STUDY ON EFFECT OF ABS CONTROL SYSTEM TO THE VEHICLE DYNAMIC BEHAVIOR DURING BRAKING ON VARIOUS SPEED AND ROAD CONDITION

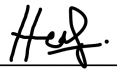
MUHAMAD ZULHILMI BIN ISMAIL

MASTER OF SCIENCE

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis/project and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science

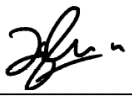


(Supervisor's Signature)

Full Name : DR. MOHAMAD HEERWAN BIN PEEIE

Position : SENIOR LECTURER

Date : 6 December 2021



(Co-supervisor's Signature)

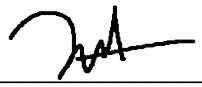
Full Name : DR. MUHAMMAD IZHAR BIN ISHAK

Position : SENIOR LECTURER

Date : 9 December 2021

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.



(Student's Signature)

Full Name : MUHAMAD ZULHILMI BIN ISMAIL

ID Number : MMM17021

Date : 6 DECEMBER 2021

STUDY ON EFFECT OF ABS CONTROL SYSTEM TO THE VEHICLE DYNAMIC BEHAVIOR DURING BRAKING ON VARIOUS SPEED AND ROAD CONDITION

MUHAMAD ZULHILMI BIN ISMAIL

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

Faculty of Mechanical & Automotive Engineering Technology

UNIVERSITI MALAYSIA PAHANG

DECEMBER 2021

ACKNOWLEDGEMENTS

In the name of Allah, the most Gracious the most Merciful.

While preparing this research, I have encountered many people in helping and guiding me to complete this research. First, I wish to express my utmost sincere gratitude to my main supervisor, Dr. Mohamad Heerwan bin Peeie and Co-Supervisor, Dr. Muhamad Izhar bin Ishak, for their valuable guidance idea, advice, inspiration, and non-stop support to give an understanding in this research. Without unceasing responses and feedback from them, this research would never be the same as presented here.

Moreover, I would like to thank Universiti Malaysia Pahang for funding my further research in Master of Science. This research was supported under the Research Development Grant Scheme (RAGS) grant in the title of Development of Regenerative Brake Timing Control to Improve the Braking Performance of Small Electric Vehicle (RAGS/1/2015/TK0/UMP/02/1). My sincere thanks go to all the staff and friends of the Mechanical Engineering Department as well as from the Electric and Electronics Engineering Department and Manufacturing and Mechatronic Engineering Department, who has helped me directly and indirectly in several ways, making my tenure at UMP pleasing and unforgettable.

Lastly and most importantly, I would like to thank my father, Ismail bin Ab Rahman and my mother, Rahimah Binti Muhamad, for their love, unconditional support, and sacrifices throughout my life, and inspiration for all these years for me to achieve greatness in my research. I acknowledge the sincerity of my parents, who constantly encourage me to carry my higher studies in this field. I cannot find the right words that could define my gratefulness for their dedication, encouragement, and confidence in attaining my goals.

ABSTRAK

Sistem keselamatan kenderaan terbahagi kepada dua kumpulan iaitu sistem keselamatan pasif dan sistem keselamatan aktif. Tujuan sistem keselamatan pasif adalah untuk melindungi pemandu dan penumpang kenderaan ketika berlakunya kemalangan, manakala tujuan sistem keselamatan aktif adalah supaya kenderaan mampu dikawal bagi menghindari perlanggaran. Contoh sistem keselamatan pasif adalah seperti, tali pinggang keledar, beg udara, sandaran kepala dan lain-lain. Anti-lock Braking System (ABS) adalah salah satu daripada sistem keselamatan aktif yang dapat mengelakkan tayar daripada terkunci dan membolehkan kenderaan dikemudi semasa brek kecemasan. Sistem keselamatan aktif adalah seperti Forward Collision Warning (FCW), Electronic Stability Control (ESC) dan lain-lain. Walaupun dengan sistem keselamatan yang aktif, terutamanya semasa melakukan brek kecemasan, tingkah laku dinamik kenderaan boleh berubah secara tiba-tiba yang akan menyebabkan kenderaan menjadi tidak stabil. Kejadian itu mungkin lebih teruk semasa brek kecemasan pada keadaan jalan yang basah. Tesis ini memfokuskan pada analisis tingkah laku dinamik kenderaan semasa melakukan brek kecemasan tanpa dan dengan sistem ABS pada keadaan jalan kering dan basah. Analisis kajian ini terbahagi kepada tiga fasa; menyiasat tingkah laku dinamik kenderaan iaitu kereta uji UMP (Proton Persona) semasa eksperimen dalam keadaan brek tanpa ABS, membuat model matematik kenderaan dan mengesahkan dengan hasil eksperimen, dan seterusnya menganalisis model simulasi dengan pelaksanaan ABS. Dari hasil eksperimen, pada keadaan jalan kering, dalam semua eksperimen yang dilakukan pada kelajuan 30 km/j, 50 km/j dan 60 km/j menunjukkan tidak ada penguncian tayar berlaku. Semasa dalam keadaan jalan yang basah, keadaan penguncian tayar dapat dilihat pada tayar hadapan bermula dari eksperimen pada kelajuan 50 km/j dan 60 km/j. Dengan menggunakan data daripada eksperimen, model matematik disimulasikan di dalam Matlab Simulink dan pengesahan model di lakukan dengan menilai perbezaan keputusan ekperimen dan simulasi mengunakan RMSE untuk kelajuan kereta, kelajuan tayar, jarak berhenti dan nisbah slip di mana semuanya di bawah 10%. Selepas itu, simulasi di ulang dengan memasukkan algoritma ABS ke dalam model matematik kenderaan. Simulasi tersebut di uji pada bagi keadaan jalan yang basah sahaja kerana pada keadaan jalan yang kering, tayar tidak berlaku sebarang penguncian tayar. Apabila ABS diaktifkan dalam simulasi, data menunjukkan bahawa kelajuan semua tayar menurun secara beransur-ansur dan tidak ada penguncian tayar. Ini menunjukkan model ini berada dalam atau bawah pada julat optimum yang ditetapkan di dalam sistem ABS.Tambahan pula, pekali gesaran antara tayar dengan jalan adalah tinggi menunjukkan bahawa kereta boleh di kawal semasa brek. Data simulasi juga menunjukkan bahawa pengurangan pada kedua-dua masa dan jarak berhenti. Daya menegak juga mengurang secara berkala.menunjukkan kestabilan kereta meningkat. Selain itu, dengan pembangunan model matematik kenderaan dalam kajian ini, pelbagai algoritma ABS untuk meningkatkan keberkesanan ABS terhadap kenderaan dapat di jalankan pada kajian akan datang.

