Modeling of Hydraulic ABS Plant and its Control By Using fuzzy Mamdani with adaptive slip Frequency to improve stopping distance and steering ability

Sumarli 2) Muchammad Harly 3) Marji
1,2,3) Engineering Faculty of State University of Malang

Abstract. Many antilock brake system ABS (what is ABS?) plant dynamics were designed and developed by researcher, it is mostly in quarter car model. Plant could be ABS with hydraulic, air or electromagnetic energy transfer of braking processes. Kind of ABS controller method were also developed and proposed to achieve the desired control response such as, stopping distance and steering ability under circumstance non-linear braking dynamics and uncertainty road surface-wheel. There is no-intelligent and artificial control event hybrid of both. PID, Observer, sliding mode, LQR, Fuzzy and Neural network are commonly used to control ABS plant. This research method proposed ABS hydraulic plant design, which controlled by Fuzzy to control slip frequency within three sample of road surface namely snow, sand and asphalt surface road. For slip control reference variable are setup in varied value to approach the optimal stopping distance. Result of simulation shown that slip of 2.35 has a superior of stopping distance control, means the shortest stopping distance compared with another setting value.

1. Introduction
A design of ABS for two wheeled vehicle consist brake master, hydraulic modulator, tyre dynamic, vehicle dynamic and wheel braking dynamic using observer controller. Vehicle velocity is used to calculate the slip ratio to get a shorted stopping distance. Experiment was conducted by implementing HIL [1]. A study to obtain the full car wheel braking model was utilizing CARSIM. Full car model was implemented to hatchback and van segments car to get the compare both performances in stopping distance [2]. A result of research about all ABS components by Modeling and simulation is explained even the result in using different simulation software has been investigated [3]. A dynamic a nonlinear observer has been implemented on an ABS Laboratory setup for a quarter car model. This controller reconstructs some of the state variables to establish a real benchmark for an ABS system of automobile. This controller was performing a short convergence, as well as robustness with respect to parameter variations [4]. A two degree of freedom PID controller is integrated into a quarter-car by developing simulation in Matlab/Simulink environment. Its simulations to get deference performance on a straight-line braking operation on two different road surface conditions was operated and investigated [5]. A non-linear control design using input-output feedback linearization approach was implemented to improve the robustness of the non-linear controller. The Lyapunov sense is utilized to analyze stability control. The results shown a superior in reducing chattering effect on the braking torque compared the standard feedback linearization method [6]. A quarter car braking model within uncertainties road and...
a Burckhardt’s tire model are subjected to two adaptive nonlinear control TABLF1 and TABLF2 to compare. The result of simulation TABLF1 perform either the optimal slip ratio or achieve a faster convergence rate, shorter distance, compared to TABLF2 controller with the same control parameters [7]. A sliding mode control is utilized to a quarter vehicle model to perform fast convergence. Its performances are verified through digital simulations and validated in real time experiment [8]. Another side an integral nested SM Block Control was designed to control an ABS by a simulation, where results show better behavior of the ABS under variations in the wheel-ground friction [9]. There are even a second order sliding mode controller to control anti-lock feature by means of sensing the wheel slip rate, ensuring a shorter braking distance and improving the vehicle safety [10]. Still using SM called a grey sliding mode controller is proposed to approach the reference wheel slip. The grey system can either provide a certain prediction capability or offers an alternative solution to conventional control methods. Simulation are validated on real time to a quarter vehicle model using a laboratory experimental setup [11]. The other novel of ABS controllers is based on digital sliding mode with only input/output measurements. The performance gives higher steady-state accuracy and smaller chattering [12][13]. This controller was also conducted in Simulink and CarSim and show can well ensure the braking comfort of the vehicle equipped with the BBW system under the premise of ensuring brake safety [14]. Otherwise, Time-Varying Sliding Mode Control (TV-SMC) is also compared with simulation results obtained with both a quarter car model