UDC 629.072.75

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AUTOMOBILE CRUISE CONTROL SYSTEM

Introduction

The intelligent transportation system is one of the highly pursued research topics in different fields of science and industry. Nowadays, the increasing number of vehicles in cities and the consequent increase in number of collisions make us think about a precise and fast responding system to solve some of these problems.

Until now there are many research groups that have developed anti-collision systems like ACC or Adaptive Cruise Control [1-4]. But either they are equipped with night vision cameras or are just able to adapt the speed to the vehicle ahead and not pass the obstacle. More updated systems are equipped with several assisting system such as GPS, or digital cameras which would make their algorithms too tedious to be used in industrial or urban areas. So this paper is a solution for these design defects.

Problem Formulation

The goals of this article are to develop an algorithm for a proper control system to control the speed and avoid collisions using a compact eye-safe laser system as a detecting eye for obstacles.

Scanning Laser System

Having a proper system to collect the information from the surrounding environment is one of the important requirements to design an intelligent system. Anti-collision designs, currently being used in the industrial market, usually take advantage of night vision cameras or laser beams with no scanning system. Both of them cause poor vision in different situations and different weather conditions.

In the designed system a scanning infrared laser block (Scanning LIDAR) is playing the role of detecting and ranging system.

An infrared laser beam lased from a diode pumped solid-state Nd-YAG laser, is used to scan the front area of a moving vehicle. The laser is q-switched by an electro-optical q-switch to provide perfect narrow pulses.

Since the beam wavelength of Nd-YAG laser is $1.064\,\mu m$, it is not eye-safe. To solve this problem an OPO – Optimal Parametric Oscillator – is mounted in the structure. The nonlinear properties of the crystal used in the OPO shifts the wave length of the passing laser beam pulses from 1.064 to 1.54 μm, which is an eye-safe wavelength for the human eye. The main signal, with 1.54 μm would be the beam scanning the area and the idler signal with 3.4 can be used for further applications to make the system more accurate.

A Galilean telescope is used as a beam expander to reduce the scattering effect. The beam expander is followed by a scanner. This mechanism is composed of two galvanometers and a flat mirror is placed on each of their rotor shafts.

The scanning mirrors are a part of the control contour. The position of the beam lased to any point of the surrounding environment is sent to the control system, which will be described later.

To collect the information about the surrounding area, a laser beam will be sent to each point by the scanner. Assume a point (x_i, y_j). When the scanner is pointing the laser beam to this point, the information about the elevation and azimuth of (x_i, y_j) will go to the receiving block of the system. Meanwhile the laser has reached the target and has reflected from its surface.

In the receiver block a NFOV (Narrow Field of View) lens, is tilted towards the direction known from the scanner galvanometers, which will capture the reflected laser pulse. The laser will pass through a narrow band optical filter and will reach the photodiode, an APD (Avalanche Photo Diode), designed for near infra-red spectrum of light.

Receiving the laser pulses from (x_i, y_j), the system will determine the distance from the obstacle using TOF (Time of Flight) method. The material, reflecting the laser pulses will also be recognized. This will be achieved by comparing the power of the pulses generated by the laser block with the power of the same pulses after receiving [5].

This way, both TOF method and impulse power measuring will provide enough information about the characteristic of the point (x_i, y_j).

The whole area in front of the vehicle can be divided into many points, as pixels. Each pixel can be described by information like azimuth, elevation, distance and reflectivity coefficient. After a complete scan of the area, a pattern can be formed to show the driver the road, the road side and any obstacle existing on them.

This scanning can be performed periodically to give the driver a real time image of the road in front.

Assuming that at the beginning of the movement the system has done a control scan of the road, the reflectivity coefficient of the road and road side can be calculated. It is understandable that whatever does not belong to these two groups will appear as an obstacle. For this, an algorithm is defined to scan the pattern line. This line includes 11 points at the lowest level of the scanner: 3 points right in front of the car, 4 at the side ends of scanning line and 4 in between. This way every time before moving, the updated information about the reflectivity of the road can be obtained.

Here onwards, reflectivity information of each and every point scanned by the system will be compared to the data from the pattern line.

