Measurement of wheel alignment using Camera Calibration and Laser Triangulation

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Abstract- **In this paper, we propose method to easily conduct the wheel alignment measurement by using Camera Calibration and Laser Triangulation. By taking advantage of laser projection which is ubiquitous in structured environments, our method makes it convenient for a mobile operation to collect the data needed for calibration. The proposed method estimates the relative position of the wheel by first determining the pose of each plane of the wheel and by comparing to standard data; we can easily find the misalignment of the wheel. The algorithm is validated first by performing experiments on simulated data and investigating its sensitivity for measurement to noise.**

Index Terms- **camera calibration, laser triangulation, alignment, angle measurement.**

I. Introduction

Camera orientation plays an important role to perform the three dimensional computer vision. Precise non-contact type three-dimensional measurements have drastically influenced physical sensing applications in many areas such as industrial production, health care, robot vision, artwork inspection, and many other engineering or science problems.

Typically, camera orientation is determined based on calibrated references via self-calibration method. This procedure is performed by lighting methods such as fringe projection, spot or line projection. The fringe projection determines the camera orientation by a transformation matrix and calibrated references [1,2]. Here, the three-dimensional vision is achieved by a phase detection algorithm. Also, a transformation matrix and references are used to determine the camera orientation in the line projection [3,4]. This method performs the three-dimensional measurement by laser triangulation. In the same manner, the camera orientation is computed in the spot projection [6].

In this paper we have used camera calibration [7] and laser triangulation together to find out the actual position of the car wheel which is measured in angle. Through this we can find out degree of misalignment. In automobile industries wheel alignment measurement is taken through sensor which is costly and we have to calibrate the sensor periodically for accurate results. So we have replaced the angle measurement sensor with camera and laser mechanism, which is more convenient in use and gives good accuracy.

In wheel alignment measurement procedure both the camera and laser source is fixed and the measurement independently carried out for the each wheel. Each time the laser beam projected on the car wheel. Wheel Rim is the one and only part which directly connects to shaft and the tyre get fitted on that shaft. Here camera is use to capture the laser projection on the rim. Due to difference in depth of the rim and tyre we easily separate ROI by using different methods like blob detection, depth map, threshold etc. In this paper we have used blob detection method for our application. Once we get the ROI the next step is to find out the edge point of laser lines on the rim. Here the laser projected on the wheel help us to identify the edge point of the rim then fit the circle on that region. Further process is on the detected region of the rim and proposed algorithm finds the angle measurement readings for that wheel.

The paper is organized as follows. In the next section, we give some pre-requisites about the geometry involved in the whole vision system. In the third section, procedure for measurement of wheel rim in which the arrangement of camera & laser and laser line 3D reconstruction is described. In fourth section, image-based parameters measurement methods are described. In section five the working procedure of the system is shown. Finally, Section six draws the conclusion.

II. Basic Notations

A usual pinhole camera model is used. A 2D image point is denoted by $\boldsymbol{p} = [\mathrm{u}, \mathrm{v}]^{\mathrm{T}}$, a 3D world coordinates point by $\widetilde{\boldsymbol{P}} = [\mathrm{X}, \mathrm{Y}, \mathrm{Z}]^{\mathrm{T}}$. The corresponding homogeneous coordinates are written by $\widetilde{\boldsymbol{p}} = [\mathrm{u}, \mathrm{v}, 1]^{\mathrm{T}}$ and $\widetilde{\boldsymbol{P}} = [\mathrm{X}, \mathrm{Y}, \mathrm{Z}, 1]^{\mathrm{T}}$. Base on pinhole model the mapping of 3D world coordinates point to 2D image point is described by

$$s\widetilde{\boldsymbol{p}} = \boldsymbol{A}\,[\boldsymbol{R} \vdots \boldsymbol{t}]\widetilde{\boldsymbol{P}}, \boldsymbol{A} = \begin{bmatrix} \boldsymbol{f}\mathbf{u} & \gamma & \boldsymbol{u0} \\ \mathbf{0} & \boldsymbol{f}\mathbf{v} & \boldsymbol{v0} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} \end{bmatrix}, \quad \text{.... (1)}$$

where s is an arbitrary scale factor that is not equal to 0. A is called intrinsic matrix which contain five parameters: $\boldsymbol{f}\mathbf{u}$ and $\boldsymbol{f}\mathbf{v}$ are the scale factors in the image axes **u** and **v**, ***(u0, v0)*** is the principal point, and γ is the skew of the two image axes which in practice is almost always set to zero. $[\boldsymbol{R}\ \boldsymbol{t}]$, called the extrinsic matrix, is composed of a rotation matrix and a translation vector from world coordinates to camera coordinates.

