Robotics and Autonomous Systems 94 (2017) 89–101

Contents lists available at ScienceDirect

Robotics and Autonomous Systems

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

Experimental verification of design automation methods for robotic finger

M. Honarpardaz [a,b,*], M. Tarkian [b], J. Ölvander [b], X. Feng [a]

[a] ABB, Corporate Research Center, Forskargränd 7, Västerås 721 78, Sweden
[b] Linköping University, Division of Machine Design, Linköping 581 83, Sweden

HIGHLIGHTS

- Introducing a generic experimental method to verify finger design automation approaches.
- Proposing methods to examine stability and performance of fingers.
- The proposed experimental method is applied on fingers designed by existing finger design automation methods.
- Results are comprehensively analyzed and compared.

ARTICLE INFO

Article history:
Received 16 January 2017
Accepted 20 April 2017
Available online 8 May 2017

Keywords:
Grippers
Fingers
Design automation
Robotics
Experimental method

ABSTRACT

Design automation of industrial grippers is a hot research topic for robot industries. However, literature lacks a standard experimental method to enable researchers to validate their approaches. Thus, this paper proposes a generic experimental method to verify existing finger design approaches. The introduced method is utilized to validate the methods Generic Automated Finger Design (GAFD), Manually Designed Fingers (MDF) and the eGrip tool. Experimental results are compared and the strengths and weaknesses of each method are presented.

1. Introduction

Robot fingers play a crucial role in success and performance of workcells as fingers are the only interfaces that connect the robot to the physical working environment. Fingers are responsible for grasping and manipulating workpieces without dropping or damaging them [1]. Therefore, designing fingers to accomplish assigned tasks is tremendously complex and requires high skills in robotics and designing at the same time [2].

Today, there is an obvious trend toward products with short lifecycles. As a result, many robot industries have been focusing on enhancing the competitiveness of robotic automation in the agile market. *SARAFun* ([3]) and *Factory-in-a-day* (Factory-in-a-day, 2016 [4]) are two large European Commission projects which are formed to enable a non-expert user to integrate a robot system for an assembly task in one single day. Currently, functional fingers industrial grippers (e.g. parallel-jaw) are designed manually, a process that requires several exhaustive and time consuming trial and error iterations even for highly skilled specialists. The average iteration time is about three to four working days and the total time for designing fingers can amount to around two weeks depending on the complexity requirements.

The present iterative procedure of manual finger design is unable to fulfill the demands of "burst" production (i.e. ramp up to full volume in very short time, run production for 3–12 months, and then change to produce a new product). Thus, finger design automation has been increasingly attracting the attention of the robot industry. However, very few researchers have been studying finger design automation and unfortunately no one has validated the proposed approaches with a generic experimental method [5]. In earlier work [6], Generic Automated Finger Design (GAFD) is proposed as a general approach to overcome drawbacks of the existing methods.

To this end, this paper proposes a generic experimental method in order to validate and benchmark GAFD. This work aims to encourage future studies to use the proposed generic experimental methods or further improvements of it, in order to enable scholars to verify their proposed frameworks and to be able to compare

* Corresponding author at: ABB, Corporate Research Center, Forskargränd 7, Västerås 721 78, Sweden.
E-mail address: mohammadali.honarpardaz@se.abb.com (M. Honarpardaz).

http://dx.doi.org/10.1016/j.robot.2017.04.011

results. The GAFD method is benchmarked against manually designed fingers by specialists, and relevant and available finger design automation methods.

The remainder of the paper is divided into sections as follows: Relevant Work section reviews the related works and the Method section describes the utilized methodology. Results are presented in the Result section, and the stability and performance of the fingers designed by GAFD and existing approaches are compared in the Discussion.

2. Relevant work

Although the importance of experimental verification has been highlighted by several scholars in the finger design research domain, very few studies have physically validated their proposed approaches [7–9]. One of the major reasons is the difficulty of accessing expensive robotic hardware such as manipulator, controller, vision system, etc. In addition, executing physical experiments requires high skills and knowledge in robot operation and experimental methodologies.

