2023 The 23rd International Conference on Control, Automation and Systems (ICCAS 2023)
Yeosu Venezia Hotel & Utop Marina Hotel, Yeosu, Korea, Oct. 17~20, 2023

Independent Speed Controller for Integrated Motion Control of Tracked Vehicle with In-Track Motors

Noor Amira Ilyanie Ruslan[1], Noor Hafizah Amer[2*], Khisbullah Hudha[3], Zulkiffli Abdul Kadir[4], Saiddi Ali Firdaus Mohamed Ishak[5] and Syed Mohd Fairuz Syed Mohd Dardin[6]

[1,2,3,4,5,6] Department of Mechanical Engineering, Faculty of Engineering,
National Defence University of Malaysia,
Kem Sungai Besi, 57000 Sungai Besi, Kuala Lumpur, Malaysia
(amirailyanie02@gmail.com; noorhafizah@upnm.edu.my; k.hudha@upnm.edu.my; zulkiffli@upnm.edu.my; saiddi@upnm.edu.my; syedfairuz@upnm.edu.my)* Corresponding author

Abstract: DC motor are known for simple design and consistency and commonly used for actuation system in most control applications. This paper presents an independent control approach for regulating the speed and motion of a DC motor in a tracked vehicle equipped with in-track DC motors. The proposed method involves the implementation of an independent open-loop controller. The open-loop control strategy is usually known to be less stable and accurate compared to closed-loop controller. However, this can be improved by an accurate system modelling to be used in the controller. In this study, the independent speed controller is developed by acquiring the speed characteristics of the DC motor in relation to its voltage input. Both DC motors on each track will be characterized and a model will be developed with these characteristics to be implemented in the open-loop control strategy. Data collection, controller development, and experimental validation will be described in this paper. The developed model shows good agreement with the actual vehicle response and open-loop controller are shown to produce the desired speed with good accuracy. The maximum percentage error obtained between the desired and actual speed of DC motor is 2%. With this controller, an integrated motion control for the tracked vehicle that governs the motion in longitudinal as well as lateral direction can be developed. It is hoped that this study can be served as an initial perspective on the development of basic control scheme, aiming to provide valuable insights for readers who are newcomers in the control field.

Keywords: tracked vehicle, DC motor, open-loop controller

1. INTRODUCTION

Tracked vehicles are vehicles that use continuous tracks instead of wheels to move over rough or soft terrain. It is frequently utilized in off-road situations to assist with navigating diverse terrains, encompassing snow, mud, steep inclines, or any combination of these challenging conditions [1]. Furthermore, it has been developed to perform tasks in various sectors, which include military sectors, and civil industries such as, agriculture, and construction [2–7]. In military applications, the tracked vehicles have long been used due to their superior off-road mobility, ability to traverse difficult terrain, and its heavy-duty capabilities. One of the primary advantages of tracked military vehicles is its ability to navigate through challenging terrain which wheeled vehicles would struggle to traverse it [8].

In addition, tracked vehicles have been widely employed in various agricultural tasks, including planting, harvesting, and crop transportation [9]. One of the most significant benefits in this sector is the ability to reduce soil compaction. Tracked vehicles distribute their weight more evenly over a larger surface area than wheeled vehicles, which reduces soil compaction and minimizes damage to crops and soil structure. Other than that, tracked vehicles are popular in the construction industry in handling various tasks including excavation and grading [10]. This is due to its advantages of the tracks in providing good stability and traction which allows the tracked vehicles to carry large amounts of heavy loads efficiently [3], [11]. Overall, the tracked vehicles remain an important aspect in various sectors due to it good traction, stability and performance.

Next, there are various types of tracked vehicle has evolved over time, with advances in technology leading to the development of more advanced and sophisticated vehicles. Regardless, the main source of traction comes from both the left and right tracks which rotational power comes from the main vehicle's powertrain. The most common powertrain in tracked vehicles is an internal combustion engine (ICE) that generates power by burning fuel inside the engine and the combustion process produces high-pressure gases that power the vehicle's tracks [12]. Meanwhile, the advancement in technology nowadays have increased the interest in electric-powered tracked vehicles that are equipped with two DC motors on each track to provide the main powertrain, which transform electrical energy into mechanical energy to propel the vehicle's tracks [13]. The use of DC motors in tracked vehicles provides several advantages, including high efficiency, precise control, and reduced emissions, making it a viable alternative to traditional ICE powered tracked vehicles.

