Self-adaptive Stable Grasp of Two-finger End-effector: A Review

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Abstract. There have been growth demands for two-finger end-effector in agricultural and industrial because of the simple structure and control strategy. This paper reviews the human grasp behaviour, design of two-finger end-effectors, and research on self-adaptive stable grasp control. Human grasp behaviors such as grasp pattern and self-adaptive grasp provide useful information for humanoid two-finger end-effector. Most of the two-finger gripper and intelligent grasp strategy are focused on the stable grasp for regular object at present time. The self-adaptive stable grasp strategies of two-finger end-effector are presented by force-closure grasps strategy, contact stability grasp strategy and grasp synthesis strategy. Self-adaptive stable grasp synthesis strategy should consider the influence factor include geometric of contact surface and interaction of center of mass. In addition, the future work on two-finger self-adaptive stable grasp for 3D irregular object and 3D soft object is also reviewed.

1. Introduction
The end-effector contacts with the object directly and grasp when a robot is working. With the increasing demand for specialized robots in coal mine rescue, submarine salvage, military reconnaissance, utilization of nuclear power and space exploration. There are some robot hands which were developed by imitating the characteristics of human hand[1], such as Utah/MIT and NASA multi-finger dexterous robot hand[2-3]. However, the multi-finger robot hand increases the difficulty of operation. To simplify the mechanical structure and controlling of robot hand, various of two-finger end-effectors are developed to perform a stable grasp[4-5]. The unstructured environment becomes a great challenge to grasp irregular object stably for a two-finger end-effector. Human hand can choose the grasp pattern, grasp area and control grasp force based on the geometrical and physical information of objects to self-adaptive stable grasp any objects accurately with the assistance of eyes. Therefore, the human hand provides a demonstration for the research of two-finger end-effector. How to develop the self-adaptive two-finger end-effector like human hand is of great important for increasing the successful rate of grasping and the intelligent level of robot.

To improve the intelligence of two-finger end-effector, the most appropriate set of contact points were chosen by neural network and grasp synthesis strategies when two-finger end-effector grasping[1][6-7]. The two-finger end-effectors were developed and can stable grasp some special 2D or 3D objects mainly based on force-closure and neural network grasp control strategy[8-9]. However, they are still insufficient to achieve self-adaptive stable grasp for irregular object in unstructured environment.

This paper discussed the self-adaptive stable grasp of two-finger end-effector. The key issues were provided about the self-adaptive stable grasp: (a) the mechanic design of two-finger self-adaptive end-
effector; (b) the grasp pattern and the influence factor of two-finger end-effector; (c) the self-adaptive stable grasp strategy. The remainder of this paper is structured as follows: Section 2 provides the exploration of the human grasp behaviour. The development details of two-finger end-effectors were presented in section 3. Section 4 described the intelligent grasp strategy of two-finger end-effector. Section 5 presented the research of self-adaptive grasp synthesis strategies of two-finger end-effector. Finally, section 6 drew some conclusions and future research directions of two-finger self-adaptive stable grasp.

2. Human grasping behaviour
The procedure of human grasping an object is shown in Figure 1: (1) location and sensing the object by vision system; (2) CNS process information that from vision system; (3) CNS choose the pre-grasp pattern; (4) tactile afferent information is translated to CNS; (5) CNS gives stable grasp control strategy and control the hand to execute the stable grasp. The human grasp behaviour gives a significant guideline of self-adaptive stable grasp of robot.

2.1. Analysis of human hand grasp pattern
Human forms rich experience of object grasping during they interact with the environment long-term. The different postures present different degree of contact and distribution of force to make sure a stable grasp[10]. Human grasp pattern was termed as precision grasp and power grasp by Napier and further classified into 10 postures, the factors that influencing the posture such as shape, size and other physical characteristics are also presented [11]. More complete grasp taxonomy was given by the construction of an expert system according to the task and the shape of rigid objects [12].

![Figure 1. The procedure of human grasping.](image)

![Figure 2. Gasp pattern analysis for different object properties[13].](image)
finger grasp pattern and its influence factors was presented. The human grasp patterns taxonomy may provide useful information for grasp pattern classification of two-finger gripper.

