

Mechatronic system for wheel geometry control

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Abstract. During the last years, the study of steering system was improved by adding the mechatronic system in the automotive industry because of increasing stability requirements. The steering system has the main role in following the imposed trajectory, even the car has not driver, being autonomous. The paper presents a method for measuring the angle between the wheels and the car body, by using a mechatronic system. The actuation comprises two electrical stepper motors, controlled with A4988 driver and Arduino microcontroller. The solution provides an increasing accuracy affording diminishing errors because of the opportunity of working directly on the car body. The measurements could be done easily without any special requirement.

1. Introduction

The mechanical steering system is a positional servo system that has to turn the wheel axle with an imposed ratio when the steering wheel is turned too. Moreover, this system has the main role of conveying the signal to the front axle and to rear axle in the same time for the newer designed solutions. During the car driving, the steering system should provide the technical parameters in order to improve the adhesion of the wheels with the road. It has to be mentioned there are some external forces acting on the tires as well as on car body, consequently they could make the force equilibrium unstable. When these unwanted situations occur, the driver decisions should be sent to the steering system rapidly and with minimum energy consumption.

Nowadays there are some new challenges regarding the demands for the integrated vehicle control systems. There are many concerns regarding the way we may improve the performances and some of them are focused on relevant control strategies with suitable software for microcontrollers. From the theoretical point of view, the mathematical models used for computing the car dynamics are more complex, due to the tire changeover parameters, due to the wear, tire pressure and road conditions.

The paper [1] proposed a control strategy for the steering system applied to an electric car whose dynamic characteristics are improved. The main rule is that of power efficiency, so the performances may include the stability of steering system too. If there is poor power, the driver fatigue, dithering and driving out of control could lead to traffic accidents. The authors have designed a controller for speed signal detection according to the power variation. A detailed description of the steering system enables the computation of the mathematical model in order to attempt the steering torque tests.

The paper [2] analyses the steering system for an axle parallel power vehicle used for autonomous driving. The main goal was to study the way the imposed trajectory is followed and how smoothly it is done. The steering system components are described by broken them into three defined parts: the first one – the steering wheel, pinion and rack; the second one – the steering gear and the third one the front axle. For each part, the non-linearity is studied. Then, there were written the mathematical models for
the kinematic term, potential term and dissipative term. After linearization, an evaluation of the proposed controller was done.

The paper [3] established the kinematic model of the active steering system with a new designed solution comprising a double planetary gear and an electric actuator additionally besides the classic steering system. The performances of the proposed system were analysed, mostly of them representing the convenience of vehicle steering.

The paper [4] is focused on the application of electric power steering (EPS) system control strategies in order to add new steering torque characteristics. There were described practical solutions for steering assistance control and for realizing high vehicle responsiveness, as well as damping compensations for steering stability. At first, based on mathematical model for the vehicle lateral dynamics there were described the strategies starting with the driver’s input. The frequencies response at high and low speed with and without EPS was computed using adequate software. Finally, a close-loop stability analysis was made, so the limits of possible values avoiding the divergent responses were emphasized.

From the vehicle stability standpoint, the sideslip angle estimation and the sideslip rate are the most important criteria. This angle is measured between the vehicle longitudinal axis and the direction of the vehicle velocity using several accurate methods, such as optical sensors, centimetric GPS, accelerometers, odometers, gyro meters, dynamometric hubs or tire force sensors in all road conditions. Regarding these procedures, there exist two main families of approaches: black-box that directly estimate the sideslip angle from measurements, and white-box that assumed the non-linear functions of the yaw rate and lateral acceleration, so direct virtual sensor approach is used [5].

The paper [6] presents the estimation of tire-road forces, vehicle sideslip angle and wheel cornering stiffness by measurements. There were used two different blocks: the first one is the sliding mode observer for measuring the tire forces and yaw rate, whose main advantage is the forces are not functions of road friction parameters; the second one is the extended Kalman filter for the sideslip angle and wheel cornering stiffness. The main conclusion is force values estimation were satisfactorily obtained, whereas the sideslip angle was robustly recorded.

