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# Recovery Technique from Classified Errors in Skill-Based Manipulation

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***Abstract:*** Dexterous manipulation is an important function for working robots. Manipulator tasks such as assembly and disassembly can generally be divided into several motion primitives. We call such motion primitives "skills" and explain how most manipulator tasks can be composed of sequences of these skills. We are currently planning to construct a maintenance robot for household electrical appliances. We considered hierarchizing the manipulation tasks since the maintenance of such appliances has become more complex than ever before. Additionally, we considered grouping errors into several classes according to their estimated causes. The reliability of the task achievement increases with the classification of errors. This paper contributes to the achievement of these concepts by showing our restoration technique for each class of error. The technique is described with the concrete examples.

***Key words:*** manipulation skill, maintenance task, error recovery

## 1. Introduction

For manipulation robots to be useful in several fields, it is necessary for robots to achieve various tasks using special techniques. By analyzing human motions in tasks such as assembly and disassembly, we found that movements consisted of several significant motion primitives. We have called these "skills" and have shown that most of the tasks of a manipulator can be composed of sequences of skills [1]–[4].

We have researched maintenance robots working in various factories and power plants. In future research, we will consider manipulation robots used for the maintenance of household electrical appliances and consumer electronics. At present, we are working toward producing a prototype of a maintenance robot for system components and personal computers (Fig. 1). Maintenance requires the use of many manipulation skills, and the composition of the tasks is complex. However, stratification of tasks makes development more manageable.

Manipulation tasks with skills are performed in theory by sequences of visual sensing, geometric modeling, planning and execution. In an ideal environment, the tasks are achieved without any errors occurring. In actual manipulation, however, errors often occur for various reasons. Various approaches for error recovery have been reported [5]–[8]. However, few methods for realistic error recovery have been proposed for the various errors that could actually occur during maintenance tasks. We have described our concept of error classification and process flow with error recovery in the task hierarchy. Errors are grouped into several classes according to their estimated causes. In this paper, we describe our restoration technique for each class of error. Error recovery can be performed effectively using the detailed restoration sequences.

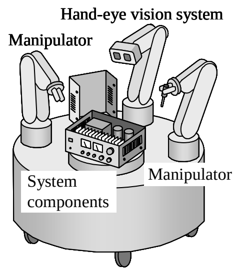


Fig. 1 Maintenance robot for audio-visual system components

The next section explains manipulation skills and the stratification of manipulation tasks. The classification of errors and error recovery in the task hierarchy are shown in section 3. The restoration sequences in each class of error are detailed in section 4.

## 2. Stratification of Tasks

This section explains our concept of skills and stratification of tasks. See References [1], [2] for more details.

### 2.1. Manipulation Skills

We analyzed human motions in such tasks as assembly and disassembly and found that the movements consisted of several significant motion primitives. We call motion primitives "skills" [1], [2]. We considered three fundamental skills: move-to-touch, rotate-to-level and rotate-to-insert, which play an important part in such tasks. A specific task is composed of sequences of skill primitives such as these three skills. Moreover, many skills such as rotate-to-bite and rotate-to-loosen skills in screwdriver tasks can be defined based on slightly changed versions of these three fundamental skills [3], [4].