2.2. Self-adaptive grasp based on human hand

Human hand is the most original tool that can grasp arbitrary objects with better self-adaptive. Each hand consists of 27 bones with at least 23 degrees of freedom at the joints[16]. The TM and MCP joint has 2 degrees of freedom (DOF), DIP and PIP joint has 1 DOF(Figure 3). Other fingers have the same kinematic chain of the index finger[17]. The contraction of extensor web (Figure 4) makes the bones rotation at the joints and forms an optimum configuration when grasp an object. In addition, the grasp force is always lead to deformation of the skin of finger when grasp a soft object and both deformation of the object and muscle of finger exist to achieve self-adaptive grasp[18]. Research showed that the anatomical structure and characteristics of human thumb-index finger provided important enlightenment of self-adaptive robot hand. The thumb circumference, index finger circumference, and fingertip span had significant effects on the probability of stable thumb–index finger power-grasp[19].

Figure 3. Kinematic model of human hand [17]. Figure 4. Extensor web of the index finger [16].

3. Development of two-finger end-effector

Most of two-finger grippers are designed by two jaws with curved or plate surface, these grippers are only used during fruit harvest or special shape objects[4-5]. The two-finger multi-link gripper was designed to adapt the shape of object. Manz et al.[20] presented a two-finger gripper (Figure 5) that actuated by only one motor, a tendon-mechanism is used to connect the motor and winding shaft which guided the two tendons to adjust the movement of each finger and grasp the different size and shape of object. Belzile and Birglen[21] presented a two-finger compliant self-adaptive gripper, each finger had three phalanges, the rotational springs were mounted on each phalange to equilibrate the actuation force of motor and transmit the force by planetary gearbox, pulley and nylon cable in turn and adapt the size and shape of object.

These grippers can achieve the stable grasp for regular object, however, a two-finger hand like human thumb-index finger is necessary to self-adaptive grasp an irregular object. Thus, the bionics design such as structure, size and material of two-finger robot hand would be useful to improve the grasp performance.

Figure 5. Two-finger adaptive gripper[20].

4. Intelligent two-finger grasp strategies

Intelligent control is increasingly used in robot grasp to improve the grasping efficiency. The intelligent control system included hand system, sensor system, and hand control algorithm[22] and
formed a coordination mode like human hand-eye coordination grasping. There have been studies highlighting two-finger grasping which mimic human intelligence so that it can replicate human grasp behavior. The neural network (NN) and fuzzy neural network (FNN) control strategy are used to training the mapping between object characteristics and stable two-finger grasp.

Grasp strategies based on NN were used to optimize grasp point, hand configuration and grasp force according to the different shape, size of objects and hand structure. Moussa[23] presented a strategy that combing expert NN and reinforcement feedback with the input geometric and spatial information of object to locate the contact points of grasp, this strategy can be applied to grasp the arbitrarily shaped objects. Bodenhagen et al.[24] presented an autonomous generated evaluated grasps to create and evaluate grasping hypothesis, increase the success ratio of grasps by hybrid of RBF network and NN method based on the co-planar and co-colour 3D contours during two-finger grasp. To deal with the fuzzy information of grasp, the FNN provided an intelligent strategy, this strategy merged the advantages of NN and fuzzy logic to constructive a nonlinear, uncertainty grasp mapping. Chen et al.[25] presented a stable two-finger grasp strategy which controls the grasping force to prevent the object slipping, friction force and grasp force (Figure 6) were detected from tactile sensor then partially-linearized neural network was used to realize the fuzzy neural network and output the possibility of friction coefficient and object damage. Petkovic et al.[26] presented an adaptive neuro fuzzy inference strategy to control the input displacement of the two-finger gripper according to the object shape.

![Image](image.png)

**Figure 6. Control system for two-finger no damage grasp[25].**

Both of NN and FNN two-finger grasp strategies were provided to improve performance of grasps. However, no field experiments of the self-adaptive grasping for irregular and deformable objects have been reported. An advanced intelligent control strategy with multi-sensor information that considers shape, size, weight, center of mass and material of 3D object is also required.

