Recovery Technique from Classified Errors in Adjustment Tasks of Domestic Appliances

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Abstract: Dexterous manipulation is an important function for working maintenance robots. Manipulator tasks such as disassembly and reassembly can generally be divided into several motion primitives. The authors call such motion primitives "skills" and explain how most manipulator tasks can be composed of sequences of these skills. In their planning to construct a maintenance robot for domestic appliances, the authors considered hierarchizing the manipulation tasks since the maintenance of such appliances has become increasingly complex. Additionally, they considered grouping errors into several classes according to their possible causes. The reliability of the task achievement was found to increase with the classification of errors. There are various kinds of tasks for maintenance robots besides disassembly and reassembly, and adjustment tasks, which are often executed in the final stage of maintenance, are also important. This paper presents a proposal for error recovery during adjustment tasks performed by a robot in the maintenance of domestic appliances.

Keywords: manipulation skill, maintenance task, error recovery**.**

1. Introduction

Manipulation robots need to achieve various tasks using special techniques to be useful in wide-ranging fields. By analyzing the motions of human hands in tasks such as disassembly and reassembly, we found that the movements consisted of several significant motion primitives. We call these motion primitives "skills" and have shown that most of the tasks of a manipulator can be composed of sequences of such skills [1]–[3].

We have already researched maintenance robots working in various factories and power plants. In our future research, we will consider manipulation robots working closer to people and used for the maintenance of household appliances and consumer electronics. At present, we are working toward producing a prototype of a maintenance robot for home audio-visual system components and personal computers (Fig. 1). The principle tasks of such maintenance robots will be not only disassembly and reassembly as considered in [3]–[5] but also adjustment tasks. Such adjustment tasks might involve rotating thumbscrews to tune various settings such as frequency, amplitude and brightness. Maintenance requires the use of many manipulation skills, and the nature and range of the tasks may be complex. However, stratification of the tasks makes development more manageable.

Manipulation tasks using 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. During actual manipulation, however, errors often occur for various reasons. Various approaches for error recovery have been reported [6]–[9]. However, few methods for realistic error recovery have been proposed for the various errors that could actually occur during maintenance tasks. We have previously described our concept of error classification and process flow using error recovery in the task hierarchy [4], [5]. Errors are grouped into several classes according to their possible causes. In this present paper, we describe a method of error recovery during adjustment tasks such as rotating knobs when maintaining domestic appliances. The reliability of the task achievement increased with the stratification of tasks and classification of errors.

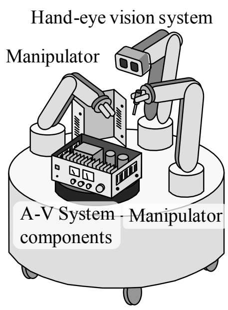

Fig. 1 Maintenance robot for audio-visual system components

The next section explains manipulation skills and skills used in adjustment tasks. The stratification of manipulation tasks is shown in section 3. Our classification of errors and error recovery in the task hierarchy intended for adjustment tasks are shown in section 4.

