Journal of Manufacturing Systems 35 (2015) 76–91

Contents lists available at ScienceDirect

Journal of Manufacturing Systems

journal homepage: www.elsevier.com/locate/jmansys

Design and manufacturing of mobile micro manipulation system with a compliant piezoelectric actuator based micro gripper

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ARTICLE INFO

Article history:
Received 12 September 2014
Received in revised form
13 November 2014
Accepted 1 December 2014
Available online 23 December 2014

Keywords:
Piezoelectric actuator
Micro gripper
Micro assembly
Handling

ABSTRACT

This paper presents a new design of mobile micro manipulation system for robotic micro assembly where a compliant piezoelectric actuator based micro gripper is designed for handling the miniature parts and compensation of misalignment during peg-in-hole assembly is done because piezoelectric actuator has capability of producing the displacement in micron range and generates high force instantaneously. This adjusts the misalignment of peg during robotic micro assembly. The throughput/speed of mobile micro manipulation system is found for picking and placing the peg from one hole to next hole position. An analysis of piezoelectric actuator based micro gripper has been carried out where voltage is controlled through a proportional-derivative (PD) controller. By developing a prototype, it is demonstrated that compliant piezoelectric actuator based micro gripper is capable of handling the peg-in-hole assembly task in a mobile micro manipulation system.

1. Introduction

In the last few years, the rapid growth of high technologies such as micromanipulation, nanotechnologies, scanning tunneling and atomic force microscopy, micro electromechanical system (MEMS), robotics etc. have needed the reliable, fast and precise actuators and sensors based systems [1–3]. Use of such actuators and sensors in the design and development of micro assembly system provides the versatility, flexibility and robustness to achieve small and medium sized batches assembled in an economical way. In this aspect, several researchers have developed mechanical grippers for robotic assembly using different miniature actuators like linear, pneumatic etc. as stated in [4–6]. The major disadvantage of these mechanical grippers is that they do not have flexible capability for compensating the misalignment of peg during robotic micro assembly. Another disadvantage of mechanical gripper is that fabrication and assembly in small scale are quite difficult for robotic micro assembly. Therefore, handling and manipulation tasks need some compliant devices which can itself accommodate the misalignment of peg during robotic micro assembly. For this purpose, different types of passive small wrist/passive compliant micro gripper have been studied as stated in [7–9]. These micro grippers perform the operation along the gravity vector and they cannot be used for actively controlling errors in other directions. In order to reduce this problem, smart actuator based active micro grippers have also been developed by Lumia and Shahinpoor (2008). For achieving the robotic micro assembly task, some compliant based smart actuators such as Ionic Polymer Metal Composite (IPMC), Shape Memory Alloy (SMA), piezoelectric etc. have been used by Lumia [10,11]. IPMC based micro grippers have compliant behavior to grasp and manipulate micro-sized flexible/rigid objects. In this aspect, Jain et al. [12–14] have also developed IPMC based compliant micro grippers for different applications of micro manipulation such as handling of miniature parts in micro factory test bed concept. The major disadvantage of IPMC is that the response time during micro gripping operation is not sufficient for holding the object in the long time range. Therefore, another approach is that we can use the piezoelectric actuator for developing the micro gripper. The major advantages of this actuator are that it has high micro/nano scale displacement, large force generation and micro/nano second-range response as compared to other smart actuators. For developing a micro gripper, the main difficulties are that the non-linear deflection actuation response of piezo bimorph through voltage in real time and controlling the position during picking and placing [15,16]. In order to attempt on this, several researchers have focused on piezoelectric actuator-based micro grippers toward achievement of micro-object manipulation as stated in [17–22] but as compared to others, this paper is mainly focused on integration of compliant piezoelectric actuator based micro gripper in mobile micro manipulation system where performances of robotic

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http://dx.doi.org/10.1016/j.jmsy.2014.12.001
0278-6125/

peg-in-hole assembly are analyzed for industrial application. Till now, there is not any appropriate solution for micro manipulation using compliant bimorph piezoelectric actuator in the real micro world. To cater this need, we propose a new design of mobile micro manipulation system along with piezoelectric micro gripper for handling the object without any destruction where mobile mechanism allows the placement of object at the desired position which is a novel part of this paper. The major advantage of this mobile micro manipulation system over fixed type micro manipulator is that it can handle the compliant/rigid objects and the complaint gripper places the object in straight manner during peg-in-hole assembly.

