator's behavior. This means that it is possible to store in advance the behavior of hands observed at the time when he manipulated a real tool.

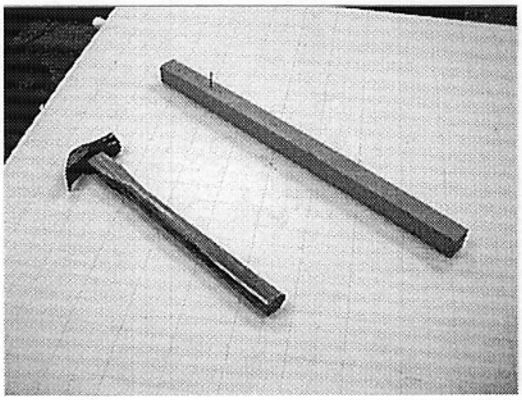

Figure 1.1: An example of a tool and object.

When a system perceives that a person is going to use a tool in order to attain its original goal, by playing back the behavior corresponding to the tool he will get real operational feeling.

Consequently, if a data glove approaches to a tool and he is going to grasp it with a grip which makes the operation possible, the system will get his virtual hand to grasp the virtual tool and generate a sequence of motion from the stored behavior. Of cause, the size of the virtual tool is not always equal to the stored one, then some translation is necessary for generating the motion.

To make clear the effect of the method proposed in this paper, we select a claw hammer as an example which is usable both as hammer and as nail extractor. A nail and a board is given as the objects of the tool (Figure 1.1).

2. FUNCTION OF A TOOL

In robotic research, the researches have been studied methods to have robot manipulators to realize a sequence of motion obtained by getting a person to do the works such as trimming, grasp, assembly and elastic object insertion.

The human behavior is measured with the motion capturing method such as a vision system, data glove or 3 dimensional position sensor, and force torque sensor is used to detect a force needed to the works. The force measurament is required for reproducing actions which need not only the position control but also the force one.

The purpose of this research is to realize a system that helps a person treat virtual ones in a virtual environment which correspond to the tools he uses every day. At present we do not intend to have five fingered robots to use scissors or a nail extractor, but if humanoid robots are introduced into human community, they may be required to adapt themselves to the tools. In the case, the method we propose in this paper will contribute to make clear the relation between tools and their functions.

As you can see from the fact that you will use a tool except a hammer to hit a nail if you find it unavailable, a tool will have not only the function peculiar to itself but also another function which is fulfilled only when there is no tool best fits to a given purpose. The latter one is not difficult to give the definition in advance, it can be inferred from observing which kind of tools the majority of men will use to attain a given goal when the most familiar tool is not available.

A vision system is reported that infers the function of an object by analizing the locus of its movement when a person uses it as tool (Sharma et al., 1997), but it is difficult to measure the grasping method or intricate motion of hands.

3. CLASSIFICATION OF USAGE OF A HAMMER

Two operations that a hammer strikes a nail and extracts it are realized with a hammer defined in this system. Action of a person manipulating a tool and movement of the tool are described in the following.

3.1 The case when a hammer hits a nail

When a person hits a nail, he uses a hammer with his right hand holding a nail with his left hand and the nail is struck along the line extended from the nail top toward the hammer head. A hammer strikes a nail lightly until the nail becomes stable, the nail is struck powerfully after it was stable. In order to realize this operation in a virtual environment, positioning of a nail with his left hand, searching for a path which leads the hammer grasped with his right hand, toward the nail tip and operation of a hammer to strike the nail are necessary.

3.2 The case when a nail is extracted

When a person extracts a nail from a plate, he first fixes a hammer to the head of a nail with his right hand, and afterwards the plate in which a nail sticks is fixed with his left hand if necessary, then the nail is extracted by pulling his right hand toward his side. In order to realize this operation in a virtual environment, after roughly setting a handle of a hammer to parallel for a nail and having searched for the path which the head of the hammer catches the nail head on, operation of the hammer is necessary. His left hand is needless in this case.

