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Intelligent jamming region division with machine learning and fuzzy optimization for control of robot's part micro-manipulative task

Changman Son

Department of Electronic Engineering, DanKook University, Cheonan 330-714, Republic of Korea

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ABSTRACT

An algorithm for an intelligent jamming region division with machine learning and fuzzy optimization for the control of a robot's part micro-manipulative task is introduced. A comparison with existing works and the advantages of the proposed algorithm in this paper are described. A quasi-static part mating (micro-assembly) is accomplished using a fuzzy coordinator combined with a learning algorithm of the jamming region division while avoiding jamming. Depending on the positional relationships between a part and an assembly hole (target) in a workspace, a specific rule base for avoiding jamming is activated. The region division algorithm merges all adjoining subregions, of which the quad-tuple control values describe similar jamming states, into one region and the weights of the subregions are adjusted. A fuzzy entropy, which is a useful tool for measuring variability and information in terms of uncertainty, is used to measure the degree of uncertainty related to an execution of the part micro-assembly task. A degree of uncertainty associated with a task execution of the part micro-assembly is used as a criterion of optimality, e.g. minimum fuzzy entropy. Through a decision-making procedure, the most appropriate quad-tuple control value with the lowest fuzzy entropy in each region is chosen as a final control value to carry out an assigned task. The proposed technique is applicable to a wide range of the robot's tasks, including choosing and placing operations, manufacturing tasks, part mating with various shaped parts, etc.

1. Introduction

This paper focuses on augmenting accurate control with some measure of intelligence. Accurate control in this paper refers to the reduction of uncertainties associated with the task execution of the part micro-assembly. The degree of uncertainty of the quad-tuple control value used for an execution of the part micro-assembly task is measured by the fuzzy entropy. As the degree of uncertainty of the quad-tuple control value decreases, its fuzzy entropy also decreases. To resolve an optimization problem that minimizes both the fuzzy entropy of the quad-tuple control value and the number of subregions that are subject to the Euclidean distance measure (Eq. (10)) described in (Step 3) of Section 2.4, all quad-tuple control values are checked to ensure they satisfy the criterion, Eq. (10). Through this optimization process, a number of subregions in the jamming diagram are to be minimized; simultaneously, a quad-tuple control value with the lowest fuzzy entropy is selected for a specific jamming state. By minimizing the uncertainties involved in the control actions, the possibility of success of the part micro-assembly task increases.

E-mail address: cmson@dankook.ac.kr

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The importance and motivation of this work is as follows. The existing works in [35–37] simply divide the jamming regions into many subregions, while the large number of initial subregions can be considerably reduced to a much smaller number of regions by the jamming region division algorithm. If the region merging process is repeated, the part mating becomes increasingly more efficient in terms of time consumption, requirement of machine memory capacity, etc. since many jamming subregions can be replaced with only a few merged regions. This process involves learning from experience and could be a significant advantage. If the part mating task is repeated, the number of subregions or merged regions will be increasingly reduced. From the results, the proposed algorithm can perform assigned tasks much faster than the existing works in [35–37].