ABSTRACT

The vehicle safety system is divided into two groups that are passive safety and active safety system. While a passive safety system's purpose is to protect the occupant during an accident, an active safety system's goal is to enable the vehicle to be controlled to avoid any collision. The passive safety system is a seatbelt, airbag, headrest, etc. Anti-lock Braking System (ABS) is one of many systems under the active safety system, a basic skid control system that can prevent the tire from locking up and enable the vehicle to steer during braking. Another active system is Forward Collision Warning (FCW), Electronic Stability Control (ESC), etc. Even with an active safety system, especially during emergency braking, the vehicle dynamic behavior may change abruptly, which can cause the vehicle to become unstable. The incident may be worse during emergency braking on the wet road condition. This study focuses on analyzing the vehicle dynamic behavior during emergency braking without and with ABS enabled in the system on dry and wet road conditions. The analysis of this study is divided into three phases; to investigate the vehicle dynamic behavior of the UMP test car (Proton Persona) during the braking experiment without ABS, development of the mathematical model of the vehicle and validation with the experimental result, and analyses of the simulation model with implementation of ABS. From the experimental results, on dry road conditions, all experiments conducted from an initial speed of 30 km/h, 50 km/h, and 60 km/h show no locking up occurred. While on wet road conditions, the lock-up condition is shown at front tires starting from the experiment at an initial speed of 50 km/h and 60 km/h. From experimental data, the mathematical model is simulated inside Matlab Simulink, and the model validation using RMSE is all under 10 % for vehicle speed, tire speed, stopping distance and slip ratio. With the addition of ABS inside the model, the simulation was repeated. Only on wet road condition is re-performed as on dry road condition there is no lock-up occur. With ABS enabled in the simulation, it is shown that the speed of all tires decreased gradually and no lock-up occurred. Thus, showing the modelling stay or lower than the optimum range of slip ratio used in the ABS. Additionally, the friction coefficient between the tire and the road was high, meaning the vehicle could be steered properly during braking. Data also shows shorter in both stopping time and stopping distance. The vertical forces also reduce periodically, showing the increase of vehicle stability. Furthermore, with the development of the mathematical model in this research, various ABS algorithms to improve the effectiveness of ABS on the vehicle can be done in future studies.

TABLE OF CONTENT

REFERENCES

A. Emheisen, A. A., Ali Ahmed, A., Ismael Alhusein, N., Alfadel Sakeb, A., & S. Abdulhamid, A. (2015). Car Wheel slip Modelling, Simulation, and Control using Quarter Car Model. *International Journal of Engineering Trends and Technology*, *28*(6), 291–293. https://doi.org/10.14445/22315381/IJETT-V28P255

Abd El-Fatah, S., Sharkawy, A.-N., Ghazaly, N., & Moaaz, A. (2021). A Comparative Study of Different Control Methods for Anti-Lock Braking System (ABS). *SVU-International Journal of Engineering Sciences and Applications*, *2*(1), 27–34. https://doi.org/10.21608/svusrc.2021.65855.1007

Abe, M., & Manning, W. (2009). Vehicle Handling Dynamics. In *Vehicle Handling Dynamics* (First Edit). Elsevier. https://doi.org/10.1016/B978-1-85617-749-8.X0001-3

Adams, L. D., Flannagan, M. J., & Sivak, M. (1995). Obstacle avoidance Maneuvers in an Automobile Simulator. In *Security* (Issue April).

Ahangarnejad, A. H., & Melzi, S. (2019). Active longitudinal load transfer control for improving vehicle's stability. *International Journal of Vehicle Performance*, *5*(1), 2. https://doi.org/10.1504/IJVP.2019.097091

Ahangarnejad, A. H., Radmehr, A., & Ahmadian, M. (2020). A review of vehicle active safety control methods: From antilock brakes to semiautonomy. *JVC/Journal of Vibration and Control*, *July*. https://doi.org/10.1177/1077546320948656

Ahmad, F., Hudha, K., Imaduddin, F., & Jamaluddin, H. (2010). Modelling, validation and adaptive PID control with pitch moment rejection of active suspension system for reducing unwanted vehicle motion in longitudinal direction. *International Journal of Vehicle Systems Modelling and Testing*, *5*(4), 312. https://doi.org/10.1504/IJVSMT.2010.038036