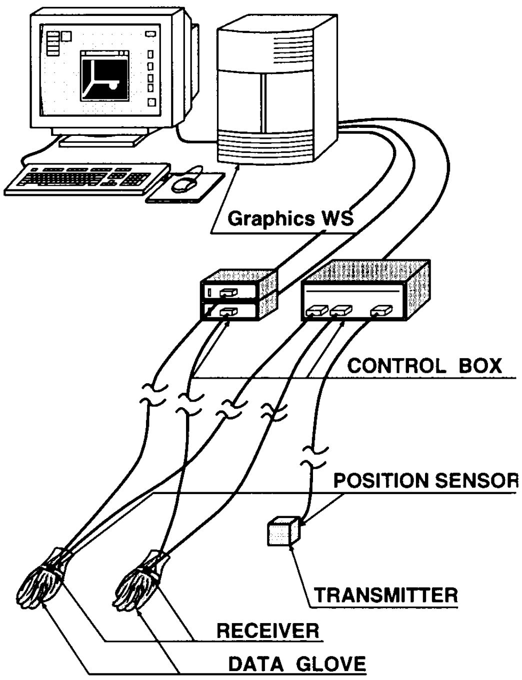

Figure 4.1: System configuration.

4. SYSTEM CONFIGURATION

System configuration is shown in Figure 4.1. By mounting data gloves and three dimensional position sensors on both hands, evry joint angle of every finger and position information are always returned to the computer. Computer utilizes this information and allows any operator to make interaction with virtual environment. The system consists of a work station OCTANE/SSI of SGI company, three dimensional position sensor ISOTRAK II of POLHEMUS Company and Super glove of NISSYOU Electronics Company

5. MOTION CAPTURE OF HANDS DURING OPERATING A TOOL

5.1 Environment of Data Acquisition

The motion of a hand during operating a tool in a real environment is captured with the magnetic position sensors.

Magnetic sensors have a weak point that it is affected by environment, and what is worse the compensation of the influence is hard because it is non linear. Fortunately, as the measuring range is from 0 to 50cm, the distortion is very little and there is no need of data calibration. Figure 5.1 shows an amount of distortion occurring in position data measured with a magnetic sensor; dotted lines show measured values.

Because the head of a hammer is made of metal, it

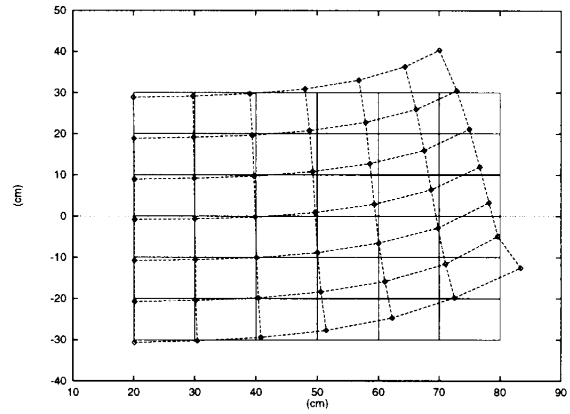

Figure 5.1: Distortion of magnetic field.

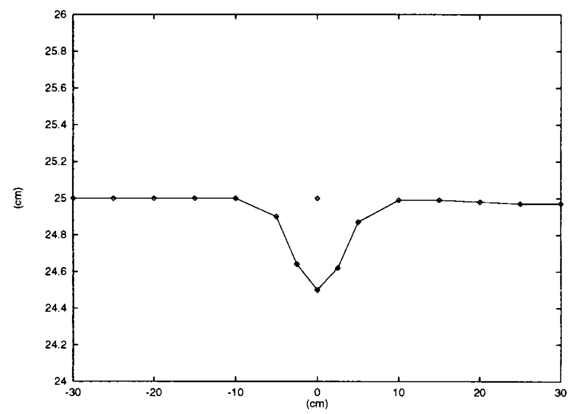

Figure 5.2: Effect caused with a hammer head.

certainly affects to the value measured with a magnetic sensor. Figure 5.2 shows the deviation in values of the magnetic sensor located at (0,25), with a transmitter located at (0,0) and a hammer moving along the horizontal line passing the point (0,20). From the result, it can be concluded that the influence of a hammer head to the magnetic field takes a maximum value when it is on the line passing both the transmitter and receiver, and is negligible when it is 10cm distant from the receiver. The motion measurament of a hammer is conducted without grasping a hammer head in a hand, no calibration is not specially taken into consideration.

