Mobile Manipulators' Object Recognition Method Based on Multi-sensor Information Fusion

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Abstract. Mobile manipulators have attracted a lot of interest recently. This paper presents an object detection method for mobile manipulator system based on multi-sensor information fusion. Firstly,the fusion method of visual and ultrasonic information has been applied to localization of the end-effector. And based on the ultrasonic array of the mobile platform, a fuzzy control method was adopted to achieve its obstacle- avoidance motion. Vision-guided object recognition and localization method is emphasizes on image-preprocessing, including that: gray treatment, the choice of threshold, binarization, erosion, dilation and group color up method. These transformations can produce clear image which could be easily recognized by the control computer. A design methodology for moment invariant recognition–based object detection is proposed. Experimental results demonstrate the validity of the approach.

Keywords: mobile manipulator,object recognition, multi-sensor.

1 Introduction

A mobile manipulator is a constrained mechanical system comprising a moving platform subject to kinematic constraints and a multiple degrees of freedom (DOF) manipulator arm mounted on it. Such systems combine the advantages of mobile platforms and robotic arms and reduce their drawbacks [1]. For instance, the mobile platform extends the arm's workspace, whereas an arm offers much operational functionality. Such system usually equipped with multiplicate sensors for its autonomous navigation in unstructured envirionment. Therefore, the redundance information must be fusioned by certain ways for its effective utilization[2-7]. The fusion method coule be divided into two categories. Some researchers integrate the sensor data directly, and use the estimated parameters and status into the path planning and operation to produce signals for robot actuator. Quite a few methods has appeared,such as rule-based sensor fusion method [8], data fusion based on the geometry and topology map [9]. Paper [10] also concluded a number of unified frame-work for the measurements in integration of sensor, including the Bayesian methods and the extention for Kalman filtering, and behavior-based algorithm. On the other hand, some reseachers was focus on high-level data fusion. In [11], authors presents a behavior-based structure. And paper [12] discussed a unified framework based on neural network. Paper [13] and [14] introuduces fusion algorithm based on neural network for object

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identification. It is obvious that neural networks and artificial intelligence methods has revealed its advanteges in this field.

For improving the intelligence and independent operational capacity of HEBUT-Ⅱ mobile manipulator system,we developed fusion methods of multi-sensor information based on fuzzy control and neural networks. The mobile manipulator system was expected to achieve improved autonomous navigation and detect the assigned object.

2 Hebut-Ⅱ Mobile Manipulator System

HEBUT-Ⅱ mobile manipulator consists of a five degree-of –freedom manipulator mounted on a differentially driven mobile platform, see in Fig.1.

Fig. 1. Hebut-Ⅱ mobile manipulator in working

2.1 Sonar Arrays in HEBUT-Ⅱ Mobile Platform

The mobile platform of HEBUT-Ⅱ mobile manipulator is Pioneer-3 mobile robot. The Pioneer-3 mobile robot has two sonar ring consisting of 16 Polaroid 6500 ultrasonic ranging sensor to coverage the space 360° around the system.

Polaroid 6500 ranging sonar system includes two parts: the control panels and the ultrasonic sensor. The distributing of these sensors enable the mobile platform to get the environmental information from variously perspective. Thus it could effectively avoid aliasing effects, and provide information for obstacle-avoidance, path-planning, object recognition and localization.

2.2 Visual System

The Visual system is an important component of the navigation system for HEBUT-Ⅱ mobile manipulator system, and its hardware components as shown in Fig. 2. Image acquisition module used to obtain digital images, comprising of SONY CCD camera and DH-CGW400 image acquisition card. Image processing module is to extract images from the original road signs and paths in the region. Path and road signs identifying is to identify the direction of the planned path and its signs, then transform the coordinates of the image and the region to the mobile base coordinate system. The identified results can be applied to the control system.

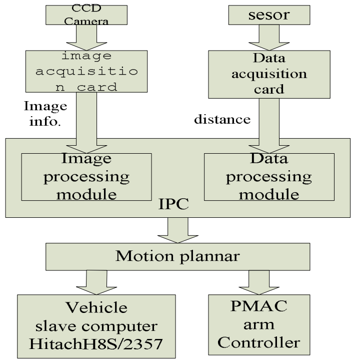

Fig. 2. The hardware configuration of mabile manipulator

The fixing location of mobile manipulator's camra is shown as Fig. 3. $O-XYZ$ is the coordinate frame of the mobile platform,origin O is located at the interaction point of the axis and floor. $O'-X'Y'Z'$ is the Camera's coordinate frame, O' is the Centre of image plane.

