Available online at www.sciencedirect.com

ScienceDirect

IFAC Papers Online CONFERENCE PAPER ARCHIVE

IFAC-PapersOnLine 48-3 (2015) 1476–1481

An Approach for Peg-in-Hole Assembling using Intuitive Search Algorithm based on Human Behavior and Carried by Sensors Guided Industrial Robot

Mustafa W. Abdullah*. Hubert Roth[a]. Michael Weyrich***. Jürgen Wahrburg**[b]**

**Institute of Automated Manufacturing and Assembly, University of Siegen, Siegen, Germany (Tel: +49-271-740 4067; e-mail: abdullah@zess.uni-siegen.de).*

***Institute of Automatic Control Engineering, University of Siegen, Siegen, Germany*

[a](e-mail: hubert.roth@uni-siegen.de)

[b](e-mail: juergen.wahrburg@uni-siegen.de)

****Institute of Automation and Software Engineering, University of Stuttgart, Stuttgart, Germany (e-mail: michael.weyrich@ias.uni-stuttgart.de)*

Abstract: Automated peg-in-hole assembling approach using Force/Torque sensor and vision system is presented in this research. The complicity of the assembling task due to parts' geometries or position uncertainty in work area are the main factors for the lack of fully automated assembling approaches nowadays in industry and specially in the automotive sector. Based on human operator handling for the assembling of peg-in-hole, an algorithm consists of six phases is developed. In one of the phases a model is created to determine the location of the hole's center during the insertion by using Force/Torque sensor data. The contact forces and torques in each step of the proposed assembling algorithms that was carried by a six degree-of-freedom (DOF) industrial robot is presented.

Keywords: peg-in-hole assembling, sensor guided, industrial robot, modeling.

1. INTRODUCTION

The assembling process in industry is a well know challenge for researchers in the last decays. However, despite of the efforts and many proposed solutions it is hardly to find an implemented fully automated assembling approach in today's industry for many peg-in-hole scenarios, such as the assembling of electronic connectors in automotive industry. This is mainly because of the nature of the assembling task in addition to the uncertainty in work environment. Thus, many assembling processes nowadays are mainly carried by human operators due to their fast reconnection and adaption to the changes in parts types or location by using their senses, i.e. vision, tactile, and kinaesthetic.

In order to increase the efficiency of the manufacturing lines, fully automated processes that take into account processes time and cost should be used. Therefore, the research on automated assembling process is still ongoing with the focus on using industrial robots to replace the human operators. There are two common approaches to automate the assembling task; either by using an offline guiding robots, pre-programmed, with extra care to position uncertainties of the parts and repeatability accuracy of robot, or by using sensors guided industrial robot that can correct the position and trajectory during the process based on the sensory data.

The human operator uses two main senses to carry the assembling task which are; the vision sense to estimate the locations of the parts and roughly mate them, and kinaesthetic sense to finalize the assembling by inserting the peg into the hole. For the industrial robot a vision and Force/Torque sensors can be used to simulate these human senses. Therefore, most of the researchers tend to use either one of these sensors or combine them together to successfully accomplish the assembling process carried by the industrial robots. This research also uses a vision system with F/T sensor to accomplish the automated assembling by imitating the human operator steps. In the next section, a short background and discussion are given on the exiting approaches to point out the needs for additional research on automated assembling topic.

2. BACKGROUND

The earliest work of automated assembling processes started at 1950s in the sector of military electronics equipments as stated in the research by W. Schneider (1958). At this stage, the focus was on how to standardize the parts interfaces so they can be assembled with pre-programmed productions lines in order to reduce the costs and time. By the end of 1960s a survey was conducted by Iredale (1969) on the state of the art of automated assembling. The author summed his survey as inadequate implantation of the automated assembling especially in the metalworking sectors. On the other hand, he concluded from his survey that due to increases in the cost of labor which was six times more than the increases in the products prices, the need for automated assembling lines will be address in the next years to keep the productions costs sufficient enough to meet the market demands. With the following years, many assembling lines in which the location of parts and system behavior are well known have been fully automated. In parallel to that, many assembling tasks, such as the assembling of car doors or electronic connectors in the automotive industry are still carried by human operators. In the last years, the research on

10.1016/j.ifacol.2015.06.295

automated peg-in-hole assembling, which addresses the mentioned non-automated tasks, gained the interest by many researchers again. This is could be mainly because of the development in the technologies of industrial robots and sensors systems. Different approaches were investigated to guide the industrial robot using sensors that can be summarized in the next sub sections.