A computer program, written in DELPHI to simulate the whole scanning and displaying system [5]. The algorithm used in this program takes advantages of 2 matrices from the scanned points. Matrix D belongs to information about distances and matrix R to reflectivity coefficients. In the program matrices are assumed to be 100?100. Each element of the matrix belongs to one position of the scanner, for instance G (x_i, y_j).

The calculated reflectivity from each point will be compared with three groups of reflectivity, defined by the controlling line. Depending on the results, three different colors will separate these scanned points from each other. Blue belongs to the road, green to side road and everything except these two will be displayed in red color.

The brightness of the colors will show the distance. Further from the system, the color will be darker. If the sent impulse is not received by the APD, then this point will be classified as unidentified and will be displayed in white color.

A yellow indicator in the display will show the way ahead. A critical distance is defined for the system. Obstacles closer than this to the vehicle will be blinking on the display. This means that if they lie on the path ahead, the controlling system will take a decision and choose the right algorithm to avoid them. Every obstacle is separated by an outline from the environment around it. Data about each obstacle, such as distance from it and its coordinates are written above it.

The Algorithm and Synthesizing of Control system

After recognizing the objects on the road, the control system has to make a decision, whether the vehicle has to change its speed or even change course and how it has to do it. Two different algorithms are suggested to reduce the speed in various situations that might happen during the movement, one by using the control on throttle valve angle and the other on pressure of brake system. Knowing the angle of the slope and the distance to the object, the system can choose one of these algorithms to provide the safest and most comfortable conditions for the passengers. Meanwhile, the safety parameters of the system will be checked by sensors to keep the vehicle in a stable situation. Parameters of safety are the difference of angular velocity of the wheels on the same axis and the difference in the angular velocity of two different axles. This way, while steering, the automobile will not slide on the road [6].

Since the information about the state vector is incomplete, modal control has been used to synthesize an ideal control system and bring the roots of the closed loop system to the positions which are known in advance. To achieve this goal, the method of standard coefficients of a characteristic equation has been used.

Knowing the transfer functions of plant W_0, regulator W_r and feedback W_{fb} and choosing the optimal functional from the criteria of minimum control module error and maximum performance speed, it is possible to choose a proper graph from fig. 1 to reduce the speed [7].

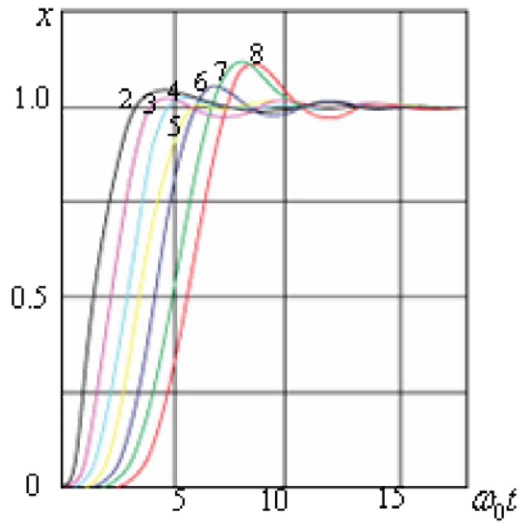

Fig. 1. Step response of the system

Two different conditions to determine the standard coefficients are considered. First, the inertia of the measurement devices is included in the transfer function of the closed loop system. Second, the closed loop transfer function is assumed without considering the inertia of the measurement devices.

1) Determining the control system factors, when inertia is included in the plant

The inertia of measuring device, speedometer, is assumed as $W_{in} = \dfrac{1}{TS+1}$, when $T = 0.2$. If the inertia will be included in the whole system before calculating the transfer functions of regulator and feedback $W_r = \dfrac{W_r^n}{W_r^{dn}}$, $W_f = \dfrac{W_{fb}^n}{W_{fb}^{dn}}$ the whole system will have the following transfer function:

$$\varphi_v^u = \frac{K_{eng} W_r W_p}{1 + K_{eng} W_r W_{fb} W_{in} W_p} = \frac{K_{eng} W_r^n W_p^n W_{fb}^n W_{in}^n}{W_p^{dn} W_{fb}^{dn} W_{in}^{dn} W_r^{dn} + K_{eng} W_r^n W_p^n W_{fb}^n W_{in}^n}$$

where

$$W_r = \frac{T_{r1}S + T_{r2}}{S}; \quad W_{fb} = \frac{T_{fb1}S + T_{fb2}}{T_{fb2}S + 1}; \quad W_p = \frac{K_0}{TS + 1}.$$

