Smart System Side Slip Tester Results Accuracy Improvement Using Exponential Filter

Arief Marwanto[1], Muhammad Qomaruddin[2], Riky Maulana Firdaus[3], Deshinta Arova Dewi[4], Tri Basuki Kurniawan[5], Imam Much Ibnu Subroto[6]
[1] Electrical Engineering Post Graduated Program, Universitas Islam Sultan Agung, Indonesia
[2,6] Informatics Engineering, Faculty of Industrial Engineering, Universitas Islam Sultan Agung, Indonesia
[3] PT. Textronic Indonesia, Indonesia
[4] Faculty of Data Science and Information Technology, INTI International University, Nilai, Malaysia
[5] Faculty of Science and Technology, Universitas Bina Darma, Palembang, Indonesia
[1]Research Fellowship, Faculty of Data Science and Information Technology, INTI International University, Nilai, Malaysia

Article Info

Article history:

Received Dec 19, 2021
Revised Apr 27, 2022
Accepted Jun 25, 2023

Keywords:

Side Slip Tester
smart system
exponential filter
android
STM32

ABSTRACT

Vehicles that are not roadworthy are very dangerous for the safety of passengers and other road users. One of the technical requirements for roadworthiness is the front wheel ring condition, which greatly affects the safety of the motorized vehicle. The front wheel pins ensure the vehicle can move in a straight line, which is related to the safety of the steering system and affects fuel efficiency. The front wheel valve inspection is carried out with a front wheel blade test tool known as the Side Slip Tester through periodic testing at the motor vehicle testing center belonging to the Transportation Service. Previously, a lot of vehicle test equipment at several test centers was not feasible and was no longer accurate. In this work, the design of a smart system for testing wheel blades on vehicles with the addition of an exponential filter to refine and reduce noise in sensor readings of ADC signals is proposed. Tests and calibrations were carried out by comparing the readings of the tool that has been made with a calibrated dial indicator. From the results of the exponential filter test, the best weight for the ADC reading filter is 0.2 because from the graph it can be seen that the response to the input signal is fast and, for noise filtering, it is very good. The calibration of the tool results in the maximum error result of 3% on the 9-mm side slip bench shear test. The proposed method is more accurate than the estimated sideslip calculation, the conventional sideslip angle measurement in a range of 10 to 130 degrees with a 10% error rate.

Corresponding Author:

Arief Marwanto,
Electrical Engineering Post Graduated Program,
Universitas Islam Sultan Agung,
Jl. Raya Kaligawe KM 4 Semarang 50112, Indonesia.
Email: arief@unissula.ac.id

1. INTRODUCTION

Bus and public transportation accidents often take many lives. To overcome this problem, the Indonesian Ministry of Transportation continues to encourage public transportation companies to have a Safety Management System, and the Regional Transportation Service together with the Police take action on passenger transport vehicles that are not roadworthy, so they are prohibited from operating [1], [2]. The roadworthiness requirements as intended are determined based on the minimum performance of motorized vehicles, including exhaust gas emissions, sound noise, main brake system efficiency, parking brake system efficiency, front wheel slip or side slip test, horn sound, the transmit power and direction of the main light beam, turning radius, accuracy of speed indicator, suitability of wheel performance and tire condition, and the suitability of the propulsion engine power to the weight of the vehicle [3]–[8].

The front wheel pins ensure the vehicle can move in a straight line, which is related to the safety of the steering system and affects fuel efficiency. Inspection of the front wheel blades is carried out with a front wheel blade test tool known as the Side Slip Tester [9]–[12]. Unfortunately, in many checking and measurement service office of the Transportation Service, it is found that the motor vehicle testing facility are with partially damaged test equipment. Those works often carried out with lack of accuracy of the slide tester results. The high cost of purchasing new equipment and maintenance for testing motor vehicles makes the implementation of the law and regulation policy has not been maximized [10], [13]–[16].

The challenges of accuracy and precision in a measurement system are crucial. Noise and interference on the transient process can be reduced by using an exponential filter of measured and discriminatory values along with a low-cut filter simultaneously [17]–[20].

