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Development of Minimal Grasper: Preliminary result of a simple and flexible enveloping grasper

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Abstract— **In this paper, we propose a new design of a flexible enveloping grasper for pick and place tasks with the low complexity in manipulation and task planning for the purpose of practical use in the near future. Flexible material for the grasper has many advantageous characteristics inherently including robustness against manipulation errors and the ability to increase contact area with a grasped object and the grasping force. Compliance of the grasper material also contributes to reduction in complexity of the processes such as the force control, sensor-motor coordination, and manipulation by self-adaptation. Two properties, flexibility and compliance, mentioned above help the proposed grasper minimize the internal forces in a passive manner and achieve the successful force distribution with self-adaptivity when performing enveloping grasping. In order to demonstrate our work, we have constructed 2 different prototypes of flexible enveloping grasper. Experimental results validate robust performances of the proposed grasper.**

I. INTRODUCTION

As illustrated in [1] the human hand has approximately 20 D.O.F and more than 17,000 tactile sensors are distributed over the outer skin of the hand. Moreover about 40% of the motor cortex of the brain is contributed to management of the control of the hands.

In mimicry of grasping tasks of human hands, a number of researches to develop anthropomorphic dexterous hands have been executed (see, e.g., [2]–[9]). Recently Dollar and Howe suggested an impressive dexterous robotic hand using SDM fingers and joints with viscoelastic materials [8]. Anthropomorphic robotic hands are advantageous in that both the precision grasp and the power grasp are possible depending on tasks and working environment. However, the state-of-the-art anthropomorphic robotic hands are not fully satisfactory in two conflicting aspects that hinder the robotic hands from commercialization. Performance and simplicity are those aspects. By performance, we mean the ability to perform fine manipulation in stable and robust ways. And by simplicity we mean mechanical and control simplicity as well as computational simplicity which directly related to the cost of products.

Firstly, as shown in [1], numerous underactuated manipulators have been proposed as an intermediate solution (see, e.g., [3], [10]–[14]) to decrease complexities of control, manipulation, and sensor-motor coordination. However, according to [15] only the Barrett hand [4] and the Shadow Hand [9] are in commercial use while the others still stay in the research platform status. Nevertheless both hands, [4] and [9], still have a drawback in their price to be put to practical use.

(a) Prototype I (b) Prototype II

Fig. 1. 2 different grasper prototypes. All prototypes are driven by a single DC motor.

Secondly, as an effort to better imitate the human hands, a number of researchers have studied the effects of stiffness or compliance of the finger material in grasping (see, e.g., [16]–[19]). The works illustrated that the compliant material reduces the degree of complexity in control while it causes the increased friction between the grasper and the target object as a result of the increased contact area. And also self-adaptation which has many advantages in robotic hands including the ability to grasp various shapes, a lower control D.O.F required, and simple H/W implementation and sensing is expected to be accomplished by the virtue of compliance of finger material.

Different types of graspers have been proposed to improve manipulability of the robotic hands for grasping tasks. Hyper-redundant robot manipulators, (as described in [20], [21]), have merits in that they are robust against unusual environment. However, these kinds of manipulators have shown a shortcoming such that as the number of joints increases the manipulability of the manipulator decreases [21] with complex inverse kinematics and computation costs.

As mentioned in [22], it is very unrealistic to satisfy all functional requirements for the broad range of tasks at the current state-of-the-art technology with accomplishing the simplified mechanical design at the same time. And also a question, whether artificial hands should look like those of humans, raised in [22] has not been clearly answered.

As an account for the previous approach, we propose a

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Fig. 2. Prototype I detail view: the active grasping part

Fig. 3. Prototype I detail view: the passive grasping part

new design of the flexible enveloping grasper for pick and place tasks which are one of the most fundamental and frequently implemented works for robotic hands used in industry [23] by the power grasping with low control D.O.F for the purpose of practical use in the near future.

Lately, ultra low-cost asymmetric graspers [24] and the TAKO gripper [25] were suggested. However, the underlying implementation approach is different from our work in that compliance and flexibility of the grasper material is not account for. What is more, the compact size and the simple sensing, grasp planning, and control embodiment of the proposed grasper are more satisfying in the real life applications.