Ahmad, F., Mazlan, S. A., Zamzuri, H., Jamaluddin, H., Hudha, K., & Short, M. (2014). Modelling and validation of the vehicle longitudinal model. *International Journal of Automotive and Mechanical Engineering*, *10*(1), 2042–2056. https://doi.org/10.15282/ijame.10.2014.21.0172

Alamdarlo, M. N., & Hesami, S. (2021). Statistical analysis of variables affecting tire - pavement friction. *International Journal of Pavement Research and Technology*, *14*(3), 378–384. https://doi.org/10.1007/s42947-020-1070-4

Alleyne, A. (1997). Improved vehicle performance using combined suspension and braking forces. *Vehicle System Dynamics*, *27*(4), 235–265. https://doi.org/10.1080/00423119708969330

Aly, A. A., Zeidan, E.-S., Hamed, A., & Salem, F. (2011). An Antilock-Braking Systems (ABS) Control: A Technical Review. *Intelligent Control and Automation*,

02(03), 186–195. https://doi.org/10.4236/ica.2011.23023

Anselma, P. G., Patil, S. P., & Belingardi, G. (2017). Rapid design of a light vehicle hydraulic brake system. *2017 2nd IEEE International Conference on Intelligent Transportation Engineering (ICITE), 2019-April*(April), 30–35. https://doi.org/10.1109/ICITE.2017.8056876

Ashtaiwi, A. (2015). Adaptive Beaconing Rate Based Stopping Distance. *Journal of Traffic and Logistics Engineering*, *3*(2), 149–154. https://doi.org/10.12720/jtle.3.2.149-154

Atmur, S. D., & Thomas E. Strasser. (1996). *Brakes Rotors/Drums and Brake Pads Particularly Adapted for Aircraft/Truck/Train/ and other Heavy Duty Applications*.

Bakhmutov, S., Umnitsyn, A., & Ivanov, V. (2019). Creation of electric vehicle ABS operation algorithm with possibility of hybrid braking based on slip-slope approach at wheels slip determining. *IOP Conference Series: Materials Science and Engineering*, *534*(1), 012034. https://doi.org/10.1088/1757-899X/534/1/012034

Balachandran, G. K., Petkov, V. P., Mayer, T., & Balslink, T. (2016). A 3-axis gyroscope for electronic stability control with continuous self-test. *IEEE Journal of Solid-State Circuits*, *51*(1), 177–186. https://doi.org/10.1109/JSSC.2015.2496360

Bentley, R. (1998). *Speed Secrets: Professional Race Driving Techniques*. https://books.google.com.my/books?hl=en&ots=2gHYqAQd1W&lr=&id=qUUSdi976hgC&oi=fnd&pg=PA4&dq=Speed+s&redir_esc=y#v=onepage&q&f=false

Bera, T. K., Bhattacharya, K., & Samantaray, A. K. (2011). Evaluation of antilock braking system with an integrated model of full vehicle system dynamics. *Simulation Modelling Practice and Theory*, *19*(10), 2131–2150. https://doi.org/10.1016/j.simpat.2011.07.002

Bhandari, R., Patil, S., & Singh, R. K. (2012). Surface prediction and control algorithms for anti-lock brake system. *Transportation Research Part C: Emerging Technologies*, *21*(1), 181–195. https://doi.org/10.1016/j.trc.2011.09.004

Bryant, A., Beno, J., & Weeks, D. (2011, April 12). Benefits of Electronically Controlled Active Electromechanical Suspension Systems (EMS) for Mast Mounted Sensor Packages on Large Off-Road Vehicles. *SAE 2011 World Congress and Exhibition*. https://doi.org/10.4271/2011-01-0269

Burgut, H. R., Bener, A., Sidahmed, H., Albuz, R., Sanya, R., & Khan, W. A. (2010). Risk factors contributing to road traffic crashes in a fast-developing country: the neglected health problem. *Turkish Journal of Trauma & Emergency Surgery*, *16*(6), 497–502.

Chih-Min Lin, & Chun-Fei Hsu. (2003). Self-learning fuzzy sliding-mode control for antilock braking systems. *IEEE Transactions on Control Systems Technology*, *11*(2), 273–278. https://doi.org/10.1109/TCST.2003.809246

Code, T. H., & Must, Y. (2004). *General rules , techniques and advice for all drivers and riders (103 to 158)- The Highway Code-Guidence - GOV.UK*. https://www.gov.uk/guidance/the-highway-code/general-rules-techniques-and-advice-for-all-drivers-and-riders-103-to-158#rule126

Corneliu, L., & Alexandru, T. (2018). Control-Oriented Models for vehicle longitudinal motion. *Journal of Engineering Sciences and Innovation*, *3*(3), 251–264.

Corrsys-Datron. (2016). *Pedal Force Transducer*.

Cummings, P., McKnight, B., Rivara, F. P., & Grossman, D. G. (2002). Association of driver air bags with driver fatality: a matched cohort study. *BMJ*, *324*(7346), 1119–1122. https://doi.org/10.1136/bmj.324.7346.1119

Cummings, P., Wells, J. D., & Rivara, F. P. (2003). Estimating seat belt effectiveness using matched-pair cohort methods. *Accident Analysis and Prevention*, *35*(1), 143–149. https://doi.org/10.1016/S0001-4575(01)00087-2

Dankan Gowda, V., Ramachandra, A. C., Thippeswamy, M. N., Pandurangappa, C., & Ramesh Naidu, P. (2019). Modelling and performance evaluation of anti-lock braking system. *Journal of Engineering Science and Technology*, *14*(5), 3028–3045.