If the world coordinate is established on a plane (z axis is perpendicular), then the point on plane is $\widetilde{\boldsymbol{P}}$= [X, Y, 0, 1]$^{\mathrm{T}}$. Let's redefine $\widetilde{\boldsymbol{P}}$as $\widetilde{\boldsymbol{P}}$=[X, Y, 1]$^{\mathrm{T}}$ and denote the *i*th column of the rotation matrix $\boldsymbol{R}$ by $\boldsymbol{r_i}$. From Eq. (1), we have

$$s\tilde{\boldsymbol{p}} = \boldsymbol{A}\,[\boldsymbol{r_1}\,\boldsymbol{r_2}\,\boldsymbol{t}]\tilde{\boldsymbol{P}}, \qquad \text{.... (2)}$$

According to the projective geometry, this plane to plane mapping can also be expressed by a projective transform:

$$s\tilde{\boldsymbol{p}} = \boldsymbol{H}\tilde{\boldsymbol{P}}, \qquad \text{.... (3)}$$

where H is a 3×3 homographic matrix defined up to a scale factor. Let's denote the ith column of H by $\boldsymbol{h}_i$. From Eqs. (2) and (3), we have

$$\boldsymbol{\lambda}\,[\boldsymbol{h_1}\,\boldsymbol{h_2}\,\boldsymbol{h_3}]\tilde{\boldsymbol{P}} = \boldsymbol{A}\,[\boldsymbol{r_1}\,\boldsymbol{r_2}\,\boldsymbol{t}], \qquad \text{.... (4)}$$

If $\boldsymbol{A}$ and $\boldsymbol{H}$ is known, then the extrinsic matrix $[\boldsymbol{R}\ \boldsymbol{t}]$ is readily computed. From Eq. (4), we have

$$\boldsymbol{r_1} = \boldsymbol{\lambda}\,\boldsymbol{A^{-1}h_1}, \boldsymbol{r_2} = \boldsymbol{\lambda}\,\boldsymbol{A^{-1}h_2}, \boldsymbol{r_3} = \boldsymbol{r_1} \times \boldsymbol{r_2}, \mathbf{t} = \boldsymbol{\lambda}\,\boldsymbol{A^{-1}h_3},$$

$$\boldsymbol{\lambda} = \frac{\mathbf{1}}{||\,\boldsymbol{A^{-1}h_1}\,||} = \frac{\mathbf{1}}{||\,\boldsymbol{A^{-1}h_2}\,||}$$

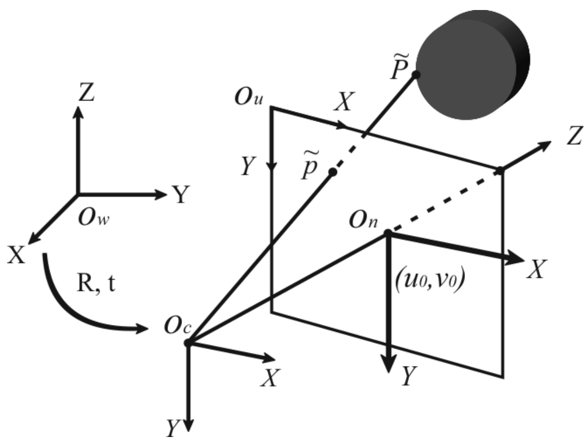


Fig.1 Projection model of camera in the structured light vision sensor.