Due to the 4th order of the denominator in the transfer function of system, it is necessary to choose the 4th order of the polynomial from the optimizing functional I [7].

$$W_p^{dn} W_{fb}^{dn} W_{in}^{dn} W_r^{dn} + K_{eng} W_r^n W_p^n W_{fb}^n W_{in}^n = s^4 + 2.1\omega_0 s^2 + 3.4\omega_0^2 s^2 + 2.7\omega_0^2 s + \omega_0^4.$$

After calculating the coefficients of regulator and feedback, system is simulated in SIMULINK and the reaction of the system to a step input with the amplitude of 20 *m/s* is shown in fig. 2.

The output of the system shows a big overshoot and long rising time. In the next step without including the inertia the control system is defined.

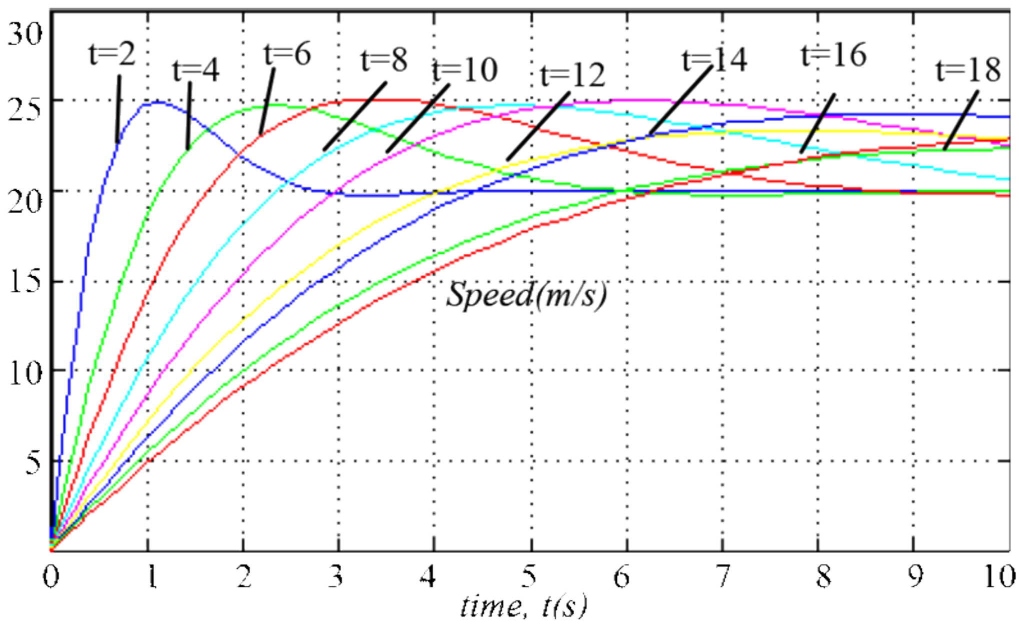

Fig. 2. Step response of the closed loop system for different rising times, from left to right t=2, 4, 6, 8, 10, 12, 14, 16, 18 *sec*, when step input is 20 *m/s*

2) Determining the control system factors, without considering the inertia

Looking at the graphs of system, optimized by I, responding to a step input source, the third order polynomial has been chosen to optimize the system. The chosen equation will provide the least overshoot, a good rising time and less oscillation compared to others.

$$W_r = \frac{T_{r1}S + T_{r2}}{S}; \quad W_{fb} = \frac{T_{fb1}S + T_{fb2}S}{T_{fb2}S + 1}; \quad W_0 = \frac{K_0}{TS + 1};$$

$$W_p^{den} W_{fb}^{den} W_{in}^{den} W_r^{den} + K_{eng} W_r^n W_p^n W_{fb}^n W_{in}^n = s^2 + 1.75\omega_0 s^2 + 2.15\omega_0^2 s^2 + \omega_0^2.$$

The system is simulated in SIMULINK and MATLAB. Results are showing that designed control blocks and their chosen coefficients are quite close to what was expected (fig. 3). Step response is simulated for different systems with different rising times.

