International Journal of Computing and Applications | **ISSN: 0973-5704**
Volume 13, Number 1, (January-June 2018), pp 117-124

IMPROVEMENT OF ANTI-LOCK BRAKING SYSTEM ON ROUGH ROAD USING INTELLIGENT ALGORITHM

N. Vivekanandan[1], Kalaskar Pratik V.[2] and A.M. Fulambarkar Principal[3]

[1]*Research Scholar* & Asst. Prof.+, Department of Mech. Engg. *DYPIET, +PCCoE, Pune, Maharashtra, India- 411044.*
Email: n.vivekanandan@pccoepune.org
[2]*Department of Mechanical Engineering, Pimpri Chinchwad College of Enginnering, Pune, Maharashtra, India- 411044*
[3]*Pimpri Chinchwad College of Engineering (PCCoE), Pune, Maharashtra, India-411044*

Abstract: Anti-Lock Braking (ABS) System is mainly used for stopping of vehicle in shortest distance without losing control that can prevent accidents. The performance of ABS on rough road surface is decreases due to improper prediction of surface and time required to respond. In this paper, deficiencies are controlled using intelligent algorithm such as neural network (NN). Neural network based on training mode, which helps to train the different road surface to control stopping distance, time and linear stability of vehicles. The Simulation model was developed for analysis compared results without intelligent algorithm. The results indicate that intelligent algorithm has significant impact on braking performance.

Keywords: Rough road surface, intelligent algorithm, neural network, simulation.

1. INTRODUCTION

In recent years of industrial revolution Indian roads seem to be flooded with more and more number of cars. Active safety of vehicle is mainly concern with Anti-lock braking system (ABS). Vehicle losses control due to wheel slip and wheel slip causes because of hard braking and different road surfaces. If braking force exceeds the force of adhesion the wheel will stop rotating and start slipping on road because there is insufficient grip to keep them turning. Due to locking of wheel the driver loses directional stability on the steering control which will improve with the help of ABS.

Due to increased popularity of sport utility vehicle, which is used on rough road surface, improvement of ABS on rough road surface is important. The braking performance is decreases which results in longer stopping distance and time due to suspension effect, tyre effect and deficiencies in algorithm. Many of researchers are studying on advances of ABS on rough road, solving the braking performance will provide increased safety.

2. LITERATURE REVIEW

The performance of ABS on rough road depends on three factors such as suspension effect, tyre effect and algorithm effect. Wietsche Clement William Penny (2016) suggested a slight modification in Bosch ABS algorithm and FTire is implemented in Matlab and results are validated with test data on both smooth and rough road surface [1]. Herman A. Hamersma (2014) suggested effect of spring and damper characteristics on braking performance. The results of semi-active suspension system have significant impact [2]. Valentin Ivanov (2015) suggested wheel slip control of all wheel drive sport utility electric vehicle on off road condition. HIL technique is used to control wheel slip and these results are validated using actual testing of vehicle demonstrator in real operational conditions [3]. Theunis R. Botha (2015) suggested prediction of rough road using digital image correlation using stereography. The LiDAR and INS sensors are used for accurate measurement of road surface [4]. Rishabh Bhandari (2011) suggested friction coefficient between tyre and road for different surfaces [5]. Bo Wang (2014) suggested six types of roads and 14 DOF of vehicle.

Simulation tests are performed on uniform and variable friction coefficient on uneven road [6]. Tiaxiong Zheng (2011) suggested the road identification methods using pressurization and depressurization time of two front wheels as well as compression and decompression [7]. Feng Tyan (2009) suggested Simulink model for road roughness and these values are classified using ISO 8608 [8]. Horia BELES (2014) suggested quarter car Simulink model to simulate how ABS works if road condition and drivers input are changed [9].

3. VEHICLE ON ROUGH ROAD

Road input excitation from rough road surface leads to a number of contributing factors to the rough road ABS problem which include, normal load variation due to axle oscillations and results in increased stopping distance and reduced lateral control of vehicle [1]. Vehicle body motion such as roll, pitch and yaw that are excited by rough road input [10].

The effective rolling radius is changed due to undulations o rough road surface. Hence, the contact between tyre and road is lost due to vertical and torsional dynamics of wheel and wheel starts oscillating. Tyre oscillation affects the performance of ABS [12].