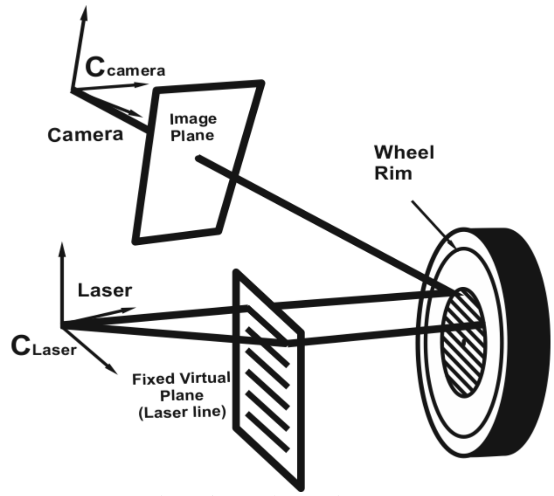
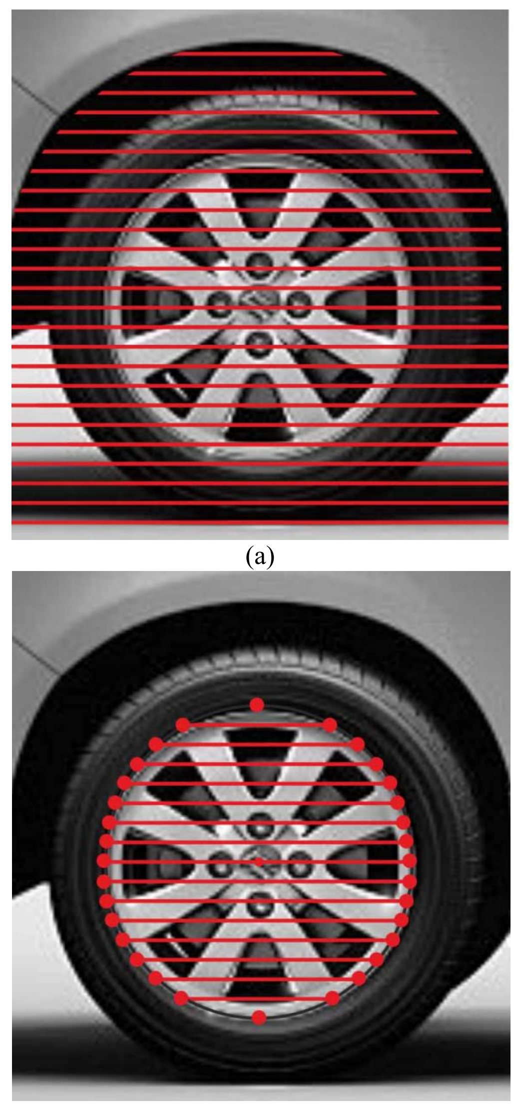


Fig.2 The sensing environment



(a)

(b)

Fig.3 a) Projection of laser on wheel b) Selection of Points

III. Measurement of Wheel Alignment

After camera calibration we get the distortion-free camera view which is most desirable for the industrial computer vision. Also we get the geometric model of the image which further use for the 3-D reconstruction [13]. Here fig.2 shows the basic arrangement of the sensing environment which we have use.

A. Arrangement of Camera and Laser

To achieve an accurate 3-D reconstruction of the wheel rim, some assumptions have been held:

1. The (m) laser line projected onto the wheel (Fig. 2) are splitted into m sets of collinear lines and each set has to be thought as a single linear object perpendicular throughout the wheel rim (Fig. 3).

2. Image points are assumed to be corrected from lens distortion with the direct method described in [10].

B. Laser line 3D reconstruction

Based on the principle mentioned discussed above, the first step of our method is to calibrate and reconstruct the laser lines in camera's coordinates. It is almost a calibration problem of structured light vision which can be found in related References [8, 9]. Here gives solution:

1) *Step-1: Get the image of the planar pattern on which the laser is projecting and correct the radial and tangential distortion parameter of the camera.*

2) *Step-2: Extract feature points of the pattern and laser in the image. In our instance, we adopted chessboard pattern and using standard corner detection algorithm to extract the corner points.*

3) *Step-3: The correspondence between image and actual planar pattern points can be used to compute homographic matrix H from Eq. (3).*

4) *Step-4: Then the geometry transform matrix [R t], from planar pattern coordinate frame to camera coordinate frame, can be compute from Eq. (5). By minimizing the re-projective errors of the planar pattern points, the well estimated [R t] can be obtained.*