Day, A. J., Ho, H. P., Hussain, K., & Johnstone, A. (2009). Brake system simulation to predict brake pedal feel in a passenger car. *SAE Technical Papers*, *4970*. https://doi.org/10.4271/2009-01-3043

Guidelines for the Selection of Speed Limit, 52 (2016).

Dewetron. (2008). Dewetron. In *Dewetron*.

DEWETRON. (n.d.). *DEWE-UPS-300-DC ... the precision signal conditioning company*.

Dhivya, P., & Murugesan, A. (2015). Intelligent Car Braking System with Collision Avoidance and ABS. *International Journal of Computer Applications*, *Ncict*, 975–8887.

Dousti, M., Baslamısli, s. C., Onder, e. T., & Solmaz, S. (2015). Design of a multiple-model switching controller for ABS braking dynamics. *Transactions of the Institute of Measurement and Control*, *37*(5), 582–595. https://doi.org/10.1177/0142331214546522

Ebrahimirad, H., Yazdanpanah, M. J., & Kazemi, R. (2004). *Slip Ratio Control of Anti-lock Brake System : Comparison of Sliding Mode and Bang-bang Controllers*.

June 2014, 1–4.

Elmas, C., Guvenc, U., & Dogan, M. U. (2015). Tire-Road Friction Coefficient Estimation and Experimental Setup Design of Electric Vehicle. *Balkan Journal of Electrical and Computer Engineering*, *3*(4), 202–207. https://doi.org/10.17694/bajece.88174

Emig, R., Goebels, H., & Schramm, H. J. (1990, October 1). Antilock Braking Systems (ABS) for Commercial Vehicles - Status 1990 and Future Prospects. *SAE Technical Papers*. https://doi.org/10.4271/901177

Erie, L. (2006). IRTAD Road Safety 2009. *Environmental Protection*, 69–73. https://doi.org/10.1063/1.3284658

Erjavec, J. (2009). *Automotive technology: A Systems Approach* (Fifth Edition).

Evans, A. (1991). Automatic Adjusting Mechanism For A Disc Brake Assembly Having A Mechanically Actuated Parking Brake. In *United States Patent*. https://doi.org/Nov, 6, 1972

Evans, L. (1986). The effectiveness of safety belts in preventing fatalities. *Accident Analysis and Prevention*, *18*(3), 229–241. https://doi.org/10.1016/0001-4575(86)90007-2

Fan, Y., & Scacchioli, A. (2013). An optimal control for a novel ABS based on vehicle dynamic load transfer effect for reducing stopping distance. *Proceedings of the American Control Conference*, 6727–6733. https://doi.org/10.1109/acc.2013.6580896

Farmer, C. M., & Lund, A. K. (2006). Trends over time in the risk of driver death: What if vehicle designs had not improved? *Traffic Injury Prevention*, *7*(4), 335–342. https://doi.org/10.1080/15389580600943369

Fenton, J. (1999). *Advances in Vehicle Design*.

Gabauer, D. J., & Gabler, H. C. (2010). The effects of airbags and seatbelts on occupant injury in longitudinal barrier crashes. *Journal of Safety Research*, *41*(1), 9–15. https://doi.org/10.1016/j.jsr.2009.10.006

Genta, G., & Morello, L. (2009a). *The Automotive Chassis: Component Design. Vol. 1*.

Genta, G., & Morello, L. (2009b). *The Automotive Chassis: System Design. Vol. 2*.

Gerard, M., Pasillas-Lépine, W., De Vries, E., & Verhaegen, M. (2010). Adaptation of hybrid five-phase ABS algorithms for experimental validation. *IFAC Proceedings Volumes (IFAC-PapersOnline)*, *43*(7), 13–18. https://doi.org/10.3182/20100712-3-DE-2013.00021

Gillespie, T. D. (1992). *Fundamentals of Vehicle Dynamics*.

GmbH, 2D Debus & Diebold Meβsysteme. (2007). *SA-WPxxxxHQ-000 Wire potentiometer*.

Gowda, D. V, & C, R. A. (2017). Slip Ratio Control of Anti-Lock Braking System with Bang-Bang Controller. *International Journal of Computer Techniques*, *4*(1), 97–104. http://www.ijctjournal.org

Groeger, J. A. (2006). Youthfulness, inexperience, and sleep loss: the problems young drivers face and those they pose for us. *Injury Prevention*, *12*(suppl_1), i19–i24. https://doi.org/10.1136/ip.2006.012070

Hafiz Harun, M., Samin, P. M., Hudha, K., Bakar, S. A. A., & Saad, A. M. (2019). Modelling and verification of tractor ride model. *IOP Conference Series: Materials Science and Engineering*, *469*(1). https://doi.org/10.1088/1757-899X/469/1/012077

Halderman, J D. (2011). *Automotive Technology*. Prentice Hall.

Halderman, James D. (2012). *Automotive Technology: Principles, Diagnosis, and Service* (Fourth Edition).

Hamersma, H. A., & Schalk Els, P. (2014). Improving the braking performance of a vehicle with ABS and a semi-active suspension system on a rough road. *Journal of Terramechanics*, *56*, 91–101. https://doi.org/10.1016/j.jterra.2014.09.004

Heisler, H. (1985). *Advanced vehicle technology assessment* (2nd editio).

