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Analyzing of flexible gripper by computational intelligence approach

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ABSTRACT

Adaptive grippers should be able to detect and recognize grasping objects. To be able to do it control algorithm need to be established to control gripper tasks. Compliant underactuated mechanisms with passive behavior can be used for modelling of adaptive robotic fingers. Undearactuation is a feature which allows fully adaptability of robotic fingers for different objects. In this study gripper with two fingers was established. Finite element method (FEM) procedure was used to optimize the gripper structural topology. Kinetostatic model of the underactuated finger mechanism was analyzed. This design of the gripper has embedded sensors as part of its structure. The use of embedded sensors in a robot gripper gives the control system the ability to control input displacement of the gripper and to recognize specific shapes of the grasping objects. Since the conventional control strategy is a very challenging task, soft computing based controllers are considered as potential candidates for such an application. The sensors could be used for grasping shape detection. Given that the contact forces of the finger depend on contact position of the finger and object, it is suitable to make a prediction model for the contact forces in function of contact positions of the finger and grasping objects. The prediction of the contact forces was established by using a soft computing (computational intelligence) approach. To perform the contact forces estimation adaptive neuro-fuzzy (ANFIS) methodology was used. FEM simulations were performed in order to acquire experimental data for ANFIS training. The main goal was to apply ANFIS network in order to find correlation between sensors' stresses and finger contact forces. Afterwards ANFIS results were compared with benchmark models (extreme learning machine (ELM), extreme learning machine with discrete wavelet algorithm (ELM-WAVELET), support vector machines (SVM), support vector machines with discrete wavelet algorithm (SVM-WAVELET), genetic programming (GP) and artificial neural network (ANN)). The reliability of these computational models was analyzed based on simulation results.

1. Introduction

Robotic grasping system is the most important task for robotics. Gripper is the key of the robotic grasping system. The gripper should be designed and controlled in order to make safe grasping of fragile and objects with different stiffness and shapes. One of the solution is to use flexible gripper structure to ensure safe grasping of any objects [1,2]. Grasping of objects is a standout amongst the most incessant subjects to manage in mechanical autonomy owe to the necessity of moving or controlling diverse items. In spite of the various benefits of the grasping techniques developed to realize grasping processes, their current limitations make them expensive and with low flexibility. The key point in the getting a handle on framework is the gripper. The gripper execution is exceptionally vital when delicate objects of distinctive firmness and shapes are controlled and thus a solid power control is critical. This issue could be overcome with the utilization of deformable or adaptable fingers which enhance the restricted competencies of mechanical unbending fingers [1,3].

The requirement for flexible fingers is the ability to make safety grasps, detect and recognize objects [4–7]. Their modalities of applications differ highly from conventional grippers since conventional grippers are equipped in a domestic environment and are usually not intended for repetitive tasks that require high precision or strong force. For such purposes, when conventional grippers must be equipped with sensors, vision sensors are popular choices [8–12]. However, they may have limitations in such environmental conditions as in darkness, in very dirty or dusty situations, in foggy conditions, or even underwater. The goal of paper [13] was to consider the synthesis of learning impedance control using recurrent connectionist structures for on-line learning of robot dynamic uncertainties in the case of robot contact tasks. The problem of vision-based robotic grasping was established in [14] where the goal was the development of a robot arm that can

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stably grasp unknown objects in real time by using visual information and visual feedback. In paper [15] was addressed object recognition for a mobile robot which is deployed in a multistory building where a neural network based retrainable framework was proposed for object recognition, which consists of four components—preprocessing, binary classification, object identification, and outlier rejection. In article [16] was considered the problem of force and position regulation for a robot finger with a soft tip in contact with a surface with unknown geometrical characteristics. Article [17] described the force control of a robot gripper that is modeled on the basis of human grasping schemes. A feedback control law was proposed in [18] for regulating the contact force exerted by a very lightweight single-link flexible manipulator when it comes into contact with a motionless object. Being equipped with embedded sensors [19] is a good choice because the information of object properties is directly provided with the influence of the environmental condition. Embedded sensors also offer great potential for improving the grasp synthesis in object recognition and manipulation due to their good sensitivity and capability of detection and recognition of grasping object. The embedding sensing capability allows changing the gripper manipulation strategy in real time to achieve an adaptive grasp.

So far there are many different applications of sensors in robotic grippers. In papers [20,21] was developed a robotic gripper with mounted sensors on fingertips of two robotic fingers. Tactile sensing-based control algorithm in the robot finger was developed to control fingertips movements by defining optimum grasp pressure and perform re-push movement when slippage was detected. In paper, we present a tactile-array sensor based on flexible piezoresistive rubber was presented in [22] and it was demonstrated in active object-classification method. It was found that the mistakes that the classification method makes using the sensor were sensible. Paper [23] shown that the various sensors can be modeled ranging from tactile sensors to human-like touch. A direct process to classify contact impressions of objects gripped by a robot hand was presented in [24] where the information about the type of contact allows the selection of the most appropriate manipulating strategy to handle the grasped object. Preliminary experiments in [25] demonstrated the ability of the sensorized gripper system to detect binary tactile images of several different objects. Paper [26] presented that generating graspability maps based on scanning the object's surface rather than the volume about the object leads to a large reduction in computation time with little loss in map quality.

