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Shape Recognition and Grasping by Robotic Hands with Soft Fingers and Omnidirectional Camera

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Abstract— **The purpose of this paper is to establish a method of shape recognition and grasping of unknown objects using a robotic hand with two soft fingers and one omnidirectional camera. For shape recognition, we propose to use a simple 2D version of the visual volume intersection method which takes advantage of a special feature of the omnidiretional camera attached to the hand. For grasping we propose a simple grasp quality criterion to obtain the best grasping position for the two soft fingers based on a visual hull in a horizontal grasp plane. We conducted several experiments and the results show the validity of the proposed method.**

I. INTRODUCTION

Grasping an object whose shape is not known a priori by a multifingered robotic hand is a basic and important problem which has not yet been solved satisfactorily. There are two main issues: one is to recognize the shape of object and the other is to plan the grasp.

Shape recognition from camera images has been studied in the filed of computer vision and many algorithms have been developed for recognizing the shape of 3-dimensional objects (e.g., stereo vision, optical flow, shape from shading, shape from silhouette, and shape from structured light). Unfortunately, however, these algorithms usually need a lot of computation and hence not suitable for real-time use. When we consider the problem of shape recognition in 2-dimensional space (plane), the method of shape from silhouette [1]-[4] will be a good candidate since this method treats the shape directly and has a very simple physical interpretation.

On the other hand, grasping and manipulation of objects by multifingered mechanical hand have been one of the major topics from the very beginning of robotics research and many performance criteria for grasp optimization have been studied [5]. Recently, in [6] a simulator for grasp analysis, called GraspIt, was developed and two performance measures are adopted to examine the grasp stability. In [7], a method of grasp optimization using the concept of required external force set was proposed. Various related works on grasping optimization were also surveyed in [7]. Most of these methods are for rigid fingers which make point contacts with grasped objects. However, rigid fingers sometimes have stability and versatility problem in practical applications. Partly because of this, hands with soft fingers have also drawn much attention [8]-[15]. However, grasping and manipulation in 3-dimensional space by a hand with two soft fingers have not been studied in detail [16].

In this paper, we propose a method of shape recognition and grasping of unknown objects using a robotic hand with two soft fingers and one omnidirectional camera. For shape recognition, we move the camera attached to the hand around the object and take multiple images of the object, and then we use a 2-dimensional version of the visual volume intersection method which is very simple and fits very well with the special feature of the omnidiretional camera. For grasping, we propose a simple quality criterion to obtain the optimla grasping positions for the two soft fingers based on a visual hull in a horizontal grasp plane. Some experimental results will be presented to show the validity of the proposed method.

II. SYSTEM CONFIGURATION

The configuration of the experimental hand system is shown in Fig.1. It consists of a robotic hand with 2 soft-fingers, a robot arm, an omnidirectional camera attached to the robotic hand, and two computers: one is for control and data processing of the fingers and camera, and the other is for controlling the arm. The two computers are connected by ethernet. Each hardware in the system will be described in the following subsections.

A. Robotic Hand

The robotic hand we have developed is shown in Fig.2. It has two fingers. Each finger has three rotational joints with motors (YASKAWA Electric Corporation, AC servo motor, reduction gear ratio 1:80) and a force/torque sensor (BL Autotec, LTD., NANO 5/4). The motors have rotary encoders