Hence, in this paper, the rough road surfaces are trained with the help of intelligent algorithm which reduces the stopping distance and control the stability.

4. MATHEMATICAL MODEL

A quarter car model, as shown in Figure 1, is considered for simplicity and due to symmetry of vehicle. The governing equation of motion of vehicle is given by

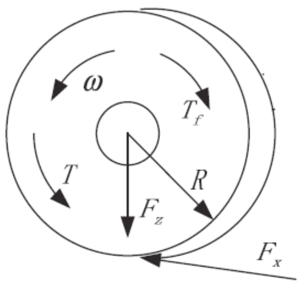


Figure 1: Quarter car model

$$F_x = -m_t \times a \tag{1}$$

$$dv/dt = a = -F_x/m_t \tag{2}$$

$$m_t = (1/4) \times m_{vs} + m_w \tag{3}$$

where, R is wheel radius, m_t is total mass of quarter vehicle, F_x is longitudinal tyre force, a is acceleration, m_{vs} is sprung mass and m_w is mass of wheel. The slip is calculated as:

$$\lambda = (V - R\omega)/V \tag{4}$$

where, λ is slip, ω is angular velocity of wheel.

When, λ = 1, the angular velocity of wheel is zero that means wheel is locked. When λ = 0, the angular velocity of wheel is freely rotating means no braking is applied. During braking, velocity of vehicle and wheel decrease but for stability V > Rω.

5. BOSCH ALGORITHM

Now-a-days, Bosch algorithm is mainly used in ABS to stopping the vehicle in minimum time and without skidding or loss of stability. The Bosch algorithm depends on two parameters maximum and minimum angular acceleration and maximum allowable slip. Bosch algorithm is a combination of electronic and hydraulic system. Wheel speed sensors are connected to the wheel which counts the rotation of wheel in every second and send the signals to electronic control unit. When brakes are applied, irrespective of drives input force, electronic control unit sends signal to hydraulic control unit according to angular velocity of wheel. Hydraulic control unit supplies the pressure to the brake according to input of electronic control unit. Hence, skidding of vehicle is avoided.

In Bosch algorithm, vehicle dynamic inputs are given such as wheel speed, vehicle speed, brake demand and brake force. The electronic control unit calculates the slip error, if slip excessive slip occurs then again the signals are send to electronic control unit and new signals are send to hydraulic control unit. The force which is applied by driver is large, so smaller force than drivers request is applied to hydraulic control unit. If excessive slip does not occur, then force is supplied according to driers request.

6. INTELLIGENT ALGORITHM

The Bosch algorithm has certain deficiencies such as it cannot predict the road surface. It supplied the same forces on different road surface when slip is occurred. Hence, performance of ABS is negatively affected on rough road surface. To remove these deficiencies an intelligent algorithm is developed. In recent years, researchers have developed many methods to predict the road surface such as digital image processing, pressurization and depressurization between two front wheels as well as compression and decompression. But these methods required a certain time to respond even if the vehicle is travelling on the same surface as on earlier.

Intelligent algorithm is helpful for predicting the road surface. It stores the data input from surface as well as train them to get desired output. The intelligent algorithm is same as that of Bosch algorithm, but only change is it predicts the road surface using Neural Network (NN) before calculating the slip value other input values are same as wheel speed, vehicle speed, brake demand and brake force.

A. Prediction of Aurface

- According to [5], there are two methods of predicting the surface such as one-point method and three-point method. These two methods are based on nature of friction curve and Burckhardt model.
- In one-point method, only one reference value of slip is predicted. At this value, the deceleration vehicle is measured. This deceleration at a particular slip is then related to different surface.
- In three-point method, the limitations were eliminated using three values of slip are predicted to evaluate surface condition. The surface condition is given by

$$\mu(\lambda) = (C_1(1 - e^{-C_2\lambda})C_3\lambda) \qquad (5)$$

where, C_1, C_2 and C_3 are constants for different road condition and λ is slip. C_1 is maximum value of friction curve, C_2 is friction curve shape and C_3 is difference between maximum value of friction curve and value of slip is one.

