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The development of a new system to measure Camber and Toe using stereo cameras

Liviu Toma Jr.[1], Fangwu Shu[1], Alimpie Ignea[2], Werner Neddermeyer[1], Michael Schnell[1]

Abstract – This paper presents a new measurement system used in car industry. The goal is to adjust the position of the front wheels of a car with respect to the axle where the wheels are mounted. For that, it is required to measure two angles. They are known in the technical literature as Camber and Toe. Our new idea was to use three stereo sensors and structured light to solve this problem. In our approach, we present two methods for measuring these two angles. The obtained accuracy is 0.085 degrees (5 minutes).
Keywords: car industry, wheel alignment, axle, Camber, Toe, stereo sensor, structure light

I. INTRODUCTION

The wheel alignment problem is an important task and concerns all car producers. There were developed a lot of measurement systems to be used for solving this problem. At the beginning there were produced systems based only on mechanical methods. The disadvantage of these methods was the time for measuring which was too long. Also, the accuracy of the measured results was influenced by the errors of the tire surfaces. The second step was to build measurement systems, which use both mechanical and optical methods for measuring. In this category we have systems based on laser technology and systems, which use cameras. The first ones have the disadvantage that they are very expansive. For the second type the accuracy is the task that must be improved. It is also important to know that the systems, which use cameras, can be based on the multi-camera concept or stereo camera concept. As one can see from the title of this paper, the method developed by us is making use of the stereo concept.

The reminder of this paper is organized as follows. In section 2 we present details about the definition of Camber and Toe. Section 3 presents the stereo sensor and the device used to project structured light. The main section of this paper is section 4, where we present the measurement system developed by us. The analysis of the measured results is presented in section 5. Section 6 concludes.

II. DEFINITION OF CAMBER AND TOE

In this section we define and then explain the two angles we want to measure with our vision system.

Camber is the inward or outward tilt of the wheel measured from top to bottom, reference [12]. This angle is adjusted to prevent excessive tire deterioration and to enhance straight ahead stability. It is measured in degrees and has several methods of adjustment. In figure 1, one can understand better the definition of this angle. In this figure, there are presented three possible situations for this angle: positive Camber, negative Camber and zero Camber.

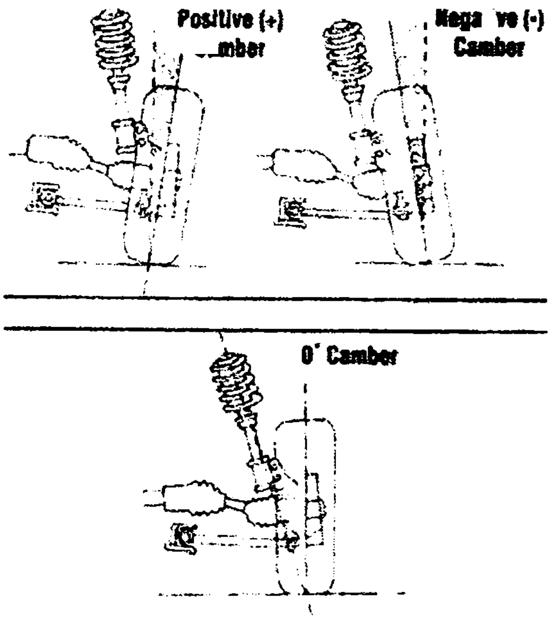

Fig 1 Definition of Camber

The angle formed by a horizontal line through the plane of one wheel versus a perpendicular line to the centerline is called the individual toe, reference [12]. This is the most critical tire angle. When a horizontal line is drawn through the plane of each wheel, and they intersect in front of the wheels, this is called toe-in or positive toe. When they intersect behind the wheels, this is called toe-out or negative toe. In figure

[1] University of Applied Sciences, Informatics Department, Neidenburgerstr 43, D-45877, Gelsenkirchen, Germany, e-mail toma@informatik.fh-ge.de, shu@informatik.fh-ge.de, werner.neddermeyer@informatik.fh-ge.de
[2] Facultatea de Electronică şi Telecomunicaţii, Departamentul de Masurari si Electronica Optica, Bd V Pârvan Nr. 2, 300223 Timişoara, e-mail alimpie.ignea@etc.utt.ro

2, one can understand better the definition of this angle.

