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Implementation of Machine Vision System for Finding Defects in Wheel Alignment

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Abstract - One of the crucial tasks in the field of automobiles is the verification of the wheel characteristic angles as the specification given by the manufacturer. The automation in the process can be done by the use of machine vision instead of the conventional way of finding the wheel angels by mounting the measurement equipment on the wheel. This paper deals with the contactless measurement of wheel angle by the use of the 3D stereo vision system. The method in this paper was tested for set of various images and the error in the angles obtained is with the pixel accuracy.

***Keywords* - Stereo vision, wheel alignment, Disparity, Rectification, epipolar lines, Depthmap.**

1. Problem Definition

Wheel alignment consists of correctly observing the wheel angle as per specification given by manufacturer. Incorrect angles may lead to irregular tyre wear and tear affecting vehicle handling and safety.

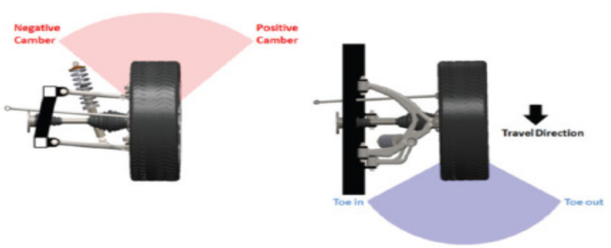

Fig. 1. Toe and camber angle [1]

Toe and camber angles of front wheels are checked and corrected during wheel alignment.

Toe Angle - The symmetric angle made by the wheel with the longitudinal axis of the vehicle. If the leading edges of the wheel are slightly pointing towards each other then it is toe-in else toe-out. [2] Following areas of performance are affected by toe settings: Tyre wear, Straight-line, Stability and corner entry handling characteristics.

Camber Angle - The angle between the vertical axes of the wheels used for steering.

Wheel is said to have positive camber if it leans away from the car else it is said to have negative camber [2]. This angle relative to the road surface has an impact on the cornering force that a tyre develops and has major impact on the road handling of the car [3]. In conventional method of error detection in wheel alignment, complex equipment for camera calibration needs to be mounted on wheel first then the actual error in wheel alignment is found out. This method requires the use of pre-marked wheels or else markers can be placed at the time of measurements manually.

The conventional method has the following drawbacks:

- A non-trivial procedure needs to be carried out in order to attach the equipment onto the wheel.
- Care must be taken while placing the instrument on the wheel in order to prevent measurement errors during movements and rotation of the wheel occurring in routine measure operations.
- The time required for measurement increases due to mounting.

In order to overcome the above mentioned drawbacks, the proposed idea is to implement a contactless measurement using stereo-vision technique.

2. Literature Review

As per above problem definition, it is necessary to find distance between camera setup and wheel to be examined. The most appropriate and efficient method is to use the stereo camera setup and finding the depth by disparity information from stereo images obtained by left and right camera. Concept of obtaining depth (Z coordinate value) by using stereo camera setup is explained below:

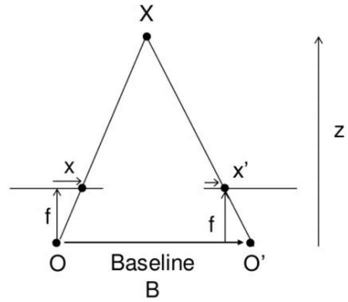

Fig. 2. Depth measurement using stereo camera setup scheme top view

X and X' are the position of left and right camera respectively. 'f' is focal length of each camera. Both cameras need to be of same specifications in order to obtain images with similar characteristics. B is baseline i.e. distance between 2 cameras. O(x,y) and O'(x',y') are the images formed. Disparity is difference between 'x' coordinates of rectified image. Methods of calibration and rectification are discussed later. The distance of the wheel from camera setup or in other words, depth, is calculated by -

$$Depth(mm) = \frac{focal\ length(mm) * baseline\ distance(mm)}{Disparity(pixels)} \quad (1)$$

3. Solution Methodology

Stereopsis is the depth impression perceived when a scene is viewed by someone with two eyes and normal binocular vision. Analogous to human eyes which are laterally spaced on the head, stereo cameras provide binocular vision that creates two slightly different images giving depth perception. Depth perception is obtained from a disparity map where disparity map is apparent difference between the pair of stereo images.

The proposed system consists of a pair of cameras setup in frontal parallel arrangement. Both right and left cameras capture the images of a wheel every time the wheel is tilted by different angles with respect to the reference image. Disparity map is obtained from the corresponding stereoscopic images. In order to get the actual depth information about images from the camera, depth map is plotted. The difference between the reference image and tilted image is in terms of the depth information. This difference is used to estimate the angle of a tilted image w.r.t the reference image by using trigonometric.

