Development of a Robot Following a Human Using Color Information

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Abstract

Carrying luggage is one of the daily tasks done in our life. It is tight work to carry heavy luggage especially for senior people. This research pays attention to helping those senior people carrying luggage by a mobile robot. The robot developed in this research aims at carrying luggage and following the possessor. Therefore, the person whose luggage is carried by the robot does not need to tell the destination to the robot. The person is also possible to stop on the way freely. The extraction method of a person that the user specifies, the following method of the person, and the control method of a mobile robot using captured images are described in this paper. The effectiveness of the developed robot is examined by the experiment performed on the corridor in the building. Some results are shown and discussion is given.

Keywords: Mobile robots, human support, color tracking, robot vision

1. INTRODUCTION

When a person becomes aged, assistance in a daily life is needed because the body becomes weak. However, vivid life can be achieved as long as there is assistance to him/her. Recently, senior citizen's ratio has increased in Japan. Therefore, the number of those who need assistance is increasing, whereas the number of those who can provide assistance is decreasing. Then, the development of a robot which assists the function of a human body becomes more and more important. Operation of carrying luggage is one of popular tasks done in our daily life. This research pays attention to helping senior people by carrying their luggage.

A robot system is proposed in this paper which finds a person who has luggage, approaches to the person, and carries the luggage in place of him/her, if he/she hopes to do so. The robot follows the person to his/her destination. Therefore, the person does not need need to tell the robot his/her destination. He/she is also possible to stop on the way freely. The system structure is explained along with the algorithms and experimental results are shown.

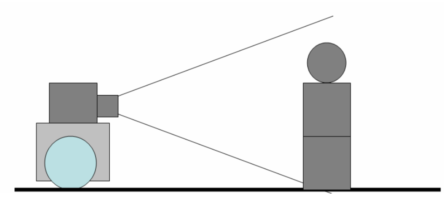


Fig. 1 A robot system

2. ALGORITHM

2.1 A luggage carrying robot system

First of all, the size of the luggage carrying robot is explained. The robot is unsuitable for carrying luggage if it is small. On the other hand, the user may feel the pressure if it is too big. Therefore, a robot of the height almost equal to the chest of an adult is introduced in this research. (**Fig. 1**)

2.2 Particle filter

The particle filter [1] is used in this research to track a particular person. The particle filter is an approximated probability distribution by a weighted sample set

$$S = \left\{ \left(s^{(n)}, \pi^{(n)} \mid n = 1 \ldots N \right) \right\} \quad (1)$$

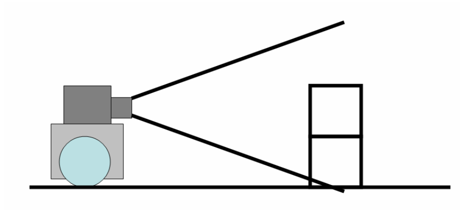
s : hypothetical state
π : probability
n : particle number

Particle filter has many advantages for tracking objects as they are robust to partial occlusion and change in shape.

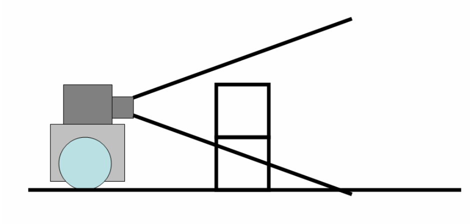
2.3 Setting of the center position of an object

A method is explained for the reduction of the influence of occlusion by the change in the distance of the object interested.

When the distance between the robot and the object is farther as shown in **Fig. 2(a)**, the camera view is given by **Fig. 3(a)**, whereas, when the distance is nearer as in Fig. 2(b), the view becomes the one depicted in Fig. 3(b). Therefore occlusion occurs when the object is nearer.

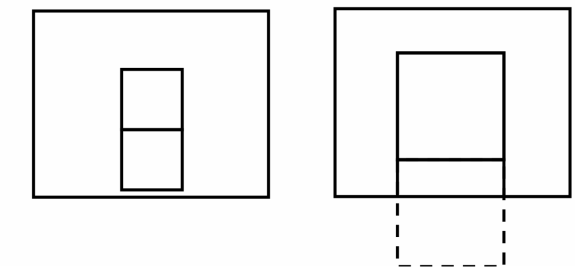


(a)



(b)

Fig. 2 Robot and an object



(a) (b)

Fig. 3 Camera view

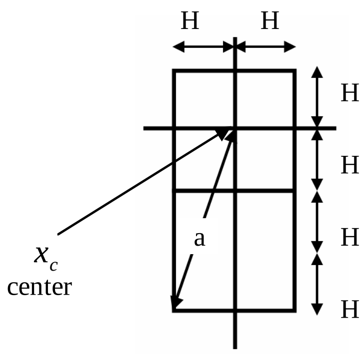
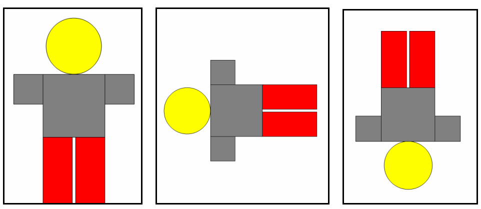


Fig.4 Shape of an object



(a) (b) (c)

Fig.5 Walking posture

To solve this difficulty, emphasis is placed on the upper part of a human body, which is realized by using a kernel centered at the center of the upper body (See **Fig.4**).