and a full–car model built in the Matlab/Simulink, where the results are benchmarked with an implementation using an Extended Kalman Filter (EKF) tracks an optimal slip trajectory [15]. SMC based Antilock Braking System including a wheel dynamics simulation, a brake torque actuation, slip control under Lugre Friction Model and Burckhardt Friction Model (BFM) [16]. By introducing a second-order factor, an improved optimal slip ratio prediction considering tire inflation pressure is proposed by using Simulink and Car-Sim software packages. Simulation results show that the braking distances and braking time under different tire pressures and initial braking speeds are effectively shortened [17]. A fuzzy system makes decision based on Obstacles, Brake force and Slip ratio. The Fuzzy system gives an P W M output based on three intensity levels of brake will be applied such as increase Brake, hold Brake and decrease Brake [18]. A new cooperative braking control strategy is proposed for a parallel HEV with both a regenerative braking system and an antilock braking system (ABS) to achieve improved braking performance and energy regeneration by using sliding, a boundary-layer method with moderate tuning of a saturation function is also investigated; based on the wheel slip ratio, battery SOC, and the motor speed, a fuzzy logic control strategy is applied to adjust the regenerative braking torque dynamically [19]. An eddy current and electro-hydraulic hybrid brake system to solve problems such as wear, thermal failure, and slow response of traditional vehicle brake system. A fuzzy controller on personal computer based on LabVIEW and Matlab was designed and a set of HIL system was constructed to validate and analyze the performance of the hybrid brake system. The result of simulation was shown the total brake time has a smaller decrease than traditional hydraulic brake system [20]. Slide mode optimizer is tuned by the fuzzy controller with a set of defined rules. Simulation results shows improvement of vehicle parameters like brake torque, deceleration, wheel slip, stopping distance [21]. A PID tuned fuzzy was used to control the slip factor of ABS, under non-linear condition of road. Two on-of conversion method to trigger the inlet and outlet solenoid are simulated to arrange the brake pressure. The weight and other parameter was also varied to get a best stopping distance [22]. A Fuzzy logic Based ABS controller for motorcycle in order to The stopping distance, braking torque are calculated analytically and Performance is verified in MATLAB/Simulink Environment [23]. The wheel speed fault of regenerative braking of ABS was covered by AFTC scheme. To control regenerative process, a sliding mode was used, that its gain can reduce maximum overshoot. Result of AFTC and Sliding mode enable to overcome up to 100% fault [24]. A new integration control design based on combined kohonen feature map associated memory and locally recurrent neural network based adaptive back through control (KFMAM-LRNNABC). LRNNABC consists of NN-Plant and NN Controller to control the brake and drive system according to behavior of the driver to improve the vehicle stability. Result of simulation prove the superior of by using this model [25]. Because high non-linearity of vehicle dynamic (covers ESP, active steering and
active suspension) and the characteristic of driver action also road environment, a “Three in one dynamics system (TODS)” plant, which can represents the best model of interaction among vehicle dynamics, driver characters and environment was good proposed. After data of driving test was clustered by using MDFC then control by GA optimized NN. The simulation result was shown better than robust control, H-infinite control, NLPC, No-integration control and feed-forward control [26].

2. Proposed hydraulic abs plant model

2.1. Linearization

Hydrodynamic of brake system is non-linear because of Bernoulli and Reynolds number. In a range of brake work, a hydrodynamic brake system can be linearized to address in a work constant of $R$ as a resistance and $C$ as a capacitance of fluid dynamic.

![Fig. 1: a basic hydraulic system](image1)

Assume at the hydraulic boundary condition like figure 1, that by small changing of pressure difference ($\Delta P$), it performs a small deference of fluid mass debit ($Q$), where flow from higher fluid pressure to the lower. In a given point of braking work increasing $\Delta P$ to be proportional with $Q$ is defined as a resistance symbolized by $R$

$$R_{ab} = \frac{\Delta P}{\partial Q_{b}}$$

(1)

![Fig. 2: linearization of $\Delta P(\partial Q)$](image2)

It is similar with proportionality of mass changing in the constant volume following by small deferent of pressure in it. The linear constant value is symbolized by $C$.