4. Experimentation

In this paper, more emphasis is given on Toe angle.
Specifications of the stereo cameras used for the experimentation purpose are as follows:

- 3MP industrial stereo cameras
- 3.5mm focal length, sensor size ½"
- Baseline distance – 200mm

The procedure starts with camera calibration by considering different checker board images taken from the stereo cameras and then using the camera calibration toolbox to calibrate.

This toolbox is provided by Caltech University [7]. The output of the complete procedure gives the intrinsic and extrinsic parameter of the camera setup.

The intrinsic parameters consist of the focal length, principal point, skew, distortion whereas the extrinsic parameter provides the value of translation vector and the rotation matrix.

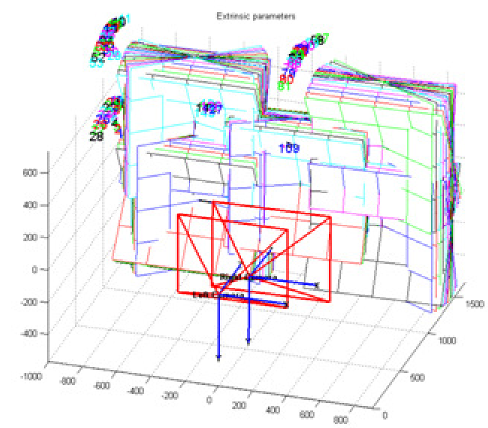

Fig. 3. Checker board at different positions and angles

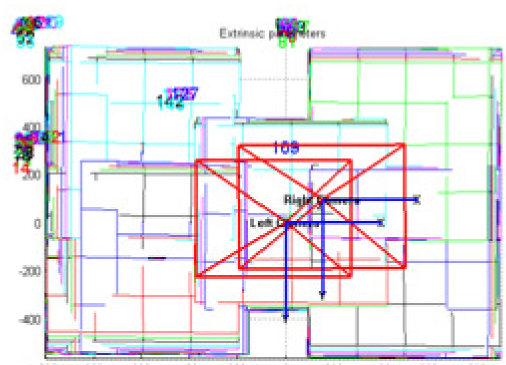

Fig. 4. Misalignment of two cameras

For the calibration purpose, 149 images of a checker board placed at different angles are taken from left as well as right camera. First step is to extract grid corners i.e. the four corner points are of each image. During the extraction, window size, width of the checker box and the number of boxes is given as input to the toolbox. Based on this, calibration is performed. The procedure is repeated by

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taking different window size sand initial guess of distortion if any. The calibration results obtained are:
Extrinsic parameters (position of right camera with respect to left camera):

Rotation vector:
om = [0.05392 0.01326 0.00595]
± [0.00860 0.01248 0.00141]

Translation vector:
T = [-154.62055 97.54445 -79.26138]
± [11.21513 10.21156 27.10516]

4.1 Rectification Procedure

As the camera setup can never be in exact frontal parallel arrangement, the epipolar lines do not pass through same feature points.

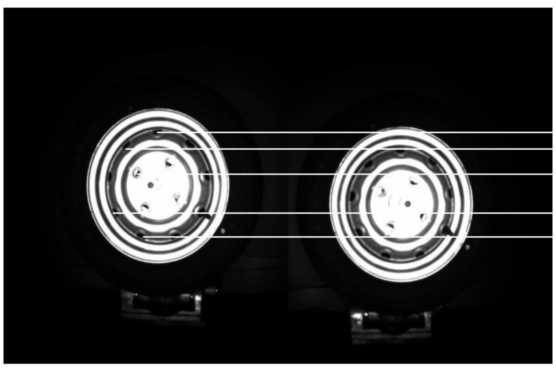

Fig. 5. Unrectified image

To minimize the reprojection distortion and to make them pas through same feature points, Bouguet's algorithm [5] is used which also maximizes the common viewing area.