5) *Step-5: Transform laser spots getting by step 2 from image coordinate frame to planar pattern coordinate frame according to Eq. (3). Expand the points' coordinates with z=0, then transform these points from planar pattern coordinate frame to camera coordinate frame under rigid transform matrix [R t].*

6) *Step-6: Place the planar pattern on another position then repeat procedures from step 1 to step 4 until adequate points are gotten for laser line fitting. Analytically, two placements of planar pattern are enough for plane fitting. But in practice, more planes are placed to improve accuracy because of noise in data.*

7) *Step-7: Using all the points (Xi, Yi, Zi) getting after step 6 to fit the laser line. By conducting procedures listed above, each laser line can be reconstructed in respective camera coordinates.*

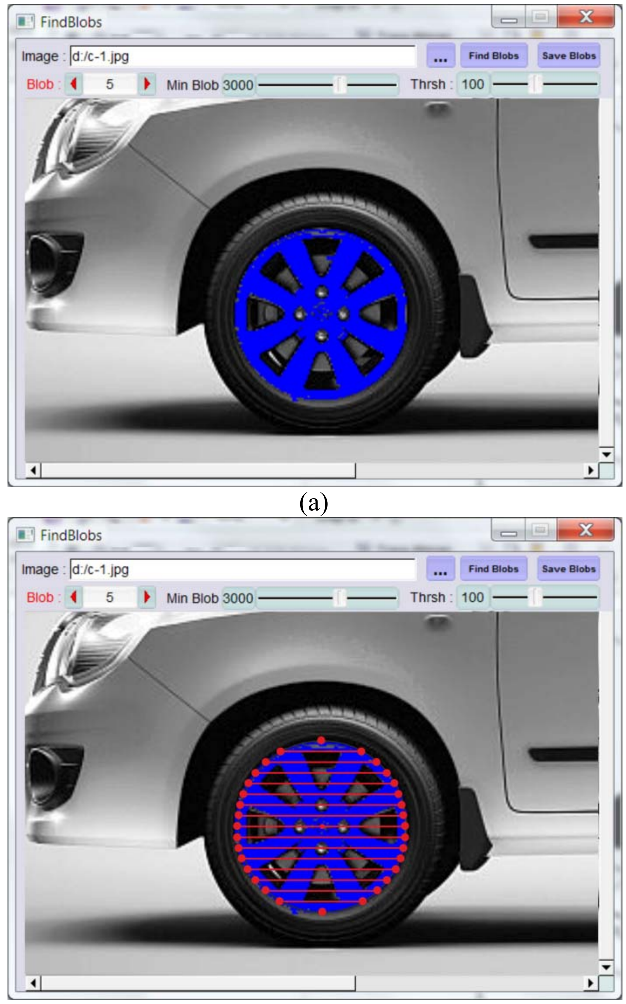
IV. Image-Based Parameters Measurement Methods

Based on the resultant images of laser projection as in fig.3 the next step is to find out the depth map of the wheel rim. Here we have used algorithm of Blob Detection from OpenCV library in Visual Studio 2012 platform. OpenCV is open source computer vision library developed by the Intel[14]. Here for blob detection we have use the *SimpleBlobDetector* which can extract the blobs based on threshold and the min blob which kept for minimum set of pixel from image. An image-based method to calculate these parameters is described in following parts.

A. Detection of wheel rim

Detection of pattern of the wheel rim there are several method can be applicable such as blob detection, depth map, threshold, disparity map, point cloud etc.

Here we have used blob detection because it gives fast performance and higher accuracy. In fig.4 the wheel rim is detected. Here we can also adjust the min blob and threshold setting for accurate detection. Figure shows the detected region of the wheel rim which is accounted for measuring the angle of the wheel with respect to shaft joint.



