Suitable Error Recovery Process using Combined Evaluation Standards in Robotic Manufacturing Plant

Akira Nakamura
Department of Information Systems
Faculty of Engineering
Saitama Institute of Technology
1690 Fusaiji, Fukaya, Saitama 369-0293, Japan

and Kensuke Harada
Robotic Manipulation Research Group
Systems Innovation Department
Graduate School of Engineering Science, Osaka University
1-3 Machikaneyama, Toyonaka 560-8531, Japan

E-mail: akira-nakamura@sit.ac.jp, harada@sys.es.osaka-u.ac.jp
https://www.sit.ac.jp

Abstract

The number of manufacturing plants where industrial robots work is increasing. Therefore, errors during work are likely to occur. For big errors, it is often necessary to go back to the previous step and resume work. There are two issues: which step to return to and what kind of work to do from the point of return. In this paper, we will show that it is good to use a combination of multiple evaluation standards to decide the planning.

Keywords: error recovery, task stratification, error classification, robotic manufacturing plant

1. Introduction

Robotic automation plants have been increasing more and more in recent years. However, on the other hand, errors are more likely to occur. It is also important to optimize the recovery process after an error occurs.[1-5] For this reason, we have continued to study error recovery.

For several years, we have been studying the systematization of the error recovery theory. We proposed a new error recovery method based on the concepts of both task stratification and error classifications.[6-9] The main part of this method consists of fundamental elements with sequences of sensing, modeling, planning, and execution (Fig. 1). If an error occurs here, the process goes to the recovery part. In this part, the error cause is estimated, error is classified, system is corrected, and process is re-executed using the corrected system with an improved reliability.

Currently, deciding both the past step that the process should return to and the recovery planning after returning has become problematic. For this, we proposed a planning of the error recovery by deriving these two factors in consideration of cost.8 In this study, we proposed a planning method for error recovery derived using various evaluation standards.

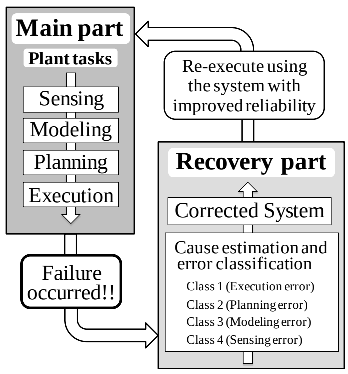

Fig. 1 Robot task system with an error recovery function

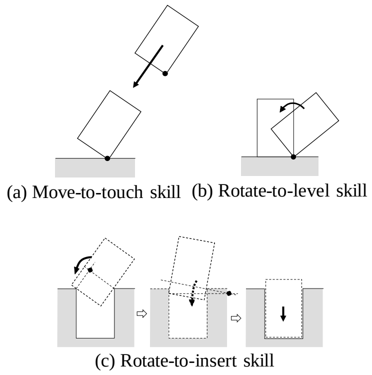

Fig. 2 Three fundamental skills

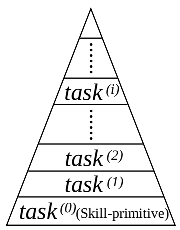

Fig. 3 Hierarchy of tasks

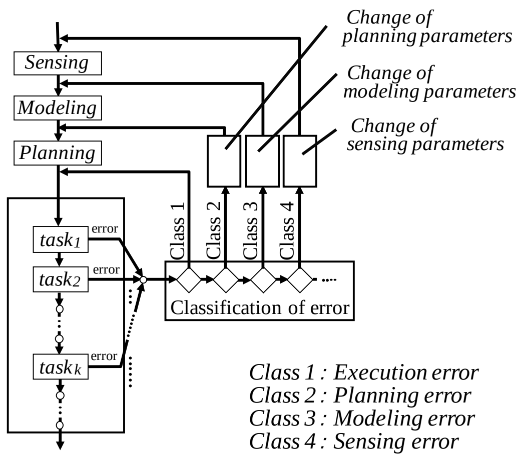

Fig. 4 Fundamental process flow with error recovery

The concept of skills, which are motion primitives, is described in Section 2. The error recovery technique is showen in Section 3. A method of recovery planning using plural evaluation standards is proposed in Section 4, and finally, a effective sample is presented in Section 5.

