Genetic Algorithms for Stable Robot Grasping

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***Abstract*—The goal of this paper is to propose an optimal positioning of robotic hand fingers, for a generic 3D object, to ensure stable grasping for an industrial pick and place process. The proposed strategy for optimal positioning based on genetic algorithms is presented. The grasping configuration is determined under several criteria that ensure the object stability. One criterion is based on Static Stability Margin (SSM) that takes into consideration the position of object center of mass in the polygon of support and a second criterion based on the Force Closure Grasping (FCG) taking into consideration the contact forces applied by the robotic hand fingertips. The optimal positioning algorithm results are presented to validate our proposal for a different kind of products.**

***Index Terms*—robotic grasping, genetic algorithms, pick and place, static stability, force closure grasping**

I. Introduction

Robotic grasping has thrived since few decades. In the aim of ensuring object stability, which is the goal of any used grasping strategy, several methods have been developed using diverse approaches. Some grasping configurations have been considered much better and more efficient than others when considering the system equilibrium by applying minimal forces to compensate every external ones. Avoiding too large forces allows to reduce the power for the manipulator actuation and the deformation of the manipulated object. Nguyen in [1] presents an algorithm for stable grasps construction and he proved the possibility of making stable all 3D force closure grasps. In literature, form closure and force closure conditions may be confused. The former implies stability when the contacts position ensures the object immobility and for the latter when the applied forces ensure object immobility. According to [2], [3], a grasping strategy should ensure stability, task compatibility and adaptability to novel objects. To ensure a stable grasping, analytical and empirical approaches were developed in the literature. Analytical approaches choose the manipulator configuration and contact positions with kinematical and dynamical formulation whereas empirical approaches use learning to achieve a grasp depending on the task and on the geometry of the object. Diverse analytical methods were developed to find a force closure grasp: In [4] force closure configuration for n contacts is synthesized by fixing n-1 contacts and searching the nth contact position using linear parametrization of a point on an object facet. Ding et al. [5] presented an algorithm to form force closure starting by a random configuration for grasp and checking if it is force closure. If it is not the case, the finger contact changes its position using the linear parametrization of a point on the object facet. In [6], an algorithm based on geometrical analysis was developed: the intersection of friction cones and the position of the wrench space center according to the convex hull. Empirical approaches avoid the complexity of computation by attempting to mimic human strategies for grasping. Data gloves hand were used by researchers for empirical approaches to learn the different joint angles [7], [8], hand preshape [9]. Vision based approach is also used to demonstrate grasping skills. A robot can track an operator hand for several times to collect sufficient data [10]–[12]. The proposed work uses Genetic Algorithms (GA) as optimization method to find sub-optimal positioning of robotic hand fingertips to ensure stable manipulation process. GA has been found to be a good choice in global optimization that can provide a near global solution [13], [14]. This paper is organized as follow: Section II will state the treated grasping problem. Section 3 will present the proposed algorithm architecture and steps. Section 4 will provide the simulation results of the proposed grasping process and section 5 will conclude the achieved work and announce the future targets.

II. Problem Statement

The goal of the proposed work is to develop an algorithm that allows an optimal positioning of fingered robotic hand for stable manipulation of industrial products. The proposed use-case concerns the products of company GCL international which consists of luxury bottle closures for high liquid value industry. The CAD files of different products are provided and based on Finite Element Analysis (FEA) software, a mesh presenting the products is generated. Based on this cloud of points, an algorithm will test all possible configurations that allows to ensure stable grasp while considering optimization criteria that are detailed in the next section. The production process consists of an assembly line for different products and a conveyor to transport the finished parts. A detection system that allows to recognize and classify the part allows to send

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the information related to the product pose and identification to the robot (the detection and recognition is not detailed in this work). We assume in the proposed work that the orientation of the parts between the pick and place phases is not changing.