Table 1
Values of constant for various surfaces [5]

Surface Condition	*C1*	*C2*	*C3*
Dry	1.2801	23.99	0.52
Wet	0.857	33.822	0.347
Snow	0.1946	94.129	0.0646
Ice	0.05	306.39	0

Using Table 1 and (5) the program is develop to calculate coefficient of friction with respect to wheel slip. Figure 2 shows the detailed evaluation coefficient of friction. Fig states that when slip is equal to 0.1, coefficient of friction is higher for all surface conditions. Further increase in wheel slip, curve is going to decrease for dry and wet surface while remains same for ice and snow surface. Therefore, wheel slip has to control in region of 0.1 to 0.2. Considering the values of coefficient of friction mu curve ABS Simulink model.

B. Random Road Analysis

ISO 8606 specifies the power spectral density values for road roughness. The roughness values cause decrease of fatigue life of tyres, decreases performance of ABS. According to ISO 8606, the road surfaces are classified into different parameters which are given in Table 2. The new roads are considered as good roughness quality; old roads are considered as medium roughness while roads consist of stones or similar material may be classified as poor or bad roughness. Therefore, for poor road surface roughness variance, mean is considered from Table 2.

Table 2
Roughness standard deviation [8]

Road class	*Roughness variance* $\sigma(10^{-3})m$	*Power spectral density*	$\alpha\left(\frac{rad}{m}\right)$
A (very good)	2	1	0.127
B (good)	4	4	0.127
C (average)	8	16	0.127
D (poor)	16	64	0.127
E (very poor)	32	256	0.127

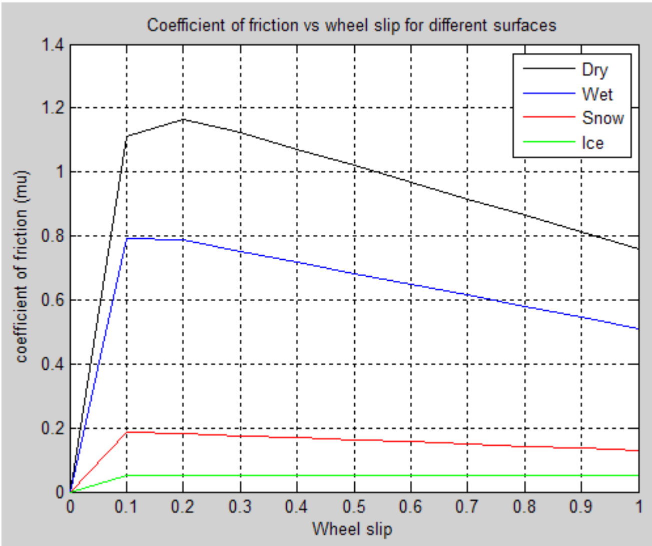


Figure 2: **Coefficient of friction as a function of slip for different surfaces.**

The Simulink model is developed for analysis of random road profile as shown in Figure 3. The random number is selected from Table 2, the velocity of vehicle is considered and feedback is given to sum block by multiplying it with alpha. The output is stored with respect to time which is amplitude of road surface.

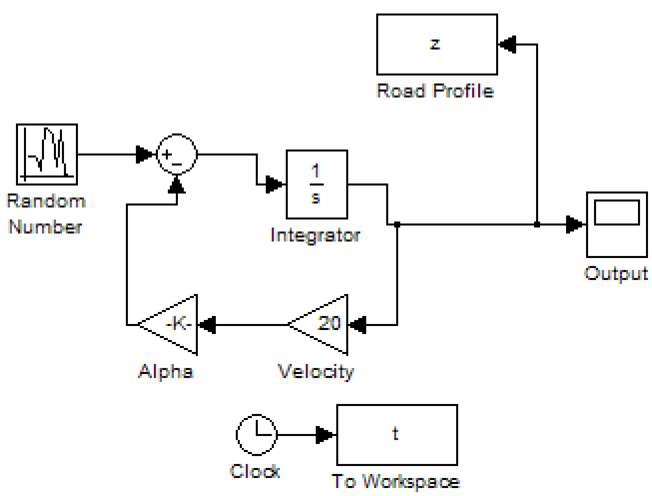


Figure 3: **Random road generator simulink model.**

C. Output of Simulink Model

Figure 4 shows the output generation of random road surface of amplitude with respect to time. Figure shows some up and down due to variation of poor road surface. Road profile is stored in *z* as shown in Figure 3.