If one mechanism has fewer active inputs than degrees of freedom, one can say that this mechanism has underactuated principle. Passive elastic elements could be used to achieve underactuated mechanism principle. These elements should reduce the not actuated degrees of freedom of the mechanism. Also, the underctuated mechanism has to have adaptive transmission mechanism i.e. when one finger phalange is blocked, the other phalanges should continue to grasp the object. If all the phalanges are stopped, the contact forces of the all phalanges should be uniform distributed through all the phalanges [27–31].

Paper [32] suggested that a robotic index finger prosthesis realized to be one degree-of-freedom by using stackable double 4-bar mechanisms and the slider crank mechanism. The proposed mechanism has several advantages; first, electrical components such as actuator and sensor could be separated from mechanical components; second, it could be fabricated structurally strong by stacking the 4-bar mechanism; third, it could be designed to be implanted in the living hand. A multi-degree of freedom robotic forceps manipulator was developed in article [33]. A new bending technique was developed with a screwdrive mechanism, which allows for omnidirectional bending motion by rotating two linkages. The screwdrive mechanism, termed double-screw-drive mechanism, was utilized in a multi- multi-degree of freedom robotic forceps manipulator for laparoscopic surgery. The problem about synthesis of an adaptive gripper with simplified structure is formulated and solved in article [34]. The synthesized gripper is mainly oriented to automatic manipulation devices. The method of kinematicly equivalent four-bar mechanisms, is applied for determining the first transfer function, respectively the grasping force values.

To improve the grasping and contact capabilities of the underactuated fingers, it is essential to analyse a finger grasp. Screw theory [35–37] can be used for contact analysis of the underactuated robotic finger. Screw theory can describe the contact conditions of the underactuated finger's phalange. The proposed finger structure in this study has torsional springs which are implemented in the every finger joint and two phalanges. The main goal of the study is to establish a soft computing based prediction model for the finger contact forces estimation in relation to contact positions of the finger with grasping objects.

Soft computing or computational intelligence tools are modeling tools which can learn the mathematical mapping between input and output parameters of nonlinear systems. According to Zadeh [38], soft computing is an emerging method which is similar with human intelligence for handling the imprecision and uncertainty. There is a need for a system that can analyze grasping forces of the robotic fingers.

Nowadays, modern computational methodologies are applied in many real problems. One of the methodologies is artificial neural network (ANN), which is applied in different engineering fields [39,40]. ANN can handle highly nonlinear problems by different training algorithms.

In this study the main goal was to make fully compliant gripper instead of adding discrete elastic elements. Finite element method (FEM) procedure is applied to optimize gripper structural topology. This procedure was known as kinematic procedure [41–46]. After the optimizing the gripper structural topology the next step was to add sensor elements in this gripper structure. These sensors could be used to perform many different measurements of the gripper characteristics. A gripper with embedded sensors was examined in this article to ensure optimal functioning of the gripper. The main aim is to optimize optimal input displacement of the gripper in regard to grasping object shape. The signals from embedded sensors were used for estimation of the grasping object shapes and therefore for optimal input displacement prediction. Aiming at ensuring optimal functioning of the gripper, many soft computing techniques are used today such as the fuzzy logic (FL) [47,48], ANN [49], neuro-fuzzy [50,51] and support vector machines (SVM) [52,53]. The basic idea behind the soft computing methodology is to collect input/output data pairs and to learn the proposed network from these data. Adaptive neuro-fuzzy inference (ANFIS) is one type of ANN models [54]. ANFIS has high learning and prediction capabilities which have implemented fuzzy logic. ANFIS was used so far in many engineering systems for control, modelling and prediction purposes [55–66]. Fuzzy logic is the main part of ANFIS. The main advantage of fuzzy logic is it not requires knowledge of physical process as a precondition [67–73]. Sensors of conductive silicone rubber are implemented in finger structure [74]. Experiments are performed with the gripper in order to extract training data of the soft computing methods.

The objective of this article investigation is to establish an ANFIS for estimation and prediction of the optimal input displacement of and adaptive robotic gripper. An attempt is made to retrieve correlation between measured input displacements and embedded sensors voltage changing in regard to optimal input displacement of the gripper. The intelligent algorithm is based on embedded sensors voltage changing to perform tasks of detection and recognition of a grasping object. The fingers of the robot gripper were equipped with embedded sensors of conductive silicone