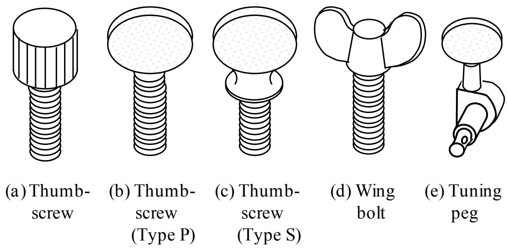

Fig. 2 Thumbscrews and similar fasteners

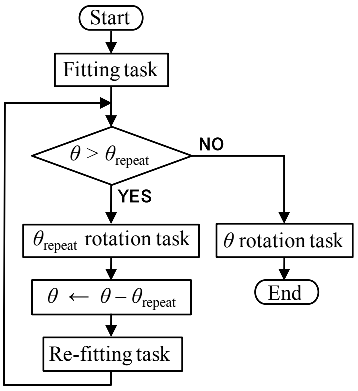

Fig. 3 Process flow of adjustment task using a thumbscrew

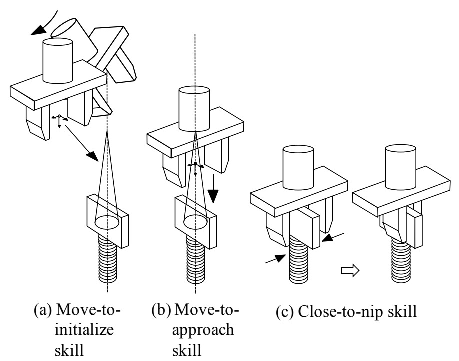

Fig. 4 Task of fitting a gripper on a thumbscrew

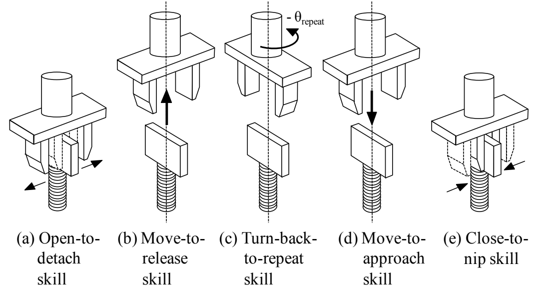

Fig. 5 Task of re-fitting a gripper on a thumbscrew

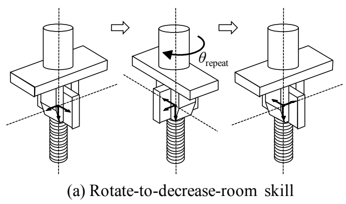

Fig. 6 Task of θ_{repeat} rotation

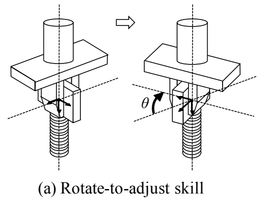

Fig. 7 Task of θ rotation

2. Manipulation Skills

This section explains our concept of skills and examples of the skills used in adjustment tasks. See References [1], [2] for more details.

2.1. Concept of Skills

We analyzed human motions in such tasks as disassembly and reassembly and found that the movements consisted of several significant motion primitives. We call such motion primitives "skills" [1], [2]. We considered three fundamental skills: move-to-touch, rotate-to-level and rotate-to-insert, all of 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 related skills such as the rotate-to-bite and rotate-to-loosen skills in tasks using screwdrivers can be defined based on slightly modified versions of these three fundamental skills. These skills are frequently used for component replacement during the repair of household appliances [3]-[5].

2.2. Skills in Adjustment Tasks

In the maintenance of household electrical appliances and home audio-visual equipment, a parts adjustment step is often needed in addition to the main tasks of disassembly and reassembly such as component replacement [3]–[5].

The knobs of adjustment screws used in maintenance tasks come in various head shapes. Figures 2(a), 2(b) and 2(c) show various types of thumbscrews including cylindrical type, "P" (plain) type, and "S" (shoulder) type. There are also wing bolts (Fig. 2(d)) and tuning pegs on string instruments (Fig. 2(e)). For simplicity, in this paper we focus on screws with flat head projections (Fig. 2(b), 2(c), 2(d), 2(e)) that can be nipped by parallel grippers.

Figure 3 shows the process flow for an adjustment task using a thumbscrew. First, a fitting task using a parallel gripper on a plain knob is performed (Fig. 4). Rotation tasks of the same angle θ_{repeat} such as π, 2π (rad) are iterated (Fig. 6), while the re-fitting tasks of the gripper are performed between successive rotation tasks (Fig. 5). Finally an adjustment task comprising rotation at a small angle θ ($\leq \theta_{repeat}$) is performed (Fig. 7). However, the value of angle θ is hardly a suitable reference value. In most cases, the values of angles θ are adjusted so that settings such as frequency, amplitude and brightness become the most suitable values. Therefore, excess rotations may often occur, and will require rotation in the opposite direction to be performed. In this paper, this process will be treated as a pattern using error recovery as shown in section 4.

3. Stratification of Tasks

Figure 8 shows a hierarchy of manipulation tasks during maintenance [4]. If we ignore the servo layer, the skill layer, which consists of elements such as the move-to-approach and close-to-nip 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 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 it in this paper.

4. 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 with respect to component replacement tasks. In this present paper, errors occurring in adjustment tasks during maintenance of domestic appliances and electronic equipment are explained and error recovery techniques in the adjustment tasks are shown.

4.1. Classification of Errors

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

・Execution error: a mechanical error caused in the manipulator mechanism such as a gear backlash.