We expect this simple H/W implementation, control method, task planning and sensing structure to bring a considerable amount of reduction in cost and complexity. In addition, this approach can be a possible interim solution to problematic issues in commercialization of dexterous robotic hands in the not too distant future.

In the following section, we introduce 2 different prototypes of the grasper, as shown in Fig. 1, and discuss about their overall characteristics, mechanical specifications, followed by preliminary experimental results.

II. Mechanical Structure and Operational Characteristics

The Minimal Grasper, the name of the proposed grasper, comes from its simplicity in H/W configuration and sensing process that requires the minimal efforts and resources for stable and robust operations of the grasper.

A. Prototype I

The prototype I is composed of 3 major parts: an active grasping part (generally known as fingers), a passive grasping part (generally called the palm), and a controller that controls a DC motor and detects the amount of currents flowing through a DC motor.

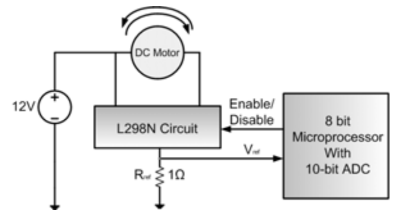


Fig. 4. Schematic of the controller

- *Active Grasping Part*: The active grasping part, shown in Fig. 2, is the part which actively creates contacts with a target object as squeezed by a DC geared motor through two identical spur gears which is one of the standard models in many fields of engineering.
  A common rubber timing belt made of polychloroprene rubber and fiberglass is used to meet the flexibility requirement and certain level of rigidity to firmly grasp various objects in real world environment. A widely used sponge which is chosen to be one of the most suitable materials for soft robotic fingers [16] is attached to the inner side of this belt to attain compliances. The sponge mainly consists of S.B.R (Styrene Butadiene Rubber) and natural rubber and both are commonly used in many industrial products such as tyres and coated papers owing to its cost-effectiveness.
  Intrinsic merits that the flexible active grasping part has over the conventional finger based robotic hands is that sensing joint torques and positions of the fingers and finding appropriate forces and wrenches to control each joint become unnecessary in this implementation simply because this grasper works without joints. In addition the active grasping part adapts itself to the shape of the grasped object while operating.
- *Passive grasping part*: The passive grasping part, shown in Fig. 3, is similar to the palm of the human hands. It does not actively create contacts with the grasped object. However, as the active grasping part squeezes, contacts between the object and the passive grasping part are constructed. It generates most of the contact surface areas which cause more friction between two objects and enhance the robustness and stability of the grasping. To increase contact surface with the grasped object, the front area of the passive grasping part is covered with the same kind of sponge attached to the active grasping part. This is a main body of the minimal grasper where most of the parts are located.
- *Controller*: A simple controller that controls a DC geared motor and measures the amount of current flowing into the DC motor is designed. The main function of the controller is to correctly control the DC motor as it grasps an object and releases the object on a target location with the right orientation. Real time control is performed by a low cost 8-bit AVR microcontroller and no additional communication channel is established other than direct wiring to a DC motor driver and a

resistor to measure the current flowing into the DC motor. Behaviors of the DC geared motor is very clear in that the direction and the speed of the motor is determined by the sign and the size of the voltage across the motor, respectively. In order to control the DC motor, a dual full-bridge DC motor driver circuit called L298N is utilized. In an effort to alleviate the number of expensive sensors such as torque, pressure, tactile, and force sensors and the computational cost to perform sensing tasks and to interpret sensing data, we simply measure the electrical current. An electrical current flowing into a general DC geared motor has a linear relationship with the torque generated by a DC motor. The current changes between different phases are represented in Fig. 7. The schematic view of the controller is given in Fig. 4.

B. Prototype II

The prototype II takes a form of a two jaw parallel gripper. The important change we add to this normal two jaw parallel gripper was a material used for contact area of the gripper.