$$C_{b} = \frac{\partial M_{b}}{\partial p} = V_{b} \frac{\partial p}{\partial P}$$

(2)
According to figure 1, the hydraulic dynamic can be developed as equation 3 up to 8 below to perform gain of getting out pressure \( P_o \).

\[
R_{ab} = \frac{P_i - P_o}{Q_b} \quad (3)
\]

\[
C_b = \frac{\partial M_b}{\partial p} = V_b \frac{\partial p}{\partial p} \quad (4)
\]

\[
C_b \cdot \frac{\partial p}{\partial t} = V_b \cdot \frac{\partial \rho}{\partial t} = Q_b \cdot \frac{\partial t}{\partial t} \quad (5)
\]

\[
C_b \cdot \frac{\partial p}{\partial t} = \frac{(P_i - P_o)}{R_{ab}}, \frac{\partial t}{\partial t} \quad (6)
\]

\[
R_{ab} \cdot C_b \cdot \frac{\partial p_o}{\partial t} + P_o = P_i \quad (7)
\]

\[
P_o(s) = \frac{P_i(s)}{(R_{ab}C_b + s + 1)} \quad (8)
\]

2.2. Hydraulic ABS design

2.2.1. Brake master pump. Brake master is constructed from a cylinder and a piston is pressed by food force. The foot force \( F_{foot} \) produce a pressure \( P_a \) depend on the cross section the compressed room \( A \) show in formula 9, where filled by fluid mass of \( M_a \), that decrease caused of compressed fluid flow to pipe B trough a small orifice \( R_{ab} \).

The output pressure of \( P_b \) then can be calculated using gain as shown by formula 10 as bellow:
\[ P_a = \frac{F_{foot}}{A} \]  \hspace{1cm} (9)

With assuming inlet valve (R_{bc}) is closed, cause hydraulic ABS in hold or dump position.

\[ P_{b(s)} = \frac{P_{a(s)}}{(R_{ab}C_{bc}s+1)} \]  \hspace{1cm} (10)

2.2.2. Abs hydraulic model. Hydraulic model is consist of two valves activated by a solenoid, namely inlet valve and outlet valve and a hydraulic pump as figured out by figure 4 and 5.

![Fig.5: wheel cylinder pressure regulation](image)

With assuming inlet valve is open and outlet valve is closed, this step to be used when the braking pressure in room C or wheel cylinder need to be increased. Source pressure \( P_b \) is already provided by brake master \( P_a \) (formula 11), it will trigger brake fluid pressure in wheel cylinder \( P_c \) depended on both gain \( ab \) and \( bc \) according to formula 12 as bellow:

\[ P_{b(s)} = \frac{P_{a(s)}}{(R_{ab}C_{bc}s+1)} \]  \hspace{1cm} (11)

\[ P_{c(s)}^{inc} = \frac{P_{b(s)}}{R_{bc}C_cS+1} = \frac{P_{a(s)}}{(R_{bc}C_cS+1)(R_{ab}C_{bc}s+1)} \]  \hspace{1cm} (12)

When hold process in room C or wheel cylinder need to be maintain then both inlet valve and outlet valve should be closed. The pressure can be calculated by gain \( bc \). \( P_{b0} \) is initial value before all valve are closed.

\[ P_{c(s)}^{hold} = \frac{P_{b(s)}}{R_{bc}C_cS+1} + P_{b(0)} \]  \hspace{1cm} (13)

\[ with \ R_{bc} = \infty \]

When hold process in room C or wheel cylinder need to be maintain then both inlet valve and outlet valve should be closed. The pressure can be calculated by gain \( bc \). \( P_{b0} \) is initial value before all valve are closed.

\[ P_{c(s)}^{hold} = \frac{P_{b(s)}}{R_{bc}C_cS+1} + P_{b(0)} \]  \hspace{1cm} (14)

\[ with \ R_{bc} = \infty \]
If brake pressure want be reduced or dumped, it is assumed inlet valve is close and outlet valve are opened and fluid pump works for sucking the fluid pressure in room C close to zero. Mathematical model can be shown in formula 15 as bellows:

\[
P_d = 0 = \frac{P_{c(d)}^{\text{dump}}}{(R_{cd} C_{d} + 1)}
\]  