5.2 Motion Capture of a Hand

The system proposed in this paper allows a person to manipulate a virtual tool according to his intention, and the operationality of the tool to be promoted by giving both his virtual hand and the virtual tool the movement reproduced using the data obtained from the operation of the real tool with his own hand in

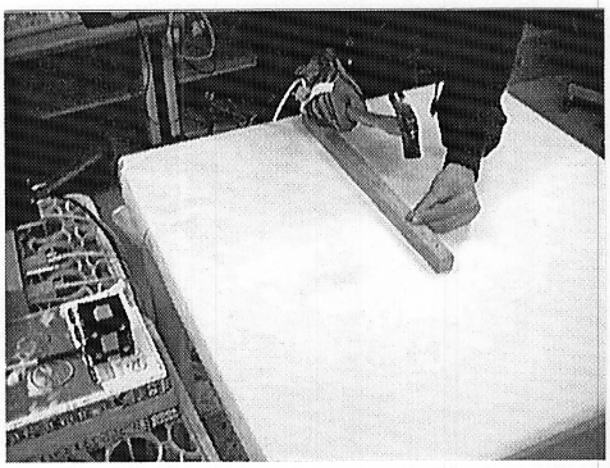

Figure 5.3: Environment for experiment.

an ideal real environment. The motion of a hand is captured 30 times in every second at both the cases when he hits a nail with a hammer and when he uses a nail extractor. Figure 5.3 shows the data acquisition process. The time taken to hit a nail is about 8 seconds and the one to pull it out is about 3 seconds.

5.3 Analysis of Hand Movement

Figure 5.4 shows the motion of a hand during a hammer is hitting a nail. You can see from the figure that the motion of hand draws a small ellipse while the nail is not yet enough driven into the board, but that the size of ellipse becomes big as the nail is firmly fixed to the board. The positional relation between a hammer and a nail is not shown here, it has become clear that the head of a hammer hits a nail not from right above but from a little aslant direction. It seems that this is due to the characteristic of our arm joints. Consequently an simple up and down motion of a hammer is not enough to give an operator feeling that he is really hitting a nail.

Figure 5.5 shows how the hand moves observed while a nail is pulled out with a claw hammer. You can see that it moves along an arc that has the nail as a center and the handle of the hammer as a radius. Comparison with the hitting operation, the motion is a two dimensional.

6. EXPERIMENTAL SYSTEM

6.1 Construction of model

In this paper, 2 models are prepared for each object including tools and objects to be operated according to the purpose in order to realize real time responsiveness, accuracy of representation and simplification

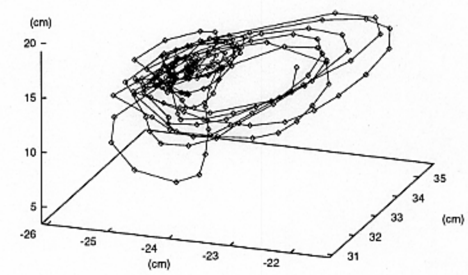

Figure 5.4: A locus of a hammer head used as hammer.

