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Computer based Wireless Automobile Wheel Alignment system using Accelerometer

Sonali Chatur
Department of Electronics Engineering, K .J. Somaiya College of Engineering, Mumbai University, Maharashtra, India

--ABSTRACT--
A computer based wireless automobile wheel alignment measurement system using accelerometer is presented in this paper, which has the advantages of simple circuit, low cost , high resolution with high working reliability. The causes and effects of improper wheel alignment by traditional methods are analyzed in the model. In this system wireless transmission techniques are adopted to transmit data between measuring unit and computer. This makes the measurement operation much easier. This paper presents unique and innovative use of accelerometer for the measurement of automobile wheel parameters, such as camber and toe. The hardware and software realizations are also explored in this paper. The system practical applications shows that its performance meets the design requirements.

Keywords *– Wheel alignment, Toe, Camber, and Accelerometer*

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I. INTRODUCTION

With the development of automobile technology, the automobile travelling speed is getting higher and higher, and the influence of automobile operation stability to automobile travelling safety is getting larger and larger. Modern passenger vehicle usually has wheel alignments both for front wheel and rear wheel. Toe, camber, steering axel inclination (SAI) and caster are most influencing parameters in almost all automobile wheel. These wheel alignments will change gradually during usage, thus many problems could be caused, such as front wheel swinging during travelling, steering wheel vibration, decreasing of the directional stability after steering, rapid tire wear, etc. Tire wear is part of the global transportation cost factors that has to be considered in economic calculations but also has an impact on energy consumption and the environment Therefore regular wheel alignments examination and adjustment should be carried out in order to restore vehicle travelling stability, travelling safety and other performance. [1]

Wheel alignment failure is one of the commonest troubles. It brings on tires abrasion, front-wheels sway and sideslip, which influence controlling stability and driving safety of the automobile. Wheel alignment detection is the most important test item of automobile safety tests. Wheel alignment integrates all the factors of steering and suspension geometry to provide safe handling, good ride quality and maximum tire life. Front wheel alignment is described in terms of angles formed by steering and suspension components. Wheel alignment detection system is appropriative equipment that inspects vehicle's wheel positioning parameters. The wheel alignment instrument detects positioning parameters including wheel toe, camber, caster, steering axle inclination(SAI) based on the establishment of the wheel geometric model and technologies of sensor, laser and image processing.[2]

II. EFFECTS OF VARIOUS ALIGNMENTS ON WHEEL PERFOMANCE

The process of tire wear is very complex. Tire wear can be caused by a number of factors. Some of these include incorrect inflation (outer edge wear equals low tire pressure), alignment issues, vehicle over-loading and worn out shocks or struts. In the conventional research, the tire wear is estimated by experiments. Otherwise, the tire wear is predicted by the tire vibration and modal analysis. The effects of various toe setting on wheel alignments can be seen from the figure 1.

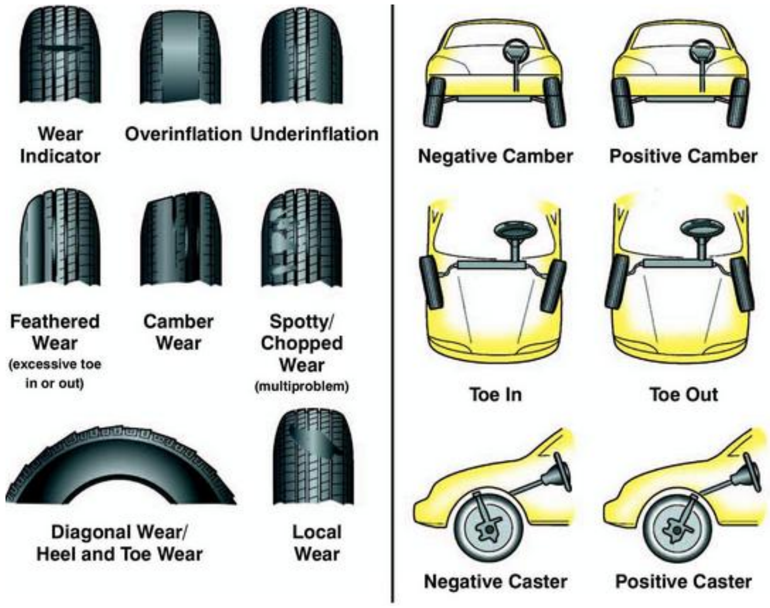

Fig.1 Effect of various alignment angles on tire [1]