(15)

2.2.3. **Wheel Braking Dynamics.** Nb is the normal force acted in dish brake, Ac is the cross section of wheel brake cylinder, Fb is brake force acted in dish for braking, \( \mu_b \) is friction coefficient of disk, Tb is torque produced by force and disk radius, Fr is wheel-ground force during braking and Tr braking torque response by wheel-ground force and wheel radius.

\[
N_b = P_c . A_c
\]  

(16)

\[
F_b = \mu_b . N_b
\]  

(17)

\[
T_b = R_b . F_b
\]  

(18)

\[
F_r = \mu_r . m . g
\]  

(19)

\[
T_r = R_w . F_r
\]  

(20)

Wheel speed \( \omega_w \) is integral of the longitudinal deceleration is produced by torque deferent between wheel-ground and dish braking in real time process. It shown by formula 21 as follows, where \( Jv \) is inertia of vehicle rigid body applied in wheel.

\[
\omega_w = \frac{V_0}{R_w} - \int_{t}^{t_e} \left( T_r - T_b \right) dt
\]  

(21)

2.2.4. **Vehicle Dynamics.** Initial condition speed and its kinetics energy will be reduced by braking force produced by wheel-ground friction \( \mu_r \) and vehicle weigh. The no slip vehicle dynamic speed (figure 6) is initial condition speed substituted by integral of vehicle deceleration is did by wheel ground brake force response. Equation 22 can be shown to calculate vehicle speed.

\[
\omega_v = \frac{V_0}{R_w} - \int_{t}^{t_e} \mu_r . g dt
\]  

(22)
2.2.5. Tire Dynamics Model. Because of non-linear characteristic of wheel-ground dynamics, magic formula proposed by pacejka (figure 7) is implemented very handy as equation 22 below:

\[ \mu_r = \frac{2}{\pi} \arcsin \left( \frac{\mu_s}{D} \right) + C_2 \ln(1 + C_3 V_v) \]

\[ B = \frac{C_s}{C \cdot D} \left[ \tan \left( \frac{C_4 + \frac{C_5}{\exp \left( \frac{C_6}{1 + V_v} \right)}}{C \cdot D} \right) \right] \]

\[ E = \frac{B \cdot S_m - \tan \left( \frac{\pi}{2C_r} \right)}{B \cdot S_m - \tan^{-1}(B \cdot S_m)} + C_7 V_v \]

\[ f = C_8 + C_9 V_v \]

Where:

\[ D = \mu_{max} + C_1 V_1 \]

\[ C = \frac{2}{\pi} \arcsin \left( \frac{\mu_s}{D} \right) + C_2 \ln(1 + C_3 V_v) \]

\[ \mu = D \cdot \sin \{ C \cdot \arctan [ B \cdot \lambda - E (B \cdot \lambda - \arctan (B \cdot \lambda)) ] \} \] (22)
2.2.6. Slip Formula Definition. Slip factor $\lambda$ is defined as equation 23 bellow:

$$\lambda = \frac{(\omega_r - \omega_w)}{\omega_r}$$  \hspace{1cm} (23)

3. Proposed abs-fuzzy control

3.1. Characteristic of designed fuzzy control

In usual ABS actuator, namely hydraulics unit performs three step brake pressure control, these are increase, hold and dump in the format of discrete, that affect linier pressure response like figure 8. This research, it is proposed a non-linier brake pressure triggering is shown in figure 9. Fuzzy control is design and evaluable to be implemented for non-linear brake pressure in brake caliper

![Fig.8: Linear pressure control](image)

![Fig.9: Proposed non-Linear pressure control](image)

3.2. Characteristic of designed fuzzy control

The fuzzy control is built from two input variables, namely error-slip and slip and three outputs variables, namely increase, hold and dump. Figure 10 is briefly shown how is the fuzzy variable is setup.
Input variable error slip has two Membership functions, namely negative error slip and positive error slip. It is used to monitor either the real slip either higher or lower than value is setup (figure 11).