In developing the control strategy for DC motors, there are several methods usually used, and each of these methods can be classified into open-loop or closed-loop controller. Most DC motor controllers falls within the closed-loop controller type. Closed-loop DC motor control is a technique used to regulate the speed and direction of a DC motor using feedback from the motor's speed or position. It is called closed-loop due to the presence of the feedback mechanism to adjust the applied voltage based on the error between the desired and actual motor response. Inversely, in open-loop control system, the feedback element is absent and the DC motor will be controlled by the developed controller with no mechanism to rectify discrepancies between the desired input and actual output. The difference for these two types of controllers is shown in Fig. 1.

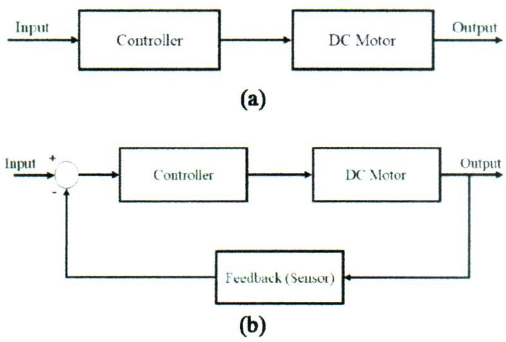

Fig. 1. General DC motor control structures: (a) Open-loop control (b) Closed-loop control

Most of the previous researchers had developed closed-loop type of control system for regulating the speed of the DC motor by employing PID controller and simulating the system using MATLAB/Simulink software [14–16]. On top of that there are also other researchers control the DC motor speed using different approaches of control algorithm such as Fuzzy Logic controller and Neural network control system [17–19]. Closed-loop controller offers more advantages in term of its accuracy and stability. On the other hand, the open-loop control strategy is usually known to be less stable and accurate compared to closed-loop controller. However, this can be improved by an accurate system modelling to minimize the prediction error for the controller. Open-loop controller is advantageous due to its simplicity, easy to maintain and generally stable. Moreover, the open-loop control is also crucial for the fundamental in developing the control system. Previously, several researchers have discussed closed-loop systems using open-loop controllers by calculating the transfer function of the DC motor to be employed in the system [16], [20-21]. In this study, independent open-loop speed controller is developed by obtaining the DC motor's speed characteristics in relation to its voltage input. Both DC motors on each track will be characterized and a model will be developed with these characteristics to be implemented in the open-loop control strategy. The controllers will be used to govern the integrated vehicle control for motions in lateral and longitudinal direction.

2. MODELLING OF A DC MOTOR

In this study, the DC motor on each track is modelled by obtaining the relationship between the operating input voltage and its subsequent angular speed of the DC motor. In this section, the variation of angular speed of the tracks with varying input voltage is recorded. The angular speed data is obtained from the rotation of the vehicle's left and right tracks while the voltage is obtained directly from the DC motor input. An instrumented small-size tracked vehicle was developed and its motion is controlled by DC motors attached to the vehicle's left and right tracks. With this setup, input voltage (V_L and V_R) supplied to the DC motor are varied while the subsequent rotational speed of the track (ω_L and ω_R) is measured. The full experimental setup is depicted in Fig. 2 and the summary of procedure to obtain the speed characteristics is shown in Fig. 3

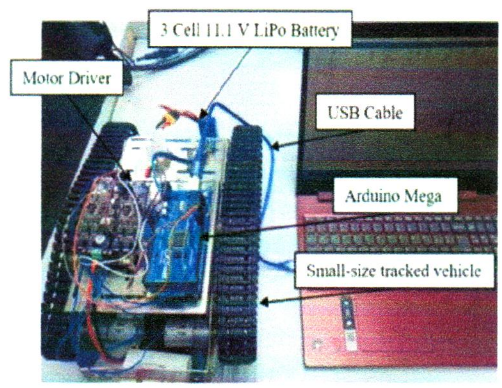

Fig. 2. Instrumentation of small-scale tracked vehicle

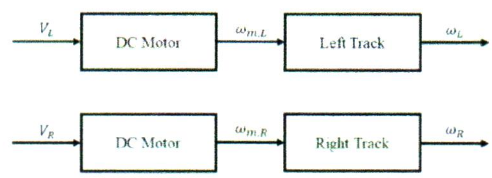

Fig. 3. Determination of speed-voltage characteristics for the DC motor

The relationship of the voltage and angular speed are obtained based on the characteristics of the motor as shown in Fig. 4. Based on the graph, there is a threshold for this motor model which is at 3.5 V, where the linear relationship can only be seen after 3.5 V. The threshold occurred due to the insufficient voltage supply for the motor to move the tracks of the vehicle. In other words, both motors need more than 3.5 V of voltage to move the vehicle track. Also, it can be seen that both of the right and left motors possess the same characteristics amid minor differences which can be attributed to the friction and irregularities between the DC motors, sprockets and tracks.