Limiting the growing rate of the target disturbance and conditional integration to prevent integral saturation should be used in a sophisticated method to optimize the effectiveness of controller implementation to regulate inertial objects with travel slowness. By considering the suggested sequence of solutions, the exponential filter of the smoothing automated adjustment system is mathematically modeled [17], [19], [21].

Measuring the side slip of camera-based tire testing is one of many studies that other researchers have conducted in relation to the Side Slip Tester. Equipment for testing vehicle skids is based on PLC and MCGS touch screens [22]–[24] and numerous studies, including in [8]–[11]. However, the slider testing results show significant variance, and whenever a tire is tested, the accuracy of the displacement sensor is too high. To alleviate these circumstances, an exponential filter is used [25]–[27], which can lower the noise in the displacement sensor reading before the microcontroller processes it. To increase the accuracy of reading ADC signals, this research aims to create and use the Smart System Side Slip Tester technology based on Android at a reasonable cost. Additionally, the Android-based technology used in the slider-slip tester application allows for real-time monitoring and storage of enormous volumes of data without the need for a separate server computer. Numerous applications of the Android OS are possible, including complicated autonomous systems, optimization processes, and sensor-based decision support systems [4], [28]–[32].

The user interface is responsive, consistent, beautiful, attractive, efficient, and forgiving with this Android technology into an easy data storage solution, which will be the theme of this research which is exciting and demanding to investigate. This description served as the basis for the invention described in this paper, an Android-based Smart System Side Slip Tester that uses an exponential filter to reduce the noise influence on ADC values [24], [28], [30].

2. RESEARCH SYSTEM MODEL

As seen in Figure 1, this study employs research and development techniques to provide side-slip test equipment with exact and accurate motorized vehicle smart systems diagrams.

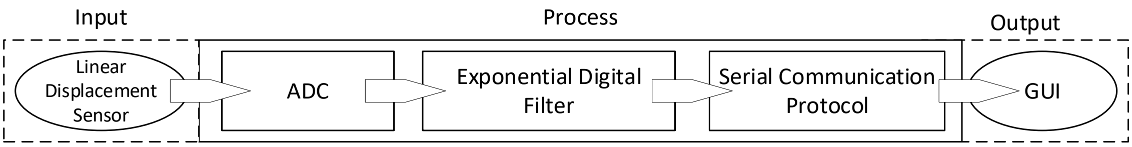


Figure 1. Diagram of the Proposed System Model

The input, process, and output make up the system. In this study, the sensor's change in resistance acts as a linear transducer, which is subsequently transformed into a voltage using a voltage divider circuit. The microcontroller's ADC pin receives the voltage from the sensor and converts it to binary data. After using an exponential filter, the ADC conversion data is then transformed into a serial protocol and supplied to the Android GUI via a UART serial connection. The system's exponential filter function seeks to remove outside noise to improve sensor readings and boost the precision of side slip measurement outcomes [33]–[36].

The side slip bench or sliding plate in the Hardware Block Diagram of Figure 2 has a linear transducer installed in it to measure the side slip of the wheels of the vehicle being tested. The signal from the sensor is then converted to digital data using the ST32F103C8T6 of ADC, which is then processed by the GUI. Android programs. employing an LCD monitor screen as a GUI viewer. A power supply circuit provides a power source to each circuit so that they can all function [37].

One operator is needed to operate the program for the vehicle testing process. The operator initially hits the start button to begin the measurement. After that, the operator instructs the driver of the car to pass the side-slip bench at a speed of 5 to 10 km/h and to turn off the engine. The sensor is detected side slides as soon as the vehicle's wheels cross the side-slip bench and display them on the monitor screen. The operator clicks the print button to print the test results as proof after receiving the results. The test result data is also saved in the data logger when the print button is hit [37].