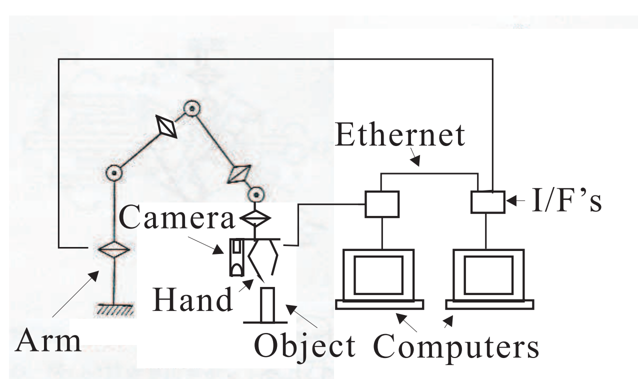

Fig. 1. System structure

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Fig. 2. Robotic hand

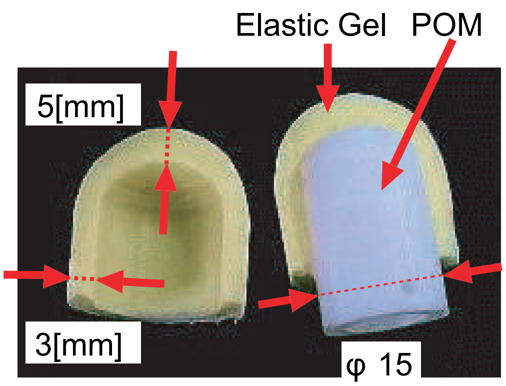


Fig. 3. Inner Structure of Soft Fingertip

which output 40960 pulses per round. The force/torque sensor is mounted between the distal joint and the fingertip. The first joint axis and the other two joint axes are orthogonal. Hence the fingertip can make three dimensional motion. The fingertips are round and covered by thin and soft skin made of elastic gel as shown in Fig.3. This skin produces a large frictional force. The computer for hand control is an Interface CTP-U14DSC (CPU: Pentium M, 1.8GHz, memory 512MB), and a simple position-based control law is implemented for this hand [16].

B. Omnidirectional Camera

The camera used in the system (Fig.4) is an omnidirectional sensor VS-C450N-TR (Vstone Co., Ltd.) consisting of a high-resolution CCD camera WAT-250C(380k pixels, Watec Co., Ltd.) and a hyperboloidal mirror. This camera can capture the visual information on 360 degree of circumferences around the camera axis in one image. This camera is attached to the base of the robotic hand as shown in Fig.2. The resolution of the camera is 640×480[pixel]).

Fig. 4. Omnidirectional camera

Fig. 5. Robotic arm

C. Robotic Arm

The robotic arm used in this research is PA-10-7C (Mitsubishi Heavy Industries, ltd., Fig.5). This arm has 7 joints and can move like our arms. The arm is controlled by DELL OPTIPLEX GX280 computer (CPU: Intel Celeron, 2.5GHz, memory 512MB).

III. SHAPE RECOGNITION

For recognizing the shape of the unknown object, we move the camera attached to the hand around the object horizontally keeping the height of the camera constant and take images of the object from different viewpoints (see Fig.6). Then by applying a two-dimensional version of the volume intersection method, we obtain the visual hull in the horizontal plane, which corresponds to a polygon circumscribing the horizontal cross section of the object (Fig7). Detailed procedure is given below.

Step 1: We extract the region of object from each image, and then perform binarization of the image and noise elimination (see Fig.8).

Step 2: Let the center of the camera filed be $p_c = [x_c \ y_c]^T$. We scan the pixels on the circle with center p_c and radius r[pixel] corresponding to the directions in the horizontal plane (r=70 for our camera) traveling in the clockwise

