ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 8, Issue 3, September 2018

Autonomous Model Vehicles: Signal Conditioning and Digital Control Design

Younis Shareef Dawood[1], Mohammed Almaged[1], Ali Mahmood[1]
[1] College of Electronic Engineering, Ninevah University, Ninevah, Iraq

Abstract*— *In recent years, rapid economic development has increased the ownership of cars and as result road accidents have grown rapidly. However, autonomous cars can reduce roads accidents effectively by maintaining a safety distance from the vehicle ahead. The core of such vehicles are sensors, which provide information about cars surrounding, as well as control systems that employ sensor input to adjust driving parameters. The main purpose of this paper is designing and implementation of reversing sensor and control system for an autonomous model car. The operational principle behind the design is to have a flashing LED, the light of which is reflected back from a close proximity object into a photodiode. The signal detected from the photodiode is fed via signal conditioning electronics, which includes circuits for current to voltage converter, signal amplification and filtering, into a digital PID controller to control the speed of the vehicle. Multisim and Matlab simulations were performed to fully test the performance of the signal conditioning circuit and digital controller design before practically implementing on PICDEMTM mechatronics demo board. The obtained results were encouraging in which the controller revealed a swift response to sensor input data.

Key words: **Autonomous Vehicles, Reversing sensor, PID controller, Digital controller.**

I. INTRODUCTION

Autonomous car, also known as self-driving car, is the vehicle with ability to sense its environment then navigate without human cooperation. Also, it is called robotic car or driverless car. The main feature of this car is employing several techniques to sense its surroundings by using different sensors such as radar, computer vision, GPS, etc. and then applying an advanced control system that uses sensor signals to make decisions in identifying navigation path and obstacle detection [1]. Autonomous cars have many potential benefits that have direct effect on human's life as they tend to increase road safety through reducing traffic collisions that might be caused by drivers' delay reactions. In term of welfare, autonomous cars relieve drivers from many driving chores and hence make long journeys much more comfortable. For traffic lights, autonomous cars provide smoother rides in which the speed of the vehicle updated automatically and thus leading to higher roadway capacity. For autonomous cars that used developed technology like Vehicle-to-Vehicle communication, traffic congestion will be minimized due to higher speed and eliminate the need for bigger safety gaps. Autonomous cars also reduce the expenses of vehicle insurance as well as reducing fuel consumption. The idea of making autonomous cars has been around since 1990s and since then, there were many researches in this filed and it became a very interesting subject. Some of these researches focused on the study of the vehicle model. In 2015, Jason et al. [2] studied the use of kinematic and dynamic models of a vehicle for a model-based control design. In their study, they included the analysis of statistics forecast errors of these kinematic and dynamic models. They used what they called a model predictive control (MPC). This approach was less computationally expensive than other techniques and it can be implemented at low vehicle's speeds. They concluded that MPC achieved accepted results in both semi and full autonomous vehicles even though they dealt with Multi-Input Multi-Output nonlinear dynamic systems. Others consider sensors as the key element for autonomous vehicles. Khalid et al. [3] discussed in their paper a single video camera as a sensor where the moving vehicle provides a sequence of colored images as an input data. They utilized this sensor for multitasks recording of the environment, roads, vehicles and traffic signs. By the help of Matlab, they performed image processing and used the sensor data to detect the desire lane.

Work in autonomous cars has grown rapidly due to advances in computing technologies sensors and actuators [2]. DC motors have been widely used in autonomous vehicle applications due to their simple design, swift response and reliability. Several academic studies investigating speed regulation approaches of DC motors have been carried out. The PID controller is considered as the most commonly used compensating technique in controlling DC motors. Tuning PID parameters is the most challenging and essential task as it has a large impact on the stability and performance of the control system. Prior to 1980s, most of the tuning processes were accomplished using the Ziegler Nichols method, which is the oldest and most common PID tuning approach. However, the Ziegler Nichols tuning techniques has several drawbacks that may lead to system overshoot, oscillation and even instability. Nowadays, due to the advances in digital computers, software tuning packages is utilized to overcome the problems associated with traditional methods and generate the appropriate tuning parameters after analyzing the system response. However, this technique requires a mathematical model of the system which can be difficult to define in some cases. In 2014, Udani et al. [4] designed a discrete PID controller to adjust the speed of DC motor using Matlab software. The tuning of the PID parameters was achieved with the aid of Matlab auto tuning feature. In the

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 8, Issue 3, September 2018

same vein, Joshi et al. [5] introduced a Simulink model of brushless DC motor. PID controller algorithm is employed to determine the duty cycle of the PWM control signal that yields a proportional voltage which operates the DC motor.