- *Active Grasping Part*: As shown in Fig. 10, an airbag is attached to the inner side of each jaw to make use of the compliance that induces self-adaptation to a grasped object. The airbag is made of commercially distributed latex rubber balloon which is fed by an air pump[1] through rubber tubes. To avoid possible damages caused by contacts with sharp edges or points of an object, additional layer of latex rubber is added on the surface of air tubes. Besides the protection of the airbag, the cover provides more friction with a target object that prevent sliding of the object. Moreover the cover helps the airbag maintain its shape in vertical direction on grasping, where deformation of the airbag in vertical direction plays an important role in grasping. The actuation is also carried out by a single geared brushless DC motor. And torque generated is transmitted by use of two spur gears and one bar with external screw whose length and radius is 100mm and 5mm, respectively. Each jaw has a hole with an internal screw through which connected to the torque transmission system. External and internal screw mechanism enables squeezing and releasing action to occur synchronously depending on the sign of voltage across the DC motor which is operated by the controller.
- *Controller*: The prototype II also works with the same controller applied to the prototype I.

III. Grasping Procedure

Makoto et al. [26] previously defined the 3 phases of enveloping grasps for cylindrical objects inspired by human grasping. The proposed graspers are designed to form an enveloping grasp all the time regardless of the shape of an object. Therefore this categorization fits well for our work with some revisions. So, let us divide the entire grasping procedure into planning, enveloping and lifting phases.

[1]In this implementation, manually operable portable CO_2 pump is used.

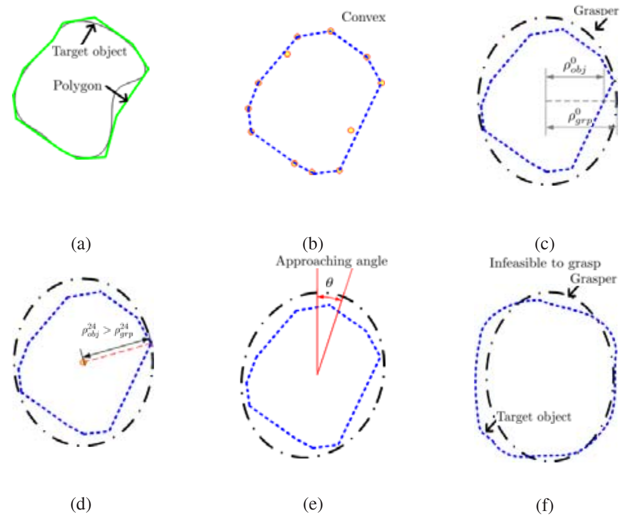


Fig. 5. Workspace of the grasper: (a) Projection of an grasped object and polygonization of the projection. (b) Construct a convex(Shown by blue dotted line) using the convex hull algorithm. Vertex of convex are shown by yellow dots. (c) Check feasibility of grasping with a given object. If feasible, calculate the approaching angle of the grasper. (d) Grasping is feasible. However the orientation needs to be modified. (e) Possible approaching angle. (f) An infeasible case.

A. Planning phase

Properties of an object are unknown in many real cases and unstructured working environment has the high degree of uncertainties that can easily cause manipulation errors such as positioning errors and force control errors. In order to get over these problems and to reach a goal of performing the optimal grasping operations, many researchers have studied the grasp planning. In this section, we will shortly mention how this grasper simplifies the grasp planning tasks to overcome uncertainties and accomplishes a successful grasping. TABLE I explains the planning phase with more details. Reminding that our goal in this paper is not to find and execute the optimal grasping with high-cost and well equipped robotic hands, as long as it shows stable grasping performances against the uncertainties and disturbances and completes a given task, we call it a successful grasp.

For the feasibility measure, we make an assumption that the grasper approaches a target object downward from the top of the object. In order to perform grasping tasks, we need to locate the grasper in a right position with a proper orientation. To confirm the feasibility of the grasping, we compare the distance from the center point of an object which is presumed to be available for a given object around its circumference of the object together to the distance from the center point of the grasper to the circumference of the grasper. We define ρ^0_{obj} and ρ^0_{grp} as a distance of the object at the virtual horizontal axis from its center point as described in Fig. 5.(c). The superscript zero indicates the angle from the horizontal line in degree. In some cases, there exist multiple number of possible grasping locations. On the other hand, as shown in Fig. 5.(d) and Fig 5.(e), the orientation of the grasper with respect to the target object

TABLE I

PLANNING PHASE

Recognition
1. Object Recognition with a video camera.
Data Acquisition
2. Data Acquisition
(a) location of an object.
(b) projection of an object.
(c) size and center of the projection.
Preprocessing
3. Polygonization for simplification (Fig.5.(a))
4. Construction of a convex of the polygon using the convex hull algorithm(Fig.5.(b))
Data Processing
5. Feasibility check
6. determining the approaching vector.