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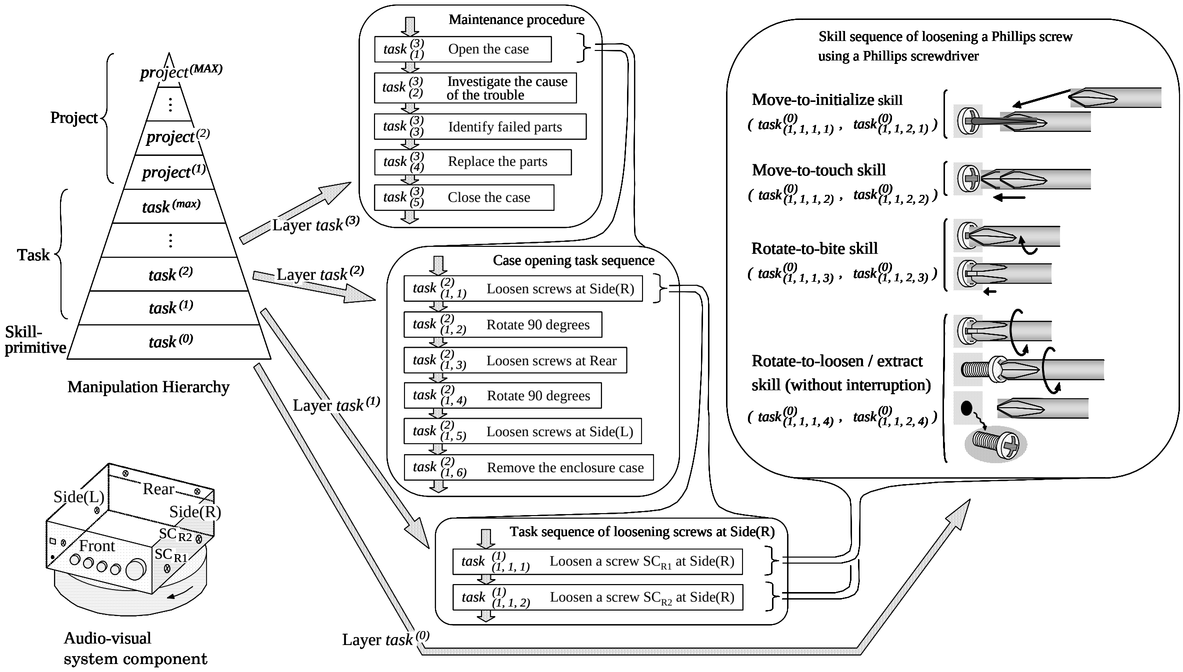



Fig. 2 Task of opening the case of an audio-visual system component

## 2.2. Stratification of Tasks

Figure 2 shows a hierarchy of manipulation tasks using the repair of system components in consumer audio-visual equipment as an example [4]. If we ignore the servo layer, the *skill* layer, which consists of elements such as move-to-touch and rotate-to-bite skills, is located in the lowest layer called the $task^{(0)}$ layer. Each skill is performed by the processes of visual sensing, geometric modeling, planning and execution. One tier above the $task^{(0)}$ layer is called the $task^{(1)}$ layer. Similarly, $task^{(i+1)}$ is composed of sequences of $task^{(i)}$ elements. The top layer, where the error recovery loop is closed, is called $task^{(max)}$ and one tier above $task^{(max)}$ is called the *project* layer. The *project* layer might also be hierarchized, but we will not discuss this here.

# 3. Error Recovery in Stratified Tasks

In an ideal environment, tasks are achieved without any errors occurring. In actual manipulation, however, errors often do occur from various causes. Our concept of error classification and process flow with error recovery in the task hierarchy are described in this section. See References [4] for more details.

## 3.1. Classification of Errors

The causes of failures can be attributable to several kinds of errors. We group the error states into several classes according to the possible causes as follows. The classes of errors are described in detail in Reference [4].

・Execution error.
・Planning error
・Modeling error
・Sensing error

Merely restoring the causes of these errors does not always solve the problem. It may be necessary to return to a previous step when the working environment is greatly changed by the error.

## 3.2. Error Recovery based on Classification

A generalized process flow of stratified tasks that takes error recovery into account has been shown in [4]. Figure 3 is an illustration of the central portion of Fig. 10 in [4]. At the confirmation step in each skill primitive $task^{(0)}_{(i0)}$ , an automatic process or a human operator judges whether the result is correct or a failure. Error recovery is performed using the following error classification. To simplify the explanation in this paper, we have not considered returning to the layer above the $task^{(2)}_{(i1)}$ layer.

Class 1: When the error is judged to be an execution error, $task^{(1)}_{(i1)}$ is executed again without a correction in the parameters.