Two steps for reducing the speed are presented, first by controlling the throttle valve and second by activating the brake [5]. If the vehicle has enough distance to the obstacle $\left(d_{LIDAR} > d_{comp}\right)$ or the angle of the road slope is “0”or “+” usually a change in the angle of the throttle valve is enough to control the speed, but if the object is too close $\left(d_{LIDAR} \le d_{comp}\right)$ or slope angle is “–”, then the braking system will be activated.

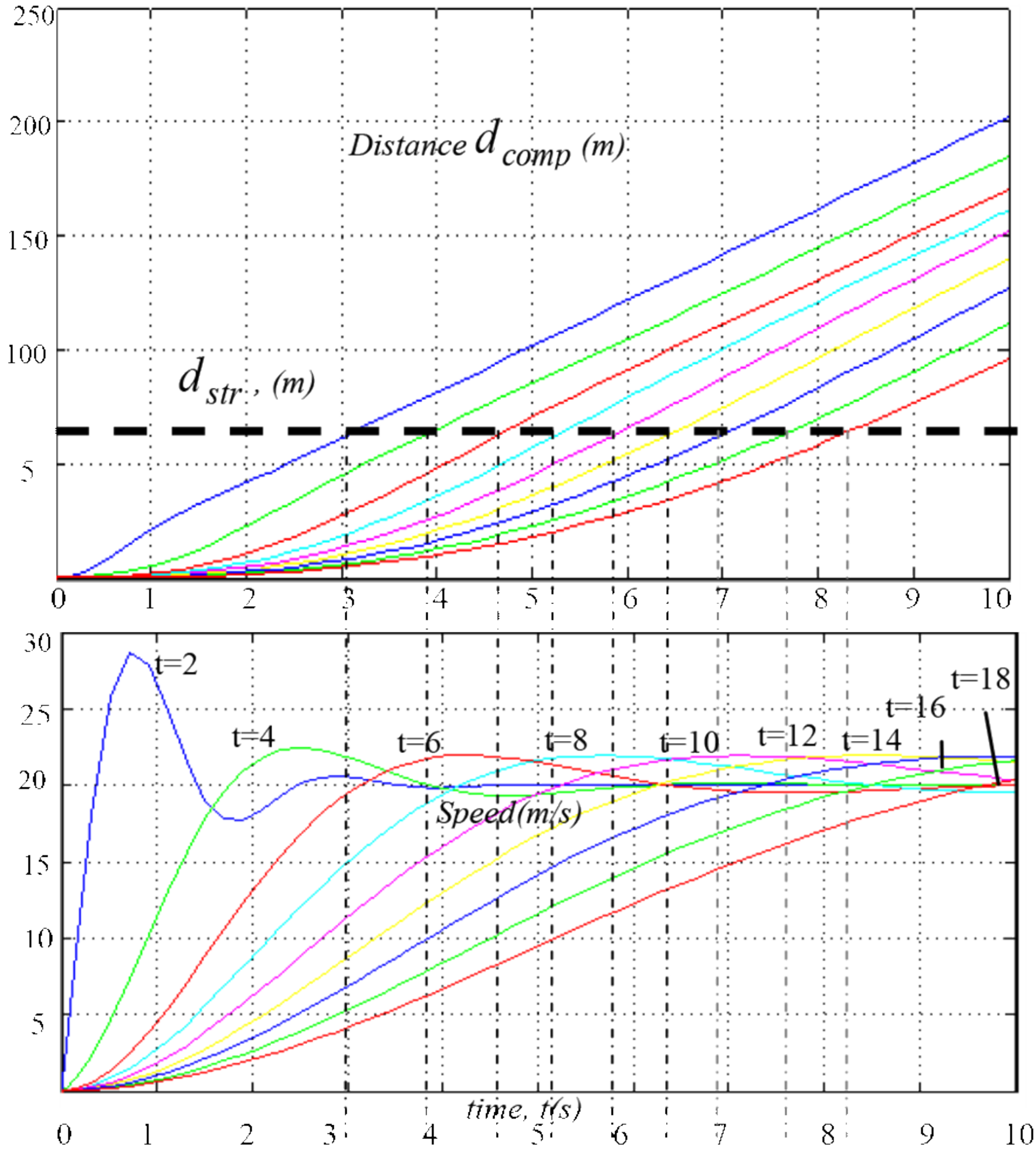

Fig. 3. Step response of the closed loop system for different rising times,

from left to right t=2, 4, 6, 8, 10, 12, 14, 16, 18 *sec*, and the distance passed by the vehicle at this time, when step input is 20 *m*/*s*

In this system the speed will not be adapted to the speed of the object, instead the control system will maintain such conditions, so that the vehicle would be able to take action and change its course of movement.