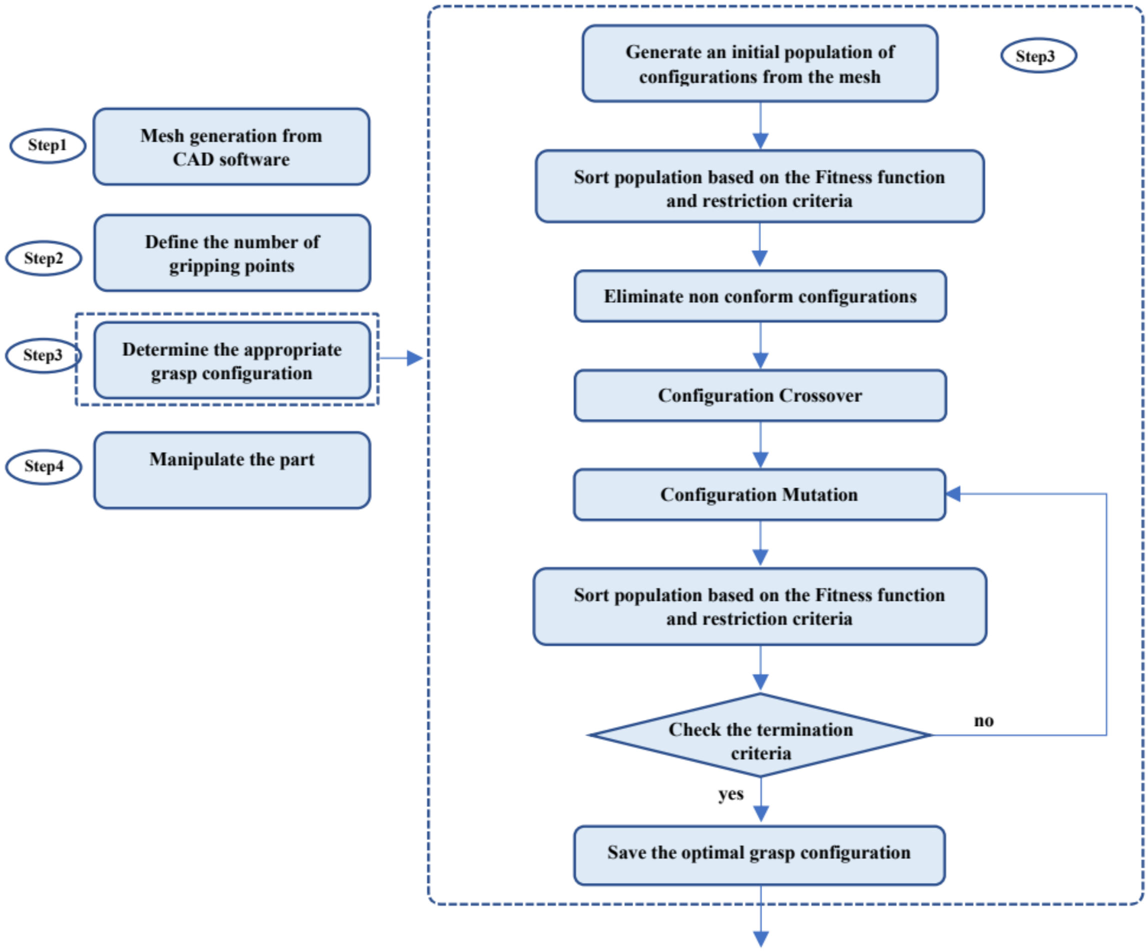


Figure 1. Flowchart of the manipulation algorithm for 3D objects w.r.t FCG and SSM criteria.

III. Overall Proposed Architecture

A. Multi Criteria Task Constraints

The proposed overall strategy of stable manipulation is presented in Fig. 1 This figure provides the required steps to find out the optimal configuration of the gripper. Step 1 is a phase based on the use of CAD software (inventor) to provide a mesh for the object to be manipulated which allows to use the different nodes generated as the set of points to test all possible configurations of grasp. This step will be developed for future work to take into consideration the deformation of the object when applying the grasping forces depending on the material properties and type of mesh. Step 2 consists of defining the gripper kinematics and number of fingertips that will be used for the grasping process. In the proposed work we consider three, four and five fingers robotic hand.