Recently, digital PID controller implemented through embedded system has been widely used in different applications. In his paper, Gohiya et al. [6] designed a digital PID controller for speed and position control of a mobile robot employed in agriculture for monitoring plants condition such as soil moisture content, temperature, humidity, etc. Optimizing PID parameters is an additional advanced stage in the design procedure of digital PID controllers. There are several soft computing techniques that are utilized in the tuning process of PID controllers. As a review, Kushwah et al. [7] introduced various soft computing techniques, such as fuzzy logic and genetic algorithm, for tuning PID controllers utilized for speed control of DC motors. Likewise, Jaiswal and Phadnis [8] proposed a genetic algorithm model to optimize the parameters (Kp, Ki and Kd) of a PID controller used for speed control of DC motor.

This paper focuses on the design process of an obstacle avoidance sensor for an autonomous model vehicle. The operational principle behind the design is to have an IR flashing LED, the light of which is reflected back from a close proximity object into a photodiode. The signal detected from the photodiode is then fed, via signal conditioning electronics, into a microcontroller to control the speed of the vehicle's motors. PID controller was initially simulated in Matlab and then practically implemented using mechatronics demonstration board.

II. SENSOR SIGNAL CONDITIONING

The sensor that has been designed consists of an IR flashing LED as a transmitter that emits a continuous beam of light and a photodiode as receiver that collects the reflection of infrared signal and produce a signal proportional to the measured distance. Photodiode is a reverse biased in which its reverse current increases when its junction is exposed to light [9]. The selected photodiode that will be used gives a maximum current of (1 uA) at a frequency equivalent to the frequency of the flashing LED. Thus, the signal conditioning circuit will initially convert the photodiode's current signal into a voltage signal then amplify this signal to a 5V range suitable for embedded system (PIC) input.

The circuit that will be used is an op-amp current to voltage converter circuit with a slight compensation for the input bias current and the input capacitance. It is important for this particular application to choose an operation amplifier with low input bias current and the ability to drive a high capacitive load and high gain bandwidth. The output from the current to voltage converter circuit

$$V_{out} = -IR_1 = -1\,\mu A \ x\ 1.25\ K\Omega = -1.25\ mV \qquad (1)$$

This is then followed by amplifying this input signal to an acceptable value that can be used by microcontrollers. To achieve an accurate amplification with a gain error of less than 10%, the maximum gain of each stage should not exceed op amps' maximum close loop gain G_max. The values of G_max are calculated as follow:

$$G_{max} = [\frac{(F_u\ /\ F_{in})}{10}] = [\frac{(1.3\ MHz\ /\ 5.3\ KHz)}{10}] = 24.4 \qquad (2)$$

Where F_u is the gain bandwidth of the selected op amp.
The total required gain is equal to ((10 vp-p)/(1.25 mvp-p)=8000). Thus, three stages of inverting amplifiers are used with an individual gain of 20 at each stage as shown in table I.

Table I Calculation of output voltages for each stage

Stage	1st	2nd	3rd
Vout	$Vout = -Vin\ (R_3/R_2)$ $Vout = -(-1.25)\ x\ (20)$ $Vout = 25\ mV\ p-p$	$Vout = -Vin\ (R_5/R_4)$ $Vout = -25\ x\ (20)$ $Vout = -500\ mVp-p$	$Vout = -Vin\ (R_7/R_6)$ $Vout = -(-500)\ x\ (20)$ $Vout = 10\ Vp-p$

The block diagram of the current to voltage converter and amplifier circuits implemented in MultiSim is shown in figure (1). The photodiode is assumed to be a square wave current source with amplitude of 1 μA, 50 % duty cycle and a frequency of 5.3 KHz.

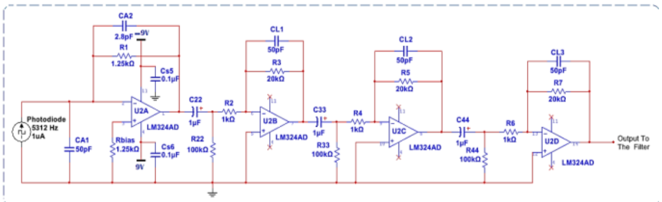

Fig 1. Voltage regulator, current to voltage converter and the amplifier circuits

The output voltage from the amplifier that corresponds to photodiode input current is illustrated in figure (2).

