Type of contribution:
Editorial
▶ Research Paper
Case Study
Review Paper
Report of Tech. Application

e-issn. 2798-5245
Mechanical Engineering for Society and Industry
Vol. 1, No. 1 (2021) pp 14-21
https://doi.org/10.31603/mesi.5263

Fuel Control Systems for Planetary Transmission Vehicles: A Contribution to the LPG-fueled Vehicles Community

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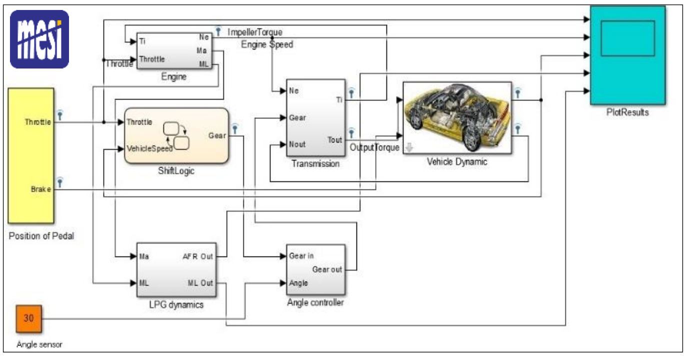

Highlights:
- The automatic transmission control system is successfully developed
- A design of transmission control circuit is presented in this study
- Controller is capable of controlling the speed gear

Abstract
The bi-fuel system vehicle (gasoline/LPG) has been developed for a long time because it has the ability to switch fuels, both built as an original equipment manufacturer (OEM) or as a modified vehicle. However, on vehicles with planetary automatic transmissions, additional control systems are needed to produce optimal performance, both on gasoline and LPG operations, especially on uphill roads. Old vehicles with planetary automatic transmissions are not equipped with road slope angle sensors, so on uphill roads and the driver has not mastered road conditions, the engine tends to stop suddenly. Therefore, this study aims to develop a fuel control system (LPG operation) on a planetary automatic transmission to control gear shifts based on the level of the road slope. A simulation with MATLAB Simulink we used to create a control system, with objective function and constraint defined. As a result, the control system can recognize the level of the road slope to control the speed gear shift. This control system is promising and reliable to be implemented in real conditions.

Keywords: LPG, Bi-fuel vehicles, Automatic transmission, Control systems

Article info
Submitted: 2021-05-01
Revised: 2021-06-11
Accepted: 2021-06-25

Publisher
Universitas Muhammadiyah Magelang

1. Introduction

Liquefied petroleum gas (LPG) is an alternative fuel used in vehicles to improve efficiency and reduce emissions. Many studies on the use of LPG as a fuel have been carried out using various variables. For instance, Nguyen [1] and Kim [2] conducted an LPG study to reduce vehicles' emissions, using the injection method. However, their research was unable to determine the transmission control system in accordance with road conditions. The performance of bi-fuel vehicles in a variety of mixers and ignition timings is also comprehensively reported by Setiyo et al. [3], [4].

Kim made observations on the Air to Fuel Ratio (AFR) characteristics of LPG in the lean mixture [5]. His research aimed to determine the effect of urban driving to economize the significant utilization of fuel. However, the drawback is the inability to transfer energy systems towards LPG characteristics, which was applied as an alternative means of fuel to the auto-ignition [6]. This research uses LPG in diesel engines, with the addition of Hydrotreated Vegetable Oil (HVO) as a fire ignition variable. The results showed a mixture of 25 LPG-75 HVO (without modification of injection strategy) and 50LPG-50HVO (an advanced injection strategy) can enhance the ignition behavior under low thermal conditions. Furthermore, the research was unable to control the power transfer system in accordance with changes in road conditions. The compression ratio effect was observed towards the increase in LPG engine power. Ravi [7] carried out experimental research using the compression ratios of 9: 1, 10: 1, 10.5: 1, and 11: 1 with various variations on the LPG engine. The results showed the effect of the compression ratio on heat efficiency, decreased hydrocarbons, and carbon monoxide. However, this research only focused on the engine and not on controlling the power transfer system.

The development of automatic transmission is in great demand by vehicle users because it offers many driving advantages, such as comfort and safety. Studies on the development of automatic transmission control systems using multi-phase strategies for power transfer clutch in hybrid vehicles have not been conducted [8]. Dong [9] developed an automatic transmission control system from a variable Internal Combustion Engine (ICE), flywheel, and electric motor (EM) to support system control. The experimental results show that driveline oscillations can be effectively reduced by coordinating slippage between the ejecting and shifting clutches. However, it did not consider the characteristics of the fuel used, as well as the road slope angle. The adaptive fuzzy iterative control strategy is used for clutch control in automatic transmission and reduces deviation to enable the smooth processing of the speed gear shifting [10]. Studies on power transfer systems capable of recognizing road slope angles, especially LPG vehicles, have not been widely conducted. Based on practical experience, the main problem with planetary automatic transmission is that the driver is not skilled and does not recognize the angle of the road, so the car is not strong enough to climb due to the inappropriate speed gear selection. Therefore, this research aims to develop an automatic transmission system in LPG vehicles to control gear shifting based on the road slope angle using a multilevel system.

