An Application of Functional Decomposition Tree Technology to Collaborative Robot Introduction Manual for Non-Experts

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Abstract
In order to reduce the cost of introducing collaborative robots, the authors are studying tablet-type electronic manuals using functional decomposition tree technology that enable non-experts (robot users) to introduce robots by themselves. Since the creation of such manuals is time-consuming, a methodology that enables experts (robot manufacturers) to create manuals for non-experts themselves is needed to promote the widespread use of collaborative robots, instead of knowledge engineers continuously creating manuals for each individual robot.

Keywords
collaborative robot, functional decomposition tree, manual,

1. Introduction

The purpose of this study is to establish a methodology for creating electronic manuals for non-experts, and to create guidelines for their construction, using the introduction manual of collaborative robots as a motif.

One of the solutions to labor shortages in the manufacturing industry is the introduction of collaborative robots, but the high cost of introducing such robots has prevented their widespread use. The authors have paid attention to the installation costs incurred by experts (robot manufacturers), and believe that if non-experts (robot users) could take charge of the installation work themselves, the robot installation costs paid to experts would be reduced. We have developed a manual for non-experts by decomposing a manual for experts into detailed procedures using a functional decomposition tree [1] for a part of the installation of a collaborative robot, and conducted evaluation experiments [2].

On the other hand, the preparation of such manuals for non-experts it is costly. In fact, when the authors created a manual for non-experts for the Palletizer X collaborative robot, it took more than one year just to create a text-based functional decomposition style manual, and more than 100 hours to create video contents to supplement the text explanations until the manual could be created so that only non-experts could go through the work. In order to make

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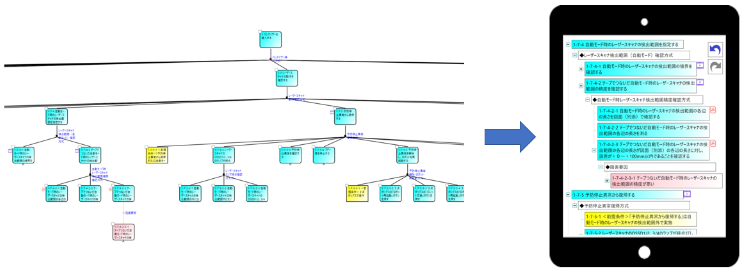

Figure 1: Diagram of a functional decomposition tree in the form of a manual (in Japanese)

manuals for non-experts practical, the cost of the creation process itself must also be reduced. For example, a methodology that enables experts themselves to create manuals for non-experts is needed. Previous studies, for example, Sannami [3], investigate how to present a manual, not on the elements that should be included in a manual. As far as the author has been able to ascertain, there are no studies on manual creation methodologies that satisfy our needs.

Therefore, in this study, we examined the elements necessary for creating manuals for non-experts to enable experts to create manuals that allow non-experts to take the initiative in implementing collaborative robotics.

2. Electronic manuals for non-experts

The manual handled in this study is a manual that is created by structuring the introduction workflow using a functional decomposition tree and converting it into a manual form (Figure1). Functional decomposition refers to the development of a desired function into a sequence of sub-functions that can achieve it [1], which is expressed in the form of a tree, called a functional decomposition tree. The manual also includes links to complementary videos that supplement the textual explanations.

3. Manual Evaluation Experiments and Results

A total of five manual evaluation experiments were conducted with non-experts as subjects, in which they performed a part of the installation work of a collaborative robot using an electronic manual that had been created. In each experiment, the experimental conditions were slightly changed, and the effects of these changes on the subjects performance were compared and categorized.

Outline of the experiment is as following. Palletizer X is a collaborative robot that performs palletizing, which is the stacking of packages on pallets that flow from a conveyor. Subjects were asked to perform three main tasks in the installation of Palletizer X, using an electronic manual as a reference. The subjects for each experiment were two people with no prior knowledge of collaborative robots. Subject interviews were conducted after each experiment. In each

Figure 2: Comparison of complementary videos for "Conducting Teaching" (in Japanese)

experiment, we analyzed the changes that affected the success of the task with reference to the results of the previous experiment, and generalized and categorized them.

Then we describe experimental results here. The authors used the manual for non-experts in the first experiment, but the subjects failed to complete the task. But by improving the manual step by step for each experiment, the success rate eventually rose to 89% to 100%. Therefore, it was found that even non-experts can take charge of the introduction work by using the introduction work manual [2].

In addition, from the changes made to the experimental conditions in each experiment, the changes that affected the success of the work were found and categorized. One of the classifications, "multidimensional expression," is described below.

One of the tasks, "conduct teaching", for example, the robot arm is operated using an attached touch panel to set the coordinate axes of the collaborative robot at the time of shipment in the direction of the actual coordinate axes at the actual site, and the tip of an instrument attached to the arm called "jig" must be aligned with the four points specified on a board called "pallet" within an error margin of a few mm. In the complementary movie of the first experiment (left side of Figure2), the robot was too close to the object, making it difficult to understand the positional relationship between the robot and the operator and the final state of the tip of the jig. As a result, the instructions were not well communicated to the subject, and the work could not be performed within the allowable error. Therefore, in the second supplemental video (right side of Figure2), we attempted a multifaceted expression by re-editing the video to include a bird's-eye view of the entire robot from above, a video showing the robot itself and the operator, and multiple viewpoints of the final state of the jig. This improved the accuracy of the work and allowed teaching to be performed at the correct position.

Some of the changes were effective in making the work more successful, as in the categories presented above, while others were not. In this study, the changes that were effective were the study focused on the changes that were effective, and divided them into eight categories.

4. Draft Guidelines for Manual Construction

A guideline was developed for the experts, not the knowledge engineers, to make them being able to make such manuals we have proposed in this paper by themselves.

Draft guidelines for the construction of a manual for non-experts:

1. The manual is to be prototyped several times using functional decomposition trees: the first time to avoid hazards, the second time to solve functional problems, and the third and later times to add words that are difficult to understand, etc. Further improvements should be made by conducting multiple experiments on the use of the manual by test subjects.
2. Be sure to write about procedures for worker safety and any terms that have different definitions for experts and non-experts.
3. The peripheral knowledge required for assembly, such as names of parts and basic work procedures, should be included in the manual or documents to be included with the manual.
4. For the procedures that the subjects were unsure of in the initial experiments, the instructions should be less granular and more specific.
5. For procedures for which the subjects do not understand the reason for the work in the initial experiments, the manual will indicate the failures that would result if the procedure were not performed.
6. For critical tasks that determine the accuracy of the entire operation, the manual's instructions should be multifaceted.
7. We will also try to describe procedures that make the work easier to perform.
8. If it is expected to facilitate assembly, instructions for manual peripherals are also provided.
9. If initial experiments reveal issues such as the manual being difficult to see or read, consider the possibility of changing the interface of the manual itself.
10. The field manual is not always correct. When errors in the field manuals are discovered through repeated experiments, the manuals themselves are revised and feedback is provided to the field.

5. Conclusion

In this study, we examined a methodology to enable experts themselves to create manuals that enable non-experts to take on the task of introducing collaborative robots. The guideline proposed in this paper is based on a single model of the Palletizer X, and is not a general one. In order to generalize this guideline to various models, we plan to apply our method for other collaborative robots, such as different models of palletizers and robots for welding, for example. We are also planning to conduct experiments in which experts will actually create manuals using the guidelines we have created. In the future, we would like to make it possible for experts to take the initiative in creating manuals for non-experts.

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