Fig.2 shows the cause & effect diagram of the manual wheel alignment with help of mechanical pointer gauge which measures the distance between center lines of front or rear tires. From the diagram it can be concluded that wrong toe setting can lead to the incorrect wheel alignment & thus results into the faster tire wear.

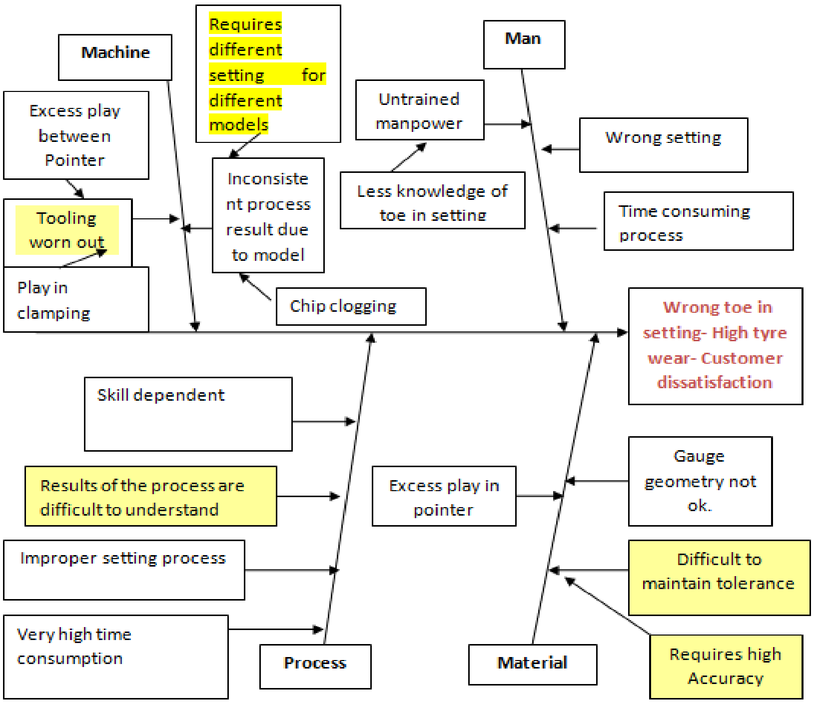

Fig. 2 Cause & effect diagram for high tire wear

3. MECHANICS OF WHEEL ALIGNMENT

There are several forces, moments and angles that prove to be very important in tire behavior. All these forces can be seen as the forces and moments acting on the tire from the road. First, there are two main angles to consider, the camber angle and the slip angle. The camber angle is the inclination angle from its vertical position while the slip angle is the difference in wheel heading and direction. These two angles are associated with the lateral force. Forces include the longitudinal force in the X direction, the lateral force in the Y direction and the normal force in the Z direction. Longitudinal force (F_X) is the result of the tire exerting force on the road and becomes negative during braking. The lateral force (F_Y) is the resultant of the forces produced by a non-zero camber angle and by a non-zero slip angle during cornering. Normal force (F_Z) can also be viewed as the negative of the upward vertical force. Moments include the overturning moment, the rolling resistance moment, the wheel torque and the aligning moment. The overturning moment (M_X) is caused by a lateral shift of the vertical load during cornering. Rolling resistance (M_Y) is created by various factors that lead to a loss of energy. The aligning moment (M_Z), also known as the self-aligning torque, produces a restoring moment on the tire to realign the direction of travel with the direction of heading when the slip angle is non-zero. It should also be noted that there is also a moment produced by the axle on the wheel. As a final point, it may be noted that when the camber angle is zero, the wheel torque (Tin), points in the negative Y direction. [3]