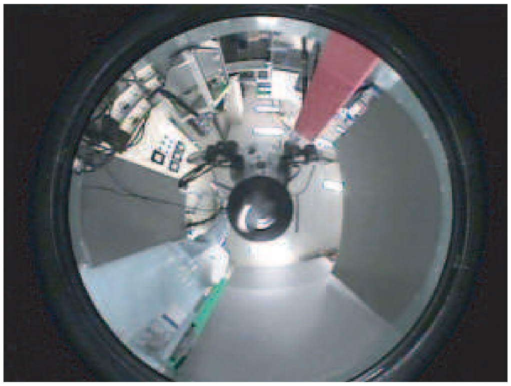


Fig. 6. Camera Image

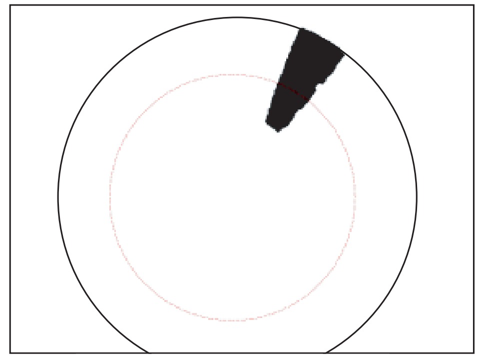


Fig. 8. Extraction of Object Image

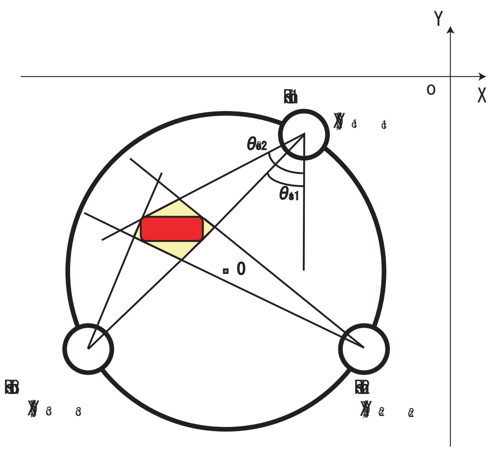


Fig. 7. 2D Volume Intersection Method

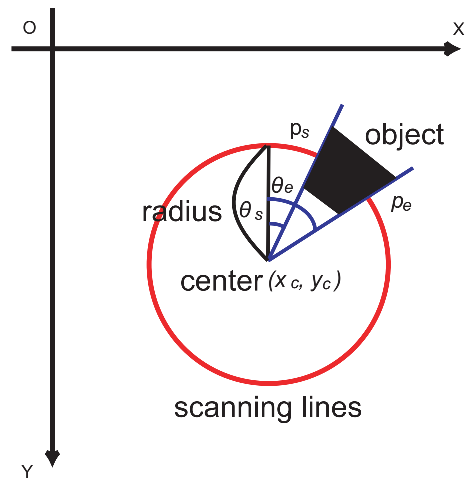


Fig. 9. Angles θ_s and θ_e

direction, and find the angle θ_s at which the pixel gets into the object region, and the angle θ_e at which the pixel gets outof it (see Fig.9).

Step 3: Using the values of θ_s, θ_e, and p_c, the starting point $p_s = [x_s \; y_s]^T$ and the ending point $p_e = [x_e \; y_e]^T$ of the object image region on the scan circule are calculated by

$$p_s = [x_c + r\sin\theta_s \quad y_c - r\cos\theta_s]^T \tag{1}$$

$$p_e = [x_c + r\sin\theta_e \quad y_c - r\cos\theta_e]^T \tag{2}$$

Step 4: We obtain the equation of the straight line on the horizontal plane going through the ith position of the camera $p_{ci} = [X_{ci} \; Y_{ci}]^T, i = (1, 2, \cdots, n)$ and p_s and ,

$$Y - Y_{ci} = \tan\theta_s(X - X_{ci}) \tag{3}$$

Similarly the straight line going through p_{ci} and p_e is given by

$$Y - Y_{ci} = \tan\theta_e(X - X_{ci}) \tag{4}$$

The region between these two straight lines (called silhouette cone) is the region where the cross-section of the object in the grasp plane exists .

Step 5: We calculate the visual hull as the intersection of all the regions obtained in the previous subsection.

IV. GRASPING

One important merit of soft fingers is that they can grasp an object not only with surface contact, but also with edge contact or even with vertex contact because they can envelope the edge or vertex by elastic deformation of the finger surface. However, this factor has not been considered before in detail in grasp optimization. Note that vertex contacts are discussed in [17] in the framework of grasping by fingers with rounded fingertips. However, the rounded fingertips are introduced mainly to guarantee the condition that the object has "a well defined and continuous surface normal everywhere."

Taking the above merit of soft fingers into consideration, we propose the following grasp quality criterion for determining the grasping position.

$$J(c_1, c_2) = k_1 d(c_1, c_2) + k_2 \alpha(c_1, c_2) \tag{5}$$

where c_i, $i = 1, 2$, is a pair of candidate contact points located on the boundary of the visual hull, $d(c_1, c_2)$ is the distance between contact points c_1 and c_1, $\alpha(c_1, c_2)$[deg] is the larger one of the absolute values of two angles α_i from the inward normal at point c_i to the line connecting the two contact points, and k_1 and k_2 are weighting coefficients.