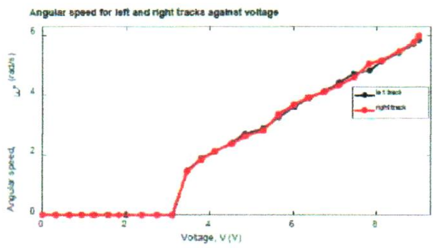

Fig. 4. Angular speed against voltage for vehicle's left and right tracks

3. DEVELOPMENT AND VALIDATION OF INDEPENDENT DC MOTOR CONTROLLER

Based on the previously obtained speed-voltage characteristics, an independent controller for both in-track DC motors is developed. An inverse database was developed from the motor characteristics in Fig. 4 to predict the required voltage (V_L and V_R) for any desired motor speed, (ω_L and ω_R), as shown in Fig. 5.

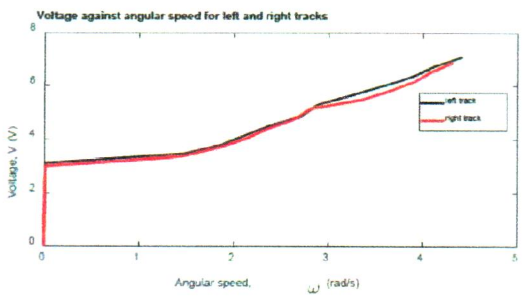

Fig. 5. Inverse model database developed from speed-voltage characteristics

With this, a linear interpolation method is used to accurately predict the voltage needed to achieve any desired track speed. With linear interpolation method, the data points from motor characteristics in Fig. 5 will be used. Each segment between each data point will be treated as a linear region and each arbitrary value (y_a) on an arbitrary point (x_a) will be determined by interpolating the pair of data ((x_i, y_i) and (x_f, y_f)) in-between them. This will be implemented to model the DC motor accurately. The resulting structure of DC motor controller is shown in Fig. 6.

$$y_a = y_i + (x_a - x_i)\frac{(y_f - y_i)}{(x_f - x_i)} \qquad (1)$$

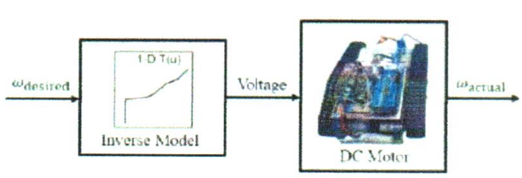

Fig. 6. Independent control structure for each in-track motor for tracked vehicle

Moreover, the experimental setup for experimental evaluation of the controller is developed using Arduino Mega 2560 connected to MATLAB Simulink software [22] which consists of digital output blocks (Pin 12 and 8) for rotation direction setting and PWM output blocks (Pin 11 and 9) for motor speed settings. Implementation of the controller is shown in Fig. 7.

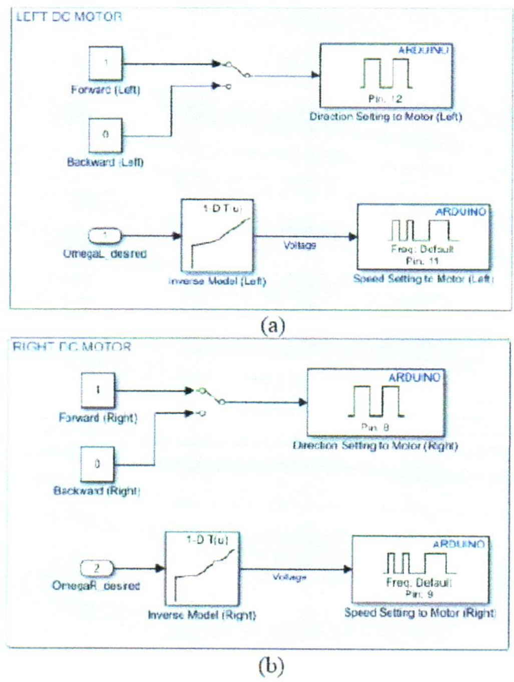

Fig. 7. Experimental setup for validation of controller for (a) left DC motor (b) right DC motor

Next, the developed motor model with open-loop control is validated by comparing the desired and actual speed of the track by varying its voltage. Desired speed is the outright speed supposed to be obtained by setting the voltage, whereby the actual speed is obtained by collecting the tracked vehicle's angular speed data during the experiment. Fig. 8 shows the results on the validation of the motor for left and right tracks. In this figure, it can be shown that both motors have good agreement between desired and actual speed produced.