Huang, S.-Y., Chen, Y.-C., & Wang, J.-K. (2016). Measurement of Tire Tread Depth with Image Triangulation. *2016 International Symposium on Computer, Consumer and Control (IS3C)*, 303–306. https://doi.org/10.1109/IS3C.2016.86

Jacob, B., & Feypell-de La Beaumelle, V. (2010). Improving truck safety: Potential of weigh-in-motion technology. *IATSS Research*, *34*(1), 9–15. https://doi.org/10.1016/j.iatssr.2010.06.003

Jafarpour, S., & Rahimi-Movaghar, V. (2014). Determinants of risky driving behavior: a narrative review. *Medical Journal of the Islamic Republic of Iran*, *28*(1), 142.

Jarašūniene, A., Jakubauskas, G., Jarašuniene, A., Jarašūniene, A., & Jakubauskas, G. (2007). Improvement of Road Safety Using Passive and Active Intelligent Vehicle Safety Systems. *Transport*, *XXII*(4), 284–289. https://doi.org/10.1080/16484142.2007.9638143

Jeong, E., & Oh, C. (2017). Evaluating the effectiveness of active vehicle safety systems. *Accident Analysis & Prevention*, *100*, 85–96. https://doi.org/10.1016/j.aap.2017.01.015

Jitesh, S. (2014). Antilock Braking System (ABS). *International Journal of Mechanical Engineering and Robotics*, *2386*(4), 253–259. https://doi.org/10.18178/ijmerr

JKJR. (2018). Buku Statistik Keselamatan. *Road Safety Department of Malaysia*, *april*, 5. http://www.jkjr.gov.my/ms/maklumat_keselamatan/statistik/Statistik---Statistic/lang,ms-my/

Jonner, W.-D., & Czinczel, A. (1978). *Upgrade levels of the Bosch ABS*. *321*(March), 313–321.

Ju, U., Kang, J., & Wallraven, C. (2019). To brake or not to brake? Personality traits predict decision-making in an accident situation. *Frontiers in Psychology*, *10*(FEB), 1–11. https://doi.org/10.3389/fpsyg.2019.00134

Julian Happian-Smith. (2002). *An Introduction to Modern Vehicle Design*.

Jung, S., Qin, X., & Noyce, D. A. (2010). Rainfall effect on single-vehicle crash severities using polychotomous response models. *Accident Analysis and Prevention*, *42*(1), 213–224. https://doi.org/10.1016/j.aap.2009.07.020

Kassim, K. A. A., Arokiasamy, L., Isa, M. H. M., & Osman, I. (2016). Automotive Consumerism towards Car Safety in Malaysia. *Procedia - Social and Behavioral Sciences*, *219*, 424–430. https://doi.org/10.1016/j.sbspro.2016.05.065

Khairnar, H. P., Phalle, V. M., & Mantha, S. S. (2016). Comparative frictional analysis of automobile drum and disc brakes. *Tribology in Industry*, *38*(1), 11–23.

Khalili, E., Ghaisari, J., & Danesh, M. (2017). Control and analysis of the vehicle motion using sliding mode controller and Carsim software. *2017 5th International Conference on Control, Instrumentation, and Automation (ICCIA)*, *2018-Janua*(2), 1–5. https://doi.org/10.1109/ICCIAutom.2017.8258643

Kistler. (2011). *WPT Sensors*.

Layne, J. R., Passino, K. M., & Yurkovich, S. (1993). Fuzzy learning control for antiskid braking systems. *IEEE Transactions on Control Systems Technology*, *1*(2), 122–129. https://doi.org/10.1109/87.238405

Li, Yong, Deng, H., Xu, X., & Wang, W. (2019). Modelling and testing of in-wheel motor drive intelligent electric vehicles based on co-simulation with Carsim/Simulink. *IET Intelligent Transport Systems*, *13*(1), 115–123. https://doi.org/10.1049/iet-its.2018.5047

Li, Yun, Ang, K. H., & Chong, G. C. Y. (2006). PID Control System Analysis and Design: Problems, Remedies, and Future Directions. *IEEE Control Systems*, *26*(1), 32–41. https://doi.org/10.1109/MCS.2006.1580152

Limpert, R. (2011). Brake Design and Safety, Third Edition. In *Brake Design and Safety, Third Edition*. SAE International. https://doi.org/10.4271/R-398

Lu, J., Filev, D., & Johnson, L. (2011). Real-time Tire Imbalance Detection Using ABS Wheel Speed Sensors. *SAE International Journal of Materials and Manufacturing*,

4(1), 1036–1047. https://doi.org/10.4271/2011-01-0981

Lu Junhui, & Wang Jianqiang. (2010). Road surface condition detection based on road surface temperature and solar radiation. *2010 International Conference on Computer, Mechatronics, Control and Electronic Engineering*, *4*(2009), 4–7. https://doi.org/10.1109/CMCE.2010.5610255

Lyckegaard, A., Hels, T., & Bernhoft, I. M. (2015). Effectiveness of Electronic Stability Control on Single-Vehicle Accidents. *Traffic Injury Prevention*, *16*(4), 380–386. https://doi.org/10.1080/15389588.2014.948618

Ma, X., Chen, F., & Chen, S. (2015). Empirical Analysis of Crash Injury Severity on Mountainous and Nonmountainous Interstate Highways. *Traffic Injury Prevention*, *16*(7), 715–723. https://doi.org/10.1080/15389588.2015.1010721

Mauer, G. F. (1995). A fuzzy logic controller for an ABS braking system. *IEEE Transactions on Fuzzy Systems*, *3*(4), 381–388. https://doi.org/10.1109/91.481947

Mayer, R. E., & Gallini, J. K. (1990). When is an illustration worth ten thousand words? *Journal of Educational Psychology*, *82*(4), 715–726. https://doi.org/10.1037/0022-0663.82.4.715

Meymand, N. E., & Gharaveisi, A. (2014). *Optimization of Bang-of-Bang TS-Fuzzy Based via*. *5*(3), 1–12.

