Road Recognition for Vision Navigation of Robot by Using Computer Vision

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***Abstract*— This paper presents a method for vision navigation of robot by road recognition based on image processing. By taking advantages of the unique structure in road images, the square images on road can be scanned while the robot is moving. In this paper we focused on the pixel position of the images of the corners of the two squares. Large scale experiments on road sequences shows the road detection method is four coordinate system, road types and scenarios. Finally, the proposed method provides highest road detection accuracy when compared to state-of-the-art methods.**

Keywords: Robot; pattern recognition; four coordinate system; Image Processing

I. INTRODUCTION

One of the most mature autonomous driving systems was developed since 1985 by Universit¨at der Bundeswehr M¨unchen (UBM) [1]. Their approach involves modeling roads as clothoids and estimating their parameters using an Extended Kalman Filter (EKF) on visual observations and odometry. This work extends that framework to dirt road detection [2], waypoint driving [3], and obstacle detection while driving off-road [4].

Vision based road detection is an important research topic in different areas of computer vision. Such as robot navigation, autonomous driving, car collisions and warning crossing detection. Outdoor navigation is an active research field in robotics. In general, vision-based methods use low-level features for road detection [5,6,7]. A forerunner system in outdoor navigation is the Navlab project developed by Thorpe et al. [8]. Road detection is one of the most renowned problems within the subfields of computer vision in terms of the amount of research, it has attracted and number of uses it has. Together with research into other subfields of artificial intelligence, road detection is crucial in order to perform many basic operations for robot navigation by using four coordinate system such as avoidances and navigation.

FOUR CORDINATE SYSTEM FOR ROBOT VEHICLE

A robot vehicle is equipped with a camera. The camera image is a rectangle of height 500 pixels and width 600 pixels. The focal length is 690 pixels. The center of projection C of the camera is 3 m above the ground.

The optical axis of the camera makes a 20 degree angle with the ground, so that the camera looks slightly downward toward the road. Large squares of size 4 m have been painted everywhere along the median lines of roads to facilitate automatic vehicle navigation. Two of the slides of the squares are parallel to the road edges. The vehicle is on a flat road where it sees only two squares. The vehicle faces the first square such that the optical axis of the camera passes through the center of the square, and is perpendicular to two sides of the square. Because the road turns, the next square is at an angle with the first square. The centers of the squares are on a circle of radius 100 meter (which is also the radius of the road turn), and the arc between the two centers is 10 degrees.

The four coordinate systems for robot navigation are selected as follow [Figure1] coordinate 0 originated at the center of projection, coordinate 1 originated at the center of the first square, coordinate 2 originated at the center of the second square, and the image coordinated at the center of the image plane. All coordinates use right-hand-rule. The X- and Z- axis of coordinate 1 and 2 are in the road plane and parallel to the two sides of the squares respectively. The relationships between these coordinates can be easily established by simple rotation and translation.