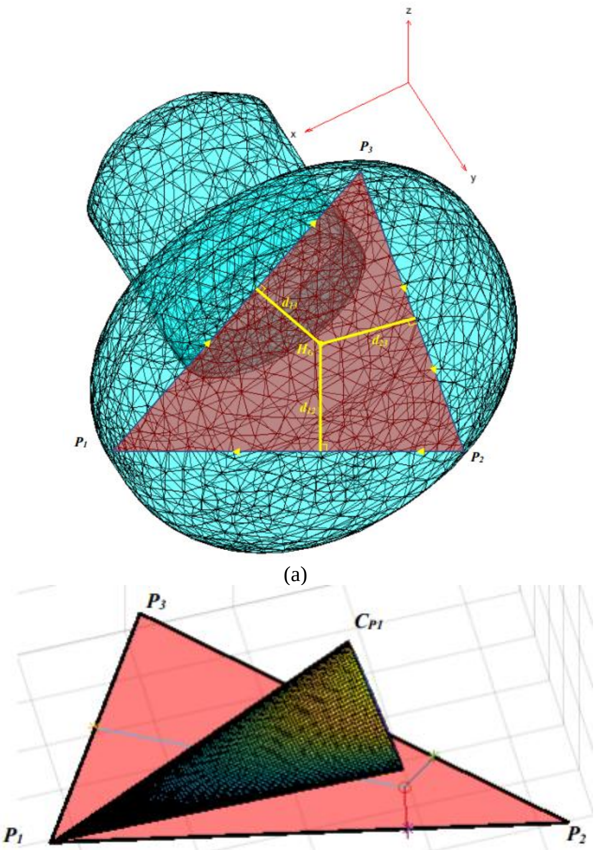
Step 3 presents the main contribution of this paper. It is detailed by the flowchart in the right side of Fig. 1 and will be precisely discussed in the next section. The algorithm considers the external shape of the object to be manipulated as a set of finite element model defined by a cloud of points generated by the CAD software. A random initial grasp from an initial population is then generated from the mesh, then, the Genetic Algorithm will provide a sub-optimal configuration. At the start, a first population of 300 to 500 configurations is generated by the algorithm randomly from the mesh. Then a fitness function based on Eq. 3 under the constraints of Eq. 1 (FCG criterion) is defined to sort the population and keep the valid configurations respecting both criteria. A Crossover between the best configurations is done and re-evaluation is processed. Multiple **mutations** come later by new nodes (points from the mesh) and a sorting is achieved by the algorithm. The **termination criteria** is defined as the Fitness Function does not or slightly change after 100 mutations. Then the algorithm generates the last best sorted configuration of the grasp. Finally, Step 4 corresponds to control the robotic hand to finalize the manipulation and pick and place process. The criteria that must be respected for stable grasping are defined in the following subsections.

B. Force Closure Grasping FCG

A grasp is considered stable when a small disturbance on the position of the manipulated object or contact force generates a restoring wrench that brings the system back to a stable configuration. FCG problem is extensively studied for objects manipulation using multi-fingered robotic hands [15]. This problem was also used for multi-mobile robots co-manipulation and transport [16], [17]. In the proposed work, 3D object manipulation is considered. According to Li et al., in [6], necessary and sufficient condition to have FCG is that the intersection of all the friction cones is not empty. In order to reduce the generated momentum around the payload Center of Mass G_{pl}, Hichri et al,. in [16] proposed to keep the projected center of mass H_{Gpl} in the polygon of support inside the projected friction cones intersection for the applied forces.

$$\sum_{i=1}^{n}(P_iG_{pl} \otimes f_{i,p,n}) = 0; \ \sum_{i=1}^{n} f_{i,p,n} = 0 \quad (1)$$

$$H_{G_{pl}} \in Convexhull(\cap C_{pm}) \| \ m = 1..n \quad (2)$$



(a)

(b)

Figure 2. Grasp polygon of support and contact force: a: support polygon formed by gripper fingertips; b: friction cone corresponding to a contact point

where n, denotes the number of contact points, C_{pi} denotes the friction cone for the contact force on P_i and $f_{m,p,n}$ is the applied normal force on the payload (cf. Fig. 3(b)).

C. Static Stability Margin SSM

Stability margins were first considered and introduced for legged walking mobile robots [18]–[20]. These criteria are adopted for robot grasping while considering the payload as the legged robot body and the contact points of feet with the ground to be the fingertips of the gripper. Static Stability Margin (SSM) is defined as the minimum distance from the center of mass projection on the ground to the boundaries of the polygon of support.

