An Obstacle Detection and Avoidance Method for Mobile Robot Using a Stereo Camera Combined with a Laser Slit

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Abstract: To detect and avoid obstacles is one of the important tasks of mobile navigation. In a real environment, when a mobile robot encounters dynamic obstacles, it is required to simultaneously detect and avoid obstacles for its body safely. In previous vision system, mobile robot has used it as either a passive sensor or an active sensor. This paper proposes a new obstacle detection algorithm that uses a stereo camera as both a passive sensor and an active sensor. Our system estimates the distances from obstacles by both passive-correspondence and active-correspondence using laser slit. The system operates in three steps. First, a far-off obstacle is detected by the disparity from stereo correspondence. Next, a close obstacle is acquired from laser slit beam projected in the same stereo image. Finally, we implement obstacle avoidance algorithm, adopting the modified Dynamic Window Approach (DWA), by using the acquired the obstacle's distance.

Keywords: Obstacle detection, Stereo camera, Passive sensor, Active sensor and Obstacle avoidance algorithm

1. INTRODUCTION

The obstacle detection is one of the serious reseach subject in the field of mobile navigation. For guaranteeing safety of the robot, it should have a robust ability for detecting and avoiding obstacles. Until now, the detection of obstacles in unstructured environment still remains as a challenging problem.

The most mobile robot used distance information in order to detect obstacles. To get information of distacne from obstacle, two types sensor systems are generally used: active range sensor [1, 7] and passive range sensor [1, 6]. A passive sensor can acquire 3D information about the environment. But they can get only sparse depth information. For example, passive stereo camera cannot extract the depth information without textured features. On the other hand, active sensors can easily get distance information but they also have limitations. The ultrasonic sensor suffers from the noise mainly caused by diffused reflection and has limited angular range of detection. Taking these limitations into account, the researches on combinding an active sensor with a passive sensor have been conducted [2-5].

Recently, vision system is being actively studied for obstacle detection and avoidance [1, 7-10]. In this paper, we propose a new obstacle detection algorithm using a stereo vision system. As shown in Fig. 1, our system is composed of a stereo camera and a laser slit, which is intended to use stereo image as passive and active sensing media for correspondence. The former one use a stereo matching algorithm to obstacle detection [16], which is possible to detect the far-off distant obstacles. The latter one applies the extraction of laser slit beam in color images to obstacle detection, which is only possible to detect the close obstacles because of low powered laser beam. Our system in this configuration also has another advantage that our stereo system mounted on a pan/tilt mechanism can be used for multi-purpose sensing modality such as visual map building, localization and face recognition.

We also apply our proposed obstacle detection algorithm, which consists of 2-layered depth information from passive and active sensing device, to Dynamic Window Approach (DWA) algorithm [11-13].

The remainder of this paper is structured as following. In section 2 we describe obstacle detection algorithm that uses a stereo camera and a laser slit and explain the proposed distance estimation method. In section 3 we present obstacle avoidance algorithm that uses the modified Dynamic Window Approach. In section 4 and 5 we describe experimental results and conclusions, respectively

Fig. 1. Home Service Robot (Hombot) equipped with a stereo camera and a laser slit generator

2. OBSTACLE DETECTION

2.1. Obstacle detection with a stereo camera and a laser slit

2.1.1. Extracting laser slit beam in Color images

In this paper we proposed an active sensing device that is composed of a stereo camera and a laser slit generator as illustrated in Fig. 2. A red-slit beam produced by the laser slit generator is marked in a captured image by stereo camera, when an obstacle get into the view range of the camera system. The distance between the obstacle and the robot system can be computed as follows.

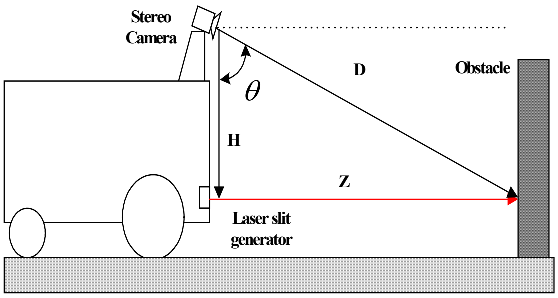


Fig. 2. The geometry between mobile robot and obstacle

Step 1. From an image, r_i, g_i and b_i are calculated on every pixel and R_i, G_i and B_i are normalized. The former one is absolute intensity and the latter one is relative intensity

$$R_i = \frac{r_i}{r_i + g_i + b_i} \quad G_i = \frac{g_i}{r_i + g_i + b_i} \quad B_i = \frac{b_i}{r_i + g_i + b_i} \quad (1)$$