TABLE II

ENVELOPING PHASE

Approaching
1. Approach to the target object.
Enveloping
2. Squeezing starts.
3. Current Check at 40 Hz.
(a) If $I_{DCM} \geq I_{th}$ stop squeezing.

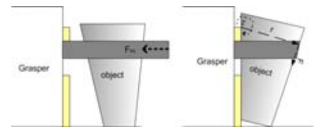


Fig. 6. self-stabilization by squeezing.

plays an important role in successful grasping. All things considered, we define the feasible grasping if the following condition is satisfied :

$$\rho^i_{obj} > \rho^i_{grp} + \rho_{th} \text{ for all } i \in [0, 360] \quad (1)$$

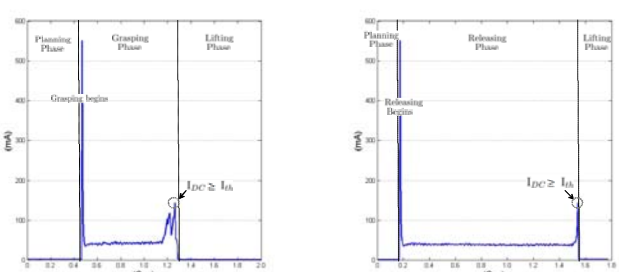
ρ_{th} is a value determined empirically. Any angles that satisfy (1), can be a candidate of the approaching angle of the grasper as depicted in Fig. 5.(e). Optimization of an approaching angle will not be discussed in this paper. Fig. 5.(f) is an illustration of an example that grasping cannot be completed successfully. By the virtue of the self-stability and the self-adaption achieved by squeezing motion and the flexible active grasping part, the grasper performs its task robust against manipulation errors. Robustness against manipulation errors enables the operation of the grasper to be fully automotive. The experimental results are given in Fig. 8. As illustrated in Fig. 2, this flexible part always constructs the closed loop around the target, and consequently force closure is achieved in a planar space. Since an object grasped by enveloping grasp stays robust to any rotational and translational disturbances in planar direction, the only concern for pick and place tasks by this grasper is a disturbances in vertical directions especially on lifting phase. This means that plenty of computational efforts to search appropriate finger positions to achieve the force closure grasp would be saved in the task planning stage which is a great advantage over other anthropomorphic robotic hands working with fingers.

B. Enveloping phase

Two main tasks in the enveloping phase are squeezing and current sensing. The fact that the active grasping part already has a closed-loop, and squeezing motion in the enveloping phase brings a great advantage in its control. As squeezing proceeds the grasper adapts itself to an object and stabilizes at some position, as shown in Fig. 6, attributed to the flexible and compliant materials of the grasper skin and a palm. Regardless of the curvature of the surface having contacts with the passive grasping part, object is reoriented in a way to maximize the contact surface with the grasper. The self-stabilization here means that it does not work out a solution of the corresponding inverse kinematics problems. Instead it constructs a stable grasp resulted from its mechanical or embodiment structure. The maximum capacity of squeeze is determined empirically. And the current change is illustrated in Fig. 7. As seen in Fig. 7, the current I_{DC} is stabilized at about 40 mA in this experiment. Fluctuation of the current at t = 1.2 sec of the grasping phase in Fig. 7.(a) can be explained that the current increase enables the grasper to gradually construct wider contact areas possible and consequently to attain successful and stable enough force distribution by the end of the grasping phase. Experimental results are given in Section V.

C. Lifting phase

The completion of squeezing is considered to be a successful enveloping grasp. Then a robotics arm to which the grasper is attached begins manipulation to properly locate the grasped object with the right orientation as planned. In experiments for this paper, however, the grasper is not operated with the robotic manipulator, but works under a manual operation by a human operator.