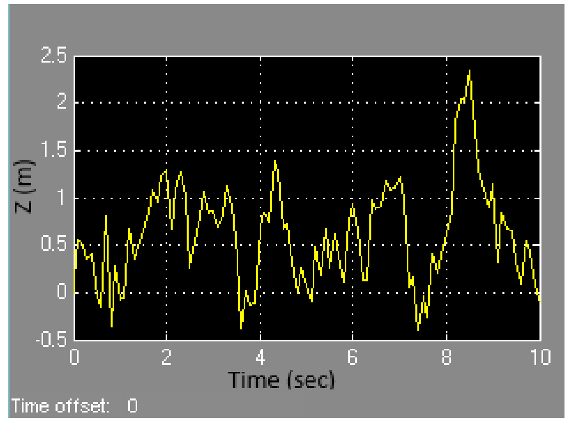


Figure 4: **Variation of rough road with respect to time.**

7. INTELLIGENT ALGORITHM USING NEURAL NETWORK

A human brain consists of a set of interconnected neurons which perform computations. The information received by neurons are processing in parallel to produce output. This biological nervous system of processing has given rise to the idea of processing the input information by computers to produce suitable output information. This type of processing by computer is called artificial neural networks (ANN) or simply neural network (NN) [13].

A set of known input and output in design can be used to train the computer. Once training program is successfully completed, the trained program is capable of producing output without going through rules of mechanics and design principles. Hence in ABS for rough road surface problem which needs several analysis and design, use of ANN saves considerable computational time. Also ANN predicts the experimental results and reduce number of experiment required for predicting suitable parameters to produce required output [13].

In intelligent algorithm, the multilayer feed forward network is used as shown in fig. 5. This type of network possesses an input, an output and one intermediate layer called as hidden layer. The neurons in the intermediator layer perform intermediator computations. The input and intermediator neurons are connected by weight function Vi and intermediator neurons and output neurons are connected by weight function Wi. the connection is only in the forward direction.

- Weights are scalars that multiply each input element.
- The summer sums the input elements, PR, together with the bias.
- A bias is a number that is added to the total from the summer.
- A translation function is one of many specific functions used in neural networking.
- Moves the input vectors into each neuron of the first hidden layer.
- Performs the bulk of the computations in most networks, Hidden layers are not always required.
- Each neuron in the output layer outputs its own result.

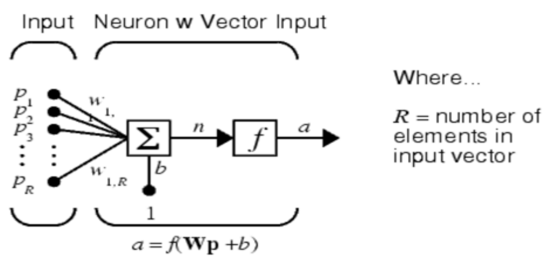


Figure 5: Multilayer feed forward network.

The output of Figure 4 is considered as an input for neural network. As a need of linear output from the road surface, have to train it to get desired output. During training mode, network uses the default Levenberg-Marquardt algorithm which is having 70% are used for training, 15% are used to validate network and remaining 15% are used as a completely independent test of network generalization. As number of hidden layer increases, error is reduced and will get more accurate solution but computational time is increased for small reduction of error. Hence, optimum number of hidden layers are selected.

The intelligent algorithm is called generalized regression which was developed by Specht. This NN do not require iterative training. It used least-mean-square of estimation of variables. Thus basis of the training is non-linear regression.

After completing training, neural network toolbox generates the Simulink model for NN which can be used for different condition of road surface. The output from Simulink model of NN is shown in Figure 6 which represents the even though surface is uneven, using NN will get steady response to control braking system.

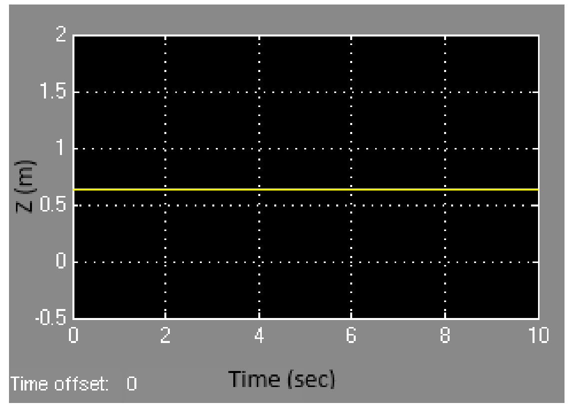


Figure 6: Output of simulink model of neural network.