2.1 Static Contact Forces Analysis

The first attempts to carry the assembling using contact force information focused on statically analysis for possible contact forces, including the friction force, to calculate the angle (θ) between the peg axis and hole axis as shown in Fig. 1

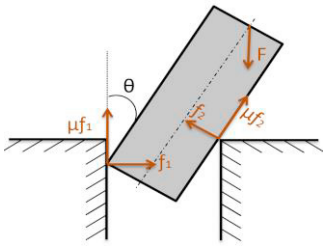

Fig. 1. Forces calculation at contact points.

Nguyen et al. (1995) carried the theoretical analysis of the interaction forces and implemented a fuzzy control for the assembling task. Kim et al. (1999) used the same method to find the directional error in small and large cases. Their approach intended to avoid the inefficiency in pervious works' algorithms where the robot has to return to the start point if it could not estimate the directional error.

2.2 Force/Torque Map

As the search for the hole location is the first step in the assembling task, Newman et al. (2001) proposed a guiding map based on interpretation of the collected force and torque data for each possible contact points between the peg and the surface where the hole is located. This generated map is used then to guide the peg in finding the centre of the hole. An example of a map for rounded peg-in-hole scenario is shown in Fig. 2.

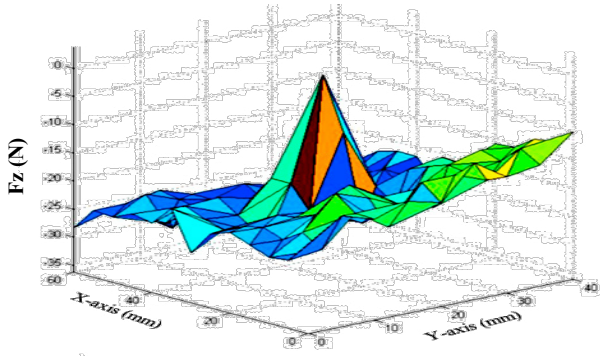

Fig. 2. F/T Map: forces on z-axis for rounded peg-in-hole.

Dietrich et al. (2010) enhance the implantation of the map for and the search strategy by taking extra care to acquisition of the data with respect to parameters sensitivity.

2.3 Contact State Estimation and Modeling

The force/torque sensor real time data are often very noisy because of the carried peg and gripper weights in addition to the dynamic behavior of the assembling task. Therefore, a contact state recognition approaches were introduced. Hirai et al. (1992) were one of the first researchers who address this topic by using geometric model for mated parts. The uncertainties problem in the force/torque sensor data and also in the position of the parts was studied by Farahat et al. (1995) to identify the contact formation in assembling. Neural networks for building the contact state classifiers were proposed by Hovland et al. (1997) and Skubic et al. (1997).

Modeling of the assembling task using hidden Markov was conducted by Lau HY (2003). Kalman filters with neural network to diffuse the signals of the system that simulate human skills for assembling was proposed by Cartesao et al. (2004). Human behavior model using pricewise ARX model was successfully implemented by Okuda et al. (2008).

Intuitive assembly strategy that does not require precise force information was deployed by Park et al. (2013). In this approach the robot arm spun the peg around the hole with specified force until the mating in successes which is similar to one of human approaches. Similar analysis using uncertain grasps and by tele-operating was proposed by Savarimuthu et al. (2013) to execute the assembling of peg-in-hole. Jasim et al. (2014) address the problem of contact state monitoring using expectation maximization based Gaussian models.

2.4 Vision System

Integration of vision systems with industrial robots to achieve the automated peg-in-hole assembling have been studied for long time in research laboratories. Pauli et al. (2001) used a vision system to servo the robot during the assembling task. In their approach, a powerful computer system was used to process the live images from two cameras and estimate the contact points. Huang et al. (2013) proposed a fast alignment for peg using two high speed cameras, one amounted on the robot end-effector and the second one mounted outside to monitor the whole work area.

2.5 State of the Art

As the implantation of visual based robot guiding in industrial environment faced many limitations due to unstable lighting sources, researchers focused on guiding the robots by using force information. In these approaches either an external Force/Torque sensor is used, or by computing the internal robot's joints torque to estimate the force at the end-effector. However, by reviewing the pervious approaches it can be concluded that the industry still luck for state of the art solution. This can be due to the following reasons: