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Computing Optimization of a Parallel Structure-Based Monolithic Gripper for Manipulation Using Weight Method-Based Grey Relational Analysis

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ABSTRACT

This study proposes an integration of the weight method and grey relational analysis to optimize a monolithic gripper. This gripper is desired for use in the assembling industry of cylindrical parts with diameters from 500 μm to 800 μm. The weight factor for each response is calculated accurately. Response surface methodology and Taguchi method are utilized to build an experiment matrix, and grey relational analysis is utilized to predict optimal results. The results found that the predicted displacement value is 0.5699 μm, and the predicted frequency value is 780.9 Hz. Compared to the initial design, the quality of responses is improved by 7.53% for the natural frequency and 35.29% for the output displacement. The error between the predicted result and the verified result is 1.15% for the natural frequency and 16.62% for the output displacement, respectively. It implies that the proposed method has a statistical accuracy.

KEYWORDS

Compliant Mechanism, GRA, Gripper, RSM, Signal to Noise, TM

INTRODUCTION

Assembling is one of the important steps in the electronics industry and related industries. Therein, small parts such as the miniaturized gear, pins, chips, male connectors must be inserted into female connectors (Ansel et al., 2002; Dechev et al., 2004; S. J. Hu & Camelio, 2016). In actual production conditions in most factories, the assembly process depends heavily on human skills. This is the cause of low production efficiency, unstable product quality, not competitive in terms of product prices, etc. In some factories, this process is replaced by industrial robots based on pneumatic and hydraulic systems (C. Chen et al., 2016; Zhong et al., 2019). However, these robots have limitations such as generating noise during operation, gripping with highly complex parts, small size components,

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difficult to process and assemble. Especially, such robots result in undesired errors during fabrication and assembly. This leads to difficulty in gripping and releasing objects. To overcome such limits, the compliant mechanism is alternatively used with the advantage of being monolithic, small, easy to fabricate, no noise (Howell, 2011). A compliant gripper (CG) is considered as an effective solution that can replace traditional robots. However, research, development, and application of the CG in the production process are still very limited. Based on the survey results, it can be seen that only one CG application study for the assembly system is performed (Ho et al., 2019a). From the problems mentioned above and the limited number of studies that have been done, research and development of CGs to overcome the above difficulties is considered essentially.

Regarding the analysis, design, and optimization of a CG, there are many approaches to implementation. However, there are two commonly used approaches: black-box approach (Nguyen et al., 2019) and kinematics-based design methods (Dsouza et al., 2018; Nandy et al., 2018; Qingsong, 2015; Tashakori et al., 2018; Xu, 2015). With a kinematics-based design method, the mathematical equations need to be established first, an optimization algorithm is then used to predict a set of optimal parameters. Through the establishment of mathematical models, it provides knowledge as well as a clear kinetic meaning. Notwithstanding, the limitation of this approach is dependent on the knowledge of designers. Also, some previous studies have shown that there have large errors between predicted results and experimental results (Ai & Xu, 2014). In contrast to the kinematics-based design methods, to avoid factors such as expert knowledge, inadequate description of deformed components, black-box approach allows the establishment of a virtual mathematical model that describes the relationship between input signals and output response. In recent years, this approach is used by many interested scientists (Dang et al., 2019; Ho et al., 2019a; K. Muriithi et al., 2017).

Moreover, the CG often faces some challenges such as a large displacement stroke amplifier, a stable force, a good resonant frequency, a light, and a simple structure. In fact, depending on the target on each specific design goal, these requirements are usually resolved through two steps as follows: Firstly, the effect of the design parameters needs to be considered. Secondly, the design parameters need to be optimized to improve the characteristics of the design (Niaki & Nikoobin, 2017). Nowadays, design optimization can be done by many different methods. For example, Liu et al. (Liu et al., 2018) used the topology method, Harfensteller et al. (Harfensteller et al., 2013) utilized the box-complex method, Ho et al. (Ho et al., 2016) applied RSM and TM, Hu et al. (C. Hu et al., 2018) used a model predictive control, etc. These methods have limitations such as long computational time and accuracy of the method depends heavily on search space as well as control parameters. To overcome these limitations, recently some hybrid algorithms and intelligent algorithms have been developed and applied with very high efficiency. It can be mentioned as an integration of the TM (Taguchi Method) and Teaching learning-based optimization (Dang et al., 2019), a hybrid approach of finite element analysis, Kriging technique, and multi-objective optimization algorithm (Nguyen et al., 2019), a hybrid approach of GRA, regression, and ANN models (Gupta et al., 2020; Shah & Bhavsar, 2019), PSO (Dey et al., 2020; Zhang & Chen, 2011).

From reviewing the literature review, it is noted that the values of the weight factor (WF) for each response are often randomly chosen or calculated by using the entropy measurement technique. However, there have not been any reports of a hybrid approach of RSM, TM, GRA based on specific weight calculation methods to optimize multi-response optimization of the CG. From the actual requirements and the issues mentioned above, inspired by the level mechanism, parallel mechanisms, and concept of compliant mechanisms, a gripper for use in the assembling industry of cylindrical parts is designed in this study. Level structure plays two roles, including displacement amplification, and it connects piezoelectric actuators (PEA) and jaws. Parallel mechanisms ensure that both CG's jaw is uniformly moving and flat.

The purposes of this paper are to design and optimize a gripper in terms of good characteristics to be used in the assembly system. Research content is limited by four points as follows: (i) CG is proposed to have an expected displacement of greater than 500 μ (the initial gap between both jaws

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