8. SIMULINK MODEL FOR ABS

The Simulink model for anti-lock braking system is developed in Matlab. The slip is considered 0.2 as discussed earlier. Brake pressure, force and mu-slip friction curve is applied to wheel to get the angular speed of wheel while vehicle speed is considered as input and mu-slip curve, weight of vehicle are applied to get the stopping distance. The loop is closed by measuring the relative slip of wheel and again give to input to stop it in less time. This was simple ABS Simulink model, for considering the NN as intelligent algorithm have to interface with the road surface and wheel.

Interface of road surface and wheel is done using the neural network switch which switches the action as per need of less coefficient of friction. The NN output and friction component are given to switch block and given the output to wheel as shown in Figure 7.

The output of Simulink model is considered depending upon the wheel speed and stopping distance. These output values are compared without intelligent algorithm.

A. Wheel Speed

In rough road surface without intelligent algorithm, time required for stopping the wheel speed is more

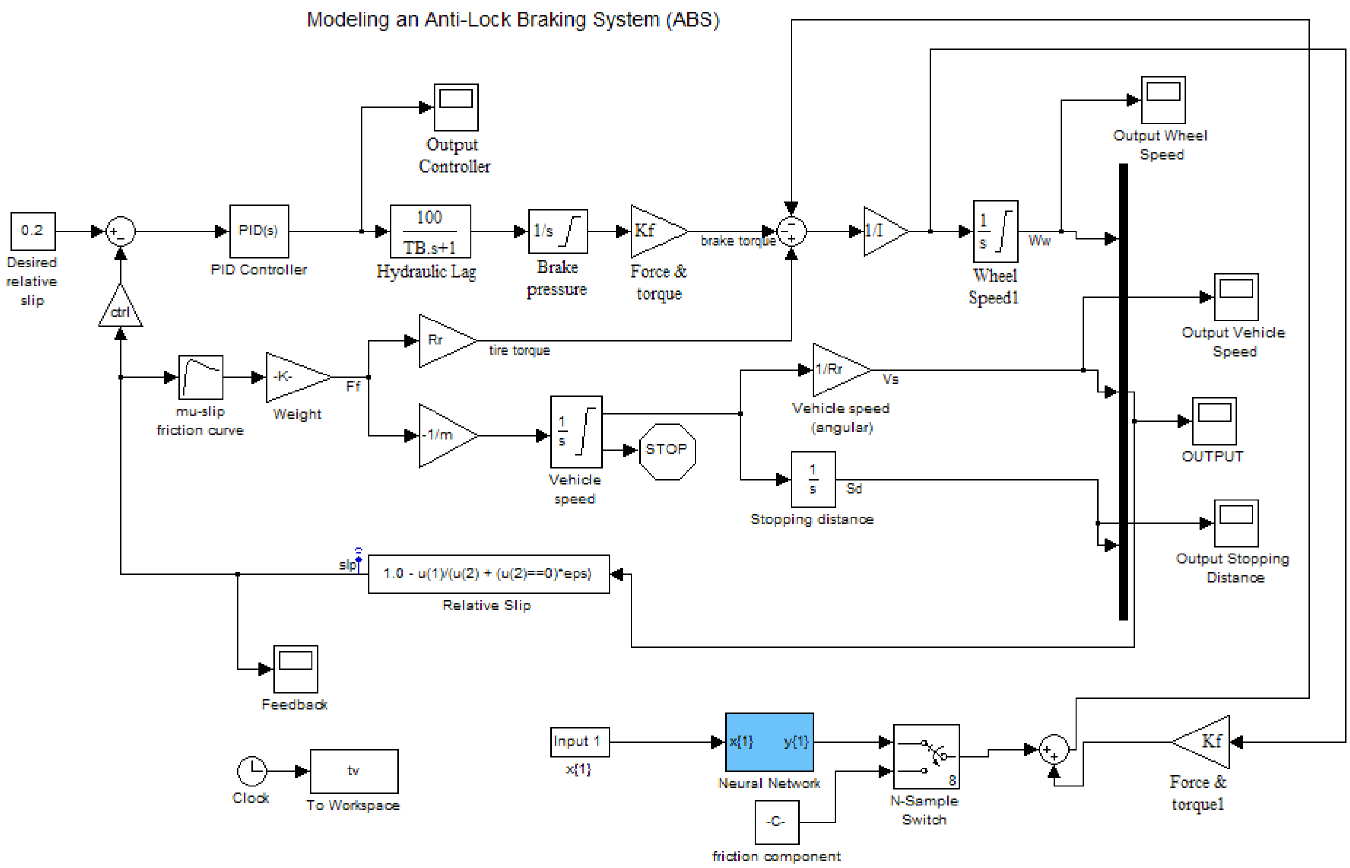
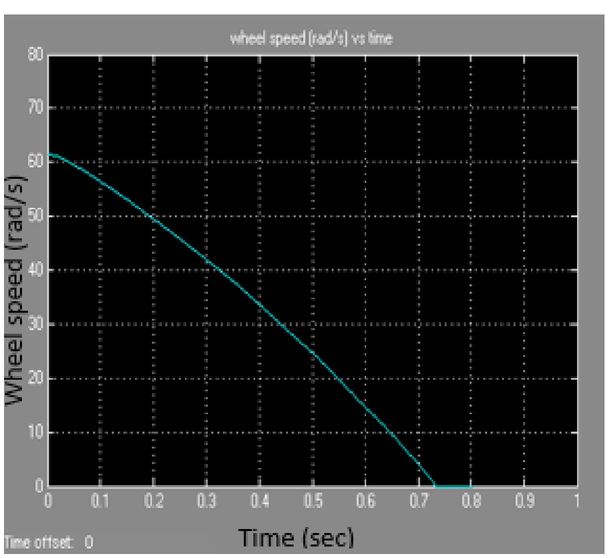