2. Method

2.1. Automatic transmission modeling

Automatic transmission modeling is made up of 8 parts, namely position of pedals, shift logic modeling, engine, transmission, LPG dynamics, angle controller, angle sensor and vehicle dynamics. The vehicle has a throttle valve pedal and brake pedal represented by the position of the pedal. Shift logic modeling is used to adjust gear shifting based on information from the throttle valve and vehicle speed. Engine to generate propulsion energy in the vehicle. The speed gear position is modeled by transmission. LPG dynamics to describe the conditions of LPG flow in a vehicle's fuel system. An angle sensor is used to determine the position of the vehicle when operating on an incline. The angle controller will provide information to the transmission based on input from the angle sensor and shift logic modeling. The movement of the vehicle while operating on the highway is modeled by vehicle dynamics. Figure 1 shows the schematic of modeling automatic transmission.

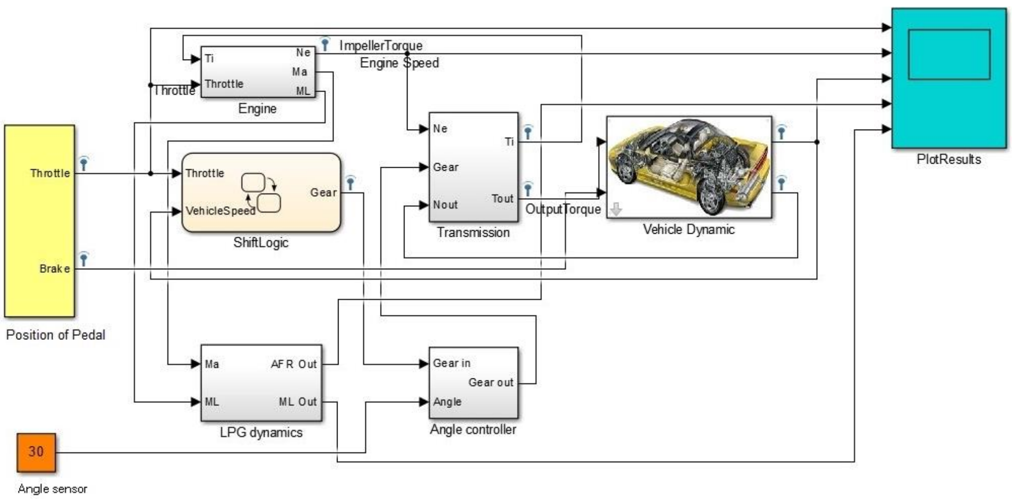

Figure 1. Schematic of modeling automatic transmission

2.2. Shift logic modeling

Shift logic modeling illustrates the speed gear shift patterns in automatic transmission. This system consists of a gear and a selection state. The gear state has 1-4 positions, while the selection state has a speed shift operation logic comprising of upshifting and downshifting. The Shift logic on automatic transmission gear control is shown in Figure 2. Shift logic modeling describes four-speed gear positions, including speed gear 1, speed gear 2, speed gear 3, and speed gear 4.

2.3. Engine modeling

Engine modeling uses a throttle valve opening operation system to input the torque converter in an automatic transmission. The engine modeling formula is presented in Equation 1. Where I_{ei} denotes the moment of inertia from the engine and impeller, N_e is the engine speed dynamics (rpm), T_e is the engine torque and T_i is the torque impeller (ft-lb) [11].

$$I_{ei} \cdot N_e = T_e - T_i \quad (1)$$

The torque mapping generated by the engine is shown in Figure 3. Engine torque is controlled by opening the throttle valve. The characteristics of the torque converter speed while operating is described in Equation 2, 3, and 4. K denotes the capacity factor, N_{in} is the speed turbine (torque converter output), R_{TQ} is the torque ratio, and N_e is the resulting engine speed (rpm).