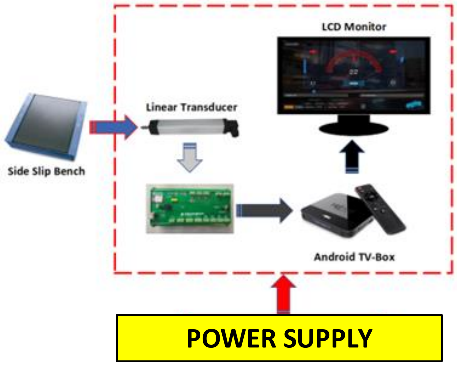


Figure 2. Hardware Block Diagram

One operator is needed to operate the program for the vehicle testing process. The operator initially hits the start button to begin the measurement. After that, the operator instructs the driver of the car to pass the side-slip bench at a speed of 5 to 10 km/h and to turn off the engine. The sensor is detected side slides as soon as the vehicle's wheels cross the side-slip bench and display them on the monitor screen. The operator clicks the print button to print the test results as proof after receiving the results. The test result data is also saved in the data logger when the print button is hit [37].

The following materials were used in the creation of the side slip tester to help in the development of the slide-slip tester:

1. Use a medium that is in direct contact with the wheels of the vehicle to be measured, such as a side slip bench or sliding plate.
2. An angle pot sensor, also known as an angle potential sensor or side slip reader, from a vehicle wheel positioned on a side slip bench [38]
3. The sensor reader STM32F103C8T6 [29]
4. Android TV Box as a data processor from a microcontroller with a GUI program

2.1. Exponential Filter Testing

The program is loaded onto the microcontroller to test exponential filters. To find the ideal weight for the vehicle side slip measurement system, this test will be conducted. The purpose of the software is to simulate noise at the microcontroller's ADC pin to read analog input from that pin. The exponential filter is a weighted mixture of the most recent input data and the prior estimate (output), where the sum of the weights is set to 1 to ensure that the output and input are equal in steady state. An exponential filter is employed to lessen the noise in the ADC reading. The following equation for an exponential filter is shown [17]:

$$y(k) = a.y(k-1) + (1-a).x(k) \tag{1}$$

Description:

x(k) : input in time step k

y(k) : filtered output at k, time step

a : a constant between 0 and 1, usually between 0.8 and 0.99. (a-1) or so-called *smoothing constant*.

When the application developer gives a new value of the desired time constant, the constant "a" is computed and kept for convenience only in systems with fixed time steps T between samples. Equation (2) shows how to obtain the new value of the desired time [17], [20]:

$$a = \exp(-T/\sigma)(\text{its equal to } \sigma = -T/\log(a)) \tag{2}$$

Description:

a : a constant between 0 and 1, usually between 0.8 and 0.99. (a-1) or called.

σ : is the filter time constant, in the same unit of time as T.

T : time since previous sample

The above exponential function must be employed with each time step in systems where data sampling occurs at irregular intervals, where T is the interval since the previous sample[31].

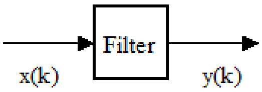


Figure 3. Notation of exponential Filter [17]

Typically, the first input is used to initialize the filter output [19] There is no filtering because "a" goes to zero as the time constant approaches 0, hence the output equals the fresh input. Since the time constant increases, a comes closer to 1, which results in extremely intensive filtering since incoming input is essentially disregarded. The filter constant definitions given here substitute for (1-a) in most of the forecasting literature. The author's background in control systems, where the most crucial dynamics are determined by the relationship to the prior value rather than the input, is the only explanation. The following predictor-corrector equivalent of the filter equation presented above can be created [17]:

$$y(k) = y(k-1) + (1-a) * (x(k) - y(k-1)) \quad (3)$$

With this form, it is more obvious that the variable estimate (the filter's output) is anticipated to be the same as the previous estimate y(k-1) plus a correction term based on the unexpected "innovation"—the difference between the new input x(k) and the forecast y(k-1)—that is, the variable estimate is predicted to be unchanged from the prior estimate. This form is also a result of the Kalman filter, the best option for estimating an issue under a specific set of assumptions, being derived from the exponential filter [17].

The exponential digital filter is outfitted with an algorithm that is embedded in the microcontroller, as seen in Figure 3. A method to reduce the noise in the ADC signal reading from the linear displacement sensor should be suggested. The microcontroller approach incorporates an exponential filter to improve the accuracy of the ADC signal reading to counteract the limitations [17], [18].