The paper [7] presents the experimental method used for measuring the sideslip angle because of its computing limitation conducting to improvements of electronic stability control (ESC). ESC systems currently available have access only to sideslip rate. In order to compute the sideslip angle, the authors have used the simplest mathematical model to capture the lateral load transfer, so the tires are calculated separately and there are summarized later. As the vehicle begins to roll and lateral acceleration increases the normal load on outside wheel increases, while the normal load on inside wheel decreases. Consequently, a mathematical model was written because of the effects of lateral load transfer on the front tires. Through experimental validation, the paper explores the issues and limitations associated with using steering torque to characterize tire forces on various road surfaces.

The paper [8] proposes a reliable and industrially viable solution to the sideslip angle estimation without any dynamic mathematical model of the vehicle. The algorithm is based on kinematic considerations augmented with heuristic, by adding an artificial damping term. The heuristic is implemented according to the following law: if the force is small, the vehicle state is estimated from the kinematic model and from the measurements; if the force is large, the lateral velocity is driven to a small value. For the experimental validation of the estimation algorithm, a rear wheel drive vehicle is equipped with 6DOF inertial measurement unit, wheel speed sensor and an optical sideslip angle sensor. The experiments were run both on high and low adherence surfaces.

The present paper concerns with a method for measuring the sideslip angle directly on the car body, so that the accuracy will increase. At the beginning of the process when the car is stationary, it is done the measuring of angle value existing between each wheel and the carriage assuming that it is the starting position. Next, we have to establish if the imposed standard is looked up in order to assure the safety driving direction.
The main reasons the angle values are controlled are the tire wear, which should be minimum and the car performance of keeping the straight trajectory for few seconds, when the driver wants to test it. Taking into account all these ideas, we may conclude that this process is done often during the car maintenance and its importance should be increased due to the consequences on the car safety.

Figure 1. The schematic of the steering system.

In figure 1 it is presented the steering system comprising the following components: the steering wheel, the superior and inferior steering columns, the steering knuckle, the pitman arm and the mechanism providing the movements.

The pinion – rack mechanism is the most often designed solution for the steering system and its reduction ratio depends on the imposed wheel angle when the steering wheel has a complete rotational movement. There are some important factors influencing the reduction ratio, such as: the diameter of the steering wheel, the pinion dimensions, the shape of the steering knuckle as well as the traction type and the weight on the front axle.

An important part of the steering system is the crank-end of connecting rod with a spherical joint affording the movement along each of the three-axis system. In order to minimize the mechanical vibrations, the pins are mounted on the helicoidally springs. The spatial movement of the steering system is transmitted through the auxiliary connecting-rod to the steering knuckle.

2. The proposed solution for measuring
Taking into account the technical particular aspects over the accurate computation of the mathematical model comprising the dynamic equations applied for the vehicle, we have proposed a mechatronic system for measuring the sideslip angle. The main advantages are: the opportunity of working directly on the car body and its chassis, so that the fed supplementary errors in the process could be eliminated from the results; the possibility of using electrical actuation with stepper motors whose movements could be very well known. Moreover, if the stepper electrical motor driver is correct chosen, the
angular micro step leads to absolutely small displacement of the wheel. During the movement, the car wheel will develop the sideslip angle, so due to the tire wear and tire-road friction forces we may only approximate their influences [9].

The schematic of the principle is presented in the figure 2 with the following components:

![Figure 2. The schematic of the proposed method.](image)

The working process based on the proposed solution is described below. At first, it has to be established the theoretical value of the angle at the starting position, so the theoretical distance recorded by the sensor mounted on the nearest position of the car body is known. Then we measure the real distance between the wheel and the car body during the movement, by using the ultrasonic sensors, so the real angular position of the wheel could be recorded. Accordingly, we will command the movement of stepper motor rod and gear to keep the sideslip angle value inside an imposed range by diminishing its value. The ratio of the gear mechanism should be computed very well and the gear accuracy should be verified too. Almost all clearances should be eliminated.

The screw-nut mechanism will rotate the wheel clockwise or counter clockwise, so that the error will be diminished. The same process is done for the both drive wheels of the car in order to keep the axle equilibrium. The three – dimensional model of the proposed system is presented in the figure 3.