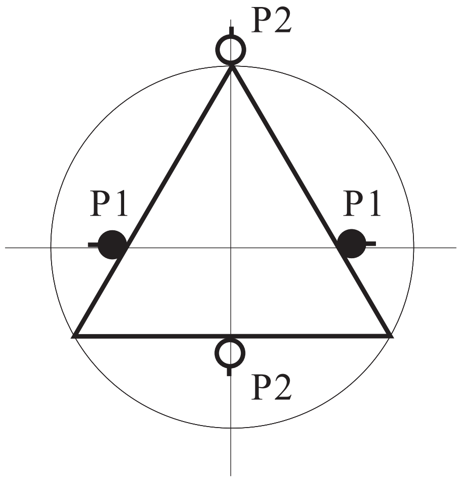


Fig. 10. Optimal Grasp Position of Triangular Prism

In order to make the problem simpler, we now make the following assumptions:
(1) The two contact points $c_i,\ i = 1, 2$, and the geometric center of the visual hull(denoted by p_g) are on a straight line.
(2) If c_i is a vertex where the two edges of visual hull cross, the value of $\alpha(c_1, c_2)$ is defined as the minimum absolute value in the interval $[\alpha_1, \alpha_2]$ (for example, if $[\alpha_1, \alpha_2] = [-30, 20]$, then $\alpha(c_1, c_2) = 0$).

Assumption (1) implies that, if the mass distribution of the object is uniform in the grasp plane, the moment due to gravitational force about the line connecting the two contact points is 0. Hence this grasping position is a desirable one from the viewpoint of rotational moment balance.

Assumption (2) means that if the edge is sharp, it is at least as desirable as nearby points for the contact point.

To see the validity of the grasp quality criterion (5), consider the case where the shape of the object in the grasp plane is a right triangle shown in Fig.10. We assume that the radius of circumscribing circle is 1 and we set $k_1 = 1$. Then for the case $0 < k_2 < 0.006$ the optimal grasping position is given by P1 in the figure. This corresponds to the case where the friction coefficient μ_f between the fingers and the object surface is very large and we do not need to care about the slippage very much. On the other hand for the case $k_2 > 0.006$ the optimal grasping position is given by P2 in the figure including one edge-contact point. This corresponds to the case where μ_f is not large enough and we need to care about the slippage.

In applying the above criterion to a visual hull obtained from the real camera system, we should be careful about the following two points:
(1) We need to establish a robust method for judging if a point on the boundary of a visual hull is really an edge worth taking into consideration. Note that there is usually various camera noises and discretization error.
(2) When the visual hull is constructed from the images taken from n difference viewpoints, there can be $2n$ edges. Most of these edges can be fake as can be easily understood from the case of a circular object.

V. EXPERIMENT

A. Shape Recognition

In our system, to make the task of extracting the image of the object simple, we use objects whose color is red, while there is no other red object or environment. Fig.6 is actually a camera image in this case.

Fig. 11. Image of Object

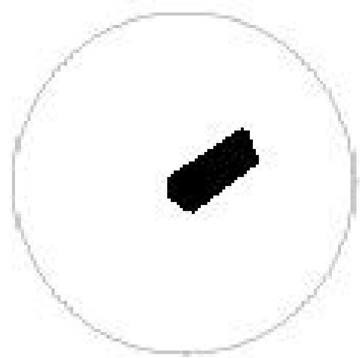
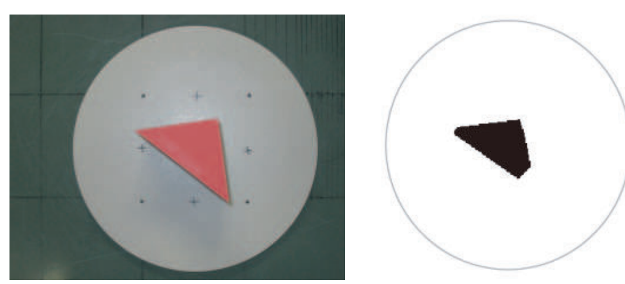