The two algorithms mentioned above will take action, when speed has to be reduced to the value calculated for the safe steering.

When a vehicle is going to turn, according to its characteristics and turning radius, it has to move with an appropriate speed.

This speed will be determined by data, received from LIDAR system and sensors. Knowing the distance, dimensions of the obstacle, speed and weight of the vehicle, the control system will calculate the final speed which it has to reduce to be prepared for steering.

System Accuracy and its Response to Instrumental Errors and Disturbances

Like any other designed system, it is necessary to know the system reaction to any type of error and disturbance that can occur or appear in the system.

Considering that range finding uses TOF method, it is understandable that an error can be caused by a change in the speed of light and also some instrumental errors happening in the digital system of counter. Applying the digital instruments and elements in the LIDAR system, will reduce the error of range finding to 0.6 - 1 *m* [8].

Rather than the accuracy of the detecting system, the effect of disturbances and errors in the speed control system has to be estimated. For this, the control system is simulated and its response to different influences has been studied.

As an example, white noise has been added to the 3-d order system with $t=6$ from fig. 3. The effect of the white noise with 10% RMSD, on the closed loop system is shown in fig. 4.

The added noise resulted in a slight distortion in output of the control system.

Forming the control system by a feedback block, built from measuring sensors and shaping filters, causes some distortions because of the dynamic behavior of sensors and filters (inertia) and error of measuring instruments.

The effect of the inertia and the error of all measuring devices, considering their real transfer functions, on the 3-d order system are presented in fig. 5.

It is seen that the system reaction to the inertia of the odometer appears in a higher overshoot in response.

In addition, the reaction of the 4th order system to the white noise and instrumental error with 10% RMSD is shown in fig. 7. To show the effect of white noise the system with raise time of $t=6$ from fig. 2 is selected.

As a result, it is shown that 4th order system in fig. 6 is responding to a step input with less overshoot and disturbances than fig. 5.