Step 2. Pixels that are expected as laser slit beam are extracted from whole image. The pixel must have larger relative intensity R_i than absolute intensity a threshold (min_{th}). Difference color value is $max(R_i$-$G_i)$ and the different color is larger than a threshold ($min\Delta_{th}$) in the pixel. In the same way, $max(R_i$-$B_i)$ is larger than the threshold.

$$R_i > \min_{th},\ R_i - \max(G_i, B_i) > \min\Delta_{th} \quad (2)$$

Step 3. A pixel that is obtained from laser slit beam can be calculated position(Y) and total intensity(I)

① Eliminate white brightness

$$r[i]_{\max} > \alpha \cdot \max(g[i], b[i]) \quad (3)$$

Where, max(g[i],b[i]) is white brightness. α is a weighting factor.(α=0.32)

② Eliminate wide red object and red peak noise

$$\hat{r}[i]_{\max} \Leftarrow r[i]_{\max} + \beta \cdot \mathrm{f}(y) + \gamma \cdot \mathrm{g}(I) \quad (4)$$

Where, f(y) is a laser slit beam's position and g(I) is total intensity. β and γ are a weighting factor.(β=0.25, γ=0.25)

Step 4. Pixels that is got from Step 1 to Step 3 means a laser slit beam's position

2.1.2 The geometry between stereo camera and laser slit

In Fig 2, a mobile robot has a stereo camera, which is on the top of the robot front and a laser slit is on the bottom of the robot front. And Fig. 3 shows the geometry between image plane and laser slit beam plane. From Fig. 2 and Fig. 3, Eq. (5), Eq. (6) and Eq. (7) can be obtained as following:

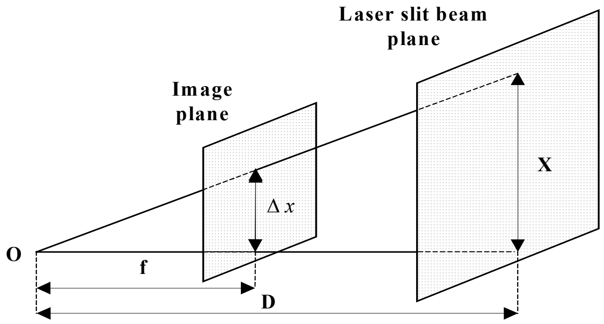


Fig. 3 The geometry between image plane and laser slit beam plane

$$D_{laser} = \frac{f}{c_y \cdot n_y} \quad (5)$$

$$Z_{laser} = D_{laser} \cdot H \cdot \cos(\theta) \quad (6)$$

$$X_{laser} = \frac{\Delta x}{f} D_{laser} = \frac{c_x \cdot n_x}{f} D_{laser} \quad (7)$$

Where, c_x and c_y are CCD sell size, n_x and n_y are x and y-direction where is axes pixel value, respectively, f is focal length and H is distance between laser slit and stereo camera

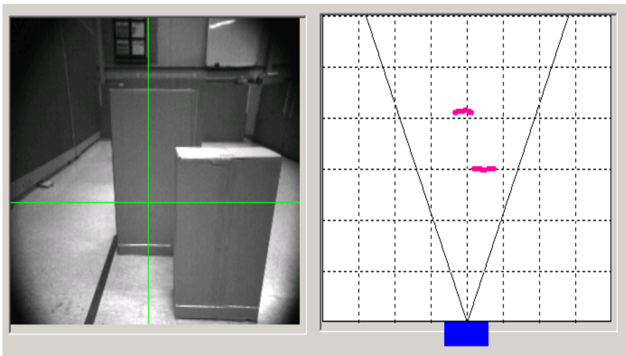


Fig. 4 An example of detecting laser slit beam

Fig. 4 shows an example of detecting laser slit beam. The distance between obstacle and mobile robot is about 60cm and 80cm, respectively.

2.2 Stereo imaging

The geometry of stereo camera is shown in Fig. 5(a). The simplest model is two identical cameras separated only in the x direction by a baseline distance W. The image planes are coplanar in this model. Since a feature(P) is viewed by the two cameras at different positions, P can be measured as P_r in the right image plane and P_l in the left image plane respectively. As a shown Fig. 5(b), the displacement between the locations of two features in the image plane is called the disparity. The plane passing through the camera centers and the feature point in the scene is called the epipolar plane. The intersection of the epipolar plane with the image plane defines the epipolar line. We assume every feature lies on the epipolar line.

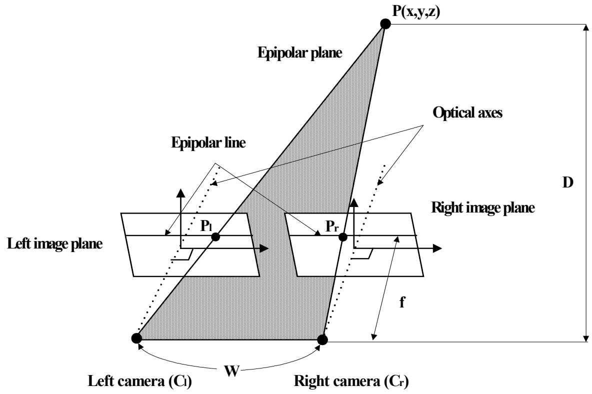


Fig. 5(a) Epipolar planes and epipolar lines

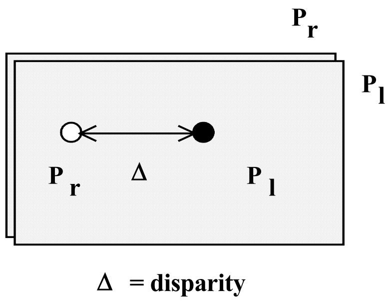


Fig. 5(b) Disparity

In Fig. 5(a) the scene point P is observed at P_r and P_l in the left and right image plane, respectively. Let assume that P, P_r and P_l are the same plane. We get:

$$D_{stereo} = \frac{W \cdot f}{P_l - P_r} = \frac{W \cdot f}{\Delta} \quad (8)$$

From Fig. 2, we get:

$$Z_{stereo} = D_{stereo} \cdot H \cdot \cos(\theta) \quad (9)$$

2.2.1 Stereo Matching

The stereo matching is to find the correspondence of every individual pixel in both images of stereo pair.

The stereo matching algorithm is divided into two categories: correlation-based and feature-based methods. Correlation-based methods apply to the totality of image points and feature-based methods attempt to establish a correspondence between sparse sets image features.[14-15]

This paper used correlation-based methods, Small Vision System(SVS).

Fig. 6 shows looking for the right image point corresponding to the central pixel of the left image window. We get following equation:

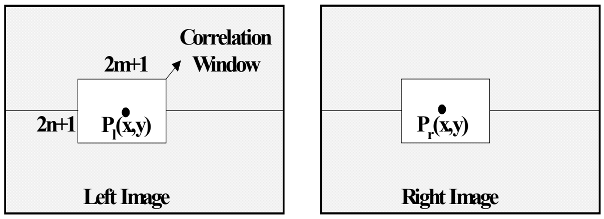
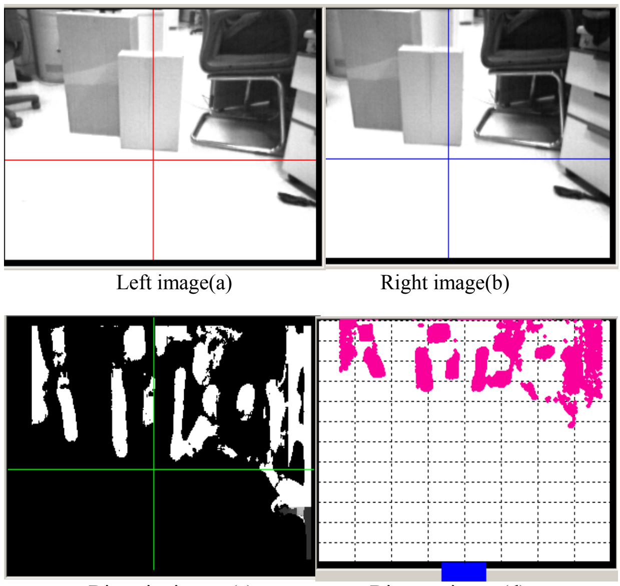