(a) Grasping (b) Releasing

Fig. 7. Current change readings of the Controller

TABLE III
MECHANICAL SPECIFICATION OF THE MINIMAL GRASPER

Prototype	Size (W * L (* H)) (mm)		Weight (g)	Material
	A.G.P	P.G.P		
I	150 * 110	75 * 78 (* 123)	589.0	Rubber belt
II	10 * 10	54 * 153 (* 96)	1201.0	Rubber airbag

IV. MECHANICAL SPECIFICATION

TABLE III shows the mechanical specification of the passive grasping part and the active grasping part of 2 prototypes of the proposed grasper. The size of the active grasping part (A.G.P) in Table III is assumed to be an elliptical shape and is described by a length of the major axis and a length of the minor axis.

V. EXPERIMENTAL RESULT

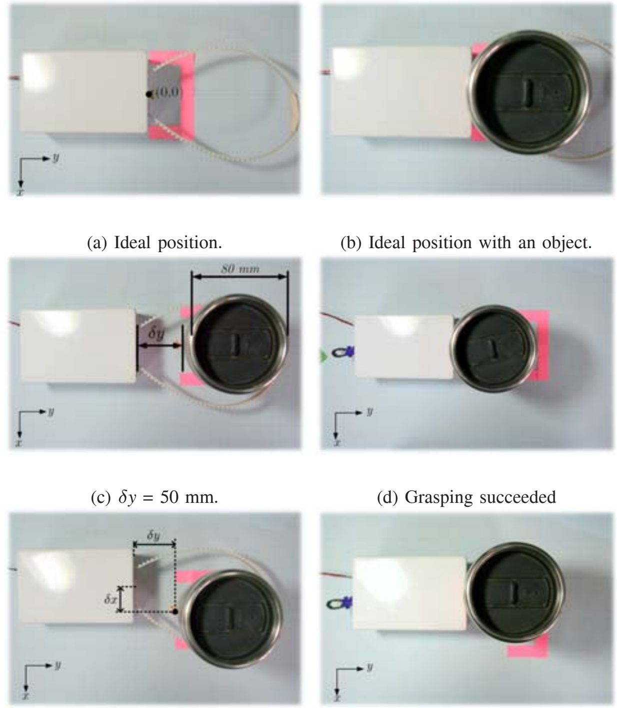
The experimental results are given in Fig. 9 and Fig. 10. Before beginning each experiment, the grasped objects were placed in the active grasping part. Ideal position for the grasping is defined as the position of an objects where no displacement of an object occurs during the enveloping phase, as seen in Fig. 8. (b). For accurate measurement, experiments were performed on a graph paper with grid resolution of 1mm . In general it shows robust grasping ability against manipulation errors. Fig 8 shows errors more than 60% of the object size in y direction and 30% of the object size in x direction have no effects on a successful grasping at the grasping velocity of 1.3 cm/s.

Fig. 9 and Fig. 10 reflect that the proposed grasper is able to grasp a wide variety of objects in different shapes in real life. The self-adaptability and the certain level of flexibility of the grasper broaden its range of application, and make the grasper work nearly independent of shape of the grasped objects. Several experiments proved that prototype I can pick and place an object of 3 kgs and prototype II can lift an object up to 1 kgs.

Some researchers have been interested in the manipulation of multiple objects by enveloping grasper [27]. Inspired by those works, we also did some experiments, grasping multiple objects based on the assumption that the target objects are feasible to grasp by the grasper. As represented in Fig. 11, multiple objects grasping tasks were successfully done under the condition that all objects are located in the working space of the grasper.

VI. CONCLUSIONS AND FUTURE WORKS

In this paper we addressed the issues that prevent the current robotic hands from commercialization and various approaches done by many researchers to overcome those difficulties. As an intermediate solution to the practical use with the current state-of-the-art technology, we propose a simple, flexible, and enveloping grasper, namely the minimal grasper. We have constructed the minimal grasper which is

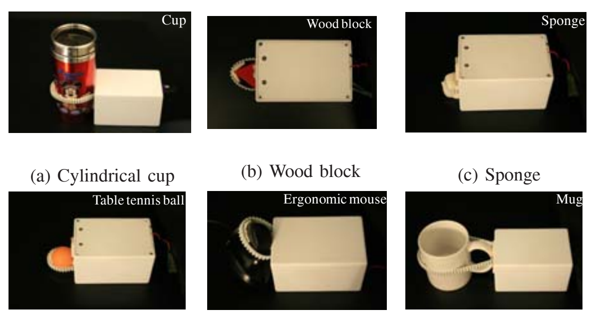


(a) Ideal position. (b) Ideal position with an object.