The value of the constant of "*a*" is acquired from the acquisition of every k input from the time constant to reach the ideal value of the slide-slip tester on the vehicle *exp* $(-T/\sigma)$, in order for the output y(k) to search for the smallest value of the weight that has been determined by parameters "*a*", in order to attain the ideal value of the slide-slip tester on the vehicle. As a result, the period $(-T/\sigma)$ which is directly proportional to the noise value, will increase as the weight value increases. The accuracy will rise linearly in step with the exponential value of time T, as stated in equations (1) and (2) if the weight value of an is decreasing and the noise is also decreasing [17].

3. RESULTS AND DISCUSSION

3.1. Graphical User interface display.

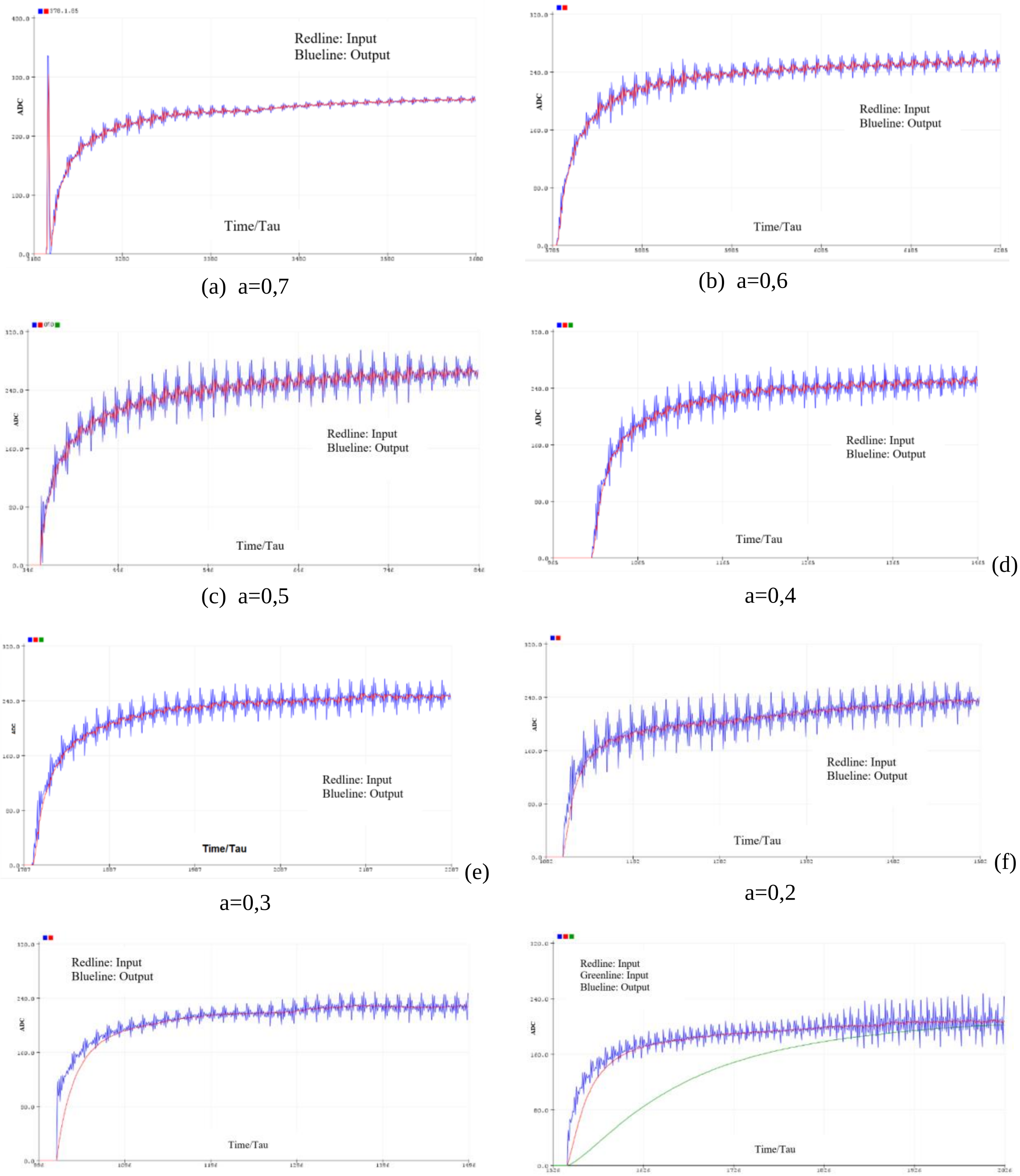
The application has a form that needs to be filled out with information about the owner of the car and their registration number. It also has a place to store the results of any vehicle tests and a graphical user interface like the one in Figure 4.