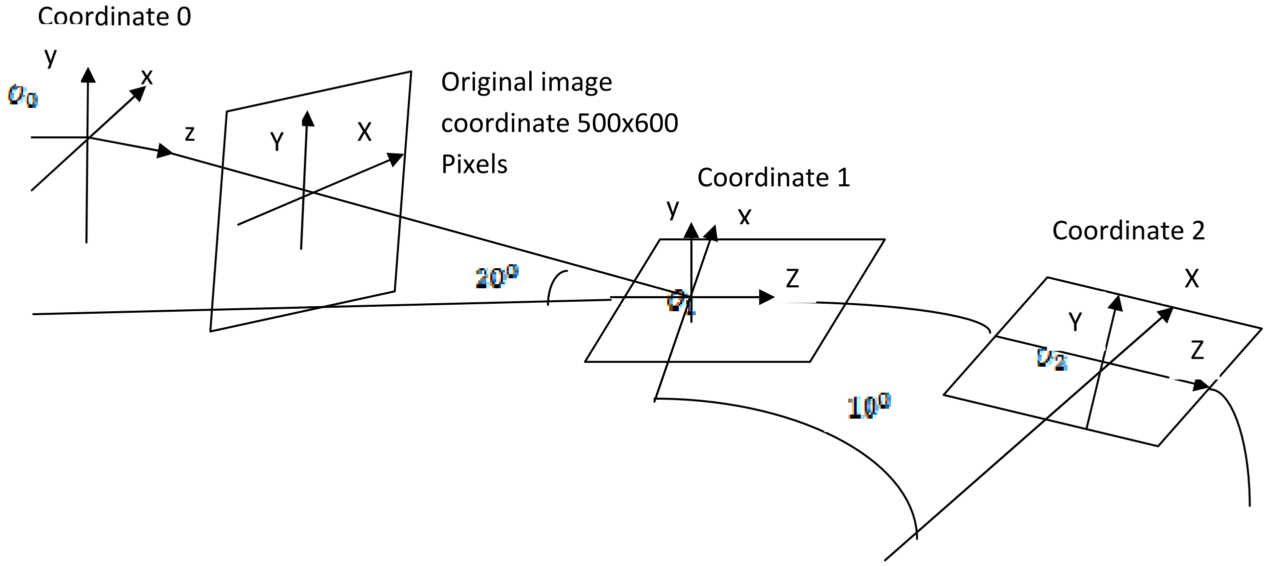

Figure 1. Robot Navigation

II. ROAD SQIARES IMAGE DETECTION METHODOLOGIES

Compute the pixel positions of the images of the corners of the two squares. To navigate, the robot computes a projectivity (i.e. homography) that transforms the images of the squares back to their actual geometry on the road, in order to compute how the road turns. To do that, it does not use the camera focal length and the camera position with respect to the road .Instead, it uses its knowledge that squares it sees are always of size 4 m, and computes a projectivity matrix using the four corners of closest squares it see

The basic idea of this solution is establishing the rotation-translation relationship between

- Coordinate 2 and coordinate 1: rotate around axis y by -10^0 and translation from O_1 to O_2.
- Coordinate 1 and coordinate 0: rotate around axis X by 20^0 and translate from O_0 to O_1.
- Coordinate 0 and image coordinate: translation and scaling.

We have taken the transformation matrix as H= $[h_{ij}]_{3\times3}$. Assume image coordinate is $[u, v, 1]^T$, and correspondent space coordinate is $[x^{'}, z^{'}, s]$. Here that the square is on a flat plane. The relations between the coordinates are shown in the following equations:

$$\begin{bmatrix} x^{'} \\ z^{'} \\ s \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \quad (1)$$

Where that x=$\frac{x^{'}}{s}$, z=$\frac{z^{'}}{s}$.

Now, we have:

$$x = \frac{h_{11}u + h_{12}v + h_{13}}{h_{31}u + h_{32}v + 1} => h_{11}u + h_{12}v + h_{13} - h_{31}ux - h_{32}vx = x \quad (2)$$

$$y = \frac{h_{21}u + h_{22}v + h_{23}}{h_{31}u + h_{32}v + 1} => h_{21}u + h_{22}v + h_{23} - h_{31}uz - h_{32}vz = z \quad (3)$$

Since we have four correspondent points, we have 8 equations, which can be expressed in the form of Ah=b:

$$\begin{bmatrix} u_i & v_i & 1 & 0 & 0 & 0 & u_i x_i & v_i x_i \\ 0 & 0 & 0 & u_i & v_i & 1 & u_i z_i & v_i z_i \end{bmatrix} \cdot \begin{bmatrix} h_{11} \\ h_{12} \\ h_{13} \\ \vdots \\ h_{31} \\ h_{32} \\ h_{33} \end{bmatrix} = \begin{bmatrix} x_1 \\ z_1 \\ \vdots \\ \vdots \\ \vdots \\ x_4 \\ z_4 \end{bmatrix} \quad (4)$$

Therefore, the H can be easily solved by $A^{-1}b$. Similarly, we can also calculate the new road coordinate of the 4 corners of the square 2.

The reconstructed squares are show as follow Figure2. Once we get the geometry relationship between square 1 and square 2, we have their position information on the road plane. Then the arc θ between the two centers of the squares can be computed by two sides of the two squares respectively. Combining with the distance D between the two centers, the radius is taken by $\frac{D}{2\sin\left(\frac{\theta}{2}\right)}$.

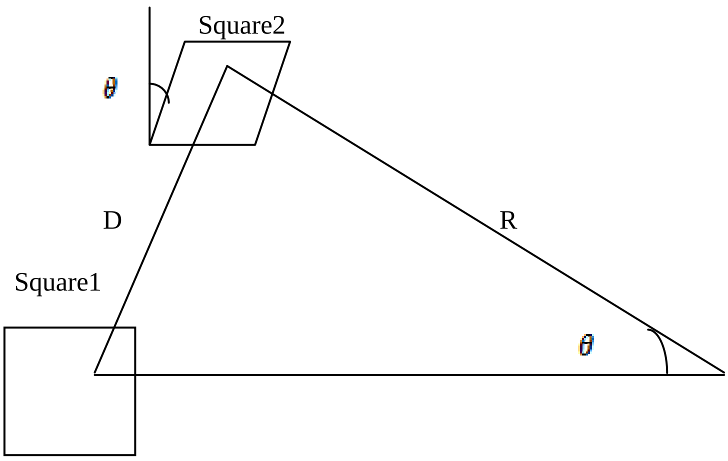

Figure 2. Geometry relationship of two squares

IV. RESULTS AND DISCUSSION

In the simulation part first we have defined the corners of the square1 in coordinate2 and square2 in coordinate1. Square1, square2 corners are converted in to image planes. It displays the image coordinates of corners and plots the two squares in the image plane as shown in the below Figure3. We have also calculated the geometry for square2 and drawn the two squares as shown in the below Figure4.

