Skill-Based Manipulation and Error Recovery in Maintenance Tasks

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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 these "skills" and explain how most manipulator tasks can be composed of skill sequences. We are currently planning to construct a maintenance robot for household electrical appliances. Skill techniques are effective when a robot needs to achieve high-accuracy results. However, since failure also occurs easily, it is important to implement error recovery technology. Various errors are classified and a new type of error recovery processing is presented in this paper.

Key words: manipulation skill, planning, modeling, visual sensing, error recovery

1. Introduction

To be useful in several fields, manipulation robots need to achieve various tasks using special techniques. We analyzed human motions in such tasks as assembly and disassembly and found that movements consisted of several significant motion primitives. We call these "skills" and have demonstrated that most tasks of a manipulator can be composed of sequences of skills [1]–[6]. We demonstrated that robots can perform various human tasks by using this concept of skills. Skill level control is positioned in the hierarchy of manipulator control between task level control and servo level control. Programmers can describe a task program easily as a sequence of these skills without taking into account servo level control. Skills in which the contact states vary during assembly and disassembly tasks are particularly significant. We considered three important fundamental skills for these tasks: "move-to-touch," "rotate-to-level" and "rotate-to-insert."

We have researched maintenance robots working in various plants, such as a nuclear power plant, and considered the skill technique used by such robots. As a target for future research, we will consider manipulation robots used for the maintenance of such items as household electrical appliances, furniture and stationery. At present, we are working to produce a prototype of a maintenance robot for system components and personal computers (Fig. 1). Recent recycling and environmental problems will increase the need for robots that perform repair and inspection. The robots open and close the equipment enclosures and replace parts (Fig. 2). It is thus necessary for these robots to be able to perform tasks requiring high accuracy, such as loosening a screw using a screwdriver.

Manipulation tasks with skills are performed by the sequences of visual sensing, geometric modeling, planning and execution. In actual manipulation, however, errors often occur for various reasons and the processes are interrupted. Failure causes can be divided into several kinds of errors such as execution errors, planning errors, modeling errors and sensing errors. Various approaches for error recovery have been studied [7]–[10]. However, few realistic methods for error recovery have been proposed for various errors that might occur when performing maintenance tasks. We have grouped the errors into several classes according to potential causes. If an error occurs, the parameters of planning, modeling or sensing are corrected by specifying the class and then the task process is performed again. We propose a method of error recovery that uses the concept of error classification. This method allows the flow of system processes,

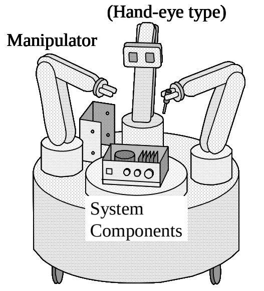


Fig. 1 Maintenance robot for system components

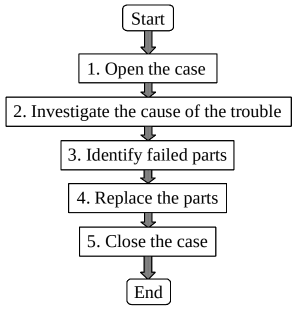
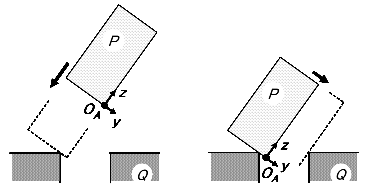
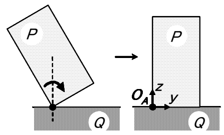


Fig. 2 Maintenance procedure



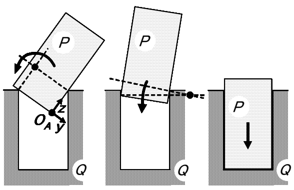
(a) Move-to-touch$_f$ skill (b) Move-to-touch$_c$ skill

Fig. 3 Move-to-touch skills



(i) (ii)

