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Adaptive neuro-fuzzy prediction of grasping object weight for passively compliant gripper

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ABSTRACT

The development of universal grippers able to pick up unfamiliar objects of widely varying shapes and surfaces is a very challenging task. Passively compliant underactuated mechanisms are one way to obtain the gripper which could accommodate to any irregular and sensitive grasping objects. The purpose of the underactuation is to use the power of one actuator to drive the open and close motion of the gripper. The fully compliant mechanism has multiple degrees of freedom and can be considered as an underactuated mechanism. This paper presents a new design of the adaptive underactuated compliant gripper with distributed compliance. The optimal topology of the gripper structure was obtained by iterative finite element method (FEM) optimization procedure. The main points of this paper are in explanation of a new sensing capability of the gripper for grasping and lifting up the gripping objects. Since the sensor stress depends on weight of the grasping object it is appropriate to establish a prediction model for estimation of the grasping object weight in relation to sensor stress. A soft computing based prediction model was developed. In this study an adaptive neuro-fuzzy inference system (ANFIS) was used as soft computing methodology to conduct prediction of the grasping objects weight. The training and checking data for the ANFIS network were obtained by FEM simulations.

1. Introduction

Significant efforts have been made to find gripper designs simple enough to be easily built and controlled, in order to obtain practical systems. To overcome the limited success of the early designs due to the cost of the control architecture a special emphasis has been placed on the reduction of the number of degrees of freedom, thereby decreasing the number of actuators. The strategy for reducing the number of actuators while keeping the hand capability to adapt its shape to the grasped object is referred to as underactuation. Papers [1–6] show that underactuation allows reproducing most of the grasping behaviors of the human hand, without augmenting the mechanical and control complexity.

A mechanism is said to be underactuated when it has fewer actuators than degrees of freedom. In order to achieve this goal, passive elastic elements are used. The transmission mechanism used to achieve such a property must be adaptive, i.e. when one or more fingers are blocked, the remaining finger(s) should continue to move. When all the fingers are blocked, the force should be well-distributed among the fingers and it should be possible to apply large grasping forces while maintaining a stable grasp.

Due to the multiple degrees of freedom of a single compliant joint, any compliant mechanism [7–13] can be considered as an underactuated mechanism. Finger compliance allows the gripper to passively conform to a wide range of objects while minimizing contact forces. Passive compliance offers additional benefits, particularly in impacts, where control loop delays may lead to poor control of contact forces. Compliance can also lower implementation costs by reducing the sensing and actuation required for the gripper.

The primary task of this study is to design one compliant underactuated gripper: for any shape of the gripping object, with passive compliance, with one active input and multi-output gripping surface, as a fully compliant mechanism with distributed compliance

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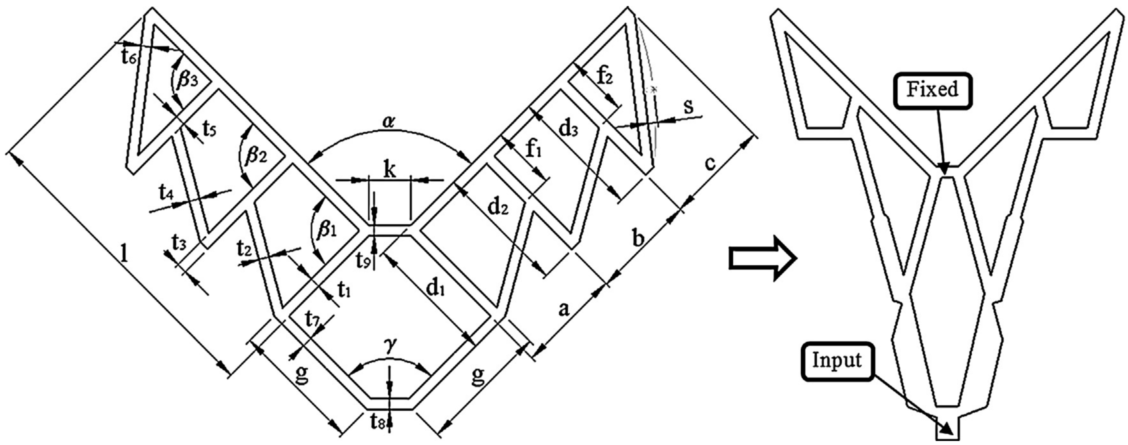

Fig. 1. (a) Initial and the (b) final structure topology of the gripper with all variable parameters.

and with one embedded sensor. The optimal topology structure of the adaptive gripper is obtained by iterative FEM optimization procedure. The main advantages of compliant mechanisms are that they can be built using fewer parts, require fewer assembly processes and need no lubrication. Special care must be taken, however, in designing compliant mechanisms in order to obtain sufficient mobility and safety against failure due to fatigue.