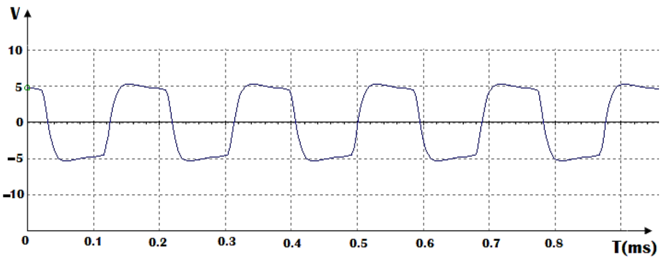

Fig 2. Amplifier output voltage

An important issue associated with IR sensors is that they give wrong detection when they used in presence of light sources like sunlight. These sources may produce a DC offset in the signal or combine the signal with a random frequency noises and hence generate an error in the measurements. For this reason, it is important to design a filter that pass only the frequency that emitted by the IR LED and remove the unwanted noise signals to achieve the desired output. The designed Butterworth filter consists of two cascaded second-order band-pass filters. The Butterworth's filter coefficients (α, a1 and b1) that define the factor in which the mid frequency of each individual filter (Fm1 and Fm2) differs from the overall band pass frequency (Fm) are listed in Table II [10].

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 8, Issue 3, September 2018

Table II Second order filter coefficients

Bessel				Butterworth				Tschebyscheff			
a_1	1.3617			a_1	1.4142			a_1	1.0650		
b_1	0.6180			b_1	1.0000			b_1	1.9305		
Q	100	10	1	Q	100	10	1	Q	100	10	1
ΔΩ	0.01	0.1	1	ΔΩ	0.01	0.1	1	ΔΩ	0.01	0.1	1
α	1.0032	1.0324	1.438	α	1.0035	1.036	1.4426	α	1.0033	1.0338	1.39

By choosing the quality (Q) of the filter to be 10, the values of the filter coefficients α, a1 and b1 are chosen from Butterworth section in the table above. Now the bandwidth of the filter can be calculated as follow:

$$B = F_m / Q = 5312/10 = 531.2\,Hz \tag{3}$$

The center frequency of each individual filter can be calculated from

$$F_{m1} = F_m / \alpha = 5312 / 1.036 = 5127.4\,Hz \tag{4}$$

$$F_{m2} = F_m \; x \; \alpha = 5312 \; x \; 1.036 = 5503\,Hz \tag{5}$$

The individual quality Qi and band pass gain Ami for both filters is the same.

$$Q_i = Q \; x \; [(1 + \alpha^2)\, b_1] / (\alpha \; x \; a_1) \tag{6}$$

$$Q_i = 10 \; x \frac{((1 + 1.036^2) x\, 1)}{(1.036 \; x \; 1.4142)} = 14.151 \tag{7}$$

$Am_i = \left(\frac{Q_i}{Q}\right) x \left(\frac{Am}{b_1}\right)^{\frac{1}{2}}$, Where *Am* the overall band pass filter gain.

$$Am_i = \left(\frac{14.151}{10}\right) x \left(\frac{1}{1}\right)^{\frac{1}{2}} = 1.415 \tag{8}$$

Now, by picking a specific value for all the capacitors (10 nf), the resistors value for both individual filters are calculated and rounded to the nearest standard values.

$$RF_{i2} = Q_i / (\pi \; x \, fm_1 \, x \, C) \tag{9}$$

$$RF_{i1} = RF_{i2} / (2 \, X \, Am_i) \tag{10}$$

$$RF_{i3} = (Am_i \; x \, RF_{i1}) / (2 \; x \, Qi^2 + Am_i) \tag{11}$$

After calculating the value of the resistors for the two stages of the filter, the circuit diagram of the fourth order MFB band-pass filter designed in MultiSim is shown in the Figure 3.