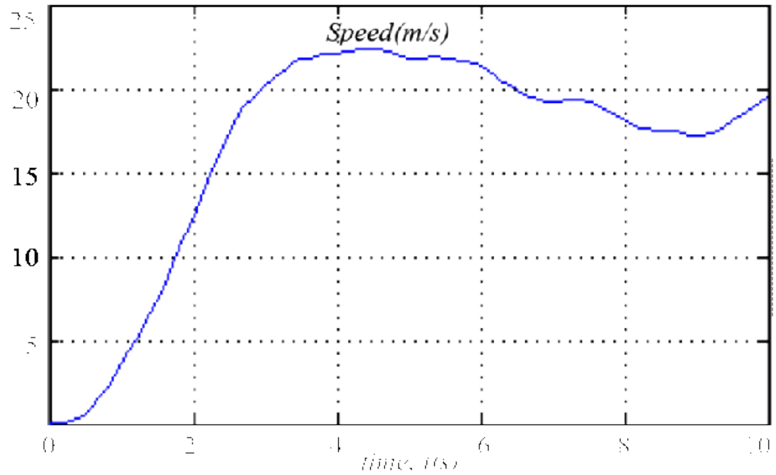

Fig. 4. Step response of the 3d order system with white noise effect

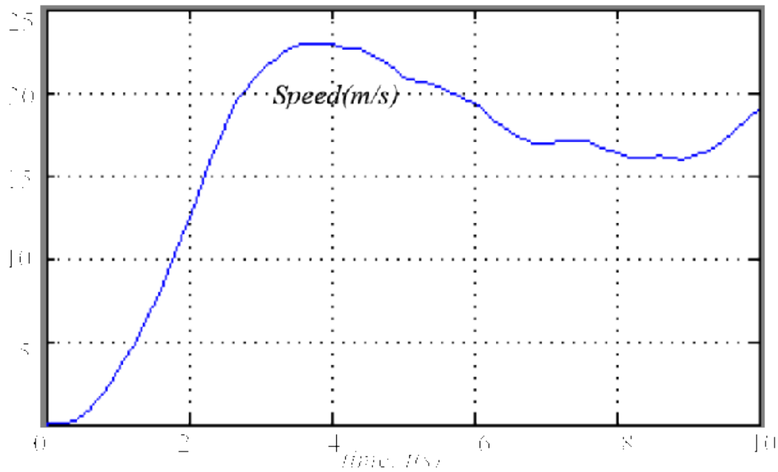

Fig. 5. Step response of the system with white noise, inertia and error of measuring instruments

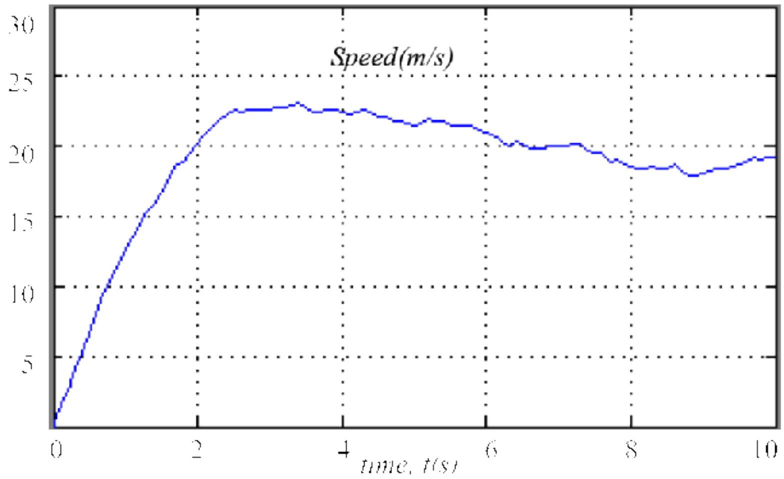

Fig. 6. Step response of the 4th order system to white noise and instrumental error

Systems Stability

The stability of the whole system is examined by Root Locus and Bode diagram. The designed systems are simulated in Matlab to see if the desired goals are achieved [9].

The simulation shows that the closed loop system is stable. The open loop system crosses the 0db at frequency of 0.232 *rad/s* and the phase margin for this point is 23.2 *deg*.

Since the coefficients of the control blocks are determined, using the denominator of the transfer function and the numerator was assumed equal to 1, changing the coefficients of the numerator in feedback and regulator can result in some changes in step response of the whole system. In addition, the calculated parameters for the control system with the help of standard coefficients method could be changed during the application. Therefore, the response of the controlled system considering the change of coefficients with 50% tolerance is simulated. The results show that none of these tolerances would bring system to instability. Moreover its noticeable that increase in t_{r2} would result in less overshoot in the response of the closed loop system, and yet system remains stable, with phase margin of 34.6 *deg* (fig. 7).