Unfortunately, almost none of the handful of studies that physically validated their approach, provide detailed information about the process of the experiment [8,10–14]. As a consequence, it is impossible to replicate the experiments and compare the results. Therefore, this work tries to initiate a mainstream method to enable scholars to compare future studies in this field.

Antony [15] points out important factors for conducting industrial experiments with quality characteristics. Quality characteristics, or response parameters, are features related to the requirements of an experiment. He encourages the following quality characteristics should be:

- Possible and simple to measure during the experiment.
- Continuous variables rather than Boolean variables with only two outcomes.
- Measurable precisely and accurately with a correct method and equipment.

According to Antony [15] and Costa et al. [16], a methodology for design of experiments may involves four phases; *planning, designing, conducting* and *analyzing*.

Planning phase

Antony [15] describes that selecting suitable responses for an experiment is critical to success of any experiment. Variables such as length, diameter, width, strength, viscosity etc. are generally better at providing information than attribute answers like pass/fail, yes/no and better/worse. The response value must be well formulated to provide valuable data for the aim of the experiment [16]. In this phase, the methodology employed for interpreting and collecting experiment data should also be considered and selected to ease the designing phase of the experiment.

Designing phase

This phase includes the following steps:

1. Designing experiments that concludes the defined response parameter.
2. Selecting the most appropriate designs for experiments.
3. Defining a design database which contains list of equipment, settings, order of running, etc.
4. Determining the principle of replication or iterations of experiment. Iterations of the experiment may eliminate certain deviations in the data that are caused by external parameters. By performing iterations, deviations in the data that are caused by external parameters may be eliminated and a statistical verification achieved [15].

Jørgensen et al. [17] recommend to avoid complex experiments with large amounts of statistical tests. It is important to keep the design of the experiment simple and transparent and also utilize understandable variables.

Conducting phase

In this phase, the experiment is conducted and results are gathered. Costa et al. [16] recommends documenting a test plan initially in order to preparing for every essential step in the actual experiment. Antony [15] mentions several significant considerations prior executing an experiment, such as environmental conditions, availability of materials, etc.

Analyzing phase

After performing the experiment, the next phase is to analyze and interpret the results so a valid and correct conclusion may be made. There are certain objectives, according to Antony [15], which can aid in the process:

- Clarifying the process variables that affect the mean process performance.
- Obtaining the process variables that affects the viability of performance.
- Determining the relation between the quality of the results and number of iterations.

Experiments that are executed in this study follow the experiment methodology proposed by Costa et al. [16] and Antony [15].

3. Proposed method

This section describes the methodology that is utilized in this article to facilitate fair benchmarking of the proposed GAFD method against existing approaches in the robot finger design research field. As illustrated in Fig. 1, the proposed method begins by designing the fingers and measuring the total design process time, then stability of the fingers is measured by conducting force and torque experiments. In the next step performance of the fingers is evaluated by pick-and-place and assembly experiments. In the last step, the footprint of the fingers is measured.

3.1. Design process time

The lead-time process of designing fingers plays an important role in comparing different finger design methods as the main purpose of design automation is to reduce the design lead-time. The design process time considers only the amount of time spend on designing fingers and it does not take the preparation and manufacturing time in to account.

3.2. Grasp stability verification

Grasp stability plays an essential role in the throughput of a robot workcell. Fingers with a more secure grasp can move workpieces with higher acceleration and deceleration, thus reducing cycle time and increasing throughput. The ideal finger design fully encompasses the workpiece (form-closure), yet it is infeasible in the most cases. Therefore, the stability of the grasp relies on upon friction (force-closure). In this work, two experimental methods are used to measure the stability of grasps. The first experiment measures the maximum disturbance force that grasps can resist without any slippage. The second method measures the maximum disturbance t that grasps can withstand before slipping.