Fig. 4 Rotate-to-level skill



(i) (ii) (iii)

Fig. 5 Rotate-to-insert skill

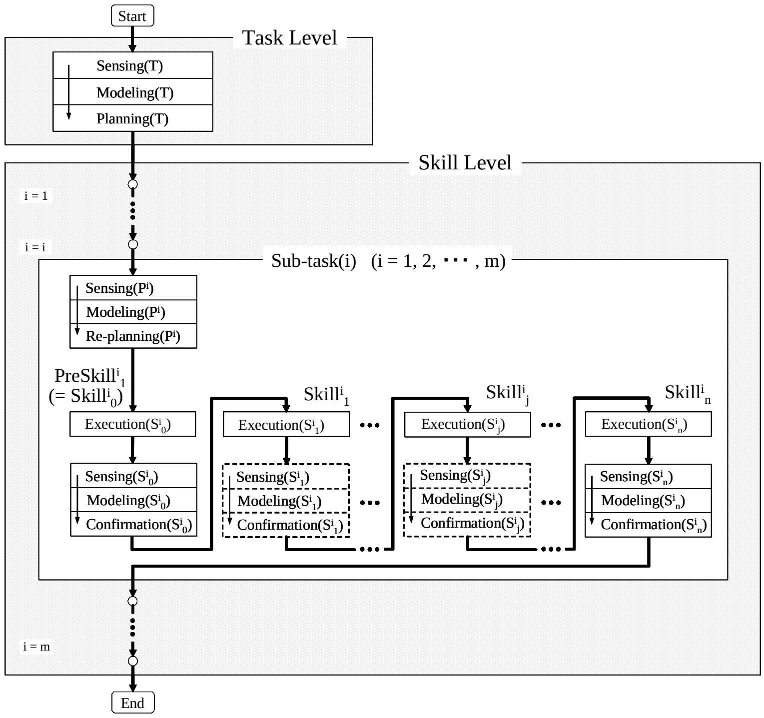


Fig. 6 Process flow

including error recovery, to be derived easily and systematically. In this paper, we explain the concept of manipulation skills and skill-based processes for maintenance, and we propose systematic classification of errors and recovery from such errors.

The next section explains manipulation skills and the composition of skill sequences. The processes of visual sensing, geometric modeling, planning and execution are then explained for task and skill levels in section 3. A maintenance robot must first of all open the case of a household appliance by loosening screws. Additional skills used in the loosening task are explained in section 4. The classification of errors and error recovery to improve the success of task achievement are shown in sections 5 and 6, respectively.

2. Manipulation Skills

This section explains our concept of skills. See References [1]–[3] for more details.

In assembly and disassembly tasks, the skills in which contact states vary are particularly significant. In References [4], [6], we considered three skills, "move-to-touch," "rotate-to-level" and "rotate-to-insert," all of which play an important part in such tasks.

(1) Move-to-touch Skill: The move-to-touch skill is defined as the transition of a grasped object *P* in a constant direction that continues until contact with another object *Q* occurs (Fig. 3).

(2) Rotate-to-level Skill: This skill is defined as the rotation around either a contact point or a contact edge to align the face of the grasped object *P* with the face of another object *Q* (Fig. 4).

(3) Rotate-to-insert Skill: This skill is the motion of rotating the object *P* obliquely into the hole in another object *Q* to insert it accurately (Fig. 5).

A specific task is composed of sequences of skill primitives such as these move-to-touch, rotate-to-level and rotate-to-insert skills. The skill sequences can be decided by several methods. We have already presented a method using variations of the number of contact points in skill primitives [4].

3. Process of Sensing, Modeling, Planning and Execution

The procedures for sensing, modeling, planning and execution are shown in Fig. 6. In this scheme, the planning of the task level is first performed, and then the executions of the skill level are performed according to the sequences derived from the task planning. See References [5] for more details. In the following descriptions, we assume that an error does not occur in each component.