The objectives of this paper are on the following points:

(a) A new design of mobile based micro manipulation system with a piezo actuator based compliant micro gripper for micro manipulation
(b) Analysis of mobile micro manipulation system for finding the throughput/speed of robotic peg-in-hole assembly and also analysis of compliant piezoelectric actuator based micro gripper for handling the object
(c) Development of a bimorph piezoelectric actuator based micro gripper along with mobile micro manipulation system and evaluation of its performance for robotic micro assembly

During handling of micro parts by a mobile micro manipulation system, the manipulation system places the object (peg) in a straight manner and micro gripper has to be intended in such manner so that it can provide the long term stability to hold the object during robotic micro assembly. For this purpose, a 3-degree of freedom (DOF) based mobile micro manipulation system along with micro gripper is designed. This system consists of a mobile mechanism, a shaft mechanism, a lead screw mechanism and a micro gripper. This mobile micro manipulation system gives appropriate trajectory/path during placing the object in a sequential manner as compared to fixed/conventional kind of manipulation system. In this paper, a kinematic analysis is carried out and throughput/speed of micro manipulation system is obtained so that object/peg can be placed in a straight manner during peg-in-hole assembly. A micro gripper is designed using bimorph piezoelectric actuators where bimorph piezoelectric actuators in cantilever configuration provides bi-directional characteristic with flexible behavior for handling the object. In order to control and analyze the bimorph behavior of piezo actuator, the voltage signal of piezo actuator is controlled through a proportional-derivative (PD) controller. An experimental performance is also carried out. This shows that the piezoelectric actuator produces maximum deflection up to 1.5 mm and generates force up to 0.203 N for handling the object. Further, a prototype of mobile micro manipulation system along with compliant piezoelectric based micro gripper is developed for demonstrating the micro manipulation and misalignment adjustment capabilities of handling the miniature parts during robotic peg-in-hole assembly.

This paper is organized as follows: the prior research work related to different type of existing micro grippers and micro manipulation systems for micro assembly are discussed in Section 2. A new design of mobile manipulation system along with a piezoelectric actuator based micro gripper for robotic micro assembly is discussed in Section 3.1. In Section 3.2, kinematic analysis of the mobile micro manipulation system is carried out. Analysis of piezoelectric actuator based compliant micro gripper toward robotic micro assembly is discussed in Section 3.3. In Section 4, the simulation results on controlling the gripping behavior of piezo actuator for micro gripper are discussed. Experimental testing setups for controlling the voltage of piezo actuator based micro gripper and robotic micro assembly is described in Section 5. The results toward robotic micro assembly by a piezo actuator based micro gripper are discussed in Section 6. The conclusion is drawn in Section 7.

2. Prior research work related to different type of existing smart actuators based micro grippers and micro manipulation systems for robotic micro assembly

Earlier, several researchers have given an extensive effort on development of different type of micro grippers using different smart materials and their micro manipulation systems for successful robotic micro assembly. These are categorized into two sub groups as under

I. Previous research work on different type of micro grippers and control methods
II. Previous research work on micro manipulation systems/stations for robotic assembly and their control methods

The details of past literature each category wise are given below.

I. Previous research work on different type of micro grippers and control methods

In the last decade, Helin et al. [23] have focused on the micro-grippers which are joined with a micro-conveyer stage. These micro-grippers are fabricated using micro stereo photolithography process and actuated by shape memory alloy wires. Qiao et al. [24] have developed a micro gripper with piezoelectric actuator where this has been made of both silicon and glass and actuation is provided to piezoelectric actuators. Fung et al. [25] have focused on development of poly-vinyli-dene-fluoride (PVDF) force sensing system for micro gripper. A two dimensional (2-D) sensing system has been designed for lifting a micro structure where force and impact detection capabilities have been demonstrated. Popa et al. [26] have developed a dynamic model of bimorph MEMS actuators where properties are similar to piezoelectric actuator whereas Dong et al. [27] have focused on actuating and sensing capability of lead zirconium titanate (PZT) micro cantilever for micro gripper. In addition, the method for the determination of the piezoelectric constant is developed once the sensing and actuating capability is measured. Rakotondrabe et al. [28] have focused on characterization, modeling and robust control of a non-linear 2-DOF piezo cantilever based micro gripper. Hoxhold et al. [29] have discussed various types of handling tools such as piezoelectric, SMA, electrostatic based flexible micro grippers and their performances for handling of components in the desktop factories. Feng et al. [30] have designed a micro-gripper driven by piezoelectric actuator based on the displacement amplification structure with the flexure hinge. Noori et al. [31] have given effect on study of different frequency on a micro gripper which uses piezoelectric actuator whereas Wang et al. [32] have focused on design, modeling, and experimental testing of a piezoelectric-driven micro gripper making use of both integrated gripping force sensor and tip displacement sensor. Further, we [33] have recently focused on control of voltage signal for piezoelectric actuator where a mathematical model for deflection and force response of piezo actuator with voltage is derived with the help of a simple first-order model under a step input voltage.

II. Previous research work on micro manipulation systems/stations for robotic assembly and their control methods

In the last decade, Zaeh et al. [34] have presented a hybrid micro-assembly system for providing manual tele-operation mode toward both the single-piece production and automated operation mode for series production of micro systems. Agnus et al. [35]