Figure 4. Graphical User Interface

On the first run, the program checks to see if the serial port on the Android TV Box is available. If it is, the program will open the serial port in accordance with the previous settings stored in the config.ini file. If the serial port is not available, the user will open a menu to select the serial port to be used. When the start button is pressed, the program will send a command to the microcontroller to start the sensor reading. It will then read the sensor reading data supplied by the microcontroller, changing the start button into a stop button. If the serial port has been established and opened.

Moreover, the stop button is used to halt the test or sensor reading and hold the test data at the same time. The program will instruct the microcontroller to stop reading the sensor when the stop button is pressed. The software is then reset to the start of the test, and the microcontroller is also reset using the reset button. When the test results are ready, the user can store them in a datalogger while simultaneously filling out a form to enter the vehicle data under test and pressing the print button to print the test results. Use the escape or cross buttons located in the top-right corner of the program to close it.

The test was run eight times with weights ranging from 0.7 to 0.1 to 0.01. Figure 5 displays the outcomes of the test using an exponential filter on the sensor input Figure 5:



(a) a=0,7 (b) a=0,6

(c) a=0,5 (d) a=0,4

(e) a=0,3 (f) a=0,2

(g) a=0,1 (h) a=0,1 (red line) and a=0,01 (green line)

Figure 5. Exponential Filter Signal Response from ADC Reading

The filter time constant divides the time in the step response plot graph, making it easier to forecast the outcomes for any time period and for any value of the filter time constant. The graph demonstrates that the red line is the input and the blue line is the output following the application of an exponential filter.

In Figure 5(a), when the weight value is 0.7, the filter output increases to 200 of its final value after a period equal to the time constant. The value increases to 220 of its final value after a period equal to two-time constants.

The outputs at 3, 4, and 5-time constants are, correspondingly, 240 of the final value. These numbers can be used for any step change magnitude because the filter is linear. Additionally, the values 0.3, 0.4, 0.5, and 0.7 denote a strong input signal and strong output from step index 1 to step index 5. While the refining value is improving and the achievement value is consistent at position 240 at weights 0.1 and 0.2, the ADC output value is becoming smoother.

The exponential filter test results graph indicates that Figure 5(a)'s weight value of 0.5 indicates that the response is too high, resulting in the presentation of significant noise. In contrast to Figure 5(a), where noise is shown to be reduced, the response of the signal noise is better at point (e) of 0.3. While the results are smoother in Figures 5(f) and 5(g), where the weight values are 0.10 and 0.01, respectively, the response to the input signal slows as the weight value decreases. The green line indicates the performance of input weighted input value, which also smooths or reduces ADC value. By increasing the ADC value and ensuring that the achievement value is constant at position 240 for weights of 0.1 and 0.2, the output value is becoming more consistent. As a consequence, it was determined to place a weight of 0.2 on the side slip test apparatus. The graph's explanation demonstrates that the response to the input signal is quick and excellent for noise filtering.

3.2. Slide-Slip Measurement Calibration

By directly comparing the tool's measurements with those from the calibrated dial indicator, the side slip tester's calibration is carried out in order to confirm that the use of an exponential filter produces accurate slide-slip data. This test seeks to confirm that the tool created complies with requirements for testing motorized vehicle side slip. The test is run on a side-slip bench shift that ranges from 1 to 10-mm. After recording the test results in a table, the percentage error is determined using the reading from the tool that was created. In this instance, calibration is performed to ascertain the extent of reading repeatability and reading deviation.