(c) δy = 50 mm. (d) Grasping succeeded

(e) δx = 25 mm. and δy = 50 mm. (f) Grasping succeeded

Fig. 8. Robustness against manipulation errors



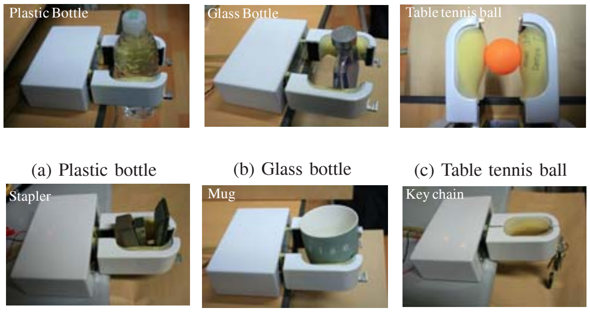
(a) Cylindrical cup (b) Wood block (c) Sponge

(d) Table tennis ball (e) Ergonomic mouse (f) Mug

Fig. 9. Experimental results I - Grasped objects by prototype I

TABLE IV
OBJECT DESCRIPTION FOR THE EXPERIMENT RESULTS I

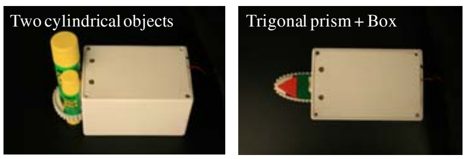
Object	Size (mm) (W*L*H)	Weight (g)	Shape primitive
Cup	80*80*180	206.59	Cylinder
Wood Block	13*13*60	9.27	Cylinder
Wood Block	27*25*24	4.98	Prism
Mug	125*80*94	369.96	Cylinder+Box
Ball	40*40*40	2.73	Sphere
Sponge	30*30*25	11.13	Box
Mouse	100*70*80	109.88	Arbitrary
Ruler	160*30*3	13.48	Plane



(a) Plastic bottle (b) Glass bottle (c) Table tennis ball

(d) Stapler (e) Mug (f) Key chain

Fig. 10. Experimental results II - Grasped objects by prototype II



(a) Two plastic cases (b) Two wood blocks

Fig. 11. Experimental Results IV - Multiple objects

able to grasp several different types of objects within 300 U.S. dollars. Two prototypes are introduced and discussed. The advantage of the prototype I is its light weight and simple control method with stable performances. The prototype II can work under various environments. Still it is heavier and air supply for the active grasping part is not available under some particular circumstances.

And the fact that every mechanical part of the grasper is commonly used one in many industrial fields has many positive points over other robotic hands when going into mass production with a great amount of reduction in manufacturing costs. The grasper also has many merits in its compact size, light weight and simple H/W implementation and control algorithms at a very reasonable cost when comparing with existing anthropomorphic robotic hands.

Even though our main goal, (which is to develop a grasper for pick and place tasks with the minimal resources and computational efforts at a reasonable cost), is achieved, it still has more rooms for improvement to be able to perform more stable and robust grasping tasks. Primarily contact force, internal force and force distribution should be discussed in depth. For the following work, we will set up a precise model of the proposed grasper to analyze the kinematics and dynamics involved. In addition the quality measure of the proposed grasper is to be studied.