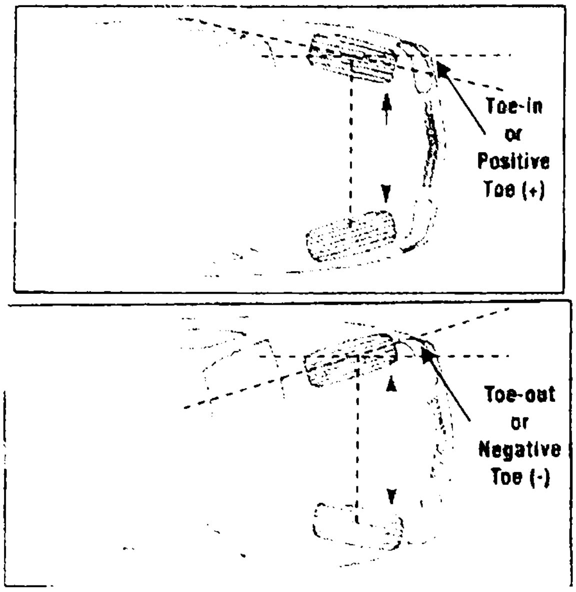

Fig 2 Definition of Toe

III. STEREO SENSOR AND LIGHT PROJECTOR

In this section we present some important aspects about the stereo sensor and the light projector we used, in order to be able to describe our system, in section 4, shortly and efficiently.

The stereo sensor, which was used in our measurement system, is the result of three years of work. One can understand all our steps concerning the building, the calibration and the verification of the stereo sensor by consulting from the reference list the following: [7], [8], [9], [10] and [11]. With this sensor one can measure the 3D position of a certain point with an absolute accuracy of 0.1 mm. The distance between the point to be measured and the stereo sensor can be adjusted between 150 mm and 500 mm without any influence to the absolute accuracy. The measurement area is defined by a square with a side of 100 mm.

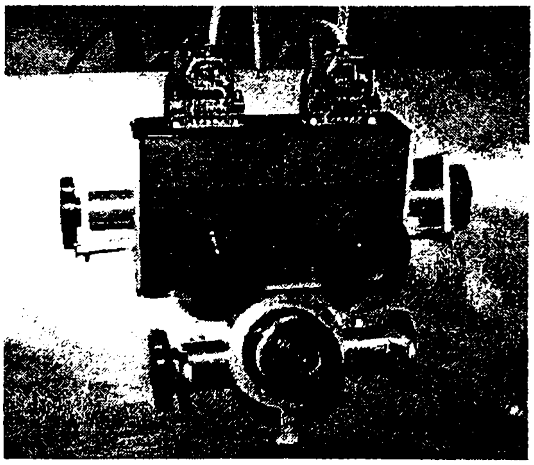

Fig. 3. Stereo sensor and light projector

In figure 3, one can see the stereo sensor. It is composed from two cameras mounted in a parallel configuration, reference [8]. After the calibration of the stereo sensor is realized, we are able to measure 3D coordinates of different points. These coordinates are measure ' with respect to t' e s ereo sensor frame. The stereo sensor frame is defined in the calibration procedure and remains fixed to the sensor after the calibration, reference [11].

The light projector can be also seen in figure 3, just below the cameras. Our goal was to be able to create on the tire surface, using light, some marks, which could be further measured with the stereo sensor.

In figure 4, one can see the shape of the structure light created by the lig' ' projec'or on '' 'ir surfac '.

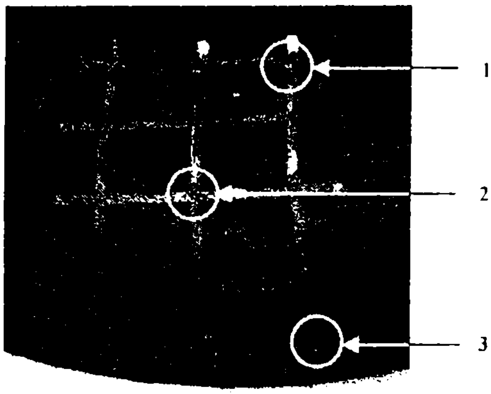

Fig. 4 Structured light projected on the tire surface

There are two possibilities to make use of this structured light. First one is to use as marks the intersections between the light and different forms existing on the tire surface. As one can see in figure 4, in this category are included points 1 and 3. The second one is to use as marks the crosses defined by the structured light itself on the tire surface. To this category belongs point 2.

IV. DESCRIPTION OF THE MEASUREMENT SYSTEM

A. *Presentation of the system*

As we said at the beginning of this paper the goal is to build a vision system for measuring Camber and Toe. Having now the explanations presented in section 2 and 3, we are able to define a mathematical model in order to reach this goal.

First of all we define a coordinate frame for the wheel. We call this, the wheel frame. The origin of this frame is situated in the middle of the tire. Axe z is perpendicular to the tire so that the plane determined by axes x and y is parallel to the tire. Axe x is horizontal. One can see all these details in figure 7. With these notations, Camber is determined by measuring the rotation of the wheel frame around x axe and Toe is given by the measured value of the rotation of the wheel frame around y axe.