In this particular study, Epanechnikov Kernel [2] defined as follows is used as a kernel.

$$k(r) = \begin{cases} \frac{1}{2} c_d^{-1} (d+2)(1-r) & \text{if} \quad r < 1 \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

d : dimension

c_d : volume of the unit d-dimensional sphere

2.4 Division of a histogram

The robot follows a walking person. The walking posture is given in **Fig. 5(a)**. It does not become those postures given in Fig. 5(b) or (c). Therefore the top and the bottom information of a person can be used.

The region of a person is divided into an upper part and a lower part as shown in **Fig. 6**. The upper half of the body is given a label 0, and the lower half of the body is given a label 1. With each part, position $x \equiv (x, y)$ has the HSV values and the label, which makes a quadruple. If H, S and V are digitized into *H*, *S* and *V* levels, respectively, they make $H \times S \times V \times 2 \equiv M$ bins. These bins are numbered and denoted by $h(x)$.

The influence of light is reduced by using the HSV color model. Therefore, *M* bins considering the two positions labeled 0 and 1and the HSV color space is employed in this research.

The distribution model $p(x_c) = \{p(x_c)^{(u)}\}_{u=1...M}$ at the center x_c is defined with each part as follows;

$$p(x_c)^{(u)} = f \sum_{i=1}^{I} k\left(\frac{\|x_c - x_i\|}{a}\right) \delta[h(x_i) - u] \tag{3}$$

δ : Kronecker delta function

u : the bin number

$$f = \frac{1}{\sum_{i=1}^{I} k\left(\frac{\|x_c - x_i\|}{a}\right)} \tag{4}$$

The parameter I is the number of all the coordinates in the squared region.

The Bhattacharyya coefficient ρ is used for the calculation of the agreement between two distributions $p(\mathbf{x})$ and $q(\mathbf{x})$, which is defined by

$$\rho[p, q] = \sum_{u=1}^{M} \sqrt{p^{(u)} q^{(u)}} \tag{5}$$

q : the target model

The coefficient ρ approaches 1 when the difference is small.

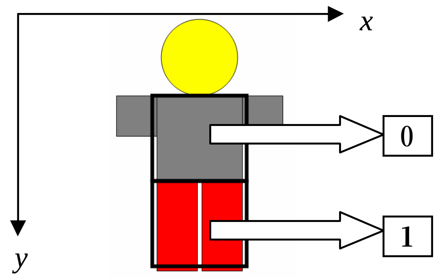


Fig. 6 Histogram division

2.5 Observation model

The shape of an object is expressed in two squares in this research. The hypothetical state is expressed by the expression given in the form of

$$\mathbf{s} = \{x, y, \dot{x}, \dot{y}, H\}. \quad (6)$$

x, y : location of the center

$\dot{x}, \dot{y}$: motion

H :length

The transition of the object at time t is expressed by the state.

$$\mathbf{s}_t = \mathbf{A}\mathbf{s}_{t-1} + \mathbf{w}_{t-1} \quad . \quad (7)$$

$\mathbf{A}$: deterministic component

$\mathbf{w}_{t-1}$: stochastic component

A present state is inferred from the previous state by matrix $\mathbf{A}$, and the noise is added by vector $\mathbf{w}$. Parameter *a* used in the kernel of Eq.(3) is computed by

$$a = \sqrt{H^2 + (3H)^2} \quad (8)$$

The weight which uses the Bhattacharyya coefficient is converted into the probability by Eq.(9).

$$\pi^{(n)} = \frac{1}{\sqrt{2\pi}} e^{-\frac{(1-\rho[p(\mathbf{s}^{(n)}), q])}{2\sigma^2}} \quad (9)$$

Finally the position of the object is decided by taking the average of the state as follows;

$$E(S) = \sum_{n=1}^{N} \pi^{(n)} \mathbf{s}^{(n)} \quad (10)$$

s : hypothetical state

π : probability

n : particle number

2.6 Mobile robot control

A camera has been installed in the developed mobile robot. We need two control strategies; one for the camera and the other for the mobile robot.