・Planning error: an error caused by inaccurate parameter values in planning. For example, a rotation task fails because of an incorrect torque setting.

・Modeling error: an error caused by differences in the real object and the geometric model in the software. For example, failure occurs because of the incorrect head shape of the thumbscrew.

・Sensing error: an error occurring during visual sensing. For example, the environment model around the thumbscrew cannot be derived correctly due to a sensing error in calibration and luminous intensity.

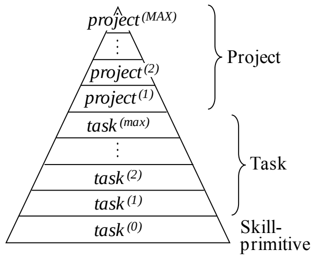

Fig. 8 Manipulation Hierarchy

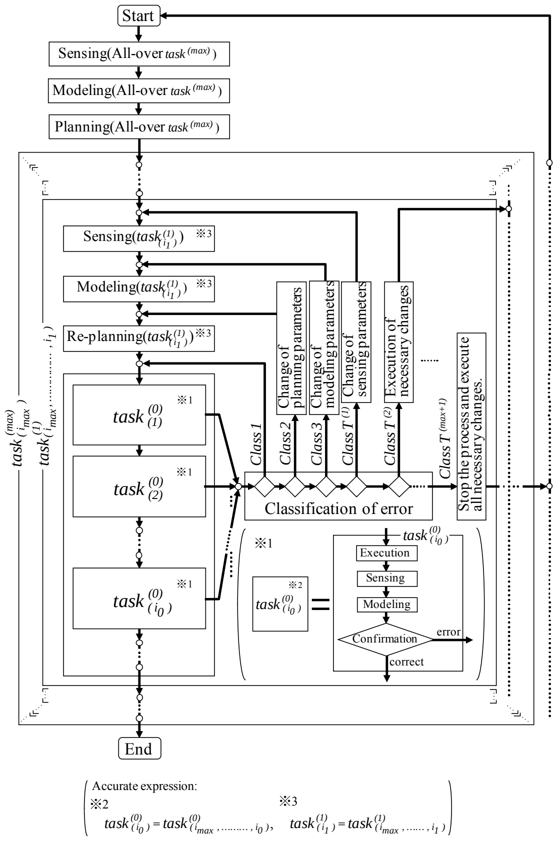

Fig. 9 Process flow with error recovery

Merely remedying 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.

4.2. Error Recovery based on Classification in Adjustment Tasks

A generalized process flow of stratified tasks that takes error recovery into account has been shown in [4]. Figure 9 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.

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.

Class $T^{(2)}$: $task^{(2)}_{(i2)}$ is executed again after the execution of the necessary changes and returns to the start of one tier above the layer $task^{(1)}_{(i1)}$.

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Class $T^{(max)}$: $task^{(max)}_{(imax)}$ is executed again after the execution of the necessary changes and returns to the start of (max - 1) tier above the layer $task^{(1)}_{(i1)}$.

Class $T^{(max+1)}$: When it is judged that too many changes will be required, the process being executed is interrupted and the process returns to the start of the overall task.

Parameters judged in any given Class are revised and error recovery is performed according to a flowchart. In most adjustment tasks, the target angle θ is decided so that another setting value such as frequency or brightness becomes the most suitable value as shown in section 2.2. Therefore, it is often necessary to rotate the thumbscrew in the opposite direction because of excess rotation. In such cases, the required change in skill sequence is performed through Class $T^{(2)}$. This means re-planning in one tier above the lowest task layer. In general, the adjustment task converges while the required rotation and the opposite rotation are being repeated. On the other hand, it may be necessary to return to a smaller angle due to excess rotation, for instance when adjustment is possible only in processes in which the frequency varies from low to high as in the adjustment of a musical instrument.

5. Conclusions

In recent years, dependability has been a frequent topic in robotics research. It is necessary to increase the reliability of the maintenance tasks performed by robots working on household appliances. Since error recovery is important, we considered a method that uses the concepts of both task stratification and error classification. In this paper, we have described our error recovery technique for adjustment tasks performed by maintenance robots. The capability to recover from errors during such tasks is improved by stratification of tasks and classification of errors.

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

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