Class 2: When the error is judged to be a planning error, $task^{(1)}_{(i1)}$ is executed again with a change in the planning parameters .

Class 3: When the error is judged to be a modeling error, $task^{(1)}_{(i1)}$ is executed again with a change in the modeling parameters.

Class 4 ( = Class $T^{(1)}$ ) : When the error is judged to be a sensing error, $task^{(1)}_{(i1)}$ is executed again with a change in the sensing parameters.

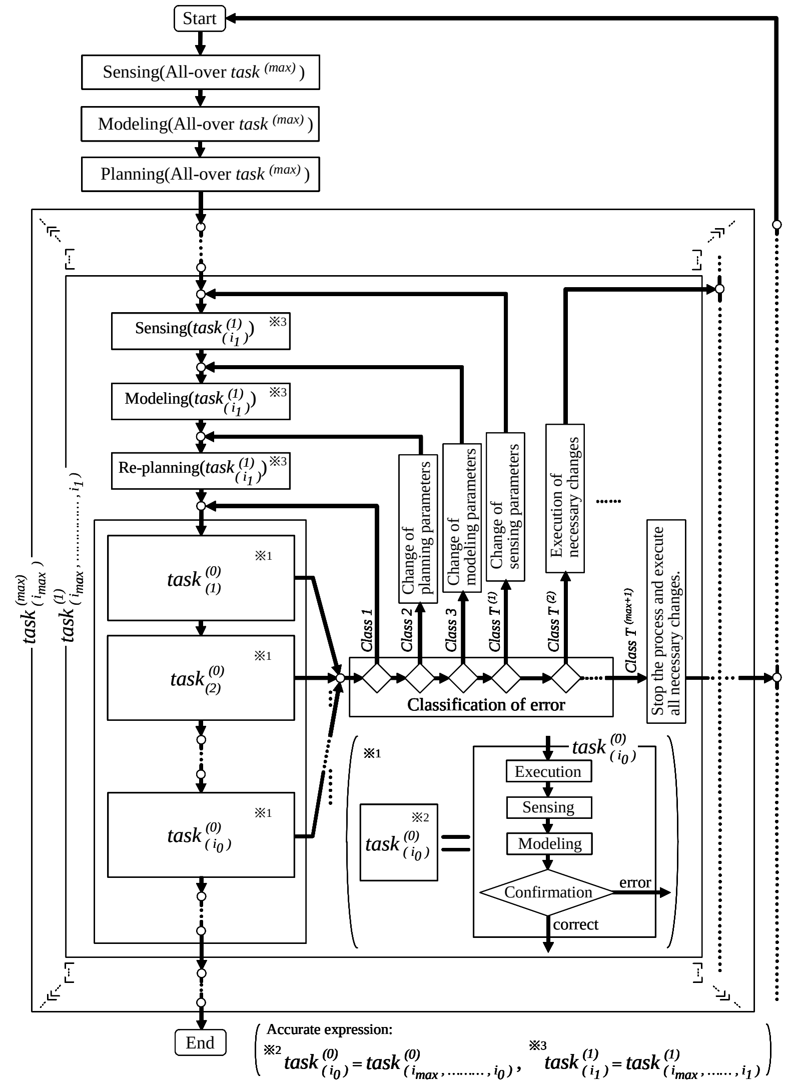



Fig. 3 Process flow with error recovery

## 4. Recovery from Classified Errors

We will explain the technique based on concrete examples using the maintenance robots.

(1) Class 1

This is a mechanical error caused in the manipulator mechanism such as a gear backlash. If the error happened by accident, the possibility of recovery succeeding is large if the robot retries repeatedly. It moves to Class 2 or more, if the task will not succeed no matter how many tries are repeated.