2. Concept of Skill

In this paper, the unit of motion is called a skill. This section explains skills which are components of human behavior and robotic motion.[10-12]

2.1. *Skill primitives*

A task such as an assembly consists of several motion primitives. Here, by analyzing human movements, we consider three skill primitives: "move-to-touch", "rotate-to-level" and "rotate-to-insert" shown in Fig 2. For tasks such as assembly, it is considered to be composed of the above-mentioned three important skill primitives and the resemble skill primitives.

2.2. *Stratification of tasks*

Figure 3 shows the hierarchy of robotic manipulation tasks. If we can ignore the servo layer, the first skill layer consists of behavioral units such as the important skill primitives mentioned above. Since tasks are composed by stratification, tasks have several layer in hierarchy in general.

3. Error Recovery

In the actual environment, unlike the ideal environment, various factors can cause errors in robotic machine performance. In this section, a concept of an error classification and our error recovery technique are described.

3.1. *Error classification*

Manipulation failures can be attributed to several types of errors. We have classified error conditions into four classes according to their possible causes: Execution, Planning, Modeling, and Sensing. Correcting the system based on the cause of these errors does not always solve the problem. For example, if the work environment changes significantly due to an error, it is necessary to return to the previous step.[6-9]

3.2. *Error recovery based on classification*

When an error occurs in an automated plant, the cause is first estimated and the equipment system makes appropriate corrections according to the estimated cause. The execution process then returns to the previous step and the task is restarted from the step (Fig. 4). As the equipment behavior is corrected, the probability of the same error occurring is reduced.

If a small error occurs, the process returns to the previous step at the lowest level (Fig. 4, Fig. 5). If a large error occurs, the process returns to the previous step in the upper hierarchy. In both cases, the process restarts from the previous step (Fig. 5).

3.3. *Candidate processes for recovery*

Consider candidates for possible error recovery processes. In the previous subsection, we showed that the steps that a process returns after an error occurs depend on its size. However, it is possible to back larger than the minimum required regression step.

Figure 6 shows a sequence of error recovery. It can be seen that the task consists of many subtasks from the start S to the goal G. In Fig. 6, errors occur along the way and how recovery is performed is shown. For more details, please refer to the Proceedings of ICAROB 2021.

4. Evaluation Standards for Selection of a Recovery Process

The previous sections have shown that many recovery processes may be generated. Therefore, it is important to limit the route by determining both the previous steps to be returned and the recovery process after returning.

At ICAROB 2020, we considered practical costs as evaluation standards and proposed an appropriate return planning method.
In this paper, we will propose a method to derive the optimal return process using various evaluation standards.

4.1. *Evaluation standards*

At ICAROB 2021, we have considered the following eight evaluation standards to select a recovery process. Here is a brief explanation. Please see ICAROB 2021 for details.

(i) Cost
Material costs, part costs, electricity bills, and planning expenses

(ii) Time
Time required for the work

(iii) Reliability
Operations for Reliability

(iv) Safety
Operations for Safety

(v) Finishing
The beauty of outward appearance

(vi) Recovery data
A sufficient amount of data

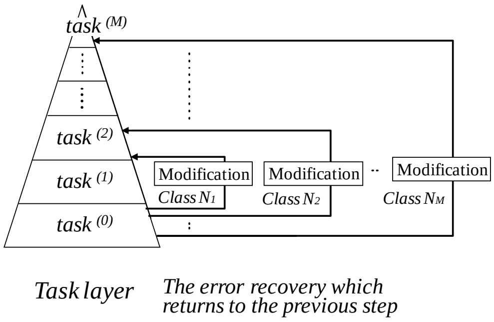

Fig. 5 The expression of task stratification and the process flow of the error recovery

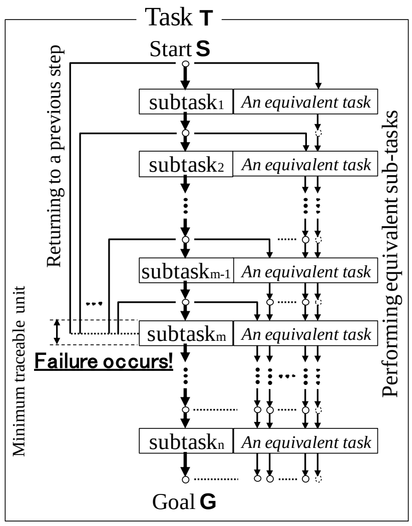

Fig. 6 Various processes of error recovery considered for a failure occurred in *subtask*$_m$