Output of fuzzy system is divided to three variables, namely increase, hold and dump. First output variable, the increase has two membership functions such as low-increase and high-increase are shown in figure 13.

Second output variable, the hold has two membership functions, namely low-hold and high-hold are shown in figure 14.
Third output variable, the dump has two membership functions, namely low-dump and high-dump are shown in figure 15.

![Fig.15: Dump output variable](image)

The proposed rule has been realized by using Simulink Matlab successfully. The rules is built to adapt and control the non-linear actuators plan, namely inlet and outlet valve, with separate or mixed operation and propagation within opening and closing action. Figure 16 shows set of rule for inlet and outlet valve during increase process. Figure 17 present their rule sets is used to control same both valve for holding pressure and figure18 for dumping step.

![Fig.16: Surf of increase rule](image)

![Fig.17: Surf of hold rule](image)
4. Simulation result and discussion

For investigation of the design model either all plant or fuzzy controller, Simulink block of Matlab have been developed. Block of plants covers brake master, ABS hydraulic model, elastic tire dynamics, wheel braking dynamic, vehicle dynamic, slip equation, and fuzzy Mamdani control shown as figure 19.

Under constantly parameter designs such as wheel, vehicle, hydraulic, brake master and disk and caliper, the disturbance variable such as magic formula of $\lambda(\mu)$ were arranged to three ground surface, namely snow, sand and asphalt look up table.

Vehicle drives in flat road with initial speed condition at 60 km/h, 100 km/h and 150 km/h. Frequency of the control parameter are setup to 5 Hz, 20 Hz and 40 Hz.

Result of simulation can be seen in table as follows:
Table 1. Stopping distance under snow road

| Frequency (Hz) | Initial speed (km/h) |
|---------------|----------------------|
|               | 60       | 100      | 150      |
| 5             | 12.3 m   | 19.3 m   | 25.5 m   |
| 10            | 11.5 m   | 17.8 m   | 23.8 m   |
| 20            | 12.5 m   | 20.5 m   | 26.1 m   |

Table 2. Stopping distance under sand road

| Frequency (Hz) | Initial speed (km/h) |
|---------------|----------------------|
|               | 60       | 100      | 150      |
| 5             | 7.9 m    | 10.5 m   | 15.8 m   |
| 10            | 7.2 m    | 9.4 m    | 13.7 m   |
| 20            | 7.7 m    | 10.3 m   | 16.1 m   |

Table 3. Stopping distance under asphalt road

| Frequency (Hz) | Initial speed (km/h) |
|---------------|----------------------|
|               | 60       | 100      | 150      |
| 5             | 6.1 m    | 8.3 m    | 12.7 m   |
| 10            | 5.3 m    | 7.3 m    | 11. m    |
| 20            | 5.9 m    | 9.1 m    | 13.1 m   |

By setting initial speed as soon as starting to full braking 150 km/hour and control frequency 5 Hz, it performs stopping time 26 sec and stopping distance 15.8 m.

Fig.20: Vehicle vs wheel speed, IS=150km/h-5 Hz

When it is setup an initial speed 150 km/hour and by using control frequency 10 Hz perform stopping time 24 sec and stopping distance 13.7 m.
Furthermore by setting brake initial speed 150 km/hour and applying control frequency 10 Hz perform stopping time 24 sec and stopping distance 16.1 m

After it is setup an initial speed 100 km/hour and by using control frequency 5 Hz perform stopping time 19.5 sec and we get stopping distance 10.5 m

An initial speed 100 km/hour also setup and by using deferent control frequency, namely 10 Hz, it perform stopping time 18.5 sec and stopping distance 9.4m
Without changing initial speed 100 km/hour but by using different control frequency, namely 20 Hz, it performs stopping time 17.5 sec and stopping distance 10.3 m.

By setting control frequency 5 Hz and low initial speed 60 km/h, it needs stopping time 13 seconds and performs stopping distance about 7.9 m.