In article [20] we used adaptive neuro-fuzzy inference system (ANFIS) methodology to create controller for input displacement control of the gripper according the grasping object shape. Afterwards in article [31] we performed kinetostatic analysis of the gripper mechanism. The main goal of this investigation will be to establish a neural network based prediction model of the grasping objects weight. Artificial neural networks (ANNs) are flexible modeling soft computing tools with capabilities of learning the mathematical mapping between input and output variables of nonlinear systems. One of the most powerful types of neural network system is ANFIS [14]. ANFIS shows very good learning and prediction capabilities, which makes it an efficient tool to deal with encountered uncertainties in any system. ANFIS, as a hybrid intelligent system that enhances the ability to automatically learn and adapt, was used by researchers in various engineering systems [15–21]. So far, there are many studies of the application of ANFIS for prediction and real-time identification of many different systems [22–24]. In [25] the effectiveness of predicting non-uniformity of the wafer surface with ANFIS was investigated under conditions of the three process parameters. A developed finite element method was used to obtain the training data and testing data about non-uniformity on wafer surface. A neuro-fuzzy model was utilized to predict the hardness and porosity of shape memory alloy in [26]; the ANFIS model predicted the variations of the porosity content and hardness of the synthesized shape memory alloy. Article [27] presented an improved ANFIS with self-feedback for the applications of time-series prediction. An ANFIS model is applied to predict the flow stress in hot deformation process of Ti6000 alloy in [28]. In [29] optimum cure time of the rubber compounds are predicted using ANFIS model. Various principles of the neural network approach for predicting certain properties of polymer composite materials are discussed in [30].

Fuzzy Inference System (FIS) is the main core of ANFIS [32–38]. FIS is based on expertise expressed in terms of 'IF–THEN' rules and can thus be employed to predict the behavior of many uncertain systems. FIS advantage is that it does not require knowledge of the underlying physical process as a precondition for its application. Thus ANFIS integrates the fuzzy inference system with a back-propagation learning algorithm of neural network. ANFIS model will be established in this study to predict the grasping object weight in relation to embedded sensors stress. The experimental training and checking data for the ANFIS network are obtained from experimental analysis. The ANFIS prediction will be compared to the experimental results.

2. Gripper structure topology

To investigate the behavior of the fully compliant underactuated adaptive gripper, many FEM simulations of the different gripper designs were performed for every design parameter changing. Fig. 1(a) shows the initial gripper topology and all parameters which were altered. The initial gripper topology was obtained according to current gripper models from references [2–6]. The FEM simulations were made to determine and verify the design of two target functions for the gripper, concave and convex shapes. According to these, the gripper should accommodate to these two main shapes. Besides, the accommodation of the gripper to many other shapes of a grasping object was verified. Only the fully compliant mechanism could establish the adaptable behavior of the gripper. Table 1 presents all optimization parameters with their ranges, initial values, optimal values and the changing increments. Some parameters were unchangeable, while some parameters depended on other parameter. After the verification, many FEM simulations for the cylindrical object with the radius $r = 25$ mm were performed. The final structure topology of the gripper is shown in Fig. 1(b). The entire FEM analysis was performed in ABAQUS software with following parameters and characteristics:

- grasping object as explicit discrete rigid element,
- finite element type for grasping object R3D4: a 4-node 3-D bilinear rigid quadrilateral, 1 mm size,
- gripper material: ABS plastic (mass density 1250 g/mm^3, Young's modulus: 2.3 GPa, Poisson's ratio: 0.37),
- solid and homogeneous section for the gripper,
- gripper as explicit 3D stress element,
- finite element type for the gripper C3D8R: an 8-node linear brick, reduced integration, hourglass control, 1 mm size.

According to the FEM simulations, it was proven that the gripper could accommodate to the different shapes and sizes of the grasping objects. Fig. 2 shows the verification of the gripper behavior for seven different shapes and sizes of the grasping objects.

After the optimization process, some small parts (holes, edge rounding, fixing part, etc.) were added according to manufacturing requirements. Fig. 3 shows the main gripper features. These are: