DETECTION OF OBSTACLE AND FREESPACE IN AN AUTONOMOUS WHEELCHAIR USING A STEREOSCOPIC CAMERA SYSTEM

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ABSTRACT

Computer Vision has been a very new field developing rapidly in recent years. One of the main advantages in this development is that the “human vision” abilities such as electronically perceiving and understanding of images are provided to apply to autonomous vehicles or mobile robots. In this paper, detection of obstacle and freespace in an autonomous wheelchair using a stereoscopic camera system is introduced. The image data captured from the real word are obtained from a multiple camera system called the stereoscopic camera system. This paper will represent two dimensional (2D) and three dimensional (3D) maps calculated based on disparity map using geometric projection. From the 2D and 3D maps, one can detect obstacles and freespaces for the objective of autonomous wheelchair control. The experimental results obtained show to illustrate the advantage of the proposed method.

KEYWORDS: stereoscopic camera system, 3D and 2D maps, autonomous wheelchair.

1. INTRODUCTION

Computer Vision consists of finding the depth of a scene from several views of it [1]. This depth is calculated for obstacle avoidance of an autonomous wheelchair on its way using a stereoscopic camera system.

Electric wheelchairs with the joystick or traditional wheelchairs controlled by hands are necessary to assist the mobility of disabled people. However, in many cases, these wheelchairs are not safe for users in the case of loss of control. For this reason, additional equipments including specialized computer, sensors and control system, are mounted on power wheelchairs and novel algorithms are utilized to enable them to be classified as smart wheelchairs [2-4].

In recent years, ultrasound and laser sensors have been used to detect obstacles and freespaces in the environment surrounding mobile vehicles [5-8]. For example, a mobile robot may be equipped with ultrasonic sensors, helping to detect freespace and obstacle for its mobile operation [9-11]. In addition to freespace detection, a Bayesian update theory is applied to compute the value, in a given direction, of “FreespaceProbability” at each point-mark [12].

The SAD correlation method, using stereo cameras, has effectively detected landmarks and corresponding images, in which block matching methods are utilized. In recent years, these have served to estimate the disparity for pixels in a pair of stereo images [13-16]. In this paper, the SAD correlation algorithm takes one pixel in an image from a region of pixels. It then finds its closest match to a pixel in the corresponding region of the other image, and creates a disparity map [17, 18].

This project proposes an approach involving the detection of freespaces and obstacles using a stereoscopic camera system. It is proposed that the camera system collects 3D information in an unknown environment. The electric wheelchair autonomously detects both the height and width of freespaces and obstacles for collision avoidance. From the left and right images captured by the camera system, the Sum of Absolute Differences (SAD) correlation method will be employed to determine stereo disparity.
Given this disparity map, a 3D point map is generated using a geometric projection, in which the height and width of a freespace or an obstacle are determined. For the goal of detecting freespaces and obstacles, a 2D distance map is converted from this 3D map. Based on the 2D map, one can calculate the autonomous avoidance of the electric wheelchair.

2. CALCULATION OF VISION IMAGES

2.1 Block Matching

Block Matching algorithm uses a window with $(2m + 1) \times (2n + 1)$ size. The window will be moved along the epipolar line [1] in the left image from the pixel $(x_0, y_0)$ in specific range of disparity $d$: $d_{\min} - d_{\max}$ (see Figure 1). While moving, the matching cost will be calculated by the SAD equation as follows:

$$SAD(x, y, d) = \sum_{k=m}^{m} \sum_{l=-m}^{n} (|I_L(x_0 + k, y_0 + l) - I_R(x_0 + k + d, y_0 + l)|)$$  

in which $I$ is the gray level of the pixel $(x_i, y_i)$.

After calculating the SAD matching cost of all window’s positions, the minimum cost will be chosen:

$$D = \min_{d_{\min} - d_{\max}} \{SAD(x, y, d)\}$$  

in which $D$ is the disparity of the pixel $(x_D, y_D)$. 

The flowchart for calculation of a pixel’s disparity using equation (1) is shown in the Figure 2.

2.2 Calculation of 3D Map

The disparity $D$ of all pixels in the image will be used to find the depth $Z$ using for geometric projection as shown in Figure 3. The depth distance will be expressed in the following equation:

$$Z = \frac{f \cdot b}{D}$$  

in which $Z$ is the distance from the camera to the real object, $f$ is the focal length of the camera and $b$ is the baseline length of the camera.

The $X$ and $Y$ parameters of a pixel on the 3D map will be then calculated as in Figure 4 using the similar triangle projection in the
following equations:

\[ X = \frac{x}{f} Z \]  (4)

\[ Y = \frac{y}{f} Z \]  (5)

in which \((X, Y)\) is the position of the object \(P\) in real world.

\[ h_l \leq Y \leq h_h \]  (6)

The flowchart for determining these pixels on the 3D map is shown in Figure 5.

2.3 Calculation of 2D Map

A 2D map is converted from the 3D map data. The 2D map will be of the axes \(X\) and \(Z\), in which the depth \(Z\) is considered as the distance from obstacle to the camera centre of the wheelchair.

The minimum distance \(Z_{imin}\) of the column number \(i\) is computed in the following equation:

\[ Z_{imin} = \min_{j=0}^{n} Z_{ij} \]  (7)

in which \(Z_{imin}\) is the minimum \(Z\) of the column number \(I, j = 0 - n\) is the numbers of the rows on the image.

The flowchart for computing \(Z_{imin}\) is shown in Figure 6.

The distance \(Z_{min}\) of the closest object appearing in front of the camera is computed as follows:

\[ Z_{min} = \min_{i=0}^{n} Z_{imin} \]  (8)
in which \( i = 0 - m \) is the number of column.

The width \( w_i \) of the freespace number \( l \) is computed in the following equation:

\[
 w_i = \sum_{r=k_l}^{k_2} X_i \tag{9}
\]

in which: \( r = k_1, k_2 \) is the first and the last position on the \( X \) axis where \( Z_i \leq Z_{\text{min}} \).

Then, the width \( w_i \) of the freespace number \( l \) will be compared to the width \( w \) of the wheelchair to see if it is really “freespace” or it is “obstacle”. If \( w_i > w \), it will be considered as freespace, otherwise it will be considered as obstacle.

3. EXPERIMENTAL RESULTS

3.1 Wheelchair Hardware System

An electrical wheelchair was installed with the Bumblebee stereoscopic camera system to produce 3D image information and some necessary devices such as Analog to Digital Converter, DAQ, mini monitor (LCD)… as shown in the Figure 7 in this paper. The height \( h \) of the wheelchair is 1.1m and its width \( w \) is 0.8m. The camera is located at the height \( h_l = 0.8m \) from the ground.

3.2 Detection of Obstacle

The environment in this experiment has one obstacle in front of the wheelchair as shown in the Figure 8. Based on the left and right images, one can compute the disparity map.

\[ \text{Figure 8: The left (a) and right (b) images.} \]

The environment has a board obstacle and two freespaces (space 1 and space 2), in which there is a small freespace (space 3) under the board obstacle. The disparity map computed from the left and right images using the block matching algorithm with the window size of 7x7 is shown in the Figure 9.

\[ \text{Figure 9: Disparity map.} \]

The 3D map is computed using the geometric projection as shown in the Figure 10.

\[ \text{Figure 10: The front – view 3D point map.} \]

The 2D map of the environment is shown in the Figure 11. In this map, the camera system can recognize the board and the freespaces around it to be an obstacle. Because the widths of the space 1 and space 2 are 0.8m, equal to the wheelchair’s width, and the height of the space 3 is 0.9m,
less than the wheelchair’s height.

Figure 14: Left (a) and right (b) images.

The wheelchair can recognize the chairs as an obstacle and two freespaces on the left and right side of the chairs in the 2D map (see Figure 15). The width of the freespace 1 is about 1m and that of the freespace 2 is 1.3m.

Figure 15: 2D map of environment with obstacle and freespaces.

When detecting the obstacle, the wheelchair will check if there is any freespace in the 2D map, from the left to the right of 2D map, and chose the larger freespace to pass through. At this position on its way, the wheelchair can recognize that the width of the freespace 2 is larger than that of freespace 1. Therefore, the wheelchair made the decision to turn right to pass through the freespace 2 and avoid the obstacle. After passing through the freespace 2, the track of the wheelchair’s motion was drawn as Figure 16.

Figure 16: Wheelchair avoidance of obstacle.

These experiments were shown to illustrate that an electric wheelchair installed with the stereoscopic camera can avoid obstacles and pass through freespaces. In this paper, the wheelchair was designed to avoid collision and go through freespaces based on 2D maps.

4. CONCLUSION

A stereoscopic camera system mounted on an electric wheelchair can recognize obstacles and freespaces on its way. Given the left and right images, the disparity map was determined. Therefore distance Z from objects in the scene to the camera centre of the wheelchair was calculated. The 2D map was obtained from the 3D map. Based on this 2D map, the wheelchair was calculated to detect obstacles and freespaces and autonomously avoid and pass through. The experimental results show that the proposed method is the effectiveness.

5. ACKNOWLEDGMENTS

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6. REFERENCES


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