(2) Class 2

This is an error caused by inaccurate parameter values in planning. The process changes according to the kind of parameter with the wrong value. The following are typical: a) When passing planning parameters are inapposite, it is necessary to derive a correct initial position and orientation and a moving path by correcting the parameters. For example, Figure 4 shows the correction of the initial region of a screwdriver by revising the angle of the vertex of the control uncertainty cone. Additionally, this case includes correction of the path by various causes such as avoiding obstacles. b) When the threshold to judge the state is inappropriate, correction must be done. For example, the threshold of the contact force value is revised if the detection of the contact condition is not achieved properly. c) When the task of manipulation doesn't advance properly, the values of power or torque must be changed. For example, the rotating torque is increased, if the screwdriver inserted in the screw doesn't rotate.

It moves to Class 3 or more, if the task will not recover properly even if a correction is done.

(3) Class 3

This is an error caused by differences in the real object and the geometric model in the software. The following two kinds of errors are considered: a) When the real object and the geometric model in the software are different, the correction must be done. For example, Figure 5 shows that the size or the type of a screw has been correctly changed.

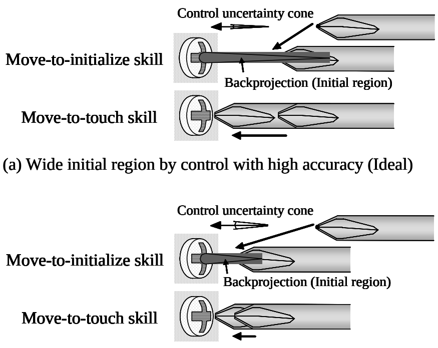
b) When the tool grasped by the manipulator and the geometric model in the software are different, the correction of the tool model must be done.

(4) Class 4

This is an error occurring during visual sensing. This error happens by causes such as inaccurate calibration of the vision system and incorrect relationships of the coordinate systems of the object and tool. Figure 6 shows the correction of the relationships of the coordinate systems of the object and tool.

(5) Additional Task

Additional tasks are necessary in some cases to perform the corrections of Class 2, 3 and 4 errors (Fig. 7). For example, additional geometry modeling of the working environment may be necessary in Class 2 a), and additional geometry modeling of the object and the tool may be necessary in Class 3 a) and 3 b), respectively. And additional geometry modeling of the working environment and calibration of the vision system may be necessary in Class 4. Furthermore, a task for changing the grasped tool might be needed in Class 3 b).




(a) Wide initial region by control with high accuracy (Ideal)

(b) Narrow initial region by control with low accuracy (Reality)

Fig. 4 Influence of control accuracy on planning

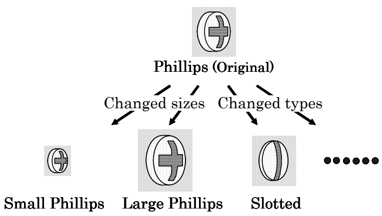



Fig. 5 Changed Models

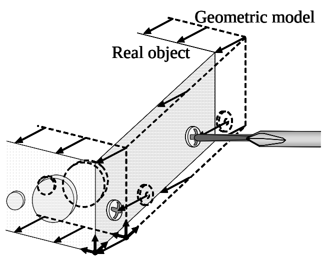



Fig. 6 Correction of position and orientation of geometric models of objects

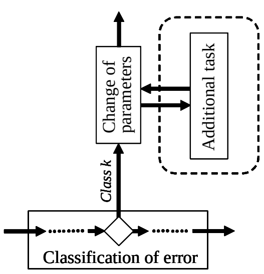



Fig. 7 Additional task

# 5. Conclusions

In recent years, dependability has been a topic in robotics research. It is necessary to increase the reliability of the maintenance robots that work on household appliances. Therefore, as error recovery technique is important, we considered a method of error recovery that uses the concepts of both task stratification and error classification. In this paper, we have described our restoration technique in detail for each class of error. The capability to recover from errors has been improved.

In the future, we will further research optimum adjustment methods for the various parameters used in error recovery and a fully automatic method to confirm achievement of tasks composed of skills. We will attempt to apply our technique to actual maintenance robots.

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