In this moment we know what we ' ave o measure so 'he nex' problem, which mus' be solved, is ' ow w' have to measure. In order to explain way we built our measurement system in the way we did, it is necessary to present here some details about the measurement procedure. A detailed description of the measurement procedure will be presented in part C of this section.

The angle information we need is obtained by knowing the orientation of the tire plane (the plane defined by axes x and y) relative to a reference plane. So, the task is to measure this tire plane. It is known that a plane is determined by at least three points, which are not all situated on the same line. Starting from the plane definition we decided to use three stereo sensors placed on a circle at equal relative distances between them, as one can see in figure 5.

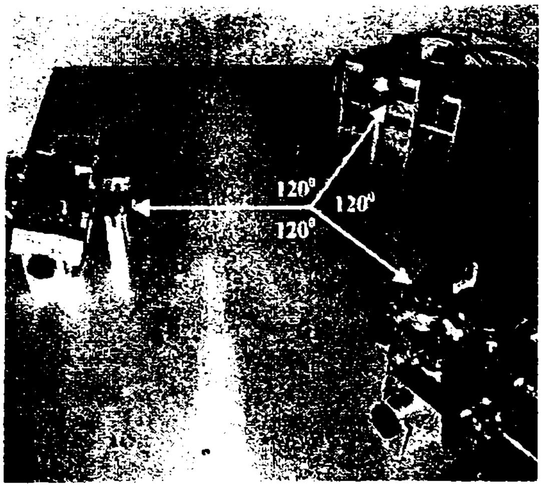

Fig. 5 Description of the measurement system

B. Calibration procedure

We explained in section 3 that in the calibration procedure of the stereo sensor is defined a stereo sensor frame, reference [11]. It means, the coordinates of the points measured with a calibrated stereo sensor are given relative to its defined stereo sensor frame.

The three stereo sensors, which are fixed on a rigid plate, as one can see in figure 5, are first calibrated (see section 3). This means, each one has its own frame. The next step is to find the relative position and orientation of these three frames with respect to a reference frame. This is in fact the calibration procedure of our measurement system.

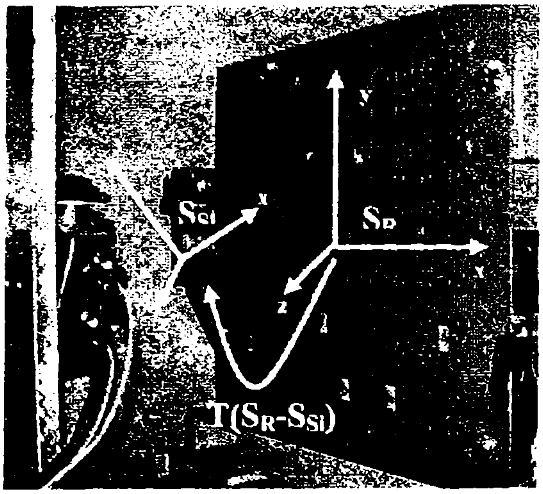

Fig. 6 Calibration of the measurement system

In figure 6, one can see the calibration plate we have used in order to compute the position and orientation of the stereo sensors frames with respect to the reference frame. We denoted with S_R the reference frame situated in the middle of the plate and with S_{S1}, S_{S2} and S_{S3} the stereo sensors frames. In figure 6, it is drawn only one sensor frame, because the situation is similar for the other two. The mathematical explanation, which follows for one sensor, will be applied in the same way for the other two sensors. With $T(S_R\text{-}S_{Si})$ we denoted the transformation from the reference frame to one sensor frame.

The calibration plate, we used, has 121 points and we know very precisely their position with respect to the reference frame. We denote the coordinates of one point from this plate with x_R, y_R and z_R. The same point will be measured with the stereo sensor and we obtain the coordinates x_{Si}, y_{Si}, and z_{Si}. According to the reference [1], between these coordinates we have the following relation:

$$(x_R \quad y_R \quad z_R \quad 1)^T = {}^{S_R}_{S_{Si}}T \cdot (x_{Si} \quad y_{Si} \quad z_{Si} \quad 1)^T \qquad (1)$$

Using more than four points for each sensor we obtain an over determinate system of nonlinear equations. According to the references [4], [5] and [6] such systems are solved in two steps. First step, we make [illegible] methods to find the solution of the system.

C. Measurement procedure

There are two different methods of measuring. Until now, we have implemented in practice only one method and obtained test results, which are presented in section 5. The second method is described shortly at the end of this section.