(Step 1) Task Level

At the task level, the skill sequence composing a given task is decided. First, visual sensing of the working environment of the robot is performed using a vision system and modeling is done. Next, planning follows, and skill command sequences and the initial position and orientation of an object to be grasped and manipulated are derived.

(Step 2) Skill Level

At the skill level, each *Sub-task(i)* $(i=1,\cdots,m)$ is performed successively and each skill $Skill^i_j$ $(j=1,\cdots,n)$ in *Sub-task(i)* $(i=1,\cdots,m)$ is executed successively. Before this sequence in each *Sub-task(i)* $(i=1,\cdots,m)$ is performed, the transition of the grasped object *P* to the initial state is completed. We represent the transition as $PreSkill^i_1$ (= $Skill^i_0$) $(i=1,\cdots,m)$.

4. Task of Loosening a Screw

We considered three fundamental skills in section 2. However, we will also consider several skills used in the task of loosing a screw. Let us consider loosening a Phillips screw using a Phillips screwdriver.

(4) Rotate-to-bite Skill: This skill is a rotation around the axis of the screwdriver to fit the tip of the screwdriver into the flutes of the screw head (Fig. 7). This skill is performed with pushing force.

(5) Rotate-to-loosen Skill: This skill is defined as an initial rotation to loosen the fixed screw (Fig. 8). This is performed by matching the axes of rotation of a part and a tool.

(6) Rotate-to-extract Skill: This skill is defined as the rotation of the screw to pull the screw out. The skill continues after the rotate-to-loosen skill.

We will consider the task of loosening a screw using a screwdriver [5]. We assume that the task of loosening a screw using a screwdriver is composed of the following skills (Fig. 9); $Skill_1$: Move-to-touch skill, $Skill_2$: Rotate-to-bite skill, $Skill_3$: Rotate-to-(loosen／extract) skill (without interruption).

5. Classification of Errors

In the processing flow described in section 3, the possibility of errors was ignored since it was assumed that all the components were operating under ideal conditions. However, errors could actually occur for various reasons. Whether an error has occurred or not is judged at $Confirmation(S^i_j)$ in each skill of the procedure flow. In the task of opening the outside case of an electrical appliance for maintenance, errors are classified as follows.

(1) Execution error

This is an error caused in the manipulator mechanism such as a backlash of a manipulator gear. There are many possible failures for a manipulator with bad accuracy, and this includes failures occurring stochastically.

(2) Planning error

This is an error caused by inaccurate parameter values in planning. For instance, when a control uncertainty cone is used for the fine motion planning of the manipulator, an error occurs due to an incorrect angle at the top of the cone.

(3) Modeling error

This is an error caused by a difference in the real object and geometric model in the computer software being used, such as CAD modeling software. This might be caused by, for example, a difference in the size, a polygonal approximation and an expression of rounding and chamfering of an edge.

(4) Sensing error

This is an error occurring during visual sensing. For example, possible causes might be occlusion, imperfect calibration or undesirable lighting conditions.

6. Error Recovery

A process flow that takes error recovery into account is shown in Fig. 10. At the step of $Confirmation(S^i_j)$ in each skill primitive, whether the result is correct or a failure is judged by an automatic process or by an operator. Error recovery is performed using the following error classification.

(1) Class 1: The sub-task(i) is executed again without correcting the parameter when it is judged to be an execution error.

(2) Class 2: The sub-task(i) is executed again with change of planning parameter when it is judged to be a planning error.

(3) Class 3: The sub-task(i) is executed again with change of modeling parameter when it is judged to be a modeling error.

(4) Class 4: The sub-task(i) is executed again with change of sensing parameter when it is judged to be a sensing error.

(5) Class 5: The process being executed is interrupted when it is judged to be required by several changes, and the process returns to the start of the task.