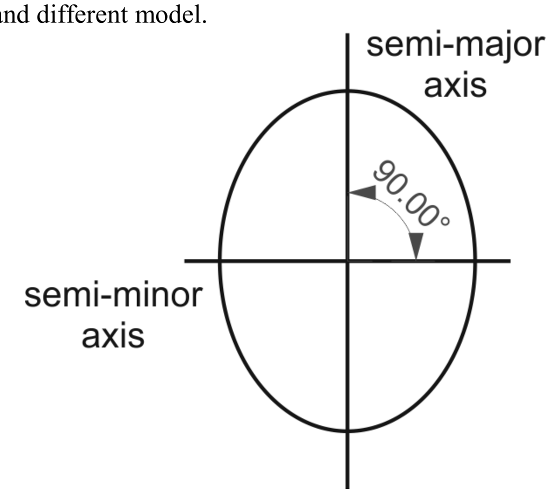
(a)

(b)

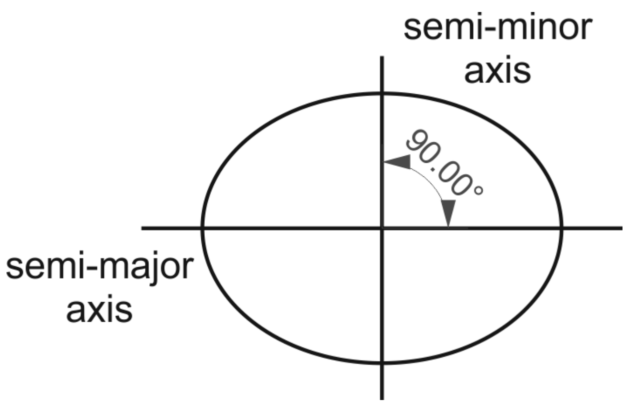
Fig.4 Blob Detection a) without laser b) with laser

B. Measure Angle of wheel rim and shaft joint

Basically the wheel rim profile is fixed circle with predefined radius which get change as the manufacturer of car and different model.



(a)



(b)

Fig.5 a, b – ellipse shape pattern of wheel rim

But the main instance of the selecting the wheel rim is clear that the radius and the shape of the wheel rim is fixed for the particular model. So if we account the measurement of wheel rim then it is unique and overall accuracy of result is on the correctness of the detection of the wheel rim.

By curve fitting method [11] we get the ellipse shape of the pattern of the wheel rim as shown in fig. 5 when the wheel is not in proper otherwise we get the full circle shape with predefined radius.

For the measurement of the wheel alignment the wheel rim is always in fixed size so we can get benefit for finding the angle of the wheel w.r.t. shaft. Ellipse shape has interesting properties [12] and is also the part of the same radius of sphere if we consider as a semi-major length of ellipse as a radius. According to the trigonometric principle of the semi-minor and semi-major length is part of the 3D sphere. So the ratio of the semi-minor axis length and semi-major axis length of the ellipse is important to find out the actual angle of the ellipse with the reference circle.

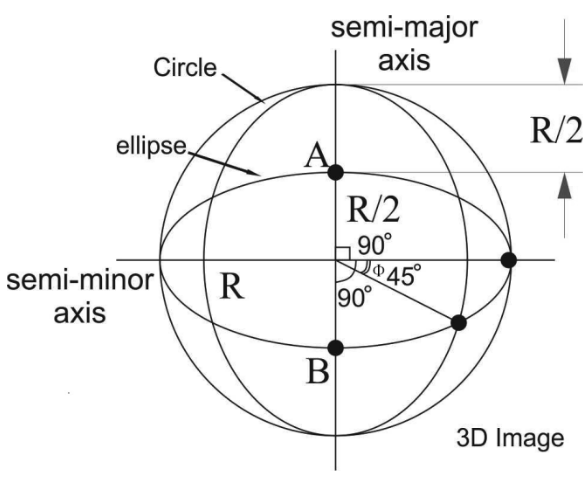


Fig.6 calculation of angle using ellipse parameter

In fig. 6 the R is radius of the sphere and A, B denotes the foci. For the angle measurement proposed algorithm is as follows.

If we consider the semi-major axis length as $X\underline{i}$ and the semi-minor axis length as Yi then the ratio of the Yi over Xi is constant for the every ellipse.

$$\left(\frac{Length\ of\ Semi-minor\ axis\ (Yi)}{Lenth\ of\ Semi-major\ axis\ \ (Xi)}\right) = constant\ ratio$$

Angle of the ellipse with reference to semi-minor axis is defined as phi.

$$\Phi = 90 - (\left(\frac{Length\ of\ Semi-minor\ axis\ (Yi)}{Lenth\ of\ Semi-major\ axis\ \ (Xi)}\right) * 90)$$

By above equation we can find out the actual angle of the wheel with reference to shaft. Here Φ gives the angle of toe out and toe in measurements. But similar way we can also find out the measurement of Camber whether it is positive or negative as shown in fig.7.