2.6.1 Camera control

The camera moves right to left to track an object. Speed of the camera is changed by the proportional control so that it captures the object at the center of the visual plane. The strategy is formulated as follows;

$$\dot{d}_c = p_c(x_t - x_c) \quad (11)$$

$\dot{d}_c$: speed of camera

p_c : proportion constant

x_t : object position

x_c : image center

2.6.2 Mobile robot control

The control of the mobile robot consists of the speed control and the control of the steering wheel. The speed is controlled so that the width of the object may become constant in the captured image. The view angle of the object is calculated from its position in the image and the angle of the camera.

The speed of the robot is controlled by the following formula;

$$s_r = p_{r1}(H_p - 2H) + i_{r1}\sum(H_p - 2H) \quad (12)$$

s_r : speed of robot

H_p : width of target

p_{r1} : proportion constant

i_{r1} : integration constant

On the other hand, the steering wheel is controlled by the following formula;

$$d_r = p_{r2}\theta + i_{r2}\sum\theta . \quad (13)$$

d_r : steering wheel angle

θ : angle of object

p_{r2} : proportion constant

i_{r2} : integration constant

3. COMPOSITION of THE SYSTEM

A person following robot system developed in this research is composed of a single camera, a video capture device, a note PC (Pentium M, 1.6GHz), and a mobile robot. The entire equipment is built on the mobile robot using a single frame of approximately 0.85 meter high. Overview of the system is given in **Fig.7**.

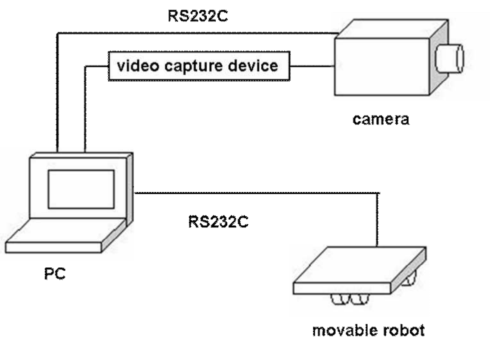


Fig. 7 Composition of the system

4. EXPERIMENTAL RESULTS

4.1 Performance of human tracking

A person wearing a light jacket with dark blue check pattern and a black pair of trousers is captured in a double green square window and the region is tracked as the person moves. The experimental result of the tracking is shown in **Fig. 8**.

4.2 Person following

We performed the experiment on person following indoors using the developed robot system. An image containing a target person was taken initially and his clothes were registered manually to the system. Then, according to the target person walking away on the corridor, the robot followed him capturing his images. The performance is shown in **Fig. 9**. The robot followed just behind a person keeping the distance constant.

5. CONCLUSIONS

In this research, a robot system was developed for following a person and carrying luggage. A satisfactory result was obtained by the experiment. However, there are some problems that the illumination and the background sometimes give negative influence to the person following because the proposed technique only uses color information. Uemura et al. [3] proposed a color region tracking technique robust to illumination change. The technique may be employed in the present system. The interactive nature of the robot system is also going to be improved to realize various robot activities.

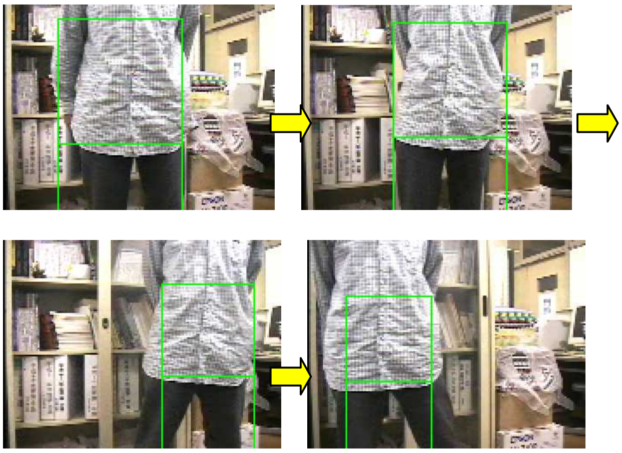


Fig. 8 Result on human tracking

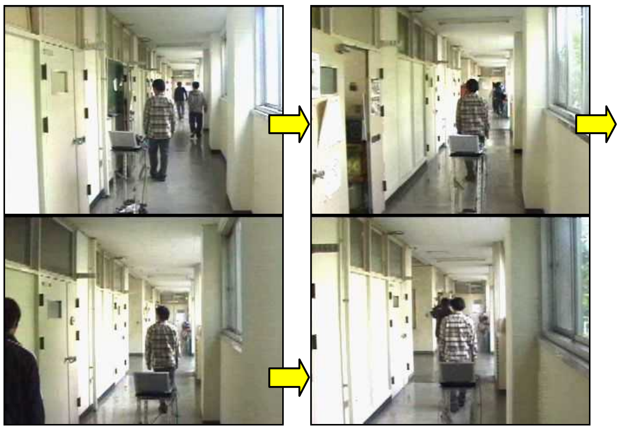


Fig. 9 The robot following a specified person

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