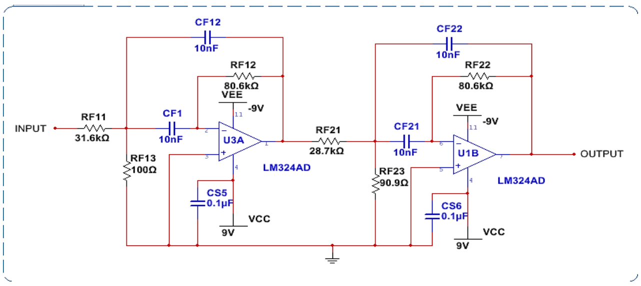

Fig 3. Fourth order MFB band-pass filter

The magnitude and the phase shift responses of this filter are shown below in figures (4) and (5) respectively. The Bode plot or the frequency response curve is shown in figure (4). It can be clearly seen that the signal is completely attenuated at low frequencies, then it will gradually increase with the frequency at a slope of +40dB / decade until it reaches its maximum value at the center frequency (Fm). After that, it will start to decline again at the same rate as the frequency increases.

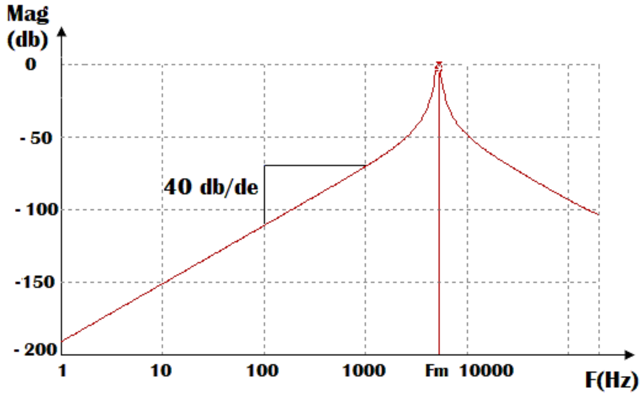

Fig 4. Magnitude response of the filter

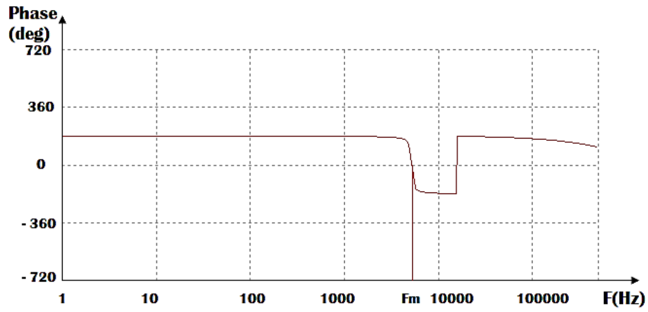

Fig 5. Phase shift response of the filter

In term of frequency response, at low frequencies, the phase angle of the output signal leads the input by +180 until it reaches to the center frequency Fm where it becomes in-phase with the input signal, then it changes to lag the input by -180 as it goes to higher frequencies.

To examine the validity of the designed filter, the input signal is mixed with low and high frequency noises that are simulated in MultiSim by a current source placed in parallel with the original current signal. Figures (6) and (7) show the filter response to low frequency noises of 100 Hz, which may arise from the sun light as a DC offset noise, and high frequency noise of 10 KHz respectively. It can be concluded from the response shown that the filter succeeded in removing high and low frequency noises and produced a pure sine wave signal.

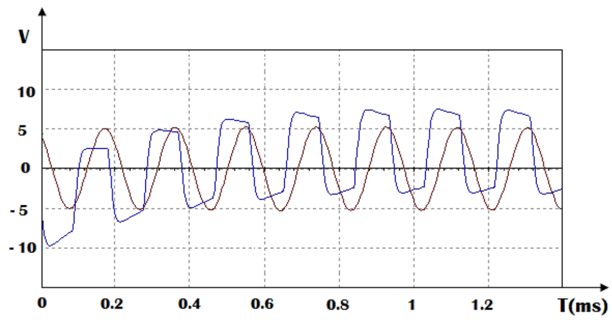

Fig 6. Filter response to low frequency noise

IJEIT
ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 8, Issue 3, September 2018