Fig. 6 Correlation window

$$C(x,y,\Delta) = \frac{\sum_{m,n}[P_l(x+m,y+n) - P_r(x+\Delta+m,y+n)]^2}{\sqrt{\sum_{m,n} P_l^2(x+m,y+n)} \times \sqrt{\sum_{m,n} P_r^2(x+\Delta+m,y+n)}} \quad (10)$$

Where, P_l and P_r are pixels in the left and right image, 2m+1 and 2n+1 are correlation window size.



Left image(a) Right image(b)

Disparity image (c) Distance image(d)

Fig. 7 Examples of detecting obstacles from a pair of images(top), Disparity image(bottom left) and Distance image

Fig. 7 shows examples of detecting obstacles from a left image(a) and a right image(b). Fig. 7(c) converts a disparity image to binary image and Fig. 7(d) is a distance image between stereo camera and obstacles.

2.3 Distance estimation

Using a passive sensor (stereo camera) and an active sensor (stereo camera and laser slit) calculate distance between mobile robot and obstacle. A passive sensor range is longer than an active sensor range. However, an active sensor is more precise than a passive sensor. Therefore, they are integrated for overcoming these shortcomings. If an obstacle is located far away mobile robot($max_{Distance}$), we can use a passive sensor's distance information($min(Z_{stereo})$). And if objects don't have features, we can get an active sensor's distance information(Z_{laser}). We can express following algorithm.

$$
\begin{aligned}
& if \sim(feature) \\
& \quad Z_{laser} \\
& else \\
& \quad if\ Z_{laser} < \max_{Distance} \\
& \qquad Z_{laser} = \min(Z_{laser}, Z_{stereo}) \\
& \quad elseif\ Z_{laser} > \max_{Distance} \\
& \qquad Z_{stereo} = \max(Z_{laser}, \min(Z_{stereo}))
\end{aligned} \tag{11}
$$

3. OBSTACLE AVOIDANCE

The Dynamic Window Approach(DWA)[11-13] is an obstacle avoidance method that takes into consideration the kinematics and dynamic constraints. Kinematics constraints are taken into account by directly searching the velocity space of mobile robot. The search space is the set of pairs(v, w) of translational velocities v and rotational velocities w that are reachable by the mobile robot. Among all velocity pairs those are selected to allow the mobile robot to be able to stop before colliding with an obstacle, given the current position, the current velocity, and the acceleration capabilities of the mobile robot. These velocities are called admissible velocities. By the admissible velocity set(v, w) is made objective function(S). This objective function is composed of target heading(θ), obstacle's distance($D_{collision}$) and velocity. In this paper, the objective function will be maximized and defined as following.

$$
S = \alpha\left(1 - \frac{|\theta - wT|}{\pi}\right) + \beta \frac{D_{collision}}{D_{\max}} + \gamma V(\vec{v}) \tag{12}
$$

$$
V(\vec{v}) = \begin{cases} \dfrac{\|\vec{v}\|}{v_{\max}} & \text{if robot is far from goal} \\ 1 - \dfrac{\|\vec{v}\|}{v_{\max}} & \text{if robot is close to goal} \end{cases} \tag{13}
$$

Where, w is rotational velocity, T is sampling Time, the maximum distance D_{max} that the robot can achieve and v is translational velocity. α, β and γ are weight factor.

4. EXPERIMENTAL RESULT

In this paper, experiments are performed with HomBot, which has been developed at the Korea Institute of Science and Technology(KIST). This robot with a PentiumⅢ @750MHz is equipped with as a main controller and SRI's MEGA-D Megapixel Stereo Head. The cameras were equipped with 6mm lenses. The cameras were mounted 8.8cm from each other(W is set to 8.8).