Figure 7: Simulink model for ABS using neural network.

due to undulations on road. The rolling radius of wheel changes due to undulations causes the loss of contact between wheel and road. Figure 8 (a) and (b) shows the wheel speed of vehicle with and without intelligent algorithm respectively. Time required for intelligent is less by 68%, graph is wheel speed in rad/s with respect to time in seconds.



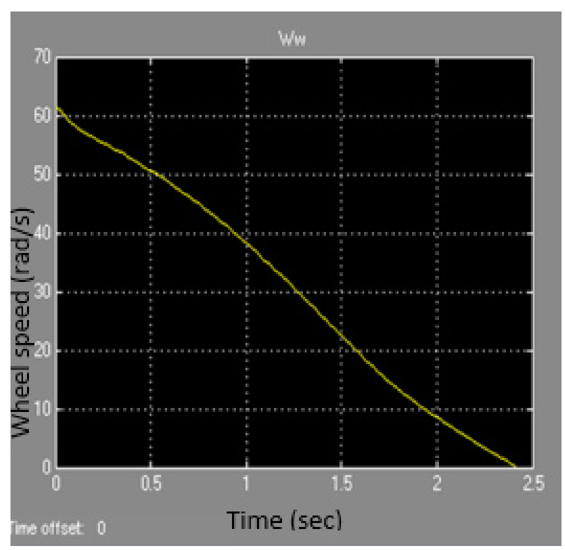
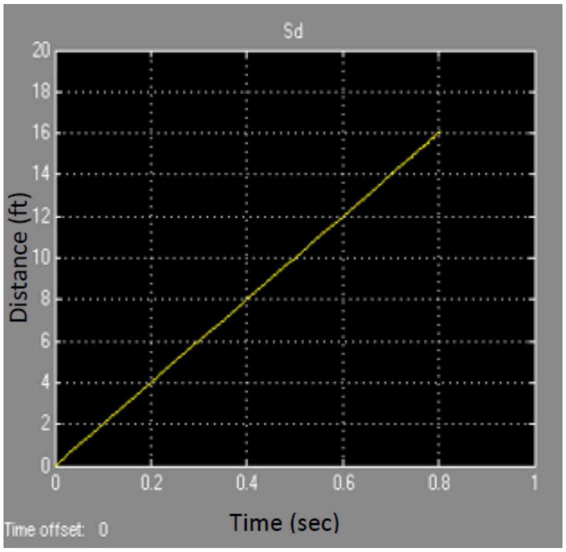


Figure 8: Wheel speed using: (a) with intelligent algorithm, (b) without intelligent algorithm.

B. Stopping Distance

ABS is mainly concern with stopping distance. As distance covered by vehicle on rough road is more due to undulations on road surface and loss of contact between wheel and road.