Minca, C., & Dincu, A. M. (2012). Tire model for simulations of vehicle motion on high and low friction road surfaces. *International Conference of Scientific Paper AFASES 2012*, *1*, 697–702. https://doi.org/10.1109/WSC.2000.899907

Ministry of Transport, M. (Ministry of T. (2019). *Transport Statistic Malaysia*. https://www.mot.gov.my/en/Statistik Tahunan Pengangkutan/Transport Statistics Malaysia 2019.pdf

Moaaz, A. O., Ali, A. S., & Ghazaly, N. M. (2020). Investigation of Anti-Lock Braking System Performance Using Different Control Systems. *International Journal of Control and Automation*, *13*(1s), 137–153. http://sersc.org/journals/index.php/IJCA/article/view/8580

Mohamed, E., Abouel-Seoud, S., & Elsayed, M. (2015). Performance Analysis of the ABS Control on Parallel Hybrid Electric Vehicle Equipped with Regenerative Braking System. *SAE International Journal of Passenger Cars - Electronic and Electrical Systems*, *8*(2), 2015-01–9131. https://doi.org/10.4271/2015-01-9131

Naim, M. (2020). *Statistik Kemalangan Jalan Raya Mengikut Jenis Kemalangan dan Kecederaan*. http://www.data.gov.my/data/ms_MY/dataset/statistik-kemalangan-jalan-raya-mengikut-jenis-kemalangan-dan-kecederaan

Nantais, N. C. (2006). *Active Brake Proportioning and its Effects on Safety and Performance*.

OECD Health Data 2019, D. S. and M. (2019). *Injuries in road traffic accidents*.

Oudghiri, M., Chadli, M., & Hajjaji, A. El. (2007). Robust Fuzzy Sliding Mode Control for Antilock Braking System. *International Journal on Sciences and Techniques of Automatic Control*, *1*(June 2007), 13–28.

Pan, H., Guo, X., Pei, X., & Dong, X. (2017). Modeling, Simulation and Experimental Analysis of Brake Pedal Feel for Passenger Car. *SAE Technical Papers*, *2017-March*(March). https://doi.org/10.4271/2017-01-1371

Pandak Jabo, N. I. (2013). *Safety Distance Awareness System for Malaysian Driver*.

Parra, A., Cagigas, D., Zubizarreta, A., Rodriguez, A. J., & Prieto, P. (2019). Modelling and Validation of Full Vehicle Model based on a Novel Multibody Formulation. *IECON 2019 - 45th Annual Conference of the IEEE Industrial Electronics Society*, *2019-Octob*, 675–680. https://doi.org/10.1109/IECON.2019.8926854

Patil, A., Ginoya, D., Shendge, P. D., & Phadke, S. B. (2016). Uncertainty-Estimation-Based Approach to Antilock Braking Systems. *IEEE Transactions on Vehicular Technology*, *65*(3), 1171–1185. https://doi.org/10.1109/TVT.2015.2413451

Patrascan, M. G., Radulescu, V. J., Ilie, V., & Fratila, G. (2015). New Aspects Regarding Control and Operation of the Autocar ABS System. *Computational Mechanics and Virtual Engineering (COMEC) 2015*, *October*, 91–95.

Pavasson, J., Ljung, A.-L., Karlberg, M., Larsson, I. A. S., Johansson, S., & Lundström, T. S. (2014). Challenges and Opportunities within Simulation-driven Functional Product Development and Operation. *Procedia CIRP*, *22*(1), 169–174. https://doi.org/10.1016/j.procir.2014.06.149

Pedro, J., & Ferro, C. (2014). *Design and Simulation of an ABS Control Scheme for a Formula Student Prototype-master*. *May*, 107.

Penny, W. C. W., & Els, P. S. (2016). The test and simulation of ABS on rough, non-deformable terrains. *Journal of Terramechanics*, *67*(9), 1–10. https://doi.org/10.1016/j.jterra.2016.05.001

Perodua. (2020). *Axia*. https://www.perodua.com.my/our-models/axia.html

Pretagostini, F., Ferranti, L., Berardo, G., Ivanov, V., & Shyrokau, B. (2020). Survey on Wheel Slip Control Design Strategies, Evaluation and Application to Antilock Braking Systems. *IEEE Access*, *8*, 10951–10970. https://doi.org/10.1109/ACCESS.2020.2965644

Rajendran, S., Spurgeon, S. K., Tsampardoukas, G., & Hampson, R. (2019). Estimation of road frictional force and wheel slip for effective antilock braking system (ABS) control. In *International Journal of Robust and Nonlinear Control* (Vol. 29, Issue 3, pp. 736–765). https://doi.org/10.1002/rnc.4366

Rajendran, S., Spurgeon, S., Tsampardoukas, G., & Hampson, R. (2017). Time-Varying Sliding Mode Control for ABS Control of an Electric Car. *IFAC-PapersOnLine*, *50*(1), 8490–8495. https://doi.org/10.1016/j.ifacol.2017.08.823

Reif, K. (2014). Brakes, Brake Control and Driver Assistance Systems. *Brakes, Brake Control and Driver Assistance Systems*. https://doi.org/10.1007/978-3-658-03978-3

Reimpell, J., & Betzler, J. W. (2005). *Fahrwerktechnik: Grundlagen*.