### 5. Self-adaptive stable grasp synthesis strategies of two-finger end-effector

It is significant that investigate the two-finger grasp strategy to grasp the 3D irregular object automatically. Two basic grasp stability strategies based on geometrical information of rigid object were presented: (i) force-closure grasps strategy; (ii) contact stability grasp strategy. Force-closure was mainly used on the wrench of force and the shape of object. Nguyen[9] addressed the judgement of force-closure grasp for planar rigid 2D object. As an extension of Nguyen’s research, Faverjon and Ponce presented the two-finger force-closure grasp algorithm for 2D curved object[27]. Shapiro et al.[28] discussed the passive force-closure criterion when two-finger grasp a planar object with an external wrench, this theory provide control strategy based on the linear force-displacement law. The contact grasp stability was demonstrated to be not only related to the local geometry of fingers and objects, but also the distance between the contact points[29]. Nakashima et al.[30] provided a simultaneous control method based on the contact modeling to prevent object slipping and ensure the motion trajectory (fingers and object) the same as desired. The relation between contact geometry grasp stability, contact stiffness and grasp stability was discussed by analyzing stable grasp planar
These research provide basic stable grasp theory of 2D object, many researchers presented the grasp synthesis strategies for 2D and 3D objects to achieve self-adaptive stable grasp based on two-finger.

5.1 Grasp synthesis strategies for 2D objects

Many efforts have been paid to two-finger grasp synthesis strategies based on 2D geometry information of object. Smith et al.[32] developed an automatic grasp algorithm considering the edge of object, friction and torque about the center of mass to resistant to slipping during grasped an 2D object by parallel-jaw gripper. Christopoulos and Schrater[33] proposed B-spline functions to approximate the uncertainty planar object shape, the force-closure was used to analyse the feasibility of stable grasp by two-jaw gripper. Noohi et al.[34] presented a force-closure probabilistic roadmaps algorithm to explore the feasible motion path and contact points of polygonal objects with two wheeled-tip fingers. Li et al.[4] presented a two-finger stable grasp strategy (Figure 7) that synthesized the spatial grasp stability and contact grasp stability to predict the grasp stability of tomato fruits. These studies demonstrated that geometry properties of object is the mainly factor that construct the stable grasp. However, there is less study on the effect of center of mass for irregular 3D object. Thus, it is of great important for self-adaptive grasp strategy based on two-finger grasp.

5.2 Grasp synthesis strategies for 3D objects

The robot hand that can manipulate the object in human environment is a great challenge for the irregularities of the 3D objects. Adan et al.[38] presented a 3D MWS grasp synthesis to grasp rigid free-shapes object, and optimized the grasp contact point with respect to force-closure, direction kernel, facing angle, distance to centroid, cone curvature and safety distance of two grasp points. The position control algorithm of the two soft fingers was developed to achieve target force in stable

Figure 7. Two-finger stable grasp strategy[4].    Figure 8. The ρ-squeeze grasp[36].
manipulating cubic object[39]. Yussofu et al.[40] presented a grasp strategy to control the velocity and normal force of finger when grasp soft, medium and rigid object based on the information of tactile sensor (Figure 9a,b). Saxena et al.[41] presented a two-finger robotic grasping strategy for 3D novel objects, the supervised learning for the good grasp point was established by logistic regression modeling.

Figure 9. (a) The adaptive grasp strategy based on hardness of object. (b) Two-finger grasp test [40]. These grasp synthesis strategies were studied by considering the geometry of object, contact force and learning on contact point respectively in order to choose the stable grasp point of 3D object. However, the self-adaptive stable grasp strategies that synthesize contact force, deformation and geometry of 3D object such as curvature of the contact point and center of mass have not been reported. The two-finger self-adaptive stable grasp strategy is a core technology for soft objects with no mechanical damage and plastic deformation grasping.

6. Conclusion
The self-adaptive stable two-finger grasp should be highly adaptive for both mechanical structure and grasp strategy. The two-finger grasp has advantage both in structure and grasp control, however, less attention has been paid to grasp pattern and the factors that affect the grasp pattern for 3D irregular object during two-finger self-adaptive stable grasping. The intelligence of grasp strategy should be improved to make sure a more efficient grasping. Due to the irregularities of 3D object, the impact factor such as geometric of contact surface and center of mass should be considered for two-finger self-adaptive stable grasp. The synthesis of the geometric property, object center of mass and contact force with artificial neural network may be a key to develop the two-finger self-adaptive stable grasp algorithm for grasping 3D irregular object. Furthermore, more attention should be paid to the self-adaptive stable grasp for 3D soft object to adapt both shape and deformation automatically without any damage and plastic deformation.

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