7. Conclusions

It is necessary to increase the reliability of maintenance robots that work on household appliances since most of the tasks have to be performed in high-precision environments. Therefore, error recovery is important. We have demonstrated a new processing flow for recovery from errors of various causes in skill-based manipulation tasks. We have expressed the procedure for error recovery systematically by taking into account the classification of errors.

In the future, we will further study optimum adjustment methods for error recovery parameters and a fully automatic confirmation method of skill achievement. We will attempt to apply our method to real maintenance robots.

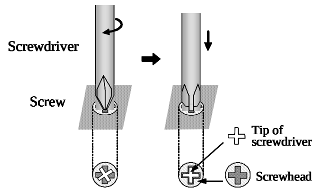


Fig. 7 Rotate-to-bite skill

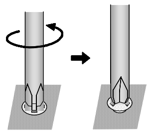


Fig. 8 Rotate-to-loosen skill

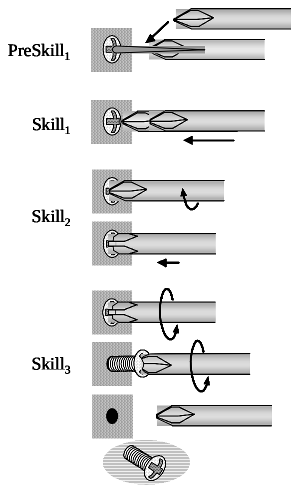


Fig. 9 Skill sequence of loosening with a Phillips screwdriver

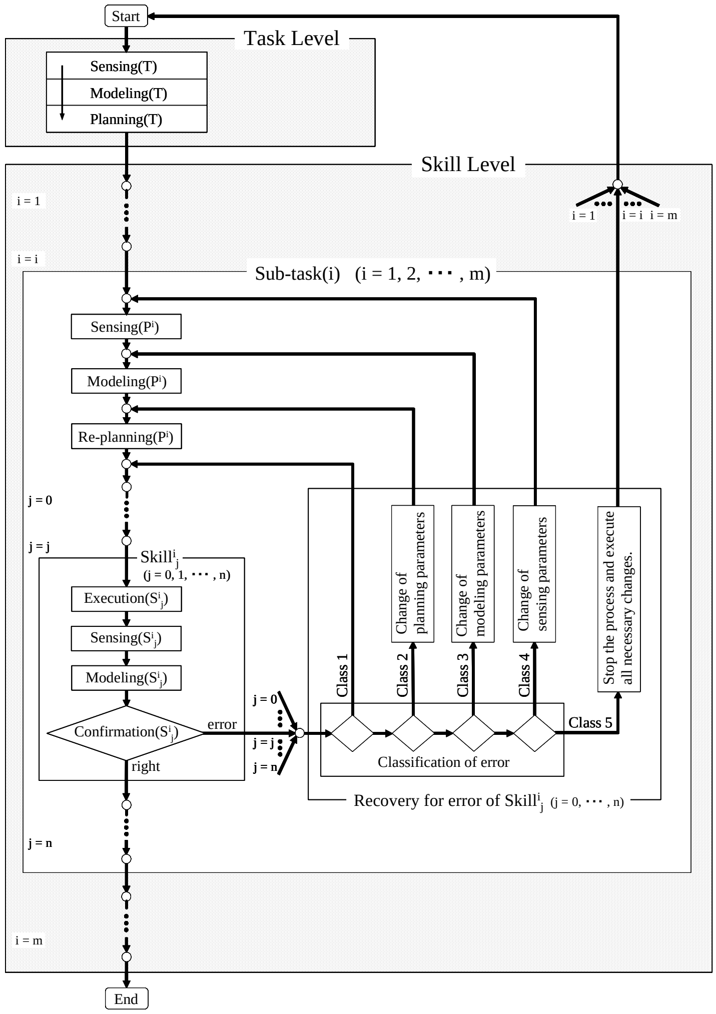


Fig. 10 Process flow with error recovery

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