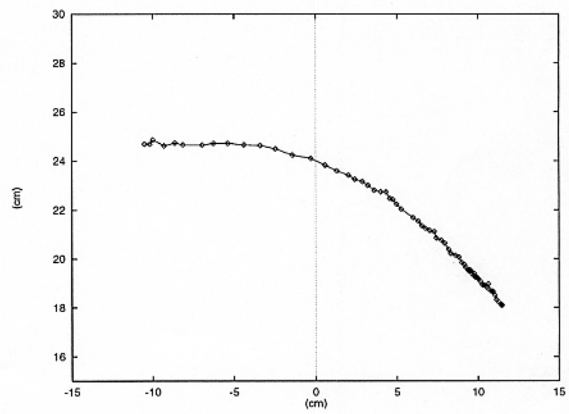

Figure 5.5: A locus of a hammer head used as puller.

of computational complexity in virtual environment. Figure 6.1 (1) shows geometric models used for representation in virtual environment, and by defining an accurate shape for each of them a realistic expression is obtained. Figure 6.1 (2) defines geometric information such as a bounding box, bounding sphere, line segment, directed line segment and plane. They are used to see if there is some interaction among objects by using interference or collision detection and relation between objects.

The semantic model shown in Figure 6.2 defines the following directed lines for each object. A directed line segment toward a finger-tip from a manual center and that toward the palm from the back of the hand are defined for both virtual hands. For a nail, a directed line segment is defined toward the point of the nail from its head. A line segment is defined along the longitudinal direction for a board.

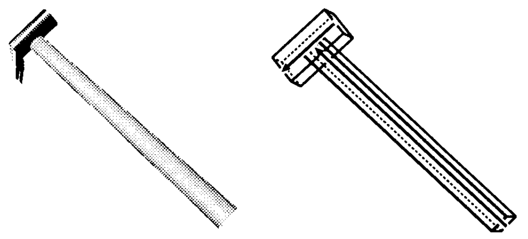

Figure 6.1: Two models prepared for a hammer.

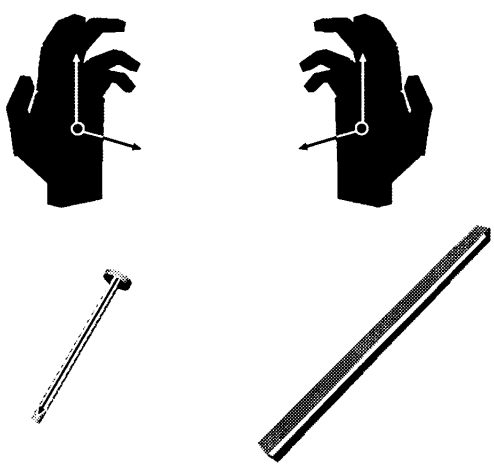

Figure 6.2: The semantic model for hands, a nail and a board.

6.2 Grasping an object with virtual hand

In the experimental system, a virtual hand is connected to a data glove and three dimensional position sensor, and operated by an operator in the real world. A tool or an object can be moved when it is grasped with either a right or left virtual hand. Condition under which a virtual hand can grasp an object is that the virtual hand is near the object and that it is going to accomplish grasping operation. In order to confirm the condition, when information acquired from a data glove shows bending of fingers, the interference check is done between the specific point a little apart from the center of a virtual manual palm and a model for interference check defined for the object. That is, relation between the apex of the virtual hand and the bounding box of the object model is examined as shown in Figure 6.3.

On the other hand, it is considered the object to have been got off when information acquired from the data glove didn't show bending of fingers.

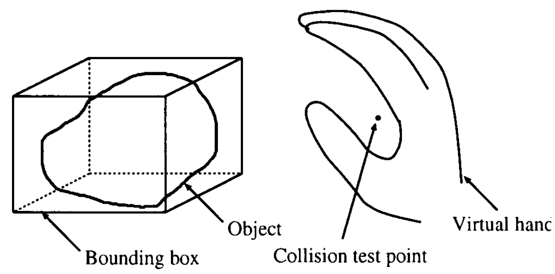

Figure 6.3: Collision detection method.