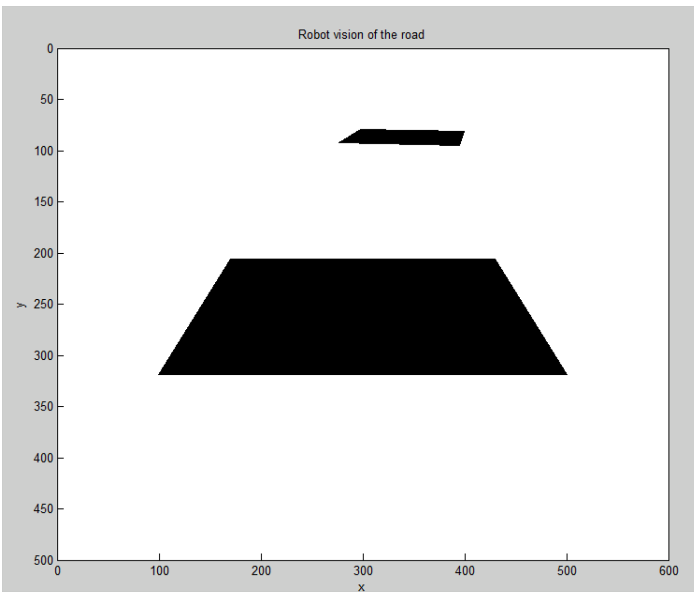

Figure 3. Simulated output for Robot vision of the road

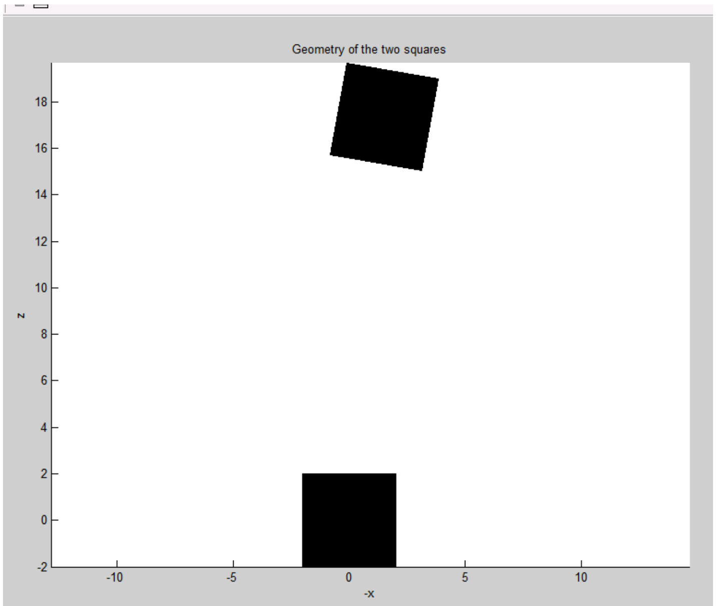

Figure 4. Simulated Output for geometry of two squares

Finally we have calculated the radius image coordinate of corners of square 1 which are shown in below table 1 and image coordinate of corners of square2 which are shown in below table 2. Transformation matrix can be calculated from image to geometry that matrix and radius also display below.

TABLE 1. Image coordinates of corners of square 1

ID	X	Y
1	170.4322	205.6852
2	99.7687	318.4832
3	500.2313	318.4832
4	429.5678	205.6852

TABLE 2. Image coordinates of corners of square 2

ID	X	Y
1	297.3911	79.6510
2	276.6427	92.3421
3	394.6090	95.0052
4	399.4584	81.6324

Transformation matrix (from image to geometry)

$$H = 1.0e+003 * \begin{bmatrix} -0.0028 & 0.0000 & 0.8405 \\ -0.0000 & -0.0082 & 2.0480 \\ -0.0000 & 0.0009 & 0.0010 \end{bmatrix} \quad (5)$$

Radius= 100.0000 degrees

V. CONCLUSION

Large scale experiments on road sequences have shown that the road detection method is robust to varying imaging conditions, road types, and scenarios (tunnels, urban and highway). Further, using the combined cues outperforms all other individual cues. Finally, the proposed method provided highest road detection accuracy when compared to state–of–the–art methods.

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