The figure 3 comprises: 1 – electrical stepper motor; 2,3 – gear mechanism; 4 – screw – nut mechanism; 5 – spherical joint.

3. The proposed solution for measuring
The experimental set-up was done using two Nema stepper motors with 1.8° step angle, electromagnetic torque 45 Ncm, the current 1.68 A and tension 12 – 24 V. The motor was controlled with the driver A4988 affording the micro stepper starting from 0.16° to the 0.1125° . The driver has some particularities consisting in reducing the noise during its working period and the necessity of cooling with a suitable solution.

The process is controlled with Arduino Uno microcontroller and the software was written accordingly for controlling two stepper motors with higher accuracy. We have tested the micro stepper functioning too.

The figure 4 presents the experimental setup where there are the following notations: 1 – stepper motors; 2 - gear mechanism; 3 – screw – nut mechanism; 4 – the Arduino microcontroller; 5 – the distance sensor.
Figure 3. The three – dimensional model of the proposed solution.

The measured values using the Arduino microcontroller and the software written for both stepper motor drivers, the distance sensors as well as the other settings is presented in the figure 5 and 6. The final results proved that the method is accurate inside the imposed range of 1 mm for the screw – nut mechanism displacement, so the steering system control is done with expected goals. The main advantage of working directly on the care body should be mentioned too.

Figure 4. The experimental set-up.
Figure 5. The experimental set–up during the measuring process.

Finally, we have done the measurements of the angular deviation of the wheel by using the laser ray that is more accurate, starting from the initial position whose angle value is zero. During the next step, we have commanded the angular movement of electrical stepper motor rod by using a driver with micro stepping characteristics. Placing the sensor tangent horizontally on the wheel external surface, we have recorded the position of the laser ray after it was reflected on a lens and on a prismatic surface with working angle about of 27°. The angular deviation was measured by recording the linear displacement between the initial and final positions of the laser ray as it is shown in the figure 7.

Figure 6. The sensor values.

Figure 7. The experimental set-up for laser ray measurements.
The main conclusion we should point out is the method afforded an accurate way of measuring the sideslip angle by using the screw-nut mechanism actuated by the electrical stepper motor.

As future work, we aim to improve the measuring system by adding a laser sensor affording the distance measured between two angular positions, so that we may record the values using the computer and the microcontroller too.

References

[1] Fan C, Guo Y Design of the auto electric power steering system controller in the Procedia Engineering 29 (2012) pp 3200 – 3206.

[2] Govender V, Muller S Modelling and position control of an electric power steering system in the IFAC – PapersOnLine 49 – 11 (2016), pp 312 – 318.

[3] Gao Z, Wang J, Wang D Dynamic modelling and steering performance analysis of active front steering system in the Procedia Engineering 15 (2011) pp 1030 – 1035

[4] Liu L, Raksincharoensak P On torque control of vehicle handling and steering feel for avoidance manoeuvre with electric power steering, Proceedings of the 17th World Congress The International Federation of Automatic Control, Seoul, Korea, (2018), pp.12073 – 12078.

[5] Selmanaj D, Corno M, Panzani G, Savaresi S M, Vehicle sideslip estimation: A kinematic based approach, Control Engineering Practice 67 (2017) pp 1 – 12.

[6] Baffet G, Charara A, Lechner D Estimation of vehicle sideslip, tire force and wheel cornering stiffness, Control Engineering Practice 17 (2009) pp 1255 – 1264.

[7] Hsu Y-H J, Laws S, Gerdes J C, Experimental studies of using steering torque under various road conditions for sideslip and friction estimation, IFAC Proceedings 40 Issue 10, (2007), pp 71 – 78.

[8] Selmanaj D, Corno M, Panzani G, Savaresi S M, Robust vehicle sideslip estimation based on kinematic considerations, IFAC PapersOnLine 50-1 (2017) pp 14855 – 14860.

[9] Olaru D, Balan M R, Tufescu A, Carlescu V, Prisacaru G, Influence on the cage on the friction torque in low loaded thrust ball bearings operating in lubricated conditions, Tribology International 107 (2017), pp 294 – 305.