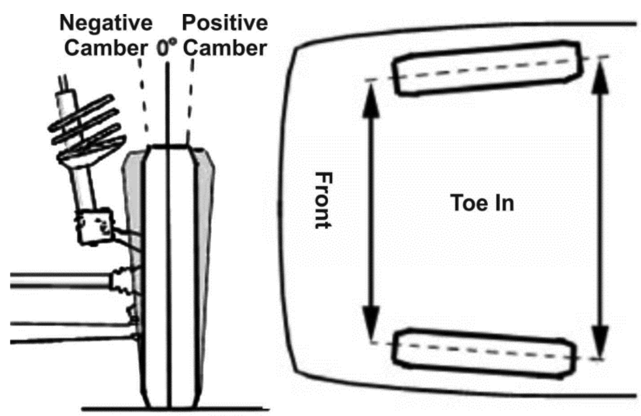


Fig.7 wheel angle measurement (i.e. camber or toe)

V. The Working Process of the System

The overall process of the measurement of wheel alignment is shown in Fig. 8 and is described as follows.

1) *System construction sets up the system hardware. Parameters calculation obtains all system parameters.*

2) *The positions of the digital camera and laser (fig.2), the laser line pattern meet the requirements described in Section 3. An image with the laser line pattern is taken, the system parameters L, d and f/a can be calculated as intrinsic parameter as shown in [8].*

3) *One images is required to calculate the angle parameter of the wheel for that the image is captured as the image centre is almost centre of the rim and the wheel is in front of the camera plane.*

4) *Grating image pro-processing is for removing the noise from acquired images. Low-pass filter image processing is used in this procedure for improving the image pixel detail.*

5) *In angle calculation, images are captured and the ROI is rectified as shown in section 4 using blob detection and curve fitting method.*

6) *Based on the angle information, 3D coordinates of data points on the object are calculated. The algorithm is described in Section 4.*

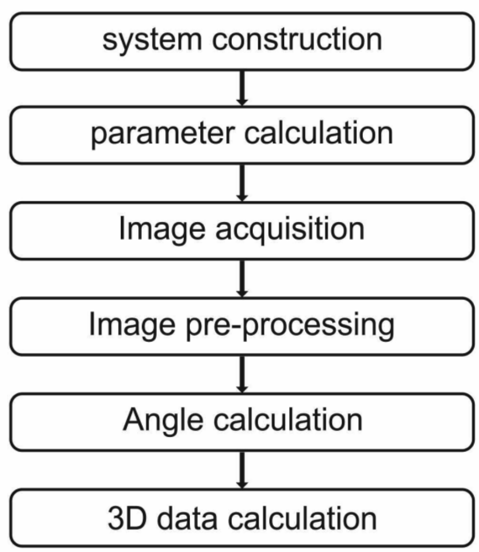


Fig.8 The overall process of measurement of wheel alignment

VI. CONCLUSION

This paper presents a new measurement technique for the contact-less type detection of measurement of wheel alignment, by means of a vision system which consists on a digital camera and a laser line pattern device. We describe several steps for achieving a good localization of projected laser line onto the wheel rim. In particular, we propose a feature point's classification dedicated to this application and a triangulation method is performed to reconstruct the 3-D laser spots onto wheel rim edges. Therefore, the distance from the wheel cross-section (nearly a 3-D line) to the camera is computed from which the alignment analysis is based on. A range for the second free mode is estimated despite the very small magnitude for this kind of misalignment which is less than angle of 10-15 degree.

The main advantage of this technique is to be an alternative method for measuring the angular position of wheel in regard to existing techniques using known pattern objects attached with wheel rim for this application. The detection of wheel angle is the most important feature of this work since such kind of misalignment accrued. In counterpart and with respect to other sensors used in the alignment systems field, vision systems generally have a very limited bandwidth. Nevertheless, the good agreement of the results with the theory and the precise location of projected laser line during the alignment process should be lead in the future to a promising measurement technique.

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