Table 1. Calibration Results

No.	Side-Slip Reading (mm)	Refference Dial Indicator (mm)	Error (%)
1	1	1,01	1,00
2	2,1	2,09	-1,00
3	3,2	3,19	-1,00
4	4,5	4,5	0,00
5	5,3	5,29	-1,00
6	6,5	6,5	0,00
7	7,3	7,31	1,00
8	8,3	8,31	1,00
9	9,2	9,23	3,00
10	10,4	10,38	-2,00

Table 1 shows that the dial indicators at the test locations display various values, which is due to the difficulty of manually shifting the side slip bench to get rounded readings in increments of 0.01 mm. The 9-mm test, where the dial indicator indicates a value of 9.23 mm and the tool indicates 9.2-mm, has the highest error percentage as shown in Table 1, which is 3%. The tool created is suitable for use as a side slip test tool on motorized vehicles, according to the calibration results. Compared to the estimated sideslip calculation results by [31], the sideslip angle measurement results in a range of 10 to 130 degrees with an error rate of 2-3 degrees, or a 10% error rate. With an error of only 3%, the results of evaluating the side slip tool with the exponential method are superior, and the side slip angle test based on the exponential equation is more accurate than[31].

4. CONCLUSION

Several conclusions were drawn from the findings of this study. According to the results of the exponential filter test, the optimal weight for the ADC reading exponential filter is 0.2, as the response to the input signal is quick and noise filtering is superb, as depicted in the graph. The 9-mm side slide bench shear test produces a maximum error of 3% after tool calibration. The evaluation of the side slip tool with the exponential method yields superior results, with an error of only 3%, and the side slip angle measurement based on the exponential equation is more accurate. Using a smart system, a combination of the STM32F103C8T6 microcontroller and Android TV Box, and a linear displacement sensor with an exponential filter applied to the sensor input reading, the Motor Vehicle Testing Department of the Department of Transportation of the Indonesian Republic can produce a motor vehicle side slip test.

ACKNOWLEDGMENTS

This study is a collaboration between Sultan Agung Islamic University (UNISSULA), Textronik Indonesia, INTI International University Malaysia, and Bina Darma University, Indonesia.