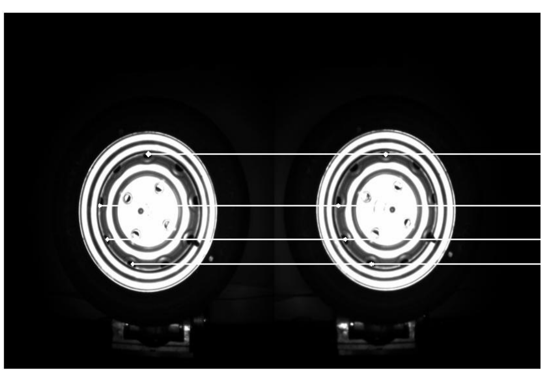

Fig. 6. Rectified image

The rotation matrix gives the rotation of right camera's image plane with respect to that of the left camera's image plane. This rotation matrix is split in half and each of the camera rotates have the rotation such that their principal rays become parallel to the vector sum of the point where the original principal rays meet. This rotation puts the camera in coplanar arrangement but not in row alignment. To make the epipolar lines horizontal, the epipole of left camera's image plane needs to be taken to infinity which will be done by Rrect. This matrix is created by individually creating unit vectors.

$$e_1 = \frac{T}{|T|} \tag{2}$$

Where e_1 is the unit normalized direction of the epipole.
To get next unit vector e_2 the cross product of e_1 with the direction orthogonal to principal ray is taken and then normalize it.

$$e_2 = \frac{[-T_y T_x \; 0]^T}{\sqrt{T_x^2 + T_y^2}} \tag{3}$$

The third vector e_3 is orthogonal to e1 and e_2.
The Rrect matrix which will take the epipole to infinity can be written as

$$R_{rect} = \begin{bmatrix} (e_1)^T \\ (e_2)^T \\ (e_3)^T \end{bmatrix} \tag{4}$$

This will rotate the left camera about the center of projection such that epipolar lines become horizontal. The required row alignment can then be found out as below:

$$R_l = R_{rect} r_l \tag{5}$$
$$R_r = R_{rect} r_r \tag{6}$$

Where r_l and r_r are the resulting rotational matrices for left and right camera respectively.
The reprojection of points in 2 dimensions into 2 dimensions can be done knowing their screen coordinates and camera intrinsic parameter. This reprojection matrix can be written as:

$$Q = \begin{bmatrix} 1 & 0 & 0 & -c_x \\ 0 & 1 & 0 & -c_y \\ 0 & 0 & 0 & f \\ 0 & 0 & -1/T_x & (c_x - c'_x)/T_x \end{bmatrix} \tag{7}$$

Except for the principal point x coordinate cx' in the right image, other parameters are from the left image. For a homogenous points and the corresponding disparity d, the point can be projected in 3 dimension using -

$$Q\begin{bmatrix} x \\ y \\ d \\ 1 \end{bmatrix} = \begin{bmatrix} X \\ Y \\ Z \\ W \end{bmatrix} \qquad (8)$$

3-D coordinates are then (X/W, Y/W).

The above Bouguet's algorithm procedure gives us the required stereo configuration.

Fig. 7. Left camera rectified reference wheel image

Fig. 8. Right camera rectified referencewheel image

Fig. 9. Left camera rectified tiltedwheel image

Fig. 10. Right camera rectified tilted wheelimage

4.2 Actual Measurement

For finding the disparity the epipolar lines need to be horizontal which are already obtained by rectification. Once the rectification is completed, 2-D disparity map is calculated. The maximum value from the disparity map is also verified using phase correlation technique. [6]

Result obtained before rectification is
Disparity[x y] = 361.7013 53.7327

Result obtained after rectification is
Disparity[x y] = 361.7013 -0.2674

The angle measurement is done using the rim of the wheel and not the tyre. Canny edge detection algorithm [3] is implemented which would extract rim of the wheel. The rim extracted would have many circular edges based on the contours present in it.