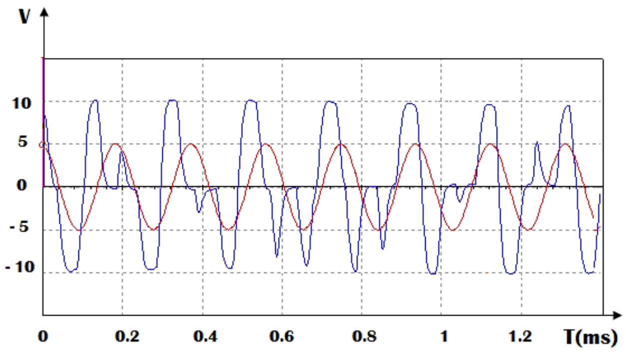

Fig 7. Filter's response to high frequency noise

III. FEEDBACK CLOSE LOOP CONTROLLER DESIGN

Feedback control systems acquire data from measurements to manipulate a control signal in order to achieve the desired response. It continuously compares the target response with the actual output to produce an error signal (e) which is modified by the controller to generate a control signal (u) that minimizes the error. The most common type of the feedback controllers is the PID controller. Each term of the three controller actions has a specific function and specifications. In general, the proportional term is used to add some gain to the system while, the derivative element is added to reduce the oscillation (peak overshoot). Finally, the integral term is used to eliminate the steady state error.

Therefore, the final output from the controller, written in continuous time domain, is equal to the summation of these three control actions.

$$U(t) = K_p\, e(t) + K_i \int e(t)\, dt + K_d \frac{d\, e(t)}{dt} \qquad (12)$$

The controller output should be digitized so it can be implemented by the digital microcontroller (PIC). The PID controller output equations are described as follow [11, 12]:

$$U(k) = K_p\, e(k) + K_i\, T_s \sum_{i=1}^{k} e(i) + K_d \frac{e(k) - e(k-1)}{T_s} \qquad (13)$$

$$U(k-1) = K_p\, e(k-1) + K_i\, T_s \sum_{i=1}^{k-1} e(i) + K_d \frac{e(k-1) - e(k-2)}{T_s} \qquad (14)$$

$$\Delta U = U(k) - U(k-1) \qquad (15)$$

$$\Delta U = K_p\,[e(k) - e(k-1)] + K_i\, T_s\, e(k) + K_d \frac{e(k) - 2e(k-1) + e(k-2)}{T_s} \qquad (16)$$

The updated value of U(k) for the next control period will become as follow:

$$U(k)_{i+1} = U(k)_i + \Delta U \qquad (17)$$

The PICDEMTM mechatronics demo board has been utilized to simulate the drive and control circuits of autonomous vehicles. This board has all necessary components such as microcontroller, serial communication, DC motor and its drive circuit, optical encoder, etc. The PIC16F917 microcontroller has been used which includes 22 available I/O pins that are dedicated connections to several components on the board. It also has 10 bits, eight multiplexed channels successive approximation analogue to digital converter with a resolution of the conversion of approximately 4.8 mv. The board is connected to the computer via RS232 for data collection. The communication between the PC and the microchip development board takes place every 100 ms. A potentiometer is used to simulate reversing sensor signal which delivers an output voltage of 0-5 V range. Thus, a 5V output from the POT corresponds to maximum speed of the motor while 0V output gives its minimum rotational speed. This signal is feed to ADC and used to adjust the set point of the close loop control system that will be employed to control the speed of the DC motor which is the most common actuator found in autonomous model vehicles. Figure (8) clarifies the relationship between the sensor circuit and the close loop control system.

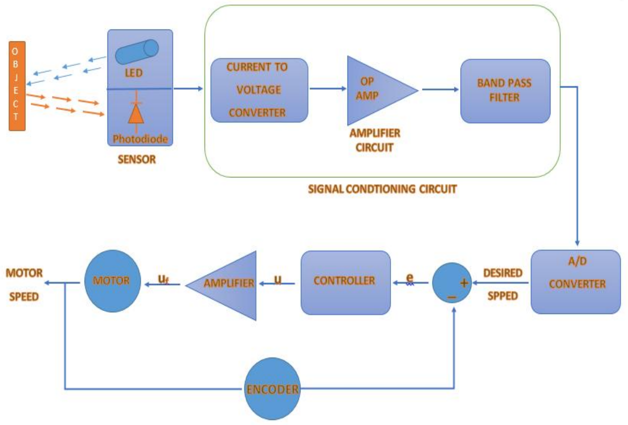

Fig 8. Functional block diagram

IV. SYSTEM SIMULATION AND EVALUATION

DC motor is a common plant component in industrial systems. It directly provides a rotary motion in response to an input electrical voltage (V). The electrical equivalent circuit of the DC motor armature consists of a resistor (R), self-inductor (L) and an induced back EMF (e). The mathematical model of DC motors is a well-known that has been explained in great details in many literatures and hence this work will not focus on the assumptions and derivation procedure. The final transfer function of a brushed DC motor is as follow [13]:

$$\frac{w(s)}{V(s)} = \frac{K}{(Js+b)(Ls+R)+K^2} \left(\frac{Rad/s}{Volt}\right) \qquad (18)$$

The above characteristic equation is constructed from the commonly used blocks in Matlab simulation library as shown in figure (9).