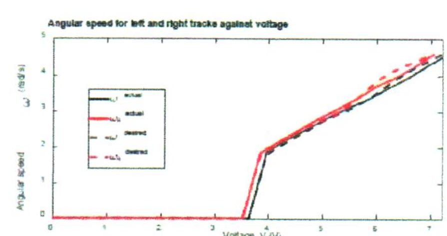

Fig. 8. Angular speed against voltage for vehicle's left and right tracks

4. CONCLUSIONS

An independent speed controller of DC motor for left and right tracks was developed based on the motor characteristics obtained experimentally. The proposed controller is then implemented and validated by an embedded Arduino Mega 2560 controller. The independent speed controller validation was done by comparing the desired speed and measured speed of the tracked vehicle's tracks. The developed model shows good agreement with the actual vehicle response and independent speed controller are shown to produce the desired speed with good accuracy with percentage error of about 2% between the desired and actual DC track speeds. It is hoped that this study can provide initial insights into the development of basic control scheme that will give impact to the readers who are still beginners in the control field.

ACKNOWLEDGMENT

The authors would like to thank the Malaysian Ministry of Education through research grants FRGS (FRGS/1/2021/TK02/UPNM/02/2) and Universiti Pertahanan Nasional Malaysia for their financial support, technical advises and the use of their research facility for this research.

REFERENCES

[1] N. A. I. Ruslan, N. H. Amer, K. Hudha, Z. A. Kadir, S. A. F. M. Ishak, and S. M. F. S. Dardin, "Modelling and control strategies in path tracking control for autonomous tracked vehicles: A review of state of the art and challenges," *Journal of Terramechanics*, vol. 105. Elsevier Ltd, pp. 67–79, Feb. 01, 2023. doi: 10.1016/j.jterra.2022.10.003.

[2] X. Wang, S. Dong, C. Zhang, and B. Jiang, "Analysis of torsion bar failure occurring during the pre-strained manufacturing for heavy off-road tracked vehicles," *Eng Fail Anal*, vol. 133, Mar. 2022, doi: 10.1016/j.engfailanal.2021.105956.

[3] B. Sebastian and P. Ben-Tzvi, "Active disturbance rejection control for handling slip in tracked vehicle locomotion," *J Mech Robot*, vol. 11, no. 2, Apr. 2019, doi: 10.1115/1.4042347.

[4] Z. Zhao, H. Liu, H. Chen, J. Hu, and H. Guo, "Kinematics-aware model predictive control for autonomous high-speed tracked vehicles under the off-road conditions," *Mech Syst Signal Process*, vol. 123, pp. 333–350, May 2019, doi: 10.1016/j.ymssp.2019.01.005.

[5] T. Liu and X. Hu, "A Bi-Level Control for Energy Efficiency Improvement of a Hybrid Tracked Vehicle," *IEEE Trans Industr Inform*, vol. 14, no. 4, pp. 1616–1625, Apr. 2018, doi: 10.1109/TII.2018.2797322.

[6] Y. Zou, F. Sun, X. Hu, L. Guzzella, and H. Peng, "Combined optimal sizing and control for a hybrid tracked vehicle," *Energies (Basel)*, vol. 5, no. 11, pp. 4697–4710, 2012, doi: 10.3390/en5114697.

[7] P. Wang, X. Rui, and H. Yu, "Study on dynamic track tension control for high-speed tracked vehicles," *Mech Syst Signal Process*, vol. 132, pp. 277–292, Oct. 2019, doi: 10.1016/j.ymssp.2019.06.031.

[8] J. Madsen, D. Negrut, and T. Heyn, "Methods for Tracked Vehicle System Modeling and Simulation," 2010. [Online]. Available: https://www.researchgate net/publication/326920675

[9] M. Saito, K. Tamaki, K. Nishiwaki, Y. Nagasaka, and K. Motobayashi, "Development of robot combine harvester for beans using CAN bus network," in *IFAC Proceedings Volumes (IFAC-PapersOnline)*, IFAC Secretariat, 2013, pp. 148–153. doi: 10.3182/20130828-2-SF-3019.00058.