Road traffic injuries. (2018). https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries

Ryb, G. E., Dischinger, P. C., & Ho, S. (2009). Vehicle Model Year and Crash Outcomes: A CIREN Study. *Traffic Injury Prevention*, *10*(6), 560–566. https://doi.org/10.1080/15389580903271401

Salehi, M., Noordermeer, J. W. M., Reuvekamp, L. A. E. M., Dierkes, W. K., & Blume, A. (2019). Measuring rubber friction using a Laboratory Abrasion Tester (LAT100) to predict car tire dry ABS braking. *Tribology International*, *131*(October), 191–199. https://doi.org/10.1016/j.triboint.2018.10.011

Samarraie, S. A. Al, Hamzah, M. N., & Nadawi, Y. K. Al. (2016). Vehicle ABS control system design via integral sliding mode. *International Journal of Automation and Control*, *10*(4), 356. https://doi.org/10.1504/IJAAC.2016.079539

Sarani, R., Hashim, H. H., Shabadin, A., Ishak, S. Z., & Voon, W. S. (2018). *Vehicle Age and Crash Severity*. *248*, 1–19.

Sato, S., & Fujimoto, H. (2008). Proposal of pitching control method based on slip-ratio control for electric vehicle. *IECON Proceedings (Industrial Electronics Conference)*, *1*, 2823–2828. https://doi.org/10.1109/IECON.2008.4758406

Savary, W., & Soennecken, H. (1975). *Lining for Brake Shoes*.

Savitski, D., Hoepping, K., Ivanov, V., & Augsburg, K. (2015). Influence of the Tire Inflation Pressure Variation on Braking Efficiency and Driving Comfort of Full Electric Vehicle with Continuous Anti-Lock Braking System. *SAE International Journal of Passenger Cars - Mechanical Systems*, *8*(2), 460–467. https://doi.org/10.4271/2015-01-0643

Savitski, D., Schleinin, D., Ivanov, V., & Augsburg, K. (2018). Robust Continuous Wheel Slip Control With Reference Adaptation: Application to the Brake System With Decoupled Architecture. *IEEE Transactions on Industrial Informatics*, *14*(9), 4212–4223. https://doi.org/10.1109/TII.2018.2817588

Scott-Parker, B., Watson, B., King, M. J., & Hyde, M. K. (2013). A further exploration of sensation seeking propensity, reward sensitivity, depression, anxiety, and the risky behaviour of young novice drivers in a structural equation model. *Accident*

Analysis and Prevention, *50*, 465–471. https://doi.org/10.1016/j.aap.2012.05.027

Shinar, D. (2007). Traffic Safety and Human Behavior. In *Traffic Safety and Human Behavior* (1st Editio). Emerald Publishing Limited.

Sira-Ramírez, H. (1992). On the sliding mode control of nonlinear systems. *Systems & Control Letters*, *19*(4), 303–312. https://doi.org/10.1016/0167-6911(92)90069-5

Sivaramakrishnan, S., Singh, K. B., & Lee, P. (2015a). Experimental Investigation of the Influence of Tire Design Parameters on Anti-lock Braking System (ABS) Performance. *SAE International Journal of Passenger Cars - Mechanical Systems*, *8*(2), 647–658. https://doi.org/10.4271/2015-01-1511

Sivaramakrishnan, S., Singh, K. B., & Lee, P. (2015b). Influence of Tire Operating Conditions on ABS Performance. *Tire Science and Technology*, *43*(3), 216–241. https://doi.org/10.2346/tire.15.430302

Soomro, M., Hassan, M. K., & Ahmad, F. (2019). Modelling and Validation of An Electronic Wedge Brake System with Realistic Quarter Car Model for Anti-Lock Braking System Design. *International Journal of Integrated Engineering*, *11*(4), 70–80. https://doi.org/10.30880/ijie.2019.11.04.008

Stephens, A. N., & Groeger, J. A. (2009). Situational specificity of trait influences on drivers' evaluations and driving behaviour. *Transportation Research Part F: Traffic Psychology and Behaviour*, *12*(1), 29–39. https://doi.org/10.1016/j.trf.2008.06.005

Straky, H., Kochem, M., Schmitt, J., Hild, R., & Isermann, R. (2001). Influences of Braking System Faults on the Vehicle Dynamics. *IFAC Proceedings Volumes*, *34*(1), 113–118. https://doi.org/10.1016/S1474-6670(17)34386-0

Tabone, M., Azzopardi, J. P., & Farrugia, M. (2019). Emulation of Vehicle Speed and Impact on Vehicle Event Data Recorder. *Proceedings of the 2018 18th International Conference on Mechatronics - Mechatronika, ME 2018*.