If the direction of travel differs from the wheel heading (if the wheel's angular displacement is different from the path the tire is following), the slip angle (α) produces a component of lateral force (F_Y). This lateral force will act through a point behind the center of the wheel in a direction such that it attempts to re-align the tire. It should be noted that the slip angle is not the same as the steering angle. [3]

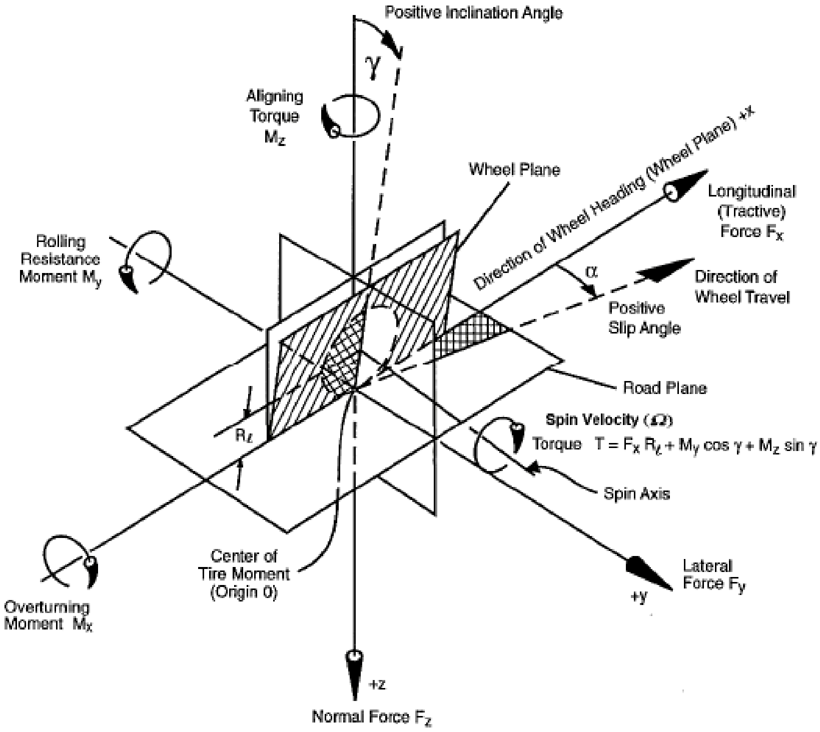

Fig. 3 Forces acting on an automobile wheel [3]

IV. MATHEMATICAL MODEL FOR CAMBER ANGLE & TOE CALCULATION

Accelerometers are sensitive to the difference between the linear acceleration of the sensor and the local gravitational field. The data sheet for any accelerometer will denote the positive x, y, and z axes on the sensor package and, by convention, these are defined so that a linear acceleration aligned in the direction of these axes will give a positive accelerometer output. A gravitational field component aligned along the same axes directions will, however, result in a negative reading on the accelerometer.

Since the accelerometer can be mounted at any orientation on the circuit board which can, in turn, be mounted at an arbitrary angle in the final product. It is more sensible to use a coordinate system aligned with the tire axes. Figure 4 shows the coordinate system which will be used in this document:

- The x-axis is aligned for camber angle with respect to gravity.

- The y-axis is aligned for toe angle with respect to gravity.

Changes in orientation are described by rotations in roll ø, pitch θ and yaw ψ about the x, y and z axes is shown in the figure.6.

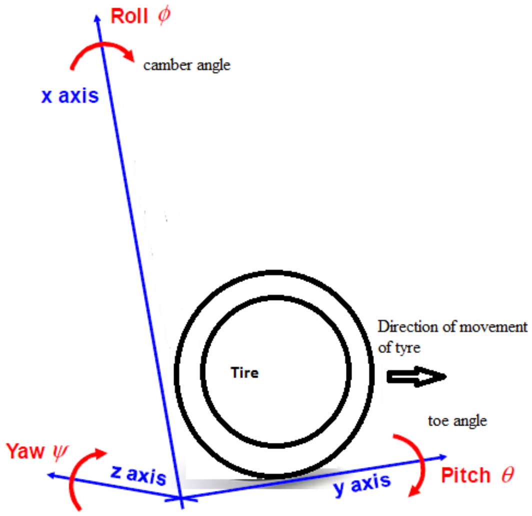

Fig 4 Axial Representation of an automobile tire

From above geometry the mathematical equations for toe angle θ with respect to gravity, camber angle ø with respect to gravity can be obtained as per Mark Pedley [4] in equation 1 and 2

$$\theta = \tan^{-1}\left(\frac{GPx}{\sqrt{GPy^2+GPz^2}}\right) \quad \text{……………………..………………………Eq.1}$$

$$ø = \tan^{-1}\left(\frac{GPy}{\sqrt{GPz^2+GPx^2}}\right) \quad \text{………...……………………..……..………Eq.2}$$

The camber angle Ø with respect to gravity is obtained. To get the camber angle γ from the camber angle Ø with respect to gravity some correction factor is added. Camber angle is equal to inclination of the wheel from its vertical position. Or more precisely, camber is the inclination from a plane perpendicular to the ground. A positive camber angle is defined to be an outward lean such that the top of the tire leans outward from the vehicle centerline. A non-zero camber angle produces a camber force directed laterally toward the low axis side, producing another component of lateral force. Thus, a negative camber angle increases the lateral or cornering force of the tire. Generally, the lateral force produced from camber is a function primarily of tire stiffness, vertical force and camber angle. While there are other secondary forces present, such as friction effects and path curvature, these are small and can be neglected for most applications. Camber force can also be affected by the shape of the crown. A very round profile develops maximum lateral force with negative camber angles and a small slip angle while camber angles in the 0° - 4° negative range are better when a flatter crown is used. For wide street radial tires, camber force tends to fall off at camber angles above 5°. With the combination of the preceding parameters, a new tire characteristic, camber stiffness, can be defined as the rate of change of camber force with change in camber angle. [3]

The equation for the lateral force component due to camber is seen in equitation 3:

$$F_Y = F_\gamma = C_\gamma . \gamma = C_C . F_V . \gamma \quad \text{…………………………………………....Eq.3}$$

F_Y is the lateral force, F_V is the normal force, γ is the camber angle, Cg is the camber stiffness and C_C is defined to be the camber stiffness coefficient. A typical C_C value would be 0.018/deg for bias-ply tires and 0.008/deg for radial ply tires. [3]

V. DESIGN OF WHEEL ALIGNMENT SENSING UNIT

Figure. 5 is the block diagram of wireless computer based wheel alignment measurement system using accelerometer. Basically it consists of measuring unit, processing unit, trans-receiving unit, converting and display unit.

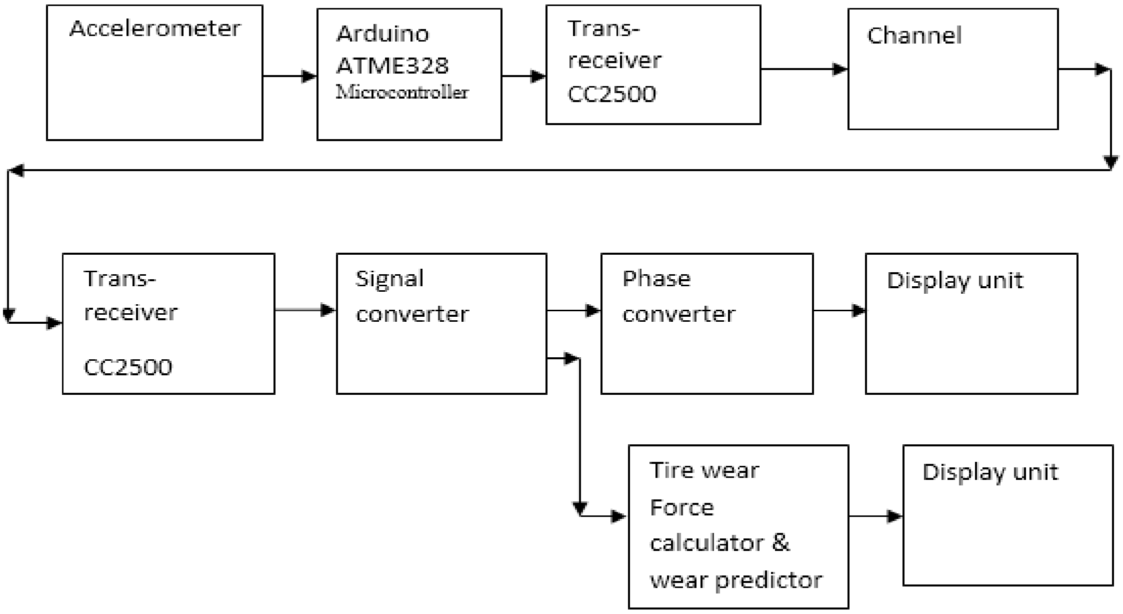

Fig.5 Block diagram of wireless computer based wheel alignment measurement system using accelerometer

5.1 Measuring unit

Measuring unit consists of ADXL335B three axis accelerometer. The ADXL335 is a small, thin, low power, complete 3-axis accelerometer with signal conditioned voltage outputs. It measures acceleration with a minimum full-scale range of ±3 g. It can measure the static acceleration of gravity in tilt-sensing application resulting from motion, shock, or vibration. The sensor is a polysilicon surface-micro machined structure built on top of a silicon wafer. Poly silicon springs suspend the structure over the surface of the wafer and provide a resistance against acceleration forces. Deflection of the structure is measured using a differential capacitor that consists of independent fixed plates and plates attached to the moving mass. The fixed plates are driven by 180° out-of-phase square waves. Acceleration deflects the moving mass and unbalances the differential capacitor resulting in a sensor output whose amplitude is proportional to acceleration. Phase-sensitive demodulation techniques are then used to determine the magnitude and direction of the acceleration. The functional block diagram of the accelerometer is shown in fig 6.