[10] P. Dudziński and A. Kosiara, "Innovative system for monitoring the tip over stability of mobile excavating machines on a tracked undercarriage," *New Trends in Production Engineering*, vol. 2, no. 1, pp. 104–111, Oct. 2019, doi: 10.2478/ntpe-2019-0011.

[11] M. Salah and A. Al-Jarrah, "Robust backstepping control for tracked vehicles under the influence of slipping and skidding," *Proceedings of the 2019 20th International Conference on Research and Education in Mechatronics, REM 2019*, vol. 5, pp. 1–6, 2019, doi: 10.1109/REM.2019.8744096.

[12] P. Sivakumar, R. Reginald, G. Venkatesan, H. Viswanath, and T. Selvathai, "Configuration study of hybrid electric power pack for tracked combat vehicles," *Def Sci J*, vol. 67, no. 4, pp. 354–359, Jul. 2017, doi: 10.14429/dsj.67.11454.

[13] A. Al-jarrah, "Controlling a Skid-Steered Tracked Mobile Robot with Slippage Using Various Control Schemes," *2019 20th International Conference on Research and Education in Mechatronics (REM)*, vol. 5, pp. 1–7, 2019.

[14] A. Ma'Arif, Iswanto, N. M. Raharja, P. A. Rosyady, A. R. C. Baswara, and A. A. Nuryono, "Control of DC Motor Using Proportional Integral Derivative (PID): Arduino Hardware Implementation," in *Proceeding - 2020 2nd International Conference on Industrial Electrical and Electronics, ICIEE 2020*, Institute of Electrical and Electronics Engineers Inc., Oct. 2020, pp. 74–78. doi: 10.1109/ICIEE49813.2020.9277258.

[15] M. S. Adli, N. H. H. Mohamad Hanif, and S. F. T. Tohara, "Brushless DC motor speed controller for electric motorbike," *International Journal of Power Electronics and Drive Systems*, vol. 9, no. 2, pp. 859–864, Jun. 2018, doi: 10.11591/ijpeds.v9.i2.pp859-864.

[16] N. M. Sultan *et al.*, "Modeling and speed control for sensorless DC motor BLDC based on real time experiment," *International Journal of Integrated Engineering*, vol. 11, no. 8, pp. 55–64, 2019, doi: 10.30880/ijie.2019.11.08.007.

[17] P. S. Vikhe, B. S. Shukla, C. B. Kadu, and V. V.

Mandhare, "Speed control of BLDC motor using open loop, PID controller and neural network," *Int J Eng Adv Technol*, vol. 9, no. 1, pp. 2210–2213, Oct. 2019, doi: 10.35940/ijeat.A9710.109119.

[18] F. Auliansyah, Sutedjo, O. Asrarul Qudsi, and I. Ferdiansyah, "Controlling speed of brushless dc motor by using fuzzy logic controller," in *Proceedings - 2020 International Seminar on Application for Technology of Information and Communication: IT Challenges for Sustainability, Scalability, and Security in the Age of Digital Disruption, iSemantic 2020*, Institute of Electrical and Electronics Engineers Inc., Sep. 2020, pp. 298–304. doi: 10.1109/iSemantic50169.2020.9234290.

[19] A. K. Naik, S. K. Kar, and B. K. Sahu, "Speed control of DC motor using linear and non-linear controllers," in *1st Odisha International Conference on Electrical Power Engineering, Communication and Computing Technology, ODICON 2021*, Institute of Electrical and Electronics Engineers Inc., Jan. 2021. doi: 10.1109/ODICON50556.2021.9428996.

[20] M. Nassim and A. Abdelkader, "Speed Control of DC Motor Using Fuzzy PID Controller," Aug. 2021, [Online]. Available: http://arxiv.org/abs/2108.05450

[21] S. Balamurugan and A. Umarani, "Study of Discrete PID Controller for DC Motor Speed Control Using MATLAB," in *2020 International Conference on Computing and Information Technology, ICCIT 2020*, Institute of Electrical and Electronics Engineers Inc., Sep. 2020. doi: 10.1109/ICCIT-144147971.2020.9213780.

[22] "Arduino Support from Simulink," [Online]. Available: *https://uk.mathworks.com/hardware-support/arduino-simulink.html*.