When control frequency increases to 10 Hz within same low initial speed 60 km/h, then it performs stopping time 11 seconds and stops a shorter distance of 7.2 m.
Hence control frequency was more increased to 20 Hz within same low initial speed 60 km/h, then it performs stopping time still 11 second but stopping distance longer 7.7 m.

Figure 29, 30 and 31 are shown the arrangement of the control of the slip in deferent frequency control. It can concluded that the frequency of slip rather similar with wheel speed response.
5. Conclusion
Based on simulation under three different wheel-ground friction, frequency 10 Hz applied to slip control was done by fuzzy logic. It can perform superior performance in the form of average shorter stopping distance compared with others by setting frequency. It can perform the best control response among different initial speeds within ABS braking process.

References

[1] Chun-Kuei Huang and Ming-Chang Shih Design of a hydraulic anti-lock braking system (ABS) for a motorcycle Journal of Mechanical Science and Technology 24 (5) (2010) 1141-1149 www.springerlink.com/content/1738-494x DOI 10.1007/s12206-010-0320-9 2010
[2] Nikhil Subhash Shewale Dr R Deivanathan Modelling and Simulation of Anti-lock Braking System, International Journal of Engineering and Technical Research (IJETR) ISSN: 2321-0869 (O) 2454-4698 (P) Volume-7 Issue-1 January 2017
[3] Khalid M Alkadah Abdulaziz S Alaboodi Anti-Lock Braking System Components Modelling, International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075 Volume-9 Issue-2 December 2019
[4] Cuauhtémoc Acosta Lúa,1 Bernardino Castillo Toledo,2 Stefano Di Gennaro,3 and Marcela Martinez-Gardea, “Dynamic Control Applied to a Laboratory Antilock Braking System,” Hindawi Publishing Corporation Mathematical Problems in Engineering Volume 2015, Article ID 896859,http://dx.doi.org/10.1155/2015/896859, 2015.
[5] Eze Paulinus, Aigbodioh Ferdinand, Muoghalu Chidiebere, Ezeanya Ifeoma Hope, “Linear Slip Control for Improved Antilock Braking System,” International Research Journal of Advanced Engineering and Science ISSN (Online): 2455-9024, 2018
[6] Samuel John, Jimoh O Pedro, Hybrid Feedback Linearization Slip Control for Anti-lock Braking System, Acta Polytechnica Hungarica Vol. 10, No. 1, 2013
[7] Youguo He ,1,2 Chuandao Lu,1 Jie Shen,2 and Chaochun Yuan,1, “Design and Analysis of Output Feedback Constraint Control for Antilock Braking System with Time-Varying Slip Ratio,”
Hindawi Mathematical Problems in Engineering Volume 2019, Article ID 8193134, 11 pages, https://doi.org/10.1155/2019/8193134, 2019

[8] Dragan Antić1, Vlastimir Nikolić2, Darko Mitić1,Marko Milojković1, Staniša Perić1, “Sliding Mode Control Of Anti-Lock Braking System: An Overview,” FACTA Universitatis Series: Automatic Control and Robotics Vol. 9, No:1, 2010, pp. 41 - 58, 2010

[9] Juan Diego Sánchez-Torres, Alexander G. Loukianov* and, Marcos I. Galicia, “Robust Nested Sliding Mode Integral Control for Anti-lock Brake System,” Int. J. Vehicle Design, Vol. x, No. x, xxxx, 2011

[10] Juan Diego Sanchez-Torres, Marcos I. Galicia and Alexander G. Loukianov, “Anti-lock Brake System Design Based on an Adaptive Second Order Sliding Mode Controller,” WAC 2012 1569538315, 2012

[11] Yesim Oniz, Erdal Kayacan and Okyay Kaynak, “Simulated and Experimental Study of Antilock Braking System Using Grey Sliding Mode Control,” 1-4244-0991-8/07/$25.00/©2007 IEEE, 2009.