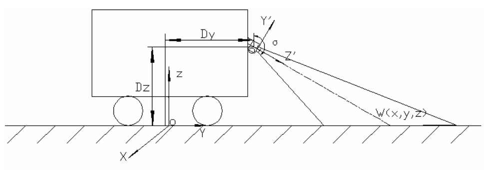

Fig. 3. The model of HEBUT-Ⅱ mobile manipulator's camera

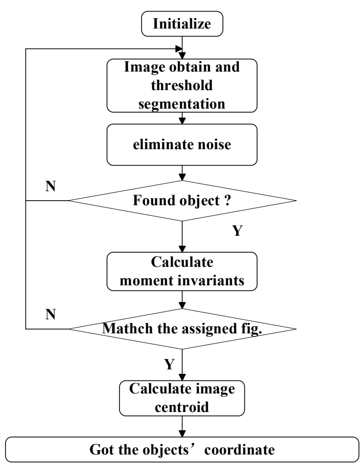

Fig. 4. The orientation flow chart of manipulator

3 Recognition Method and Motion Planning

3.1 Localization and Recognition Method Based on Fusion of the Visual and Ultrasonic Sensor Information

In this paper, we adopted the fusion of ultrasonic sensor information and visual information to recognize task object. The orientation process is shown in Figure 4.

The shape of the object is the basis for visual analysis and its recognition.We use local moment invariants to recognize the shape of the objects.

Although the task object's image has already very clear after segmentation and denoise processing, we should calculate the moment invariants of the object for enhancing further stability. The common characteristics of the objectives include gray (color) feature, texture feature, and shape features, and etc. The moment invariants method uses the same centre moment of the image on the translation, rotation and scale transformation to identify the shape of an object.

We definite the (p+ q)- order moment of a digital image f(x, y) as follows:

$$m_{pq} = \sum_x \sum_y x^p y^q f(x, y) \tag{1}$$

Then m_{pq} is identified by f(x, y), conversely, f(x, y) is be determined. The (p+q)-order centre moment of f(x, y) is defined as:

$$\mu_{pq} = \sum_x \sum_y (x - \bar{x})^p (y - \bar{y})^q f(x, y) \tag{2}$$

$\bar{x} = m_{10} / m_{00}$, $\bar{y} = m_{01} / m_{00}$。($\bar{x}, \bar{y}$) is the center (gravity center)coordinates of the image. The (p+q)- order attributive center moment of f(x, y) can be expressed as:

$$\eta_{pq} = \frac{\mu_{pq}}{\mu_{00}^{\gamma}} \tag{3}$$

In which, $\gamma = \frac{p+q}{2} + 1$, $p + q = 2, 3, \ldots$

Then we can get 4 unchanged moments for translation, rotation and scale transformation:

$$\phi_1 = \eta_{20} + \eta_{02} \tag{4}$$

$$\phi_2 = (\eta_{20} - \eta_{02})^2 + 4\eta_{11}^2 \tag{5}$$

$$\phi_3 = (\eta_{30} - 3\eta_{12})^2 + (3\eta_{21} - \eta_{03})^2 \tag{6}$$

$$\phi_4 = (\eta_{30} + \eta_{12})^2 + (\eta_{21} + \eta_{03})^2 \tag{7}$$

$$\phi_5 = (\eta_{30} - 3\eta_{12})(\eta_{30} + \eta_{12}) \times [(\eta_{30} + \eta_{12})^2 - 3(\eta_{21} + \eta_{03})^2] + (3\eta_{21} - \eta_{03})(\eta_{21} + \eta_{03}) \times [3(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2] \tag{8}$$

$$\phi_6 = (\eta_{20} - \eta_{02})[(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2] + 4\eta_{11}(\eta_{30} - \eta_{12})(\eta_{21} + \eta_{03}) \tag{9}$$

$$\phi_7 = (3\eta_{21} - \eta_{03})(\eta_{30} + \eta_{12}) \times [(\eta_{30} + \eta_{12})^2 - 3(\eta_{21} + \eta_{03})^2] + (\eta_{30} - 3\eta_{12})(\eta_{21} + \eta_{03}) \times [3(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2] \tag{10}$$

The formulas (4)-(10) are the seven moments of the image, and they have the unchanged nature for translation, scaling, and rotation. Normally, the shape of an object could be identified only by 4 moments.