VII. ACKNOWLEDGMENTS

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REFERENCES

[1] L. Birglen, T. Laliberete, and C. Gosselin, “Grasping vs. manipulating,” *Advanced Robotics*, vol. 40, pp. 7–31, 2008.
[2] J. Salisbury and J. Craig, “Articulated hands: Force control and kinematic issues,” *International Journal of Robotics Research*, vol. 1, no. 1, pp. 4–17, 1982.
[3] S. Jacobsen, E. Iversen, R. Johnson, and K. Biggers, “Design of the utah/ mit dextrous hand,” in *International Conference on Robotics and Automation*, 1986.
[4] “http://barrett.com/robot/index.htm.”
[5] F. Lotti, P. Tiezzi, G. Vassura, L. Biagiotti, G. Palli, and C. Melchiorri, “Development of ub hand 3: Early results,” in *International Conference on Robotics and Automation*, 2005.
[6] J. Butterfass, M. Grebenstein, H. Liu, and G. Hirzinger, “Dlr-hand ii: next generation of a dextorus robot hand,” in *International Conference on Robotics and Automation*, 2001.
[7] H. Kawasaki, T. Komatsu, and K. Uchiyama, “Dexterous anthropomorphic robot hand with distributed tactile sensor: Gifu hand ii,” *IEEE/ASME Trans. on Mechatronics*, vol. 7, no. 3, pp. 296–303, 2002.
[8] A. M. Dollar and R. D. Howe, “Simple, robust autonomous grasping in unstructured environments,” in *International Conference on Robotics and Automation*, 2007.
[9] “http://shadowrobot.com.”
[10] S. Hirose and Y. Umetani, “Soft gripper,” in *Proc. of ISIR*, 1983.
[11] B. Massa, S. Roccella, M. C. Carrozza, and P. Dario, “Design and development of an underactuated prosthetic hand,” in *International Conference on Robotics and Automation*, 2002.
[12] M. C. Carrozza, C. Suppo, F. sebastiani, B. Massa, F. Vecchi, R. Lazzarini, M. R. Cutkosky, and P. Dario, “The spring hand: Development of a self-adaptive prosthesis for restoring natural grasping,” *Autonomous Robots*, vol. 16, no. 2, pp. 125–141, 2004.
[13] M. Kaneko, M. Higashimori, R. Takenaka, A. namiki, and M. Ishikawa, “The 100 g capturing robot - too fast to see,” *IEEE/ASME Trans. on Mechatronics*, vol. 8, no. 1, pp. 37–44, 2003.
[14] G. A. Bekey, R. tomovic, and I. Zeljkovic, *Dextrous robot Hands*. Springer-Verlag New York, 1990.
[15] L. Biagiotti, F. Lotti, C. Melchiorri, and G. Vassura, “How far is the human hand, a review on anthropomorphic end effectors,” *University of Boglona internal document*, 2002.
[16] K. B. Shimoga and A. A. Goldenberg, “Soft materials for robotic fingers,” in *International Conference on Robotics and Automation*, 1992.
[17] M. R. Cutkosky, J. Jourdain, and P. Wright, “Skin materials for robotic fingers,” in *International Conference on Robotics and Automation*, 1987.
[18] J. K. Salisbury, “Decision and control including the symposium on adaptive processes,” in *International Conference on Robotics and Automation*, 1980.
[19] A. M. Dollar and R. D. Howe, “Towards grasping in unstructured environments: Grasper compliance and configuration optimization,” *Advanced Robotics*, vol. 19, no. 5, pp. 523–543, 2005.
[20] G. S. Chirikjian and J. W. Burdick, “Design and experiments with a 30 d.o.f robot,” in *International Conference on Robotics and Automation*, 1993.
[21] J. S. Pettinato and H. E. Stephanou, “Manipulability and stability of a tentacle based robot manipulator,” in *International Conference on Robotics and Automation*, 1989.
[22] A. Bicchi, “Hands for dexterous manipulation and robust grasping: A difficult road toward simplicity,” *IEEE Trans. on Robotics and Automation*, vol. 16, no. 6, pp. 652–662, 2000.
[23] A. Bicchi and V. Kumar, “Robotic grasping and contact: a review,” in *International Conference on Robotics and Automation*, 2000.
[24] H. Nikhil, W. Dale, and K. Navdeep, “Designing ultra-low cost asymmetric grippers for human tasks,” in *RSS Workshop on Robot Manipulation: Intelligence in Human Environments*, 2008.
[25] N. Hiroki, O. Katsuhisa, N. Akiko, N. Arata, and Y. Kazuya, “The tako(target collaborativize)-flyer a new concept for future satellite servicing,” tech. rep., Institute of Electonics, Informationand Communication Engineers, 2001.
[26] M. Kaneko, Y. Hino, and T. Tsuji, “On the phases for achieving enveloping grasps,” in *International Conference on Robotics and Automation*, 1997.
[27] K. Harada and M. Kaneko, “Enveloping grasp for multiple objects,” in *International Conference on Robotics and Automation*, 1998.