The current trend in the area of robot's part assembly with machine learning and fuzzy optimization is largely covered in [2–5,7,9–14,18–26,28–30,33–40]. Aliev [2] proposes a decision theory which is capable to deal with vague preferences and imperfect information. Armaghan [3] proposes using knowledge acquisition as a basis for seeking solutions from non-compensatory multi-criteria decision aids. Chen [7] proposes an algorithm to cluster multiple and parallel data streams using spectral component similarity analysis. Civicioglu [9] introduces an artificial cooperative search algorithm for numerical optimization problems. Couso [10] deals with the similarity and dissimilarity measures between fuzzy sets. Dai [11] defines the concepts of knowledge information entropy, knowledge rough entropy, and knowledge granularity measure for set-valued information systems. Dai [12] focuses on constructing uncertainty measures in incomplete information systems by pure rough set approach. Fabrizi [13] shows how to enrich a topology-based map with a geometric information useful for generation and execution of plans associated with a robot's manipulative task. Fan [14] develops a generalized fuzzy linear programming method for dealing with uncertainties expressed as fuzzy sets. Gutiérrez [19] describes an approach for analysing classifiers based on two measures: accuracy and sensitivity. Jiang [22] defines the distance measures between intuitionistic fuzzy soft sets and gives an axiom definition of intuitionistic entropy for an intuitionistic fuzzy soft set. Kurtoglu [23] develops a mathematical model to investigate a flexibility of two-assembly lines in a manufacturing system. Lee [24] proposes an approach that takes as a starting point the simple and intuitive observation that close objects should fall within the same cluster. Li [25] introduces an axiomatic definition of the similarity measure of intuitionistic fuzzy sets. Liao [26] addresses a finite element method for extracting and representing characteristics of surface micro-geometry of assembly components. Miranskyy [29] describes the use of word entropies for the classification of software traces. Mulder [30] describes a general definition for the concept 'optimal clustering' which is applicable to overlapping clusterings. Wei [38] introduces three methods for estimating the ability of a fuzzy entropy to measure the roughness of a rough set. Xiao [40] presents a real time planning and control for robot manipulators in a reconfigurable workcell.

Son [35–37] dealt with the robot's part micro-assembly problems without considering the jamming region division proposed in this paper. The algorithms for material handling and part mating in Brooks [5] and Lozano-Perez [28] are based on geometrical or topological computations that have no endemic intelligence. A great deal of work has not been performed in which intelligence functions such as reasoning, inferencing, learning, and decision-making have been applied to a robot's part assembly. Moreover, essentially no extant work has been undertaken that proposes the use of machine intelligence with a measure of optimality (such as minimum fuzzy entropy) for a jamming region division in a robot's part assembly. Also, previous practical works related to applications of fuzzy systems such as the proposed algorithm in this paper and [1,6,8,27,32] are not easy to find. [1] proposes a perceptual model based on fuzzy system to be used in a hybrid deliberative-reactive architecture and uses this perceptual model an approximate world model can be built so that the robot can plan its motions for navigating in an office-like environment. [6] develops a practical algorithm to prioritize the service attributes to be improved based on a fuzzy zone of tolerance. [8] describes a hybrid fuzzy and neural approach with virtual experts and partial consensus to enhance the accuracy and precision of dram price forecasting. [27] proposes an adaptive interval type-2 fuzzy sliding mode control for a class of unknown nonlinear discrete-time systems corrupted by internal noise and external disturbance. [32] presents a method for dealing with feature subset selection based on fuzzy entropy measures for handling classification problems.

In this paper, an algorithm for an intelligent jamming region division with machine learning and fuzzy optimization for the control of a robot's part micro-manipulative task is presented. The algorithm of the jamming region division has various intelligent functions such as inferencing used in the fuzzy coordinator of Section 2.2, decision-making with the fuzzy optimization described in Sections 2.3 and 2.4, and learning as described in Section 2.4, etc. In order to address the uncertainty problems associated with the part micro-assembly procedure, a fuzzy set theory is introduced so that the procedure can be optimized using appropriate cost functions. A fuzzy entropy is introduced because it is employed as a useful tool that can measure the degree of uncertainty related to an execution of the part micro-assembly task. Through a decision-making procedure, the most desirable plan for a specific task execution that satisfies a certain criterion, e.g. minimum fuzzy entropy, is determined and the selected plan is finally fed to the lower level of the system.

An overall control strategy for the part micro-assembly task is shown in Fig. 1. This paper is organized as follows. In Section 2.1, a quasi-static part mating problem and sensor systems for obtaining the part's position information are described. A fuzzy coordinator for the control of the part micro-assembly task is discussed in Section 2.2. A particular assembly type, such as a right side, left side, or vertically straight approach to a target, determines which specific fuzzy rule base is activated to avoid jamming. In Section 2.3, an introduction of uncertainty and a measure of uncertainty with fuzzy entropy associated with the part micro-assembly task are described. In Section 2.4, a learning algorithm of an intelligent jamming region division is described. The region division algorithm merges all adjoining subregions, (of which the quad-tuple control values describe similar jamming states), into one region on a jamming diagram and the weights of the subregions are then adjusted.