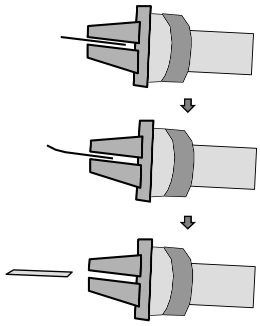

Fig. 7 The sticker sticking task

(vii) Tool
Unique tools for special tasks

(viii) Operator skill
Skills of expert craftsmen

4.2. *Simultaneous use of evaluation standards*

In ICAROB 2020, only cost was considered as an evaluation standard; in ICAROB 2021, the number of evaluation standards was increased to eight. However, it was supposed to be used independently for process evaluation. In this paper, several evaluation standards are used at the same time to show their advantages.

5. Precedence of Recovery Processes Based on Combined Evaluation Standards of Recovery

5.1. *Specific tasks to consider recovery*

Figure 7 shows the sticker sticking by the manipulation robot. Here, check whether the product tag sticker is attached in the correct position, and reattach it if necessary.

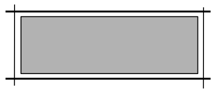

Fig. 8 Pasted exactly in place

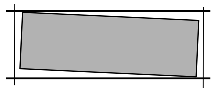

Fig. 9 Pasted slightly out of position

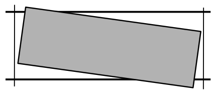

Fig. 10 Pasted far out of position

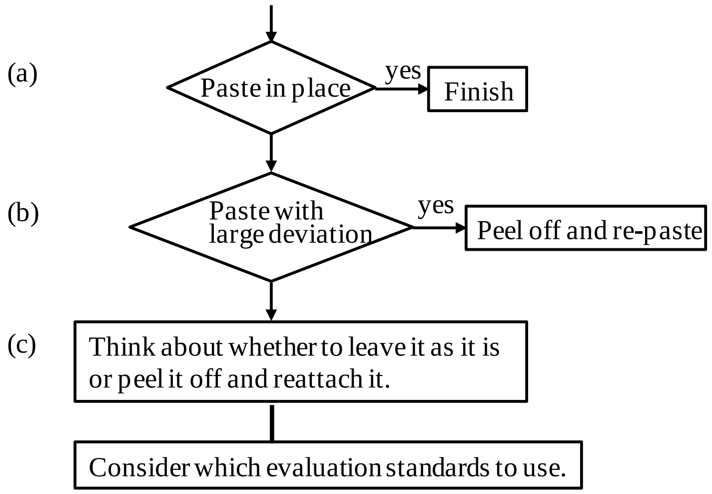

Fig. 11 The error recovery path for pasting position of the tag sticker

Figure 8 shows the case where it can be pasted in place. Figure 9 does not deviate significantly from the fixed position, but it is a case where it is necessary to confirm the actual situation and consider whether to leave it as it is or to reattach it. Figure 10 is pasted with a large deviation from the fixed position, and it is necessary to re-paste it.

Figure 11 summarizes the entire error recovery related to the task of sticking the product tag sticker in place in one figure.

5.2. *Task selection using evaluation standards*

Figure 11 shows the error recovery path for attaching the product tag sticker. In fact, in most cases, the fixed position pasting is successful (Fig.11(a)). If it is significantly misaligned, peel it off and reattach it (Fig.11(b)). The case between them is difficult (Fig.11(c)). There are two choices: leave it as it is or peel it off and reattach it. Here, we use three evaluation standards: cost Jc, time Jt, and finishing Jf.

Use a scraper to peel off the seal. A scraper is a very good tool when used lightly. Let's assume that the virtual unit of the evaluation standard is J_0. Based on this, (Case 1) and (Case 2) are compared. (Case 1) $J_c = 0$, $J_t = 0$, $J_f = 0$, Total $J = 0 + 0 + 0 = 0$, (Case 2) $J_c = K_cJ_0$, $J_t = K_tJ_0$, $J_f = K_fJ_0$, Total $J = K_cJ_0 + K_tJ_0 + K_fJ_0$. From the comparison between (Case 1) and (Case 2), we can see that it is better to leave (Case 1) as it is. (Case 2) is difficult to execute because it involves the risk of finishing.