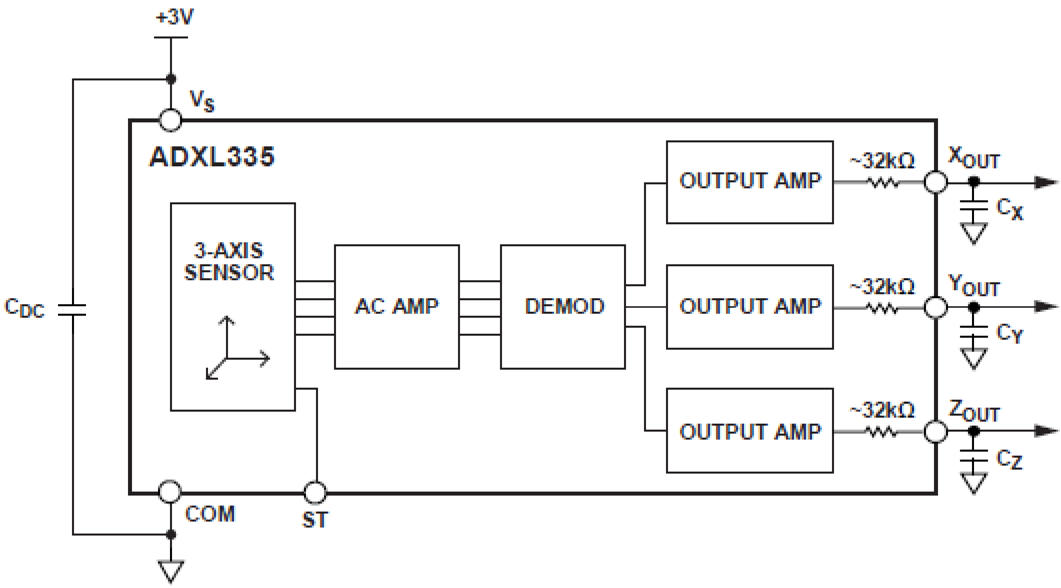

Fig. 6 Functional block diagram of the accelerometer [4]

Here this accelerometer is exclusively used to obtain the toe angle and camber angle of automobile wheel. This measuring unit provides x, y, and z voltages proportional to angles mentioned above. For the further processing these voltages are applied to the processor.

5.2 Processing unit

Processing unit consists of ATME328 8bit microcontroller. It is a high Performance, low Power AVR 8-Bit microcontroller advanced RISC architecture. Looking towards the depth of the thesis and available time allotted arduino is really absolute solution to work with. In the arduino kit microcontroller ATME328 is used thus it satisfies selection criterion. Output voltage of ADXL335 accelerometer is applied to the analog inputs A0-A2 of arduino.

5.3 Trans –receiver

Available information signal from arduino is transmitted by this block. Here measuring unit and display unit needs 30 feet separation thus wireless transmission technique is used. CC2500 is the ultimate solution for these type of applications. Along with CC2500 PIC F1824 14 pin microcontroller is used. CC2500 and PIC F1824 platform is readily available in the market, looking towards vast and depth of this thesis this readymade platform is used. Generally in wireless communication techniques CC2500 is widely used. Thus to avoid further problems while communicating with the computer when number of Trans-receiving devices are present channel id and device id is assigned. Channel id is 9 and devise id is 1 in this particular case. Serial communication method is used.

5.4 Receiver section

Trans-receiver: At the receiver side this is the first block. Function of this block is to receive transmitted signal. This signal is fed to serial to USB converter.

Serial to USB converter: There is an interface required to provide voltage compatibility as Trans receiver units work at TTL logic levels. This signal is applied to computer.

Converter, Phase converter and display unit: In the VB.net platform all the converter, phase converter and display units are designed. Available signal is concatenated so x, y and z parameters needs to separate so logic is developed and all the three signals and concatenated string is displayed in text boxes as well. Retrieved signal is mathematically processed to obtain phase i.e. angles in degree. Now error correction factor need to add to obtain desired toe and camber angles. Display unit displays the toe and camber angle in the text boxes on the display page.

The logical implementation includes software design part of the computerized wheel alignment system. This design is heart of the system. Further it also covers display unit, this unit is going to give proper guidelines for the user who is going to use this measurement system. Here the camber and toe parameters are obtained in terms of angle. In the previous chapter the mathematical model designs mentioned. With reference to that, the phase calculators are designed through software. The display unit is designed by software as well. Here visual basic .NET (VB .NET) language is used. For that Microsoft visual studio is required. It is an integrated development platform.

5.5 Design steps for software implementation

Step 1: Programming for setting the baud rate 9600
Step 2: Programming for the separation of string
Step 3: Program design for obtaining the camber and toe angles
Step4: Monitoring page design

Step 1: Programming for setting the baud rate 9600

Here the baud rate is set to 9600 .At the transmitter side baud rate is set to the same value as well. Baud rate is the rate at which the data is sent so it is mandatory that at transmitter and receiver side it must be same. The programming at the arduno processing unit of the input voltage is given below. The flow diagram is shown in figure 4.3. At the start of program the arduino pins needs initialization so as per the requirements the pins are assigned. Baude rate is also set to 9600. Channel and device id assigned, this is to avoid the conflict if more than one devices used by the arduno and more than one user using the channel. Thus channel id and device id is very important at the time of initialization. Serial communication is set up, so serial data is received and displayed. This data is in the form of string and same string is then transmitted to computer for further analysis of the string.