Tang, Y., Zhang, X., Zhang, D., Zhao, G., & Guan, X. (2013). Fractional order sliding mode controller design for antilock braking systems. *Neurocomputing*, *111*, 122–130. https://doi.org/10.1016/j.neucom.2012.12.019

Tavernini, D., Velenis, E., & Longo, S. (2017). Feedback brake distribution control for minimum pitch. *Vehicle System Dynamics*, *55*(6), 902–923. https://doi.org/10.1080/00423114.2017.1293275

Termous, H., Shraim, H., Talj, R., Francis, C., & Charara, A. (2019). Coordinated control strategies for active steering, differential braking and active suspension for vehicle stability, handling and safety improvement. *Vehicle System Dynamics*, *57*(10), 1494–1529. https://doi.org/10.1080/00423114.2018.1521001

Thompson, J. P., Baldock, M. R. J., Mathias, J. L., & Wundersitz, L. N. (2013). An

examination of the environmental, driver and vehicle factors associated with the serious and fatal crashes of older rural drivers. *Accident Analysis & Prevention*, *50*, 768–775. https://doi.org/10.1016/j.aap.2012.06.028

Todorovic, M., Vukcevic, B., Cabarkapa, M., Vukcevic, N., Boljevic, T., & Radojevic, N. (2018). The assessment of airbag deployment and seatbelt use in preventing facial injuries. *Forensic Science, Medicine and Pathology*, *14*(4), 503–508. https://doi.org/10.1007/s12024-018-0020-9

Tsai, M.-T. (1999). *Disk Brake Device*.

Useche, S., Serge, A., & Alonso, F. (2015). Risky behaviors and stress indicators between novice and experienced drivers. *American Journal of Applied Psychology*, *3*(1), 11–14. https://doi.org/10.12691/ajap-3-1-3

Uzunsoy, E. (2018). *A Brief Review on Fuzzy Logic Used in Vehicle Dynamics Control*. *2*(June), 1–7.

Valiente, R., Zaman, M., Ozer, S., & Fallah, Y. P. (2019). Controlling steering angle for cooperative self-driving vehicles utilizing CNN and LSTM-based deep networks. *IEEE Intelligent Vehicles Symposium, Proceedings*, *2019-June*(May), 2423–2428. https://doi.org/10.1109/IVS.2019.8814260

van der Merwe, N. A., Els, P. S., & Žuraulis, V. (2018). ABS braking on rough terrain. *Journal of Terramechanics*, *80*(March), 49–57. https://doi.org/10.1016/j.jterra.2018.10.003

Vashit, D., & Kumar, N. (2017). A REVIEW OF ACTIVE AND PASSIVE AUTOMOTIVE SAFETY SYSTEMS. *Intenational Journal of Engineering Sciences & Management Research*, *4*(4), 9–16.

Wanaskar, V., Chaudhari, S., Shendge, P. D., & Phadke, S. B. (2021). Extended Nonlinear Two-Time Scale Estimation Approach for Antilock Braking Systems. *IEEE Transactions on Industrial Electronics*, *68*(10), 10040–10049. https://doi.org/10.1109/TIE.2020.3022519

Wang, P., Rau, P.-L. P., & Salvendy, G. (2010). Road Safety Research in China: Review and Appraisal. *Traffic Injury Prevention*, *11*(4), 425–432. https://doi.org/10.1080/15389581003754593

Wellstead, P. E., & Pettit, N. B. O. L. (1997). Analysis and redesign of an antilock brake system controller. *IEE Proceedings - Control Theory and Applications*, *144*(5), 413–426. https://doi.org/10.1049/ip-cta:19971441

Wilson, R. J., Fang, M., Cooper, P. J., & Beirness, D. J. (2006). Sleepiness Among Night-Time Drivers: Relationship to Blood Alcohol Concentration and Other Factors. *Traffic Injury Prevention*, *7*(1), 15–22. https://doi.org/10.1080/15389580500412929

Wu, M.-C., & Shih, M.-C. (2003). Simulated and experimental study of hydraulic anti-lock braking system using sliding-mode PWM control. *Mechatronics*, *13*(4), 331–351. https://doi.org/10.1016/S0957-4158(01)00049-6

Xiong, Y., Xiaoyan Li, Yong He, Min Wu, & Yonghong Long. (2014). Design and application of testing system for pneumatic ABS ECU. *Proceeding of the 11th World Congress on Intelligent Control and Automation*, *2015-March*(March), 3612–3617. https://doi.org/10.1109/WCICA.2014.7053317

Xsens Technologies B.V. (2009). *MTi and MTx User Manual and Technical Documentation*.

Yadav, D. K. (2015). Modeling an intelligent controller for anti-lock braking system. *International Journal of Technial Research and Application*, *3*(4), 122–126.

Yonggon Lee, & Zak, S. H. (2002). Designing a genetic neural fuzzy antilock-brake-system controller. *IEEE Transactions on Evolutionary Computation*, *6*(2), 198–211. https://doi.org/10.1109/4235.996019

Zamzamzadeh, M., Saifizul, A. A., Ramli, R., & Soong, M. F. (2016). Dynamic simulation of brake pedal force effect on heavy vehicle braking distance under wet road conditions. *INTERNATIONAL JOURNAL OF AUTOMOTIVE AND MECHANICAL ENGINEERING*, *13*(3), 3555–3563. https://doi.org/10.15282/ijame.13.3.2016.2.0292

Zulhilmi, I. M., Heerwan, P. M., Asyraf, S. M., Sollehudin, I. M., & Ishak, I. M. (2020). Experimental study on the effect of emergency braking without anti-lock braking system to vehicle dynamics behaviour. *International Journal of Automotive and Mechanical Engineering*, *17*(2), 7832–7841. https://doi.org/10.15282/ijame.17.2.2020.02.0583

Zulhilmi, I. M., Heerwan, P. M., Eiman, R. I. M., Izhar, I. M., & Asyraf, S. M. (2019). Investigation on Vehicle Dynamic Behaviour During Emergency Braking at Different Speed. *International Journal of Automotive and Mechanical Engineering*, *16*(1), 6161–6172. https://doi.org/https://doi.org/10.15282/ijame.16.1.2019.6.0468