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 8, Issue 3, September 2018

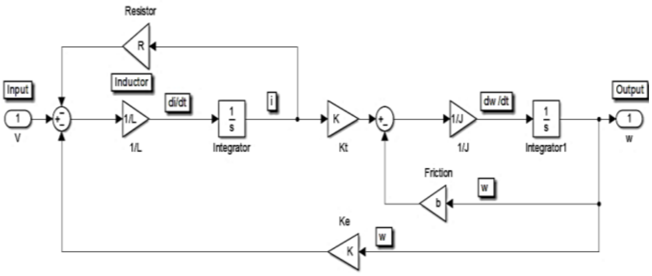

Fig 9. Simulink of a DC motor mathematical mode

This model is converted into a subsystem that requires the input parameters of the DC motor. Then, the PID controller block is used to implement a discrete-time controller for the simulated model. PID controller gains are tuned automatically using PID tuner tool. In addition, manual tuning is used for fine adjustments of the system transient parameters. Several simulation tests have been performed to obtain optimal values for the PID controller gains.

Then, the Zero-Order Hold block is utilized to convert the sensor analogue signal with a continuous sample time to an output signal with a discrete sample time. The sample time is set to 0.05 sec which is similar to the PIC built in ADC desired sampling time. The signal from the reversing sensor is simulated using a set of unit steps input. Then, a scaling factor is used to match the full range of sensor output voltage with the DC motor full speed range. The final block diagram that contains all the blocks of the whole system is shown in figure (10):

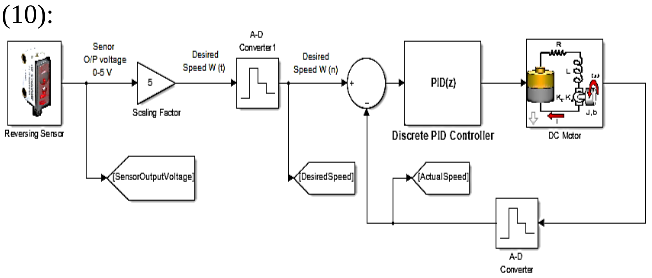

Fig 10. Final block diagram

Multiple simulation tests have been performed to obtain the optimum values of PID controller. The first test, shown in figure (11), was carried out without any torque disturbance or sensor disturbance. Several unit step functions were combined together to simulate different case scenario of sensor readings. These functions deliver an output voltage of 0-5 V range. Thus, a 5V output corresponds to free space and hence maximum speed of the motor while 0V output resembles a detected obstacle and thus gives a minimum rotational speed output.

PID controller seems to work well in achieving the demanded speed with an insignificant amount of peak overshoot and have no steady-state errors.

Practically, there is always a certain amount of noise that comes with the sensor reading. Thus, it is important to be added to the simulated system and test the response accordingly. The PID controller response of motor speed after adding the sensor noise is shown in figure (12).

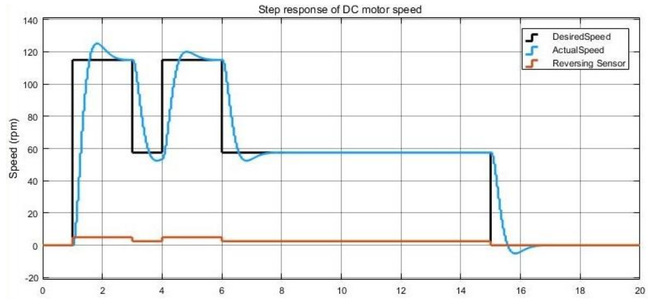

Fig 11. Step response of DC motor speed

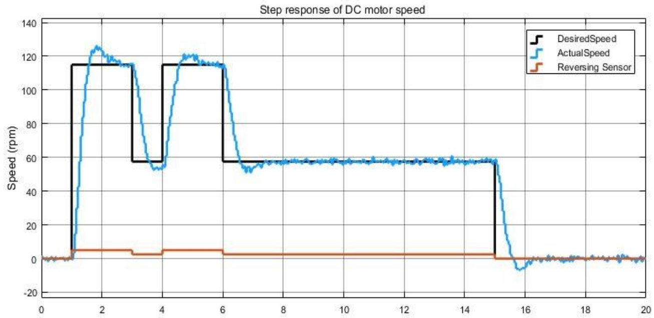

Fig 12. Step response of DC motor speed with sensor noise

In order to test controller performance, it is also important to explore the sensitivity of the controller to external plant disturbances. Therefore, an additional but opposite to rotational torque of motor torque is inserted in the initial Simulink model of the DC motor to represent the effect of a load being applied to the motor. The step response of the system output with both sensor noise and torques disturbance is shown in figure (13).