We carried on the computation of the same object's image and the data was shown in the table 1. We could determinate symbol of the object according to the image invariable moment and then carry on the following operation.

The experimental result of this method is shown in Figure 5. The end-effector was lacalizated at assigned task point, with the position error in ±10mm.

Table 1. The invariable moment of figures

Test #	ϕ_1	ϕ_2	ϕ_3	ϕ_4
1	0.1584	0.000008	0.000004	0.000001
2	0.1598	0.000010	0.000005	0
3	0.1602	0.000011	0.000007	0
4	0.1573	0.000007	0.000004	0
5	0.1578	0.000012	0.000005	0.000001
6	0.1580	0.000014	0.000006	0
7	0.1575	0.000008	0.000007	0
8	0.1611	0.000009	0.000008	0
9	0.1577	0.000007	0.000006	0
10	0.1582	0.000011	0.000007	0

Fig. 5. The experimental result of manipulator localization

3.2 Obstacle Avoidence and Motion Planning Based on the Multi-sensor Information

Based on the combination of fuzzy logic and behavior control, this section propose a new method to the navigation in unstructure environment. In order to ensure mobile robot to reach the goal without collision with unknown obstacles, we must use sensors to obtain information of external environment.

This paper adopts a new "Perception - Movement" behavior control based on fuzzy logic for Mobile manipulator. It takes advantage of fuzzy logic to integrate multiple "Perception - Movement" behavior.

Also,we integrate the perception and decision-making in the same mode to improve the real-time performance and reliability of the system.

The fuzzy logic we adopted is shown in Figure 6. By the ultrasonic sensor array installed in the head of mobile platform,the system get the enviromental information, that is the distance information of obstacals on left and right. The output variable is the rotation angles in the direction of advance.

The test Platform of Fuzzy obstacle avoidance algorithm is Pioneer 3H8-AT model Intelligent Mobile platform.

The input variables of the fuzzy controller is the distance got from the ultrasonic sensors. If the set of the value about the fuzzy language variable of the distance signals is: {near distance, middle distance, long distance}, which simplifies expressed as: {ND, MD, LD}.

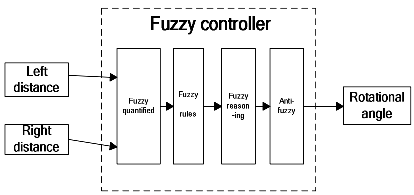

Fig. 6. The fuzzy logic of mobil emanipulators

Then according to the distance the actual domain of the input variables is [500 mm, 1500 mm]. Chose the calculation domain as [-5, 5], and using linear transformation, then

$$x = \frac{1}{100} x^* - 10 \tag{11}$$

x^* is the actual distance value and x is the discrete domain point, $k = \frac{1}{100}$ is scale factor.

The fuzzy membership function of the input distance shown as Figure 7 .

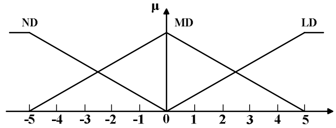

Fig. 7. The membership function of the input variable “Distance”

Table 2. The evaluating table of the fuzzy variable of input distance

	-5	-4	-3	-2	-1	0	1	2	3	4	5
ND	1	0.8	0.6	0.4	0.2	0	0	0	0	0	0
MD	0	0.2	0.4	0.6	0.8	1	0.8	0.6	0.4	0.2	0
LD	0	0	0	0	0	0	0.2	0.4	0.6	0.8	1

The output variable of the fuzzy controller is the robot's rotational angle in the forward direction. We definite the output set of the fuzzy language as follows:

{turn right, turn right a little, go ahead, turn left a little, turn left},

which simplifies expressed as: {TR, TRL, GA, TLL, TL}, in which,

TR = turn right

TRL = turn right a little

GA = go ahead

TLL = turn left a little

TL = turn left

The actual domain of the rotational angle is [-30°, 30°],

Define left turning is positive and the calculation domain as [-4, 4]. Using linear transformation, then,

$$y = \frac{2}{15} y^{*} \tag{12}$$

y^{*} is the actual Rotation angle and y is the discrete domain point, $k = \frac{2}{15}$ is scale factor.