Step 2: Programming for the separation of string

The serial data from transmitter is in the form of string so it is necessary to separate x, y and z. here is the program designed to separate each parameter. Simple if else loop is used to separate the string.

Step 3: Program design for obtaining the camber and toe angles

The output from measuring unit is in terms of x, y and z these values are with respect to gravity. For the computerized wheel alignment measurement, measuring parameters are camber and toe in terms of angle, so mathematical model is applied. With reference to that mathematical model camber angle and toe angles are obtained. While achieving the desired angles it is observed that in VB .NET platform the angles were in degree radiance. By applying simple mathematical formula the angles are now obtained in degree, but still these values of camber and toe angles are with respect to gravity so correction factor is added to get the toe and camber angles.

Step4: Monitoring page design

One of the very important reason behind use of visual studio platform is, it is very user-friendly. So monitoring page is very important. This is display section of the project. Here each and every step is displayed as per the steps designed above. Starting with string which is obtained from measuring unit. All the developments in the available data is displayed in the text boxes. Monitoring page designed is shown in the fig. 7.

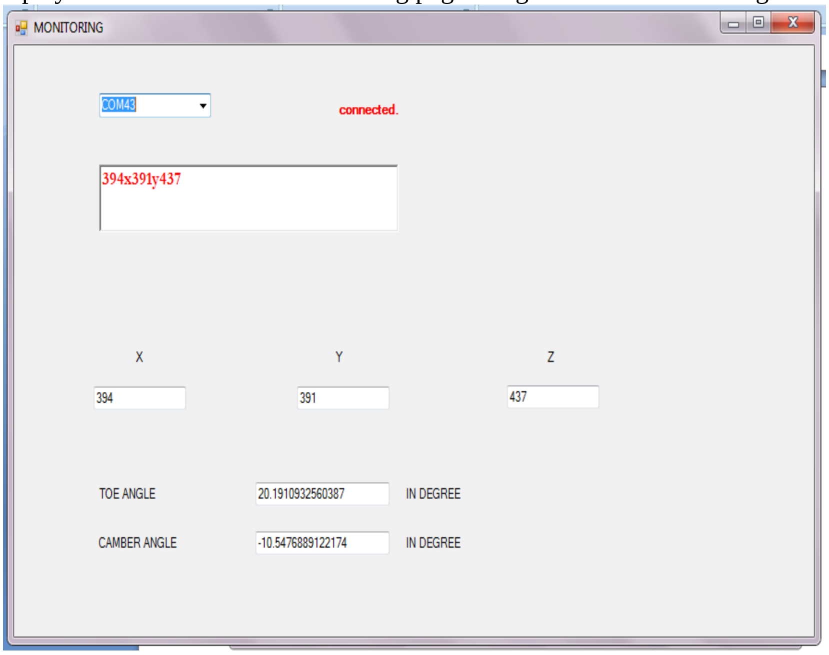

Fig.7 Display of monitoring page

VII. CONCLUSION

The wheel alignment angles have great influences to automobile operational performance, such as travelling safety and driving stability. In order to maintain automobile performance, regular examination and adjustment of wheel alignment angles are need by means of wheel alignment system. In this paper computer based wireless wheel alignment using accelerometer is presented, it has advantages of simple electronic circuit, low cost, high operational reliability, high resolution and high measuring precision. Some correction factors are also introduced in the calculations to obtain the actual angles from the angles with respect to gravity, it is observed during the practical implementations of the alignment system. Wireless communication method is adopted to transmit the data between measuring unit and computer this makes the system operation much easier. The system practical inspection shows that its performance meets the design requirements.

This system can be implemented for almost all types of four wheelers where the wheel alignment is required. The another advantage of this method is that it is less time consuming hence it can also be implemented in formula 1 racings where there is least time available for tire change over in between two laps.

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