6.3 Condition for data reconstruction

6.3.1 Static condition

The semantics model shown in Figure 6.1 is defined for a hammer, and those shown in Figure 6.2 are defined for the virtual hand, nail and board. In the experimental system, it is judged to be going to strike a nail with a hammer when the following conditions hold. When a left hand grasps a nail and a right hand grasps a hammer, relation between the directed line segment of the left virtual hand and that of the nail becomes as shown in Figure 6.4 (1). And when the relational between the directed line segment of the right virtual hand and that of the hammer become the state shown in Figure 6.4 (2). When the head **A** of the hammer(Figure 6.4 (2)) with keeping the current status approaches the nail head **A'**(Figure 6.4 (1)). When the head of the hammer(**A** in Figure 6.4 (2)) approaches the nail head(**A'** in Figure 6.4 (1)) with keeping the status mentioned above, and the point of the nail(**B** in Figure 6.4 (1)) comes right above the directed line segment of the board(**B'** in Figure 6.4 (1)) the following dynamic condition in the next section is verified.

When the right virtual hand grasps a hammer, if the relation between the directed line segment of the virtual hand and that of the hammer has become the state shown in Figure 6.5 (2), it is judged to be going to extract the nail with the hammer. When the head of the hammer(**A** in Figure 6.5 (2)) approaches the nail head(**A'** in Figure 6.5 (1)) with keeping the status mentioned above, and the point of the nail(**B** in Figure 6.5 (1)) comes right below the directed line segment of the board(**B'** in Figure 6.5), the following dynamic condition in the next section is verified.

When it is used as nail puller, there is no constraint on the position, and action of the left virtual hand.

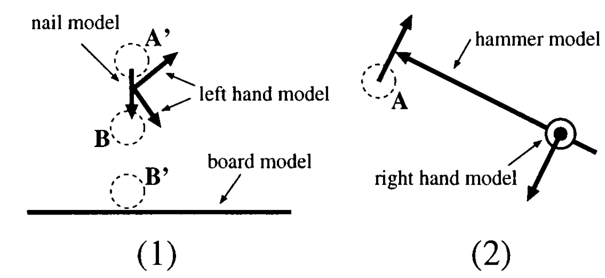

Figure 6.4: Relation amang hammer used as hitter, hands, a nail and a board.

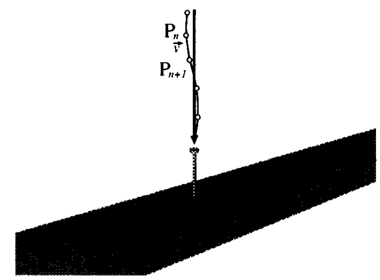

Figure 6.6: Dynamic condition for hitting a nail.

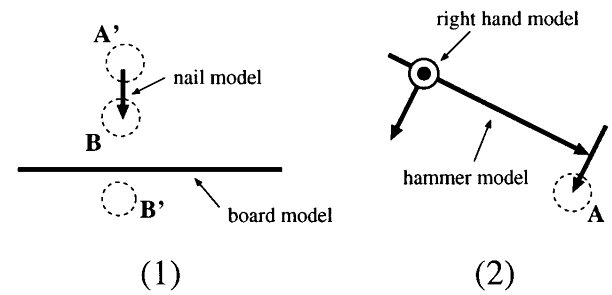

Figure 6.5: Relation among hammer used as extracter, a hand, a nail and a board.

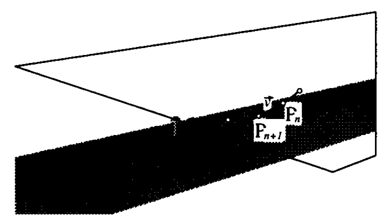

Figure 6.7: Dynamic condition for extracting a nail.

6.3.2 Dynamic condition

In case to reproduce data only with the static condition, it is impossible to examine what kind of path a hammer has passed to approach a nail.

On this account, the experimental system keeps values of three dimensional position sensor to watch the action of the virtual hand when it grasped an object.

Striking a nail case

When a hammer was swung down for a nail, that is, if the directed line segment set on the extended line of the nail and the vector calculated from each position information provided from three dimensional position sensor have the same direction, the virtual hand motion measured beforehand is reconstructed.(Figure 6.6).