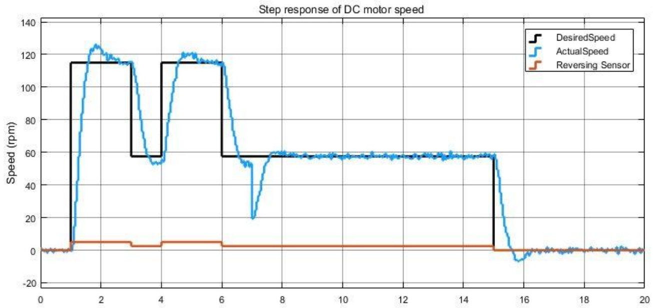

Fig 13. Step response of DC motor speed with sensor noise and torque disturbance

Another test is made for higher sensor noise value with torque disturbances at multiple points. The desired and actual motor speeds are as shown in figure14.

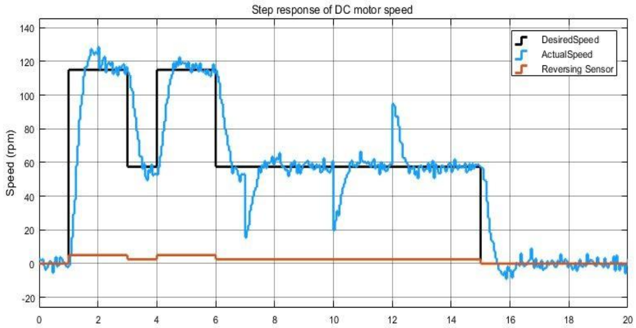

Fig 24. Step response of DC motor speed with high sensor noise and torque disturbance

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 8, Issue 3, September 2018

In all cases, PID controller performs well in terms of reaching demand and rejecting disturbance. However, there were slight oscillations produced by the controllers that could be real problem in autonomous vehicle application. This slight fluctuation may cause car jerk whilst approaching the desired speed.

After completing the Simulink of the system and getting acceptable results, the same proportional, integral and derivative controller parameters were used to practically implement the control system on the PICDEMTM mechatronics demo board. Referring to the PID tuner, the controller gains were as follow; Kp = 17.995,Ki = 41.892 ,Kd = - 0.685. The actual speed data collected from the brushed DC motor on the board via serial port and plotted in Matlab is shown in figure (15).

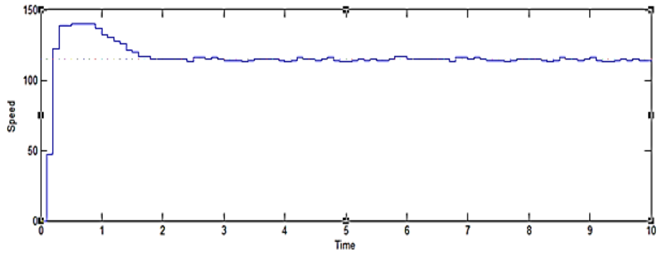

Fig 15. PID close loop system response

It can be clearly seen that the PID controller have a good performance in terms of reaching the desired demand. However, it reveals a significant level of overshoot. Thus, manual fine-tuning is introduced to reduce the peak overshoot. This was accomplished by reducing the value of Kp and increasing Kd while Ki was kept constant. Figure (16) shows the response of the final tuned parameters. Figure (16) reveals that the manual tuned response has less overshoot but a longer rise and settling times.

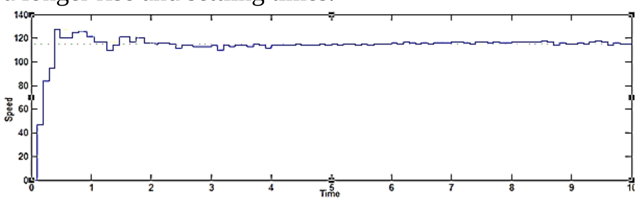

Fig 16. Manual fine-tuning system response

V. CONCLUSION

This paper focused on designing of a complete control system for model car to be autonomous. It started with multiple signal conditioning circuits for the sensor including current to voltage converter, signal amplification, signal filtering and analog to digital conversion. Then, digital PID was designed using MATLAB/SIMULINK to control the speed of the model car which is represented by its DC motors. Finally, PICDEMTM mechatronics demo board has been used to apply the simulation result on.