For the SSM problem, let's assume that the payload is presented by a 3D mesh with a set of nodes generated by a CAD software (cf. Fig. 3(c)).

Let $R(G_{pl}, \vec{x}_{pl}, \vec{y}_{pl}, \vec{z}_{pl})$ be the frame linked to the payload with respect to the reference frame $R(O, \vec{x}, \vec{y}, \vec{z})$. $P_{i\,/\!/(i=1..n)}$ are the positions of the contact points of the gripper fingertips, $H_{i,j}$ is the projection of the payload center of mass G_{pl} on the edge linking two consecutive points P_i and P_j and $d_{i,j}$ is the stability margin (the distance from G_{pl} to segment P_iP_j) on the same edge defined in [16], [17].

$$d_{i,i+1} = d(H_{Gpl}, (P_iP_{i+1})) \quad (3)$$

The proposed algorithm targets **to maximize the minimum** of $d_{i,i+1}$ to ensure higher stability of the manipulation process. The following assumptions are considered for the proposed work:

- The payload configuration and orientation remain unchanged during the manipulation process;
- The pick and place process is ensured in a reduced speed and only static stability evaluation is considered. Future work will include Dynamic stability evaluation for higher production rate and thus higher velocity using the robot.
- The stability criteria are evaluated by projecting the algorithm results in horizontal plane as the payload orientation remains the same and the process has a low velocity.
- The payload is represented by a set of points generated by the FEM software, only external nodes are extracted from the mesh to be processed by the proposed algorithm since the manipulation and contact forces are happening only on the object surface.
- All nodes generated by the mesh are accessible by the robotic hand fingertip.

IV. Proposal Validation


(a) (b) (c)

Figure 3. CAD models of tested products: a: product of GCL group; b: random product 1; c: random product 2.

The algorithm results were generated by an Intel Core I7 11800H CPU 2.30 GHz system for three different products (cf. Fig. 3). Fig. 4 and 5 presents the simulation results of finding sub-optimal positioning of robot fingertips to ensure stable manipulation while respecting SSM and FCG. It is shown according to the results how the algorithm generates a configuration that keeps the payload center of mass G_{pl} inside the polygon of support and inside the intersection of friction cones to reduce the generated torque about G_{pl}. The results are provided within less than 200ms. The results were also checked using the developed criterion of Liu in the study of [6]. It was demonstrated that for each configuration, the origin of the wrench space is inside the convex hull of intersection of the wrench spaces of each contact force (cf. Fig. 6). In order to test the algorithm reliability, we imported CAD model of company product which is symmetric, and we made also test on generic products with random external shapes. Fig. 3 presents the CAD files of the different tested products. Fig. 4 presents the 3D final results for three, four and five fingers grasp. Fig. 5 presents the corresponding 2D results with the contact points friction cones presented and Fig. 6 presents the corresponding wrench space for each configuration. The red polygon represents a random configuration from the starting population considered by the genetic algorithm as an initial randomly selected start configuration. The blue polygon is the final result of the algorithm specifying the positions of robotic hand fingertips that can ensure stable grasp. Table I provides the SSM value evolution from the initial random configuration to the final grasp provided by the algorithm. It shows how the SSM values are improved based on the optimization algorithm. Fig. 5 shows the position of center of mass and the intersection of friction cones which guarantee the FCG aspect and ensure stable grasp according to Li et al. [6].