REFERENCES

[1] T. B. Joewono and H. Kubota, "Safety and security improvement in public transportation based on public perception in developing countries," *IATSS research*, vol. 30, no. 1, pp. 86–100, 2006.
[2] P. Ricardianto, N. S. Hidayat, P. Manik, P. Widiyanto, and P. C. Susanto, "GUIDELINES FOR MEASURING THE SUCCESS OF TRAFFIC SAFETY ACTION PLAN," *International Journal of Research In Commerce and Management Studies (ISSN: 2582-2292)*, vol. 3, no. 1, pp. 37–50, 2021.
[3] Q. Xiaojie, W. Qiang, Y. Zhao, W. Yunlong, W. Guotian, and L. Degang, "A technigue exploitation about anti-slide tire polyploid on ice-snow road in winter," in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 2017, p. 012161.
[4] H. F. Grip, L. Imsland, T. A. Johansen, T. I. Fossen, J. C. Kalkkuhl, and A. Suissa, "Nonlinear vehicle side-slip estimation with friction adaptation," *Automatica*, vol. 44, no. 3, pp. 611–622, 2008.
[5] D. K. Johnson, T. R. Botha, and P. S. Els, "Real-time side-slip angle measurements using digital image correlation," *J Terramech*, vol. 81, pp. 35–42, 2019.
[6] S. Cheng, L. Li, and J. Chen, "Fusion algorithm design based on adaptive SCKF and integral correction for side-slip angle observation," *IEEE Transactions on Industrial Electronics*, vol. 65, no. 7, pp. 5754–5763, 2017.
[7] A. Gajek and P. Strzępek, "The analysis of the accuracy of the wheel alignment inspection method on the side-slip plate stand," in *IOP Conference Series: Materials Science and Engineering*, IOP Publishing, 2016, p. 012037.
[8] A. Hac and M. D. Simpson, "Estimation of vehicle side slip angle and yaw rate," *SAE transactions*, pp. 1032–1038, 2000.
[9] C. Jin, L. Shao, C. Lex, and A. Eichberger, "Vehicle side slip angle observation with road friction adaptation," *IFAC-PapersOnLine*, vol. 50, no. 1, pp. 3406–3411, 2017.
[10] M. Yang, L. Li, and W. Zheng, "Analysis on Side Slip Characteristics of Multi-axle Vehicle Tire," in *2015 International conference on Applied Science and Engineering Innovation*, Atlantis Press, 2015, pp. 812–815.
[11] L. Shao, C. Jin, C. Lex, and A. Eichberger, "Nonlinear adaptive observer for side slip angle and road friction estimation," in *2016 IEEE 55th Conference on Decision and Control (CDC)*, IEEE, 2016, pp. 6258–6265.
[12] A. Hac, D. Nichols, and D. Sygnarowicz, "Estimation of vehicle roll angle and side slip for crash sensing," *SAE International*, pp. 1–529, 2010.
[13] N. K. Cooperrider, T. M. Thomas, and S. A. Hammoud, "Testing and analysis of vehicle rollover behavior," *SAE transactions*, pp. 518–527, 1990.
[14] K. A. Grosch and A. Schallamach, "The load dependence of laboratory abrasion and tire wear," *Rubber Chemistry and Technology*, vol. 43, no. 4, pp. 701–713, 1970.
[15] I. Konstantinou, K. Sedlan, and W. Versteden, "Tire Models for Simulation of Extreme Handling Test Maneuvers," *ATZ worldwide*, vol. 122, no. 6, pp. 16–21, 2020.
[16] H. Dugoff and B. J. Brown, "Measurement of tire shear forces," *SAE Transactions*, pp. 316–324, 1970.
[17] Greg Stanley, "Exponential Filter," *https://gregstanleyandassociates.com/whitepapers/FaultDiagnosis/Filtering/Exponential-Filter/exponential-filter.htm*, Sep. 28, 2020.
[18] C. McDonald and S. Yüksel, "Exponential filter stability via Dobrushin's coefficient," 2020.
[19] D. R. Towill, "Exponential smoothing of learning curve data," *THE INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH*, vol. 15, no. 1, pp. 1–15, 1977.
[20] S. Castan, J. Zhao, and J. Shen, "New edge detection methods based on exponential filter," in *[1990] Proceedings. 10th International Conference on Pattern Recognition*, IEEE, 1990, pp. 709–711.
[21] R. M. Firdaus, B. Supriyo, and A. Suharjono, "Electronic and GUI Developtmen of Roller Brake Tester," in *Journal of Physics: Conference Series*, IOP Publishing, 2019, p. 012070.