The results show that the speed of DC motors of an autonomous model car can be controlled based on the distance of the nearest object in the rear side of the car based on distance measuring using IR flashing LED sensor. Also, it showed that the PID gives good response of zero steady state error with 0.36 second rise time and maximum overshoot of less than 10% which is very acceptable to cars.

REFERENCES

[1] S. Thrun, "Toward robotic cars," Commun. ACM, vol. 53, pp. 99-106, 2010.

[2] J. Kong, M. Pfeiffer, G. Schildbach, and F. Borrelli, "Kinematic and dynamic vehicle models for autonomous driving control design," in Intelligent Vehicles Symposium, 2015, pp. 1094-1099.

[3] K. B. Isa and A. B. Jantan, "An autonomous vehicle driving control system," International journal of engineering education, vol. 21, p. 855, 2005.

[4] M. Udani, N. Patil, and D. Mehta, "Speed Control of DC Motor using Digital Control System," International Journal of Engineering Research & Technology (IJERT), vol. 3, 2014.

[5] B. Joshi, R. Shrestha, and R. Chaudhar, "Modeling, Simulation and Implementation of Brushed DC Motor Speed Control Using Optical Incremental Encoder Feedback," in Proceedings of IOE Graduate Conference, 2014.

[6] C. S. Gohiya, S. Sadistap, S. Akbar, and B. Botre, "Design and development of digital PID controller for DC motor drive system using embedded platform for mobile robot," in Advance Computing Conference (IACC), 2013 IEEE 3rd International, 2013, pp. 52-55.

[7] M. Kushwah and A. Patra, "Tuning PID controller for speed control of DC motor using soft computing techniques-A review," Advance in Electronic and Electric Engineering, vol. 4, pp. 141-8, 2014.

[8] M. Jaiswal and M. Phadnis, "Speed control of DC motor using genetic algorithm based PID controller," International Journal of Advanced Research in Computer Science and Software Engineering, vol. 3, 2013.

[9] B. Carter and R. Mancini, Op Amps for everyone: Newnes, 2017.

[10] G. Held, Introduction to light emitting diode technology and applications: Auerbach Publications, 2016.

[11] M. Kocur, S. Kozak, and B. Dvorscak, "Design and implementation of FPGA-digital based PID controller," in Control Conference (ICCC), 2014 15th International Carpathian, 2014, pp. 233-236.

[12] J.-S. Wang and G.-H. Yang, "Data-driven output-feedback fault-tolerant compensation control for digital PID control systems with unknown dynamics," IEEE Transactions on Industrial Electronics, vol. 63, pp. 7029-7039, 2016.

[13] I. Dimeas, I. Petras, and C. Psychalinos, "New analog implementation technique for fractional-order controller: a DC motor control," AEU-International Journal of Electronics and Communications, vol. 78, pp. 192-200, 2017.

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 8, Issue 3, September 2018

AUTHOR BIOGRAPHY

Younis S. Dawood received PhD in optimization control systems in 1991, from Hatfield University United Kingdom, the MPhil's degree in control system engineering/ intelligent systems, UAV's in 1988, from Hatfield University United Kingdom and Bachelor's degree in Electrical engineering from the Kiev Academy, Ukraine, in 1978.His current research in optimal and intelligent control systems.

Mohammed Nussrat Younus Almaged received a BSc degree in Mechatronics Engineering from Mosul University in 2011. After the graduation, he started his career working in power plant as a field engineer. In 2015, he achieved his MSc in Mechatronics Engineering from Newcastle University. Then, he started his academic journey working as a lecturer at Nineveh University. His current research interests include sensors design and fabrication using smart materials**.**

Ali Khaleel Mahmood received MSc in Mechatronics Engineering in 2014 from Newcastle University, Newcastle upon Tyne, United Kingdom and BSc in Mechatronics Engineering in 2010 from University of Mosul, Mosul, Iraq. His research of interest is in Automation and control, Autonomous Vehicles and Embedded Systems.