The fuzzy membership function of the output angle is as shown in Figure 8.

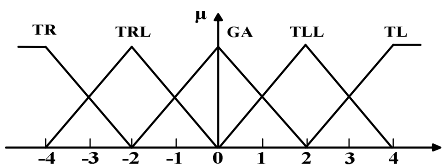

Fig. 8. The membership function of the output variable "Angle"

The evaluating value of the fuzzy variables of the output angle is as shown in Table 3:

Table 3. The evaluating table of the fuzzy variable of output angle

	-4	-3	-2	-1	0	1	2	3	4
TR	1	0.5	0	0	0	0	0	0	0
TRL	0	0.5	1	0.5	0	0	0	0	0
GA	0	0	0	0.5	1	0.5	0	0	0
TLL	0	0	0	0	0	0.5	1	0.5	0
TL	0	0	0	0	0	0	0	0.5	1

If D_R is the distance between the robot's right side and the obstacles, and D_L is the distance between the robot's left side and the obstacles, U is the output. Suppose thar 1 to 9 rules can be expressed with R_1, R_2, $\cdots$, R_8, R_9, The obstacle-avoiding rules are as the following formes,

R_1: IF $D_R = ND$ AND $D_L = ND$ THEN $U = TRL$

R_2: IF $D_R = ND$ AND $D_L = MD$ THEN $U = TLL$

R_3: IF $D_R = ND$ AND $D_L = LD$ THEN $U = TL$

R_4: IF $D_R = MD$ AND $D_L = ND$ THEN $U = TRL$

R_5: IF $D_R = MD$ AND $D_L = MD$ THEN $U = GA$

R_6: IF $D_R = MD$ AND $D_L = LD$ THEN $U = TLL$

R_7: IF $D_R = LD$ AND $D_L = ND$ THEN $U = TR$

R_8: IF $D_R = LD$ AND $D_L = MD$ THEN $U = TRL$

R_9: IF $D_R = LD$ AND $D_L = LD$ THEN $U = GA$

The total control rules of the system R could be obtained through AND method.That is,

$$R = \bigcup_{i=1}^{9} R_i \tag{13}$$

The fuzzy relations may express as follows:

$$R = \bigcup_{i=1}^{9} [(D_{Ri} \times D_{Li})^T \circ U_i] \tag{14}$$

By variable ΔD_R and ΔD_L ,we can obtain the output

$$U^{'} = (\Delta D_R \times \Delta D_L)^T \circ R \tag{15}$$

According to above nine fuzzy rules, we can obtain the final real-time control table as table 4 shows:

Table 4. The rogatory table of fuzzy control

	-5	-4	-3	-2	-1	0	1	2	3	4	5
-5	-1	1	2	2	2	3	3	3	4	4	4
-4	-1	-1	1	2	2	2	3	3	3	4	4
-3	-1	-1	0	1	2	2	2	3	3	3	4
-2	-2	-1	-1	0	1	2	2	2	3	3	3
-1	-2	-2	-1	-1	0	1	1	2	2	3	3
0	-3	-2	-2	-1	-1	0	1	1	2	2	3
1	-3	-3	-2	-2	-1	-1	0	1	1	2	2
2	-3	-3	-3	-2	-2	-2	-1	0	1	1	2
3	-4	-3	-3	-3	-2	-2	-2	-1	0	1	1
4	-4	-4	-3	-3	-3	-2	-2	-2	-1	0	0
5	-4	-4	-4	-3	-3	-3	-2	-2	-2	-1	0

The output in Table 4 is fuzzy value which could not be directly used to control. We adopted the weighted average method to non-fuzzy and got the rotation angle.

4 The Experimental Results

Experimental results of HEBUT- II mobile manipulator system is shown as Fig.9. At first, obstacle appears in the front of the system, the system turns to avoid it, and at last the system successfully steer clear of the obstacle.

Fig. 9. Obstacle-avoidence experiment

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