The method, which we have implemented, is based on identifying marks of type noted with 3, as one can see in figure 4. This method used the fact that on the surface of the tire there are several profiles, which modify the shape of the structured light projected on it. Because these shape modifications are very small we had to develop image processing algorithms to provide us enough and accurate information. We have used sub-pixel accuracy and segmentation methods according to the references [2], [3] and [11].

Our goal is to identify points, which are in the same plane and of course this plane must be parallel to the tire plane. As one can see in figure 7, there are some profiles having circle shape on the surface of the wheel. The big advantage for these circles is that they define, at least theoretically, each one a plane, which is parallel to the tire plane.

The structured light allows us to take for each stereo sensor maximum three points per circle. This way, we can use maximum nine points to compute the plane where the circle is situated. Using the best-fit method we eliminate from these points those, which have big errors and finally, compute a plane parallel with the tire plane. Having this plane, we can compute the values for Camber and Toe.

The second method is based on identifying marks of type noted with 2, as one can see in figure 4. The idea is to use the light crosses for identifying which pixel from the image obtain with one camera of the sensor corresponds to a certain pixel from the image obtained with the other camera. This way, we can measure the 3D coordinates for a lot of points belonging to the light lines projected on the tire. With this information the next step is to calculate the tire plane and its orientation relative to a reference plane.

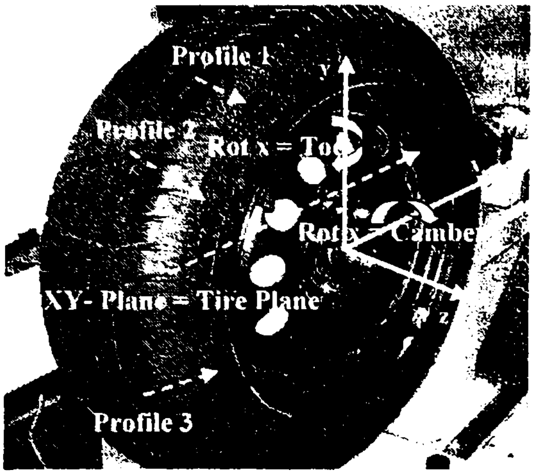

Fig 7 Explanations for the measurement procedure

V. ANALYSIS OF THE MEASURED RESULTS

To test our system we use a special device having a wheel and the possibility to adjust it at different angles between –3 and 3 degrees for both Camber and Toe. Before we start a normal measurement the wheel is fixed so that, the special device indicates 0 for both Camber and Toe. For this position, we make a zero measurement. It means all the measurements, which follow to this zero measurement, are done relative to this zero wheel frame.

For the diagrams, which follow we have measured ten different orientations of the wheel, but sometimes keeping one angle fixed. On the horizontal scale we have represented the real value of the angle in degrees. On the vertical scale we have represented the difference between the measured value and the real value of the angles. The unit used for this difference is the minute.

In figure 8, one can see the distribution of the errors for Camber. They are situated between 0.38 and 4.06 minutes.

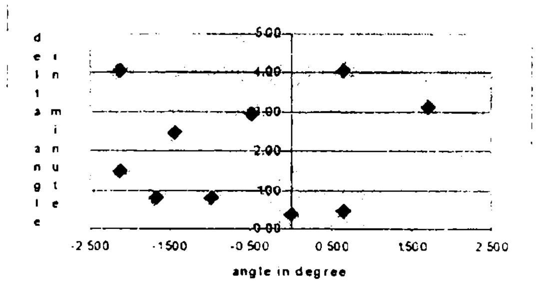

Fig 8 Distribution of the errors for Camber

In figure 9, one can see the distribution of the errors for Toe. They are situated between -0.38 and 4.86 minutes.

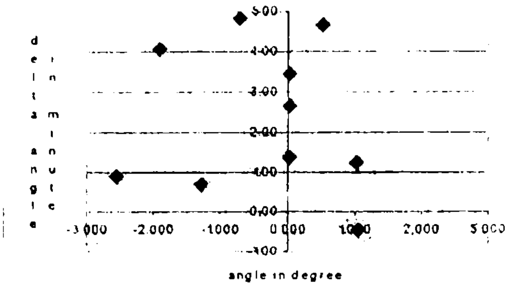

Fig 9 Distribution of the errors for Toe

VI. CONCLUSIONS

We have succeeded to build a vision system using simple methods and cheap components with a good accuracy. These first results obtained in the measurement procedure confirm us the fact that our vision system could be further developed and improved. Using the second method, improving the quality of the structured light and developing better image processing algorithms and mathematical algorithms we will be able to reach the accuracy of 0.1 minutes with our vision system.

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