Nail puller case

When a hammer came close to a nail head so as to catch on it, that is, if each position information of the hammer provided from three dimensional position sensor moves on the tangent plane of the nail head, the virtual hand motion measured beforehand is reconstructed(Figure 6.7).

6.4 Reconstruction of action

In the experimental system, an object can be moved with right or left virtual hand. Data recorded are, however, ones acquired from the sensor at a particular position where a nail is struck or extracted. Reconstruction of action at an arbitrary position in virtual environment is not attained by reproducing simply the stored data. On this account, a coordinate transformation of data recorded is necessary in reconstruction. Let the coordinate of the data and the homogeneous transformation matrix when they are collected be $\vec{x}$, and $\boldsymbol{T}_{origin}$ respectively. And let the homogeneous transformation matrix of the hammer and a coordinate to be calculated be $\boldsymbol{T}_{hammer}$ and $\vec{x}'$ respectively. Then, the following equation holds:

$$\vec{x}' = \vec{x} \times \boldsymbol{T}_{origin}^{-1} \times \boldsymbol{T}_{hammer} \qquad (6.1)$$

Coordinate transformation of measurement data is done using this expression (6.1).

7. CONCLUSION

For action such as striking or extracting a nail using a hammer in virtual environment, good eyesight effect has been attained and operational feeling has been improved. In the experimental system, both position and angle error rates occurring when a virtual hand grasps a tool are set within ±10%.

Validation on whether this value gives sense of incongruity to the action reproduced or not is necessary. For tools with the similar facility but with a little dis-

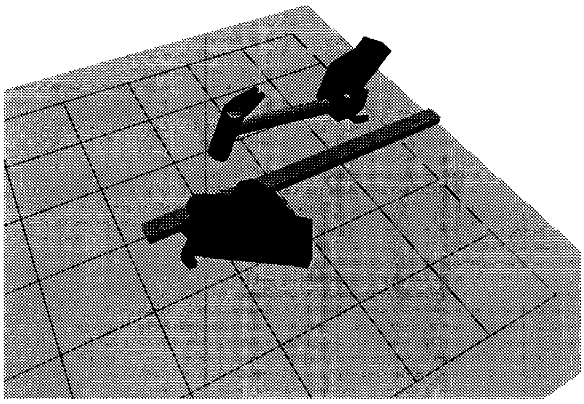

Figure 6.8: A situation a hammer is used as hammer.

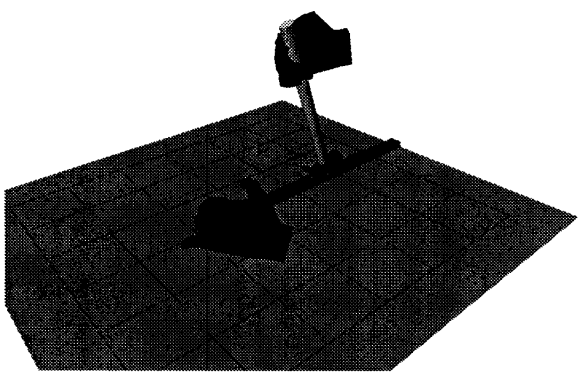

Figure 6.9: A situation a hammer is used as extracter.

tinction in dimension / shape, scale transformation will accomplish the saving in data preparation and sharing of data.

It is impossible to manipulate a hammer which must be supported with both arms in real environment by one arm in virtual environment. Consequently, extracting special features of objects and tools becomes very important. The special features of objects is equal to two kinds of model defined according to the purpose in the experimental system and the position relation to drive measurement data. At present, extracting these special features is performed by hand. As a number of objects is just three including a hammer, nail and board, the quantity of this work doesn't become problem in particular. There is the need that feature extraction process must be automated in order to adapt a lot of objects to this system. To offer this experimental system for practical use in future, various tools like drivers, cutting pliers, wrenches except for hammers will be introduced into the system and they need to function effectively.

It is considered that the directed line segment model is effective in case of a hammer and nail. But in case of the hammer with no nail puller, either side of the head can beat a nail. In this case, a simple segment model is more advantageous than a directed line segment one.

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