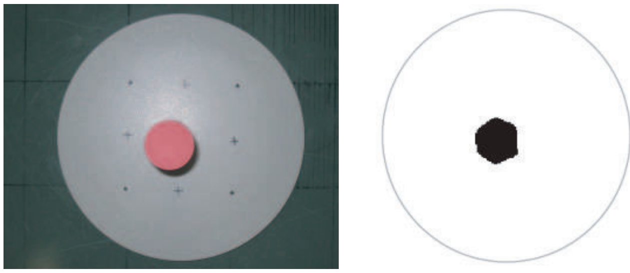
Fig. 12. Result of Shape Extraction



(a) Real shape (b) Recognized shape

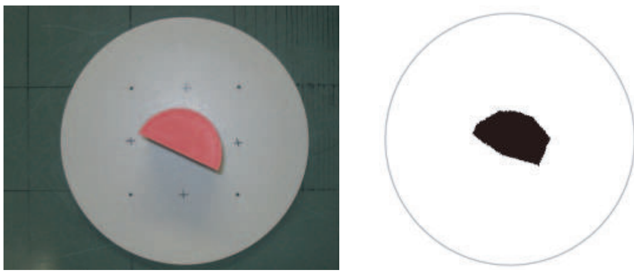
Fig. 13. Triangular Prism

In order to see the validity of the proposed approach for shape recognition, we have obtained visual hulls for several prisms (and columns) with different cross-sections.
(a) Rectangular prism with depth 33[mm], width 67[mm],



(a) Real Shape (b) Recognized Shape

Fig. 14. Cylindrical Column



(a) Real Image (b) Recognized Shape

Fig. 15. Half-Cylindrical Column

and height 138[mm]. The picture taken from the top is shown in Fig.11. The obtained visual hull is shown in Fig.12.
(b) Triangular prism whose bottom is a right triangle with side lengths 67[mm], and height 138[mm]. The result is shown in Fig.13 (a) and (b).
(c) Circular column with radius 18[mm] and height 138[mm]. The result is shown in Fig.14(a) and Fig.14(b).

(d) Half-cylindrical column with rradius 18[mm] and height 138[mm]. The result is shown in 15(a) and (b).

As can be seen from these results, the system is not accurate enough yet. We need to improve the system with respect to camera calibration, noise elimination, etc.

B. Grasping

We have performed an experiment of grasping for the rectangular prism shown in Fig.11. The grasp quality criterion (5) was evaluated based on a polar coordinate representation θ, $h(\theta)$ of the visual hull (θ is the angle taken from the upward virtical line with plus sign in the clockwise direction, and $h(\theta)$ is the radius in the direction of θ) given in Fig.16. The value of criterion as a function of angle θ is given in Fig.17. Hence the minimum value of the criterion is attained at the grasping angle $\theta = 150$[deg]. The motion of the system for shape recognition and grasping the rectangular prism is shown in Fig.18 and in the accompanying video.

VI. CONCLUSIONS AND FUTURE WORKS

A. Conclusions

A method of shape recognition and grasping of unknown objects by a robotic hand with two soft fingers and one omnidirectional camera has been proposed. For shape recognition, a simplified 2D version of the visual volume intersection method has been proposed that takes advantage of a special structure of the omnidiretional camera we are using. For grasping, A simple grasp quality criterion to obtain the best grasping positions for the two soft fingers has been proposed based on a visual hull in a horizontal grasp plane.Several experiments have been performed and the results show the validity of the proposed method.