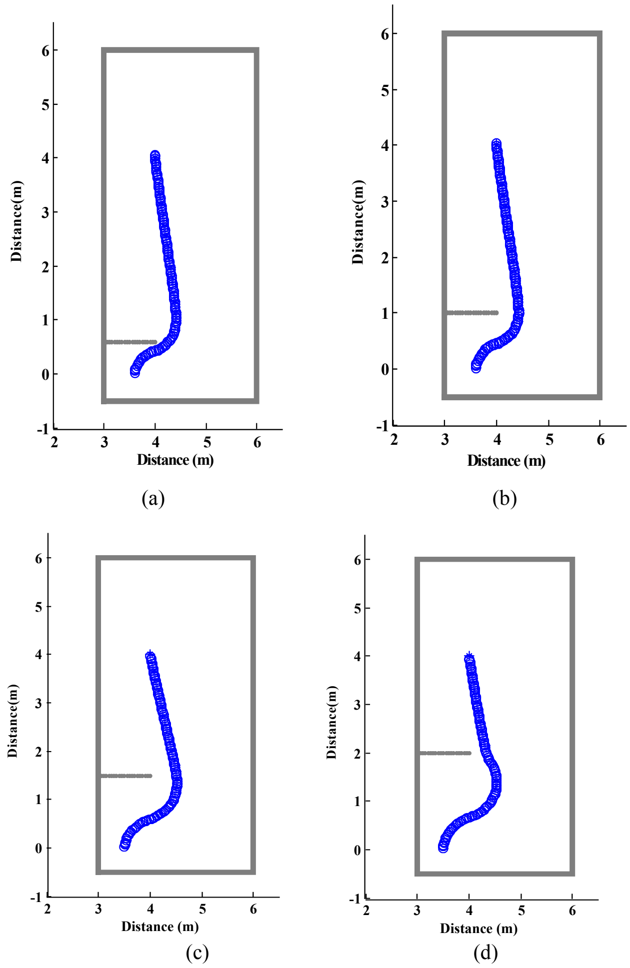


Fig. 8 Simulation result: (a) 0.6m, (b) 1m, (c) 1.5m, (d) 2m

Experiments are conducted in indoor environment. The tilt angle(Θ) of the stereo camera during the experiment was set to 20^{o}.(In Fig.2) The camera was mounted at H=60cm (In Fig.2). It can robustly detect the obstacles within 0.6~3m range. An image is captured in 320×240 pixels. As a shown Fig. 4, an active sensor minimum range is 0.6m and maximum range is 1m. Fig. 7 shows distance information is computed by disparity. A passive sensor range can be up to 3m.

We simulated the DWA algorithm using the Matlab. You can see the specification of this simulation as following: the maximum translational velocity V_{max} is set to 0.2m/s, rotational velocity W_{max}=7.5degree/s, translational acceleration Acc=0.2m/s^2, sampling time T=0.2ms and maximum angle Θ =±90degree/s. Fig. 8 shows the trajectories of DWA with four different distances between a mobile robot and an obstacle as initial condition, Fig. 9 shows that in the case of obstacle avoidance, distance between a robot and an obstacle. In Fig. 9, when sensing distance is within 1~2m range, the mobile robot can be better to avoid obstacle. However, when sensing distance is over 2m, the mobile robot can be worse for avoiding obstacle.

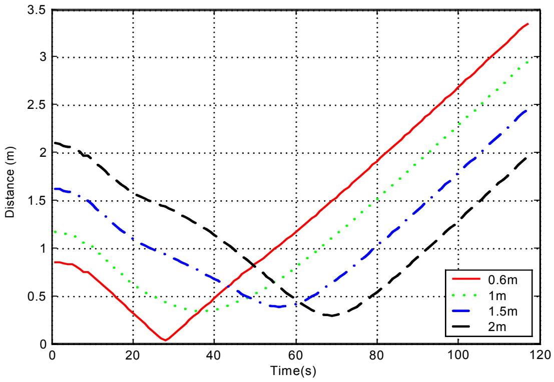


Fig. 9 The simulation result of experimental at 0.6m distance, at 1m distance, at 1.5m distance and at 2m distance

5. CONCLUSIONS

In this paper, we propose new obstacle detection system using only a vision system. This system could overcome shortcomings of vision system. Obstacles without a texture can be detectable by the active sensor and a far-off obstacle can be obtained with a disparity picture from image pair by a passive sensor

Because the vision system is affected by either the change of illumination or on poorly configured light condition, vision sensor cannot detect objects.

Using obstacle avoidance algorithm with DWA simulation results are showed. We will implement this algorithm in mobile robot system.

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