Figure 9 (a) and (b) shows stopping distance (in ft) with respect to time (in sec) with and without intelligent algorithm respectively. By using intelligent algorithm stopping distance is reduced to 41%.



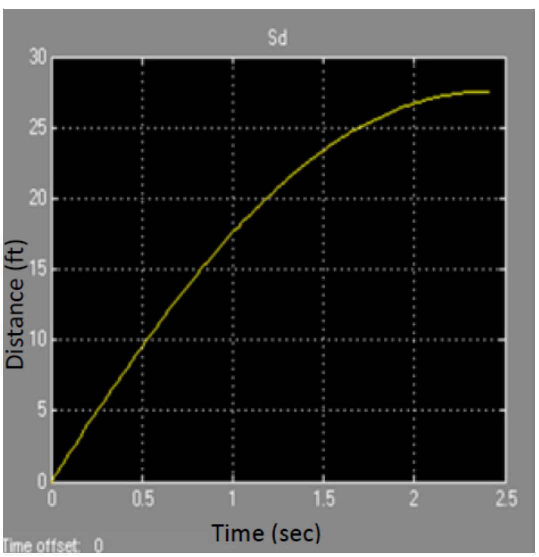


Figure 9: Stopping distance using: (a) with intelligent algorithm (b) without intelligent algorithm.

C. Results

Table 3
Result table

S. No.	*Parameters*	*With intelligent algorithm*	*Without intelligent algorithm*	*Percent decrease*
1	Wheel speed stopping time	0.8 sec	2.4 sec	68%
2	Stopping distance	16 ft	27 ft	41%

9. CONCLUSION

In this paper, the intelligent algorithm with neural network is studied. The Bosch algorithm is modified with ability of predicting the road surface using intelligent algorithm. The Simulink model is developed for rough road surface and anti-lock braking system. The output road surface is trained in neural network toolbox to get desired output. The result table shows that intelligent algorithms are more beneficial in rough road conditions.

References

[1] Wietsche Clement William Penny, Pieter Schalk Els, The test and simulation of ABS on rough, non-deformable terrains, Journal of Terramechanics, 2016.

[2] Herman A. Hamersma, P. Schalk Els, Improving the braking performance of a vehicle with ABS and a semi-active suspension system on a rough road, Journal of Terramechanics, 2014.

[3] Valentin Ivanov, Dzmitry Savitski, Klaus Augsburg, Phil Barber, Bernhard Knauder, Josef Zehetner, Wheel slip control for all-wheel drive electric vehicle with compensation of road disturbances, Journal of Terramechanics, 2015.

[4] Theunis R. Botha, P. Schalk Els, Rough terrain profiling using digital image correlation, "Journal of Terramechanics, 2015".

[5] Rishabh Bhandari, Sangram Patil, Ramesh K. Singh, Surface prediction and control algorithms for anti-lock brake system, 2012.

[6] Bo Wang a, Hsin Guan a, Pingping Lu a, Anjing Zhang, Road surface condition identification approach based on road characteristic value, Journal of Terramechanics, 2014.

[7] Taixiong Zheng, Ling Wang, Fulei Ma, Research on road identification method in Anti-lock Braking System, Procedia Engineering, 2011.

[8] Feng Tyan, Yu-Fen Hong, Shun-Hsu Tu, Wes S. Jeng, Generation of Random Road Profiles, Journal of Advanced Engineering Vol. 4, No. 2, pp. 151-156/ April 2009.

[9] Horia Beles, Nicolae Chioreanu, Tudor Mitran, Research Regarding Development of Mathematical Model to Optimize Operation of ABS, Annals of The University of Oradea, 2014.

[10] Reul, M., Winner, H., Enhanced braking performance by integrated ABS and semi-active damping control. In: Proceedings of the 21st (esv) International Technical Conference on the Enhanced Safety of Vehicles. Stuttgart, Germany, 2009.

[11] Hossein Mirzaeinejad, Mehdi Mirzaei, A novel method for non-linear control of wheel slip in anti-lock braking systems, Control Engineering Practice 18 (2010) 918–926.

[12] Adcox J, Ayalew B, Rhyne T, Cron S, Knauff M. Interaction of antilock braking systems with tire torsional dynamics. Tire Sci Technol TSTCA 2012;40(3):171–85.

[13] S. S. Bhavikatti, Fundamentals of Optimum design in Engineering, textbook, pp.238-246.