6. Conclusion

If an error occurs in Robotic automated plants, the process advances to the recovery part. Many types of recovery processes can be selected. In ICAROB 2021, we showed a method to derive a suitable process using only one evaluation standard at a time selected from various standards.

However, in this paper, we used multiple evaluation standard at the same time to help select the recovery process. Specifically, the recovery process was selected using three of the eight evaluation standards. How to combine the evaluation standards used and how to find the optimal recovery process are future issues.

References

1. B. R. Donald, Planning multi-step error detection and recovery strategies, Int. J. Robot. Res., 9(1) (1990) 3-60.
2. T. Niemueller, G. Lakemeyer and S. S. Srinivasa, A Generic Robot Database and its Application in Fault Analysis and Performance Evaluation, in Proc. IEEE/RSJ Int. Conf. on Intell. Robots Syst., (Vilamoura, Portugal, 2012), 364-369.

3. E. D. Lello, M. Klotzbucher, T. D. Laet and H. Bruyninckx, Bayesian Time-Series Models for Continuous Fault Detection and Recognition in Industrial Robotics Tasks, in Proc. IEEE/RSJ Int. Conf. on Intell. Robots Syst., (Tokyo, Japan, 2013), 5827-5833.
4. E. Krabbe, E. Kristiansen, L. Hansen and D. Bourne, Autonomous Optimization of Fine Motions for Robotic Assembly, in Proc. IEEE Int. Conf. Robot. Autom., (Hong Kong, China, 2014), 4168-4175.
5. A. S. Wang and O. Kroemer, Learning Robust Manipulation Strategies with Multimodal State Transition Models and Recovery Heuristics, in Proc. IEEE Int. Conf. Robot. Autom., (Montreal, Canada, 2019), 1309-1315.
6. A. Nakamura, K. Nagata, K. Harada, N. Yamanobe, T. Tsuji, T. Foissotte and Y. Kawai, Error recovery using task stratification and error classification for manipula-tion robots in various fields, in Proc IEEE/RSJ Int. Conf. on Intell. Robots Syst., (Tokyo, Japan, 2013), 3535-3542.
7. A. Nakamura, K. Nagata, K. Harada and N. Yamanobe, Technique of Recovery Process and Application of AI in Error Recovery Using Task Stratification and Error Classification, J. Robotics, Networking and Artificial Life, 5(1), 2018, pp. 56-62.
8. A. Nakamura, N. Yamanobe, I. R. Alpizar, K. Harada and Y. Domae, Cost-oriented Planning for Error Recovery in an Automation Plant, J. Robotics, Networking and Artificial Life, 6(4), 2020, pp. 225-230.
9. A. Nakamura, N. Yamanobe, I. R. Alpizar, K. Harada and Y. Domae, Using Various Evaluation Standards to Determine an Error Recovery Process in an Automation Plant, in Proc. ICAROB 2021, pp. 321-327.
10. T. Hasegawa, T. Suehiro and K, Takase, A robot system for unstructured environments based on an environment model and manipulation skills, in Proc. IEEE Int. Conf. Robot. Autom., (Sacramento, USA, 1991), 916-923.
11. A. Nakamura, T. Ogasawara, T. Suehiro and H. Tsukune, Fine motion strategy for skill-based manipulation, Artificial Life and Robotics, Springer, 1(3), 1997, pp. 147-150.
12. A. Nakamura, K. Kitagaki and T. Suehiro, Using simplified geometric models in skill-based manipulation, Advanced Robotics, 18(8), 2004, pp. 835-858.

Authors Introduction

Prof. Akira Nakamura

He received the Ph.D. degree in Electrical Engineering from Keio University in 1991. From 2021, he has been working as a Professor at Faculty of Engineering of Saitama Institute of Technology. His research interests include robot planning, vision and control system.

Prof. Kensuke Harada

13. He received his Doctoral degrees in Mechanical Engineering from Kyoto University in 1997. From 2016, he has been working as a Professor at Graduate School of Engineering Science, Osaka University.