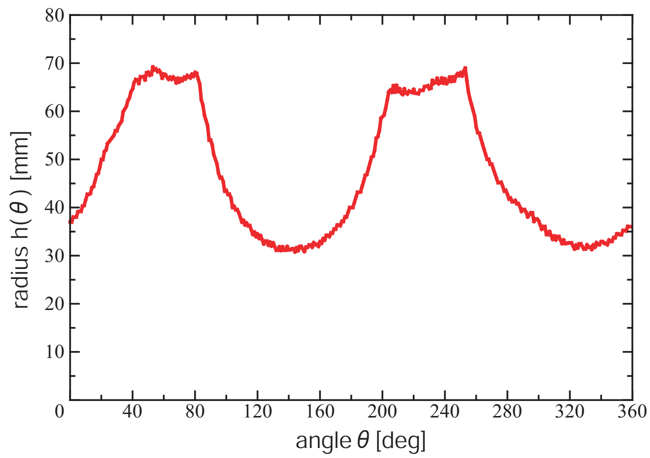


Fig. 16. Polar Coordinate Representation of Visual Hull for Rectangular Prism

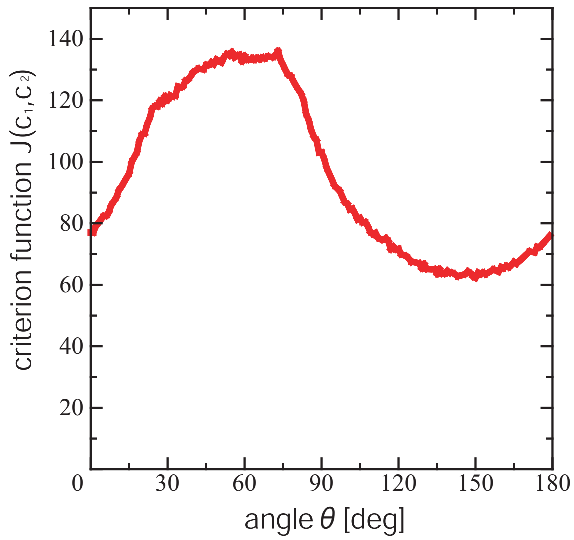


Fig. 17. Value of Criterion as a Function of Angle θ

B. Future Works

It sould be noted that our approach at the moment just looks at a cross section of the object, so it may run into the object as it goes to grasp it since the arm approaches from above. This problem should be addressed in the future. Extensions of the proposed method to various more complicated cases are possible. For example, the case where the objects are not prismatic but have different cross-sections along the vertical axis can be handled effectively by calculating several visual hulls in several horizontal planes at different

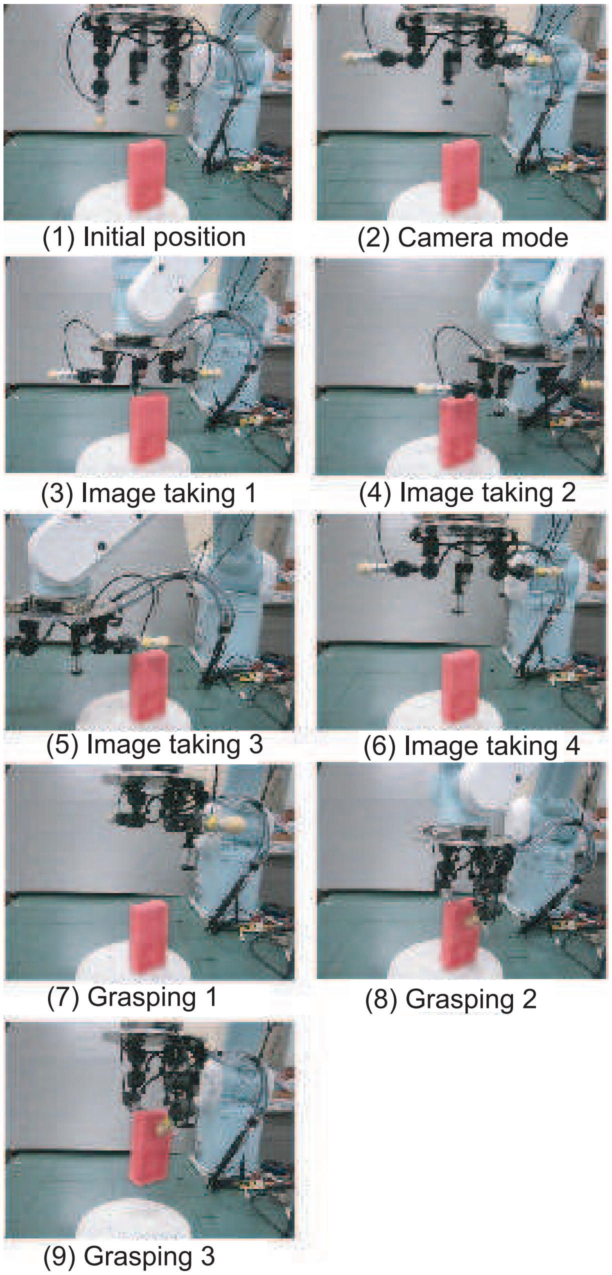


Fig. 18. Experiment of Grasping a Rectanglar Prism

heights. The case of hands with three or more fingers can also be effectively handled. There are also various directions in which we can extend the proposed grasp performance criterion. One interesting direction is to relax the condition that the two contact points should go through the geometric center.

VII. ACKNOWLEDGMENTS

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