[12] Darko B. MITIĆ, Staniša Lj. PERIĆ, Dragan S. ANTIĆ, “Digital Sliding Mode Control of Anti-Lock Braking System,” Advances in Electrical and Computer Engineering Volume 13, Number 1, 2013

[13] Gian Paolo Incremona, Enrico Regolin, Alessio Mosca and Antonella Ferrara, “Sliding Mode Control Algorithms for Wheel Slip Control of Road Vehicles,” researchgate Conference Paper · May 2017 DOI: 10.23919/ACC.2017.7963616, 2017

[14] Shuai Chen, Xilong Zhang, and Jizhong Wang, “Sliding Mode Control of Vehicle Equipped with Brake-by-Wire System considering Braking Comfort,” Hindawi Shock and Vibration Volume 2020, Article ID 5602917, 13 pages https://doi.org/10.1155/2020/5602917, 2020

[15] Sulakshan Rajendran, “Time-Varying Sliding Mode Control for ABS Control of an Electric Car,” ScienceDirect, 2017

[16] Ayush, Abhishek Kumar, Amitosh Kumar, S. Sridevi, K. Venkateswaran, “ABS using Fuzzy Logic in MATLAB and Its Hardware Implementation,” International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-8 Issue-2, July 2019

[17] Li, Guoxing, Wang, Tie, Zhang, Ruiliang, Gu, Fengshou and Shen, Jinxian, “An Improved Optimal Slip Ratio Prediction considering Tyre Inflation Pressure Changes,” Hindawi Publishing Corporation Journal of Control Science and Engineering Volume 2015, Article ID 512024, 8 page http://dx.doi.org/10.1155/2015/512024, 2015

[18] Dankan Gowda V.1, Ramachandra A., Thippeswamy M. N., Pandurangappa C.4, Ramesh Naidu, “Modelling And Performance Evaluation Of Anti-Lock Braking System,” Journal of Engineering Science and Technology Vol. 14, No. 5 (2019) 3028 – 3045 © School of Engineering, Taylor’s University, 2019

[19] Guodong Yin, and XianJian Jin, “Cooperative Control of Regenerative Braking and Antilock Braking for a Hybrid Electric Vehicle,” Hindawi Publishing Corporation Mathematical Problems in Engineering Volume 2013, Article ID 890427, 9 pages http://dx.doi.org/10.1155/2013/890427, 2013

[20] Ren He,1 Xuejun Liu,1,2 and Cunxiang Liu2, “Brake Performance Analysis of ABS for Eddy Current and Electrohydraulic Hybrid Brake System,” Hindawi Publishing Corporation Mathematical Problems in Engineering, Volume 2013, Article ID 979384, 11 pages, http://dx.doi.org/10.1155/2013/979384, 2013

[21] Ujwal, Krishna, “Fuzzy based Adaptive Control of Antilock Braking System,” International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181 IJERTV5IS050236 (This work is licensed under a Creative Commons Attribution 4.0 International License.) http://www.ijert.org Published by : Vol. 5 Issue 05, May-2016

[22] Chih Kheng Chen, “PID type fuzzy control for antilock brake system with parameter adaptation,” JSME international journal, 2004
Acknowledgment
Thank you for PNPB State University Of Malang for supporting and financing this research

1) Sumarli is a lecturer and researcher in the field of vehicle technology and education in state university of malang. He finished is bachelor degree and mastered degree at educational in the same university. He also finished his mastered degree at mechanical engineering in university of gajah mada.

2) Muchammad Harly is a lecturer and researcher in the field of vehicle stability control, mechatronics and artificial intelligent in engineering faculty in state university of malang. He finished is bachelor degree at mechanical engineering in university Widyagama, his mastered degree at automotive design and his PhD. at electrical engineering and artificial intelligent in institute technology of sepuluh nopember Surabaya.

Marji is a Professor and dean of engineering faculty in state university of malang. His activity is as a lecturer and researcher in the field of vehicle control in the same university. He finished his bachelor in mechanical engineering in the same university, his mastered graduate and Ph.D. In work health and vehicle safety in university of airlangga surabaya.