[22] W. Luty, "Experimental research on tyres in transient sideslip conditions," *Archiwum Motoryzacji*, vol. 66, no. 4, pp. 23–32, 2014.
[23] T. G. Crainic, M. Gendreau, and J. Y. Potvin, "Intelligent Freight Transportation Systems: Assessment and the Contribution of Operations Research," *Transp Res Part C Emerg Technol*, vol. 17.6, no. August, pp. 541–557, 2009.
[24] J. W. Shao, F. Lin, and Z. Z. Ye, "Research on Automatic Verification Device for Vehicle Sideslip Tester," in *Applied Mechanics and Materials*, Trans Tech Publ, 2012, pp. 1263–1266.
[25] M. Gadola, D. Chindamo, M. Romano, and F. Padula, "Development and validation of a Kalman filter-based model for vehicle slip angle estimation," *Vehicle System Dynamics*, vol. 52, no. 1, pp. 68–84, 2014.
[26] W. Botes, T. R. Botha, and P. S. Els, "Sideslip Angle Estimation Using a Kinematics Based Unscented Kalman Filter and Digital Image Correlation," in *The IAVSD International Symposium on Dynamics of Vehicles on Roads and Tracks*, Springer, 2019, pp. 1635–1642.
[27] K. Nam, S. Oh, H. Fujimoto, and Y. Hori, "Estimation of sideslip and roll angles of electric vehicles using lateral tire force sensors through RLS and Kalman filter approaches," *IEEE Transactions on Industrial Electronics*, vol. 60, no. 3, pp. 988–1000, 2012.
[28] P. Wang, B. Liang, W. You, J. Li, and W. Shi, "Automatic Android GUI traversal with high coverage," in *2014 Fourth International Conference on Communication Systems and Network Technologies*, IEEE, 2014, pp. 1161–1166.
[29] J. González Fiances, "Marcador electrónico utilizando microcontrolador STM32 comandado desde Android mediante bluetooth," 2020.
[30] J. Ma, C. Wu, and S. Yan, "Vehicle Dynamic State Estimation Using Smartphone Embedded Sensors," *Sensors & Transducers*, vol. 160, no. 12, p. 111, 2013.
[31] H. F. Grip, L. Imsland, T. A. Johansen, J. C. Kalkkuhl, and A. Suissa, "Vehicle sideslip estimation," *IEEE control systems magazine*, vol. 29, no. 5, pp. 36–52, 2009.
[32] D. Selmanaj, M. Corno, G. Panzani, and S. M. Savaresi, "Vehicle sideslip estimation: A kinematic based approach," *Control Eng Pract*, vol. 67, pp. 1–12, 2017.
[33] H. F. Grip, L. Imsland, T. A. Johansen, T. I. Fossen, J. C. Kalkkuhl, and A. Suissa, "Nonlinear vehicle side-slip estimation with friction adaptation," *Automatica*, vol. 44, no. 3, pp. 611–622, 2008.
[34] C. Voser, R. Y. Hindiyeh, and J. C. Gerdes, "Analysis and control of high sideslip manoeuvres," *Vehicle System Dynamics*, vol. 48, no. S1, pp. 317–336, 2010.
[35] W. Liu, X. Xia, L. Xiong, Y. Lu, L. Gao, and Z. Yu, "Automated vehicle sideslip angle estimation considering signal measurement characteristic," *IEEE Sens J*, vol. 21, no. 19, pp. 21675–21687, 2021.
[36] B. Ma, Y. Liu, Y. Gao, Y. Yang, X. Ji, and Y. Bo, "Estimation of vehicle sideslip angle based on steering torque," *The International Journal of Advanced Manufacturing Technology*, vol. 94, pp. 3229–3237, 2018.
[37] R. Li, Y. Yu, W. Ji, Y. Sun, and G. Tian, "Electric Vehicle Tires Test Bench Design for Laboratory," in *2022 IEEE Transportation Electrification Conference & Expo (ITEC)*, IEEE, 2022, pp. 479–484.
[38] L. Li and F.-Y. Wang, *Advanced motion control and sensing for intelligent vehicles*. Springer Science & Business Media, 2007.

BIOGRAPHY

Dr. Arief Marwanto received his Ph.D. in electrical engineering from the University Technology Malaysia (UTM). He is currently a senior lecturer in the electrical engineering program at UNISSULA and will begin a research fellowship at INTI International University, Malaysia, in 2023. Dr. Muhammad Qomaruddin received his doctoral studies in the field of information systems at the University of Technology Malaysia (UTM). He is currently a senior lecturer in the informatics engineering program at UNISSULA. Mr. Riky Maulana received his master's degree studies at the Semarang State Polytechnic; he is now the proprietor of Textronik Indonesia, a company that operates in the electronic control instrumentation industry. Dr. Deshinta Arrova Dewi received her doctoral studies in information systems at the University of Technology Malaysia (UTM); she is currently a senior lecturer at the Faculty of Data Science and Information Technology, INTI International University, Malaysia. Dr. Tri Basuki Kurniawan received his doctoral studies in information systems at the University of Technology Malaysia (UTM); he is currently a senior lecturer at the Faculty of Science and Technology at Bina Darma University in Palembang, Indonesia. Dr. Imam Much Ibnu Subroto received his doctorate in informatics engineering from the University of Technology Malaysia (UTM). He is now a senior lecturer in the informatics engineering program at UNISSULA.