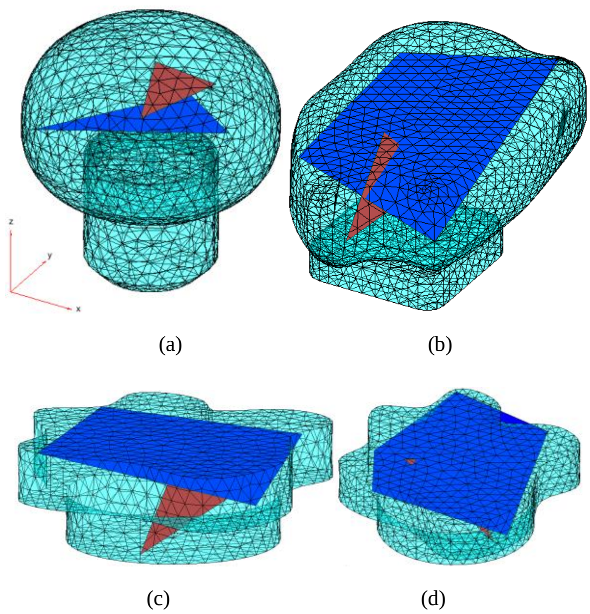


Figure 4. Algorithm results for stable grasp configuration in 3D: red: random initial configuration, blue: final grasp configuration. a: three fingers positioning; b and c: four fingers positioning; d: five fingers positioning.

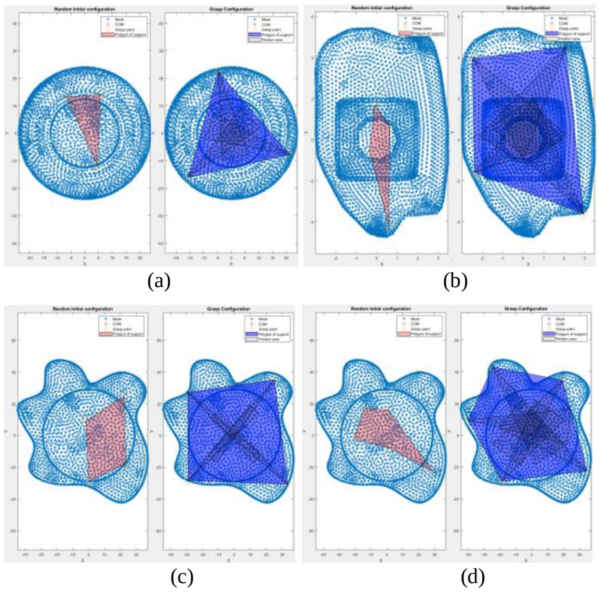


Figure 5. Algorithm results for stable grasp configuration - Top view: a: three fingers positioning; b and c: four fingers positioning; d: five fingers positioning.

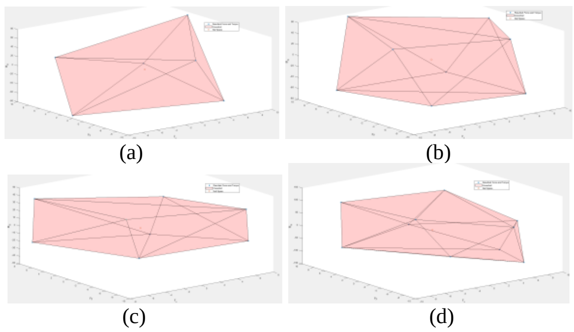


Figure 6. Grasp positioning wrench space: a: three fingers positioning; b and c: four fingers positioning; d: five fingers positioning.

TABLE I. SSM IMPROVEMENT FROM INITIAL TO FINAL GRASP CONFIGURATION

	Initial random grasp SSM	Final Grasp SSM
Fig. 5. a	0.784	10.69
Fig. 5. b	0.28	2.37
Fig. 5. c	1.38	28.98
Fig. 5. d	6.18	26.7

V. CONCLUSION

This paper presented the first results of a sub-optimal positioning algorithm based on Genetic Algorithms optimization method for stable grasping using multi-fingered robotic hand. The algorithm allows to generate a configuration of positioning of robot hand fingertips around a 3D object in a way that ensures its stability for a manipulation process while respecting Static Stability Margin and Force Closure Grasping criteria. The theory of both criteria was presented, and the algorithm steps and architecture were explained. The results of simulation for three, four and five fingers positioning were demonstrated, and the stability was checked according to Liu method [6]. The algorithm results are promising and quite fast to be adapted to industrial production rate while using industrial robots acting in higher speed pick and place process. For this, as future work we target to add the Dynamic Stability criterion in our positioning algorithm while considering the pose change between the pick and place phases which provide more restricted areas for the grasp to be taken into consideration.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

A wrote the paper under the supervision and guidance of BC; all authors had approved the final version.

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