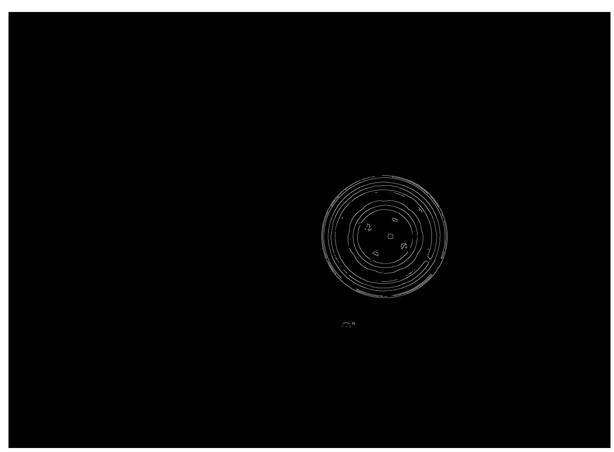

Fig. 11. Contours of rectified referencewheel image from left camera

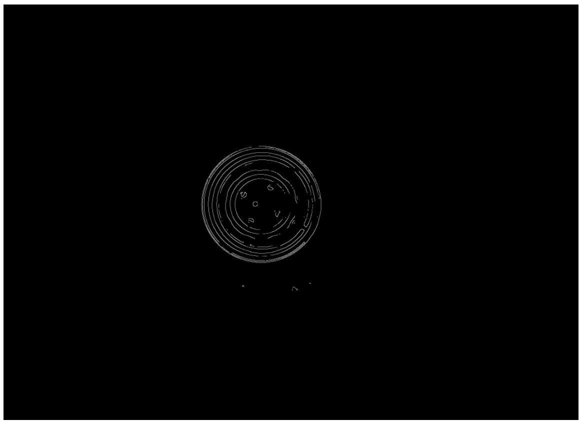

Fig. 12. Contours of rectified reference wheel image from right camera

Similar procedure is applied for every reference and tilted set of wheel images.
The required portion of interest is the outermost edge of the rim i.e. outermost contour. This can be extracted by using the morphological operations of closing followed by erosion.

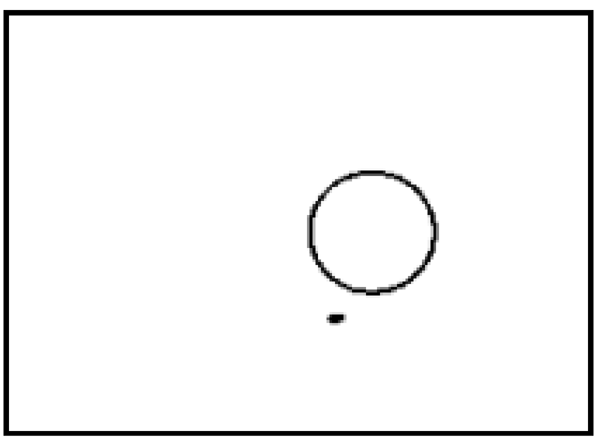

Fig. 13. Outermost edge of rectified reference wheel image from left camera(image inverted from original image for illustration)

The disparity is then calculated. As per the above mentioned formula for finding depth, depthmap is calculated by using the values from disparity map.
Camera calibration results can be used to find out the actual width of wheel from the width of wheel in pixels. The difference between the depth information of the reference wheel and tilted wheel will give the difference in terms of depthand that can be represented in angle using the concepts of trigonometry.

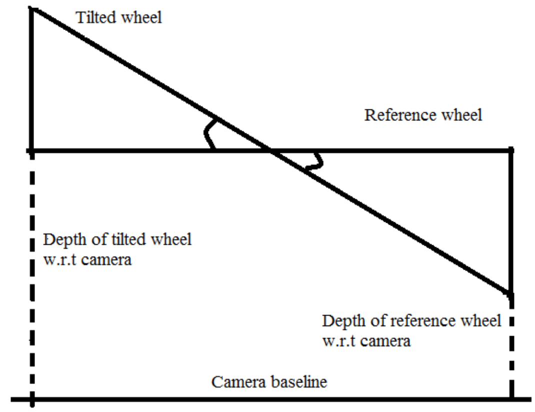

Fig. 14. Trigonometry concept

5. Result

Measurements were done for Toe angle and similar process can be followed for the camber angle.
Distance between wheel and camera obtained is 1.2 meters approximately and angle for maximum tilt obtained is 140. Different sets of tilted images were tried and the angle between Reference wheel(wheel without any tilt in steering) and wheel turned with specific angle was found out.

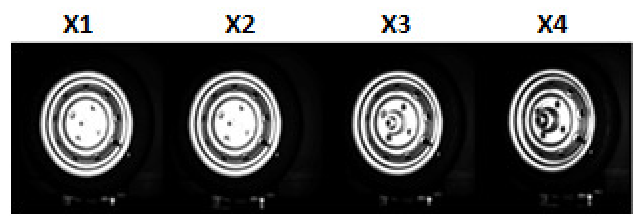

Fig. 15. Gradual tilting of wheel

Table 1.Comparison of actual and obtained angle

Image	Actual	Obtained
X1	1^o	0.730088^o
X2	2^o	1.579332^o
X3	8^o	7.405030^o
X4	15^o	14.210152^o

6. Conclusion

Machine vision can be implemented to measure the parameters of an object by using depth information obtained. This project thus successfully uses the concepts of stereo vision in the field of wheel alignment.
The current work can be expanded to find the error in angles of rear wheels and also frame angles. The proposed work done in Matlab can be implemented using OpenCV. A GUI can be designed which can facilitate the reading of

images and calculating the required angles. The program developed using OpenCV can be ported on a portable FPGA and microcontroller combination there by designing and developing a portable embedded system.

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