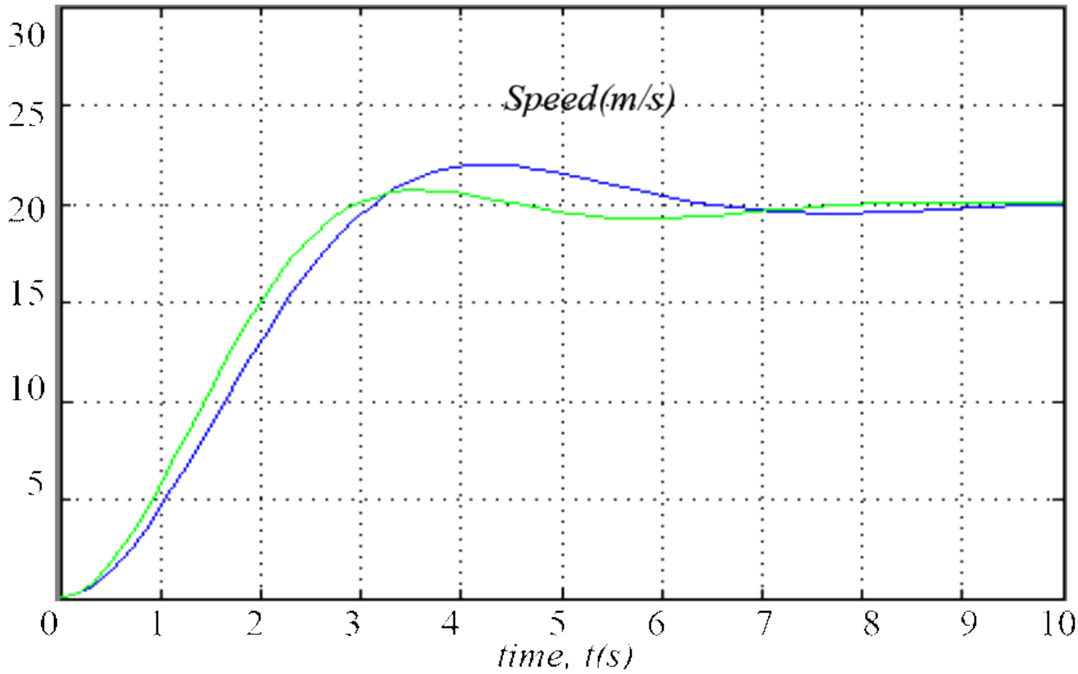

Fig. 7. Step response of the system with $t=6$ when $T_{r2} = 0.6$ (blue), and $T_{r2} = 0.9$ (green)

Changing this coefficient, we can achieve an optimal response. Increase in the coefficient T_{r2}, will result in a response with smaller overshoot and adequate rising time.

The Experimental Approach to Control the Angular Velocity Using MEMS Gyro ADXRS300

An experimental approach was planned to study the dynamic behavior of the automobile and the measuring device (gyro-sensor). At first the behavior of the car (Suzuki Baleno) while steering with increasing speed was studied (tab. 1). The car was moving on a road with the width of 2 *m*, internal radius 15 *m* and external radius 17 *m*, while the speed of movement was increasing.

***Table* 1.**

The change of the speed and its effect on behavior of the car

Automobile speed (*km*/*h*)	**Behavior of Automobile**
>15	The body of car starts tilting toward the external circle
>25	Loose items in the car start moving towards the external circle
>30	Tires start screeching. The speed can be increased further.
>35	Screeching gets louder. The car is still under control.

40	Automobile is out of control. Trying to keep the car on the track using the steering wheel is in vain. The car starts moving towards the external circle until the break system gets activated.

The speed values presented in tab. 1 are related to the turning radius and angular velocity of the car. Hence, an experiment was planned to take in to account the value of angular velocity of the car while turning, using MEMS gyro ADXRS300 [10].

***Table* 2.**

Automobile speed and the related output voltage of ADXRS300

Speed of Automobile, *km/h*	**Output voltage of ADXRS300, *v***
>15	~ 2,825
>25	~ 3,254
>30	~ 3,478
>35	~ 3,242
40	>3,47

As a result the critical angular velocity of the car equals to 3.47 *v* at the output of the sensor, and if it goes higher, the car will be out of control (tab. 2).

If the speed is higher than 35*km/h*, the car will be unstable.

The experiment shows that independent of the turning radius, for the angular velocity, directly proportional to 3,478 *v*, the system is out of control, and speed control block has to be switched on.

Conclusion

In this paper a transmitter and receiver system for a LIDAR system are presented. Using the TOF method, it can determine the distance of the vehicle to any object in the path of the vehicle. The model of the system is designed in DELPHI.

Suggested algorithms will make the system capable of controlling the speed and prepare the vehicle for safely changing its course. Depending on the distance of the vehicle to the obstacle and also the slope angle of the road, either one of the systems, throttle valve or brake control will be chosen. Meanwhile, the safety parameters of the whole system will be controlled.

An optimized control system is defined for the system, using modal control of programming control methods. The step response of the system is simulated in the SIMULINK for different rising times. The system is studied under the effect of disturbances and errors. The change of the parameters calculated by the system of standard coefficients can reduce the overshoot of the system.

The stability of the closed loop system is examined by Root Locus criteria. Using Bode diagram and open loop system, 0db cross frequency and phase margin of the system have been determined.

An experiment has been provided to test the behavior of the car while turning. A MEMS gyro-sensor was used to measure the angular velocity of the car while turning and send the critical value of the velocity to the control system.

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