Microrobot based micro-assembly sequence planning with hybrid ant colony algorithm

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1 Introduction

The determination of assembly plans has strong influence on the costs of assembly processes [1]. Assembly planning tries to determine a feasible method and layout to assemble a product from the original components with minimum cost or shortest time. Assembly sequence planning is one of the key parts of assembly planning. An assembly sequence plays the leading role of an assembly plan and it affects other aspects of the assembly process, such as resources, assembly line layout, efficiency, and cost, as well as various details in the product design.

Assembly planning has been widely researched in the macro world. There are many models and algorithms to illustrate and solve assembly planning problems. Earlier studies are based on graph search theory [2], and recent studies are based on artificial intelligence (AI). However, in the micro world, little attention has been devoted to assembly planning problem. The complexity and scaling effects may be the main reasons that limit the development of micro-assembly. There are several differences between micro and macro assembly for the micro-scaled sizes [3, 4].

In the micro world, micron precision is often required [5]. Closed loop strategies are used and real-time vision feedback is always needed for this application. The sensors must be extremely small and sensitive. In the macro world, the mechanics of manipulation are predictable. But in the micro world, surface-related forces, such as electrostatic, Van Der Waals force and surface tension forces become dominant over gravitational forces. Due to the scaling effect, manipulation in the micro world is completely different from manipulation in the macro world. In the micro world, microscopes and tools limit one's ability to directly see or sense the objects to be handled. The tools

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used to manipulate the objects have fewer degrees of freedom, and there is no feedback [5].

For these differences, microrobot-based micro-assembly cannot simply employ the conventional assembly concepts, thus developing slowly. Most of the micro-assembly systems are independent and have their own specific applications. Haruo [6] developed an assembly system for micro-optical products, with the exclusive lens handling and image processing technologies, bringing automation and greater accuracy to inserting a micro lens and attaching it to a CCD and lens frame. Fatikow S et al. [7, 8] (1999) proposed a desktop micro-assembly system with microrobots. The microrobot with piezoelectric legs has three degrees of freedom and is equipped with a changeable gripper. One robot can transport parts while another performs assembly, or they can cooperate during an assembly. Li ZB et al. [9] (2005) develop an omni-directional mobile microrobot-based micro-assembly system. The cm$^3$ sized microrobot with three degrees of freedom is driven by three electromagnetic micromotors, the microrobot can perform micro-assembly tasks with the guidance of microscope vision system.

In this paper, based on the micro-assembly system [9] of Shanghai Jiao Tong University (SJTU), the assembly sequence planning problem of the microrobot-based micro-assembly system is considered. Due to the constraint of size, the functions of microrobots are limited; they can only receive instructions and implement simple tasks. So the complex assembly tasks must be decomposed and planned into subtasks which are suitable for microrobots. In this way, the micro-assembly planning problem is one of the key problems for microrobot-based micro-assembly system and will be discussed in the following sections.

The paper is organized as follows. Section 2 presents the problems of microrobot-based micro-assembly sequence planning firstly, and then the assembly model is given and transfers the problem into a combinatorial optimization problem. A particle swarm optimization (PSO) improved hybrid ant colony optimization (ACO) algorithm called PS-ACO is presented in Sect. 3, which is used as the intelligent method for solving the combinational optimization problem; the performance of the hybrid algorithm is analyzed with several standard examples. In Sect. 4, the PS-ACO based algorithm for solving micro-assembly sequence planning is provided, and some case studies are presented in Sect. 5. Section 6 concludes the paper.

2 Microrobot based micro-assembly sequence planning

2.1 Microrobot based assembly system of SJTU

The microrobot-based assembly system of SJTU consists of a HOST computer, vision system, micro-assembly platform, microrobot and assembly controller, as shown in Fig. 1. Figure 2 gives the picture and 3D view of the microrobot used in the micro-assembly system of SJTU.

The HOST computer is the main processing computer in the assembly system; the micro-robot is controlled by the HOST through the assembly controller and performs the assembly operations on the micro-assembly platform. The vision system, including a microscope camera and global vision camera, is used to monitor the whole assembly procedures, and position information can also be obtained with the vision data.

The electromagnetism micro-motor driven microrobot in Fig. 2 is an omni-directional mobile robot [9]. There are three motors of the microrobot, but two of the micro-motors (the castors in the behind, see the left part of Fig. 2) are