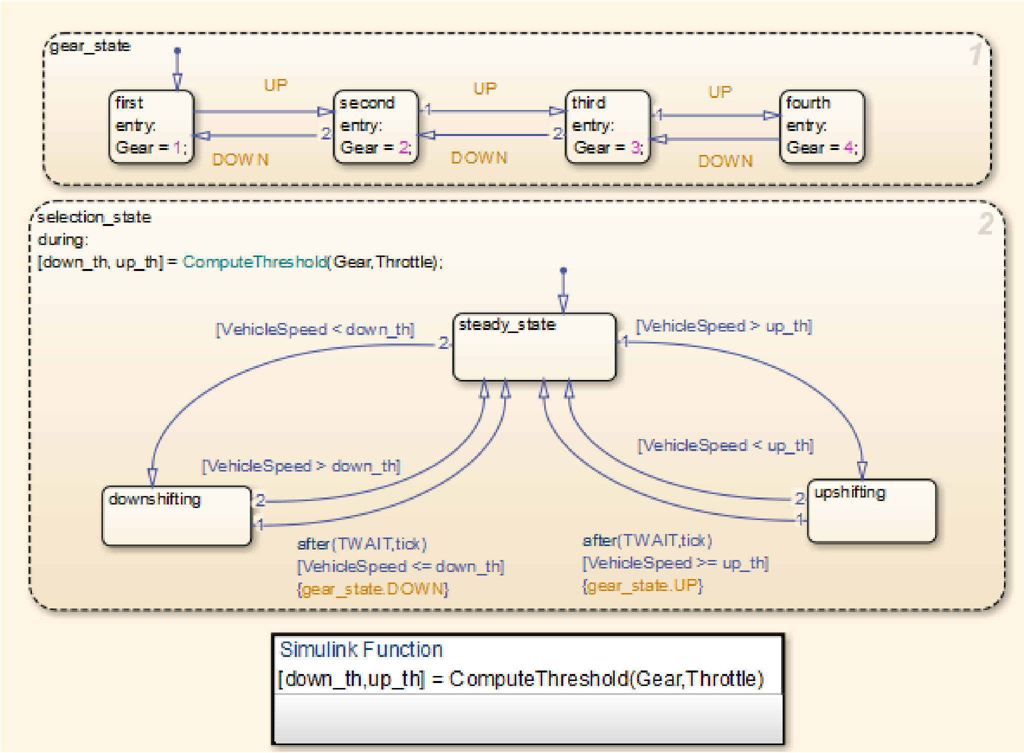

Figure 2. Shift logic on automatic transmission gear control

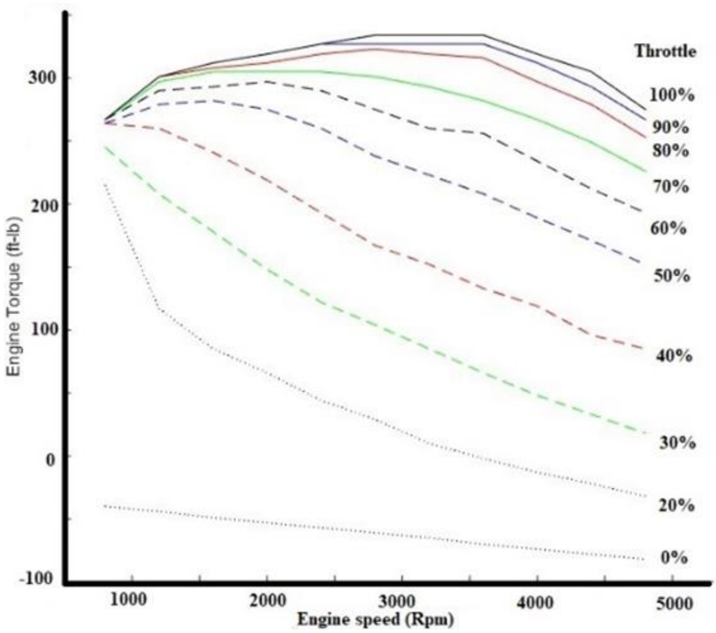

Figure 3. The torque mapping generated by the engine

$$T_i = \frac{N_e^2}{K^2} \quad (2)$$

$$K^2 = f_2.\frac{N_{in}}{N_e} \quad (3)$$

$$R_{TQ} = f_3.\frac{N_{in}}{N_e} \quad (4)$$

2.4. Transmission

This modeling has several parts consisting of the transmission ratio formulation modeling and torque converter. The modeling transmission consists of the static gear ratio positions, as shown in Equations 5, 6, and 7. R_{TR} is the transmission ratio, T_{in} is the input transmission, T_{out} is the output torque, and N_{out} is output speed (rpm). Torque converter models a hydraulic clutch that works to disconnect and connect the engine speed to the transmission. The torque converter works on the principle of two turbines side by side. Turbine one is known as a pump impeller. Turbine two is known as the turbine runner. Media for transferring power from the pump impeller to the turbine runner uses oil. The transmission ratio position provides information about the speed gear position when the vehicle is running. Figure 4 shows modeling of transmission parts.

$$R_{TR} = f_4(gear) \quad (5)$$

$$T_{out} = R_{TR}.T_{in} \quad (6)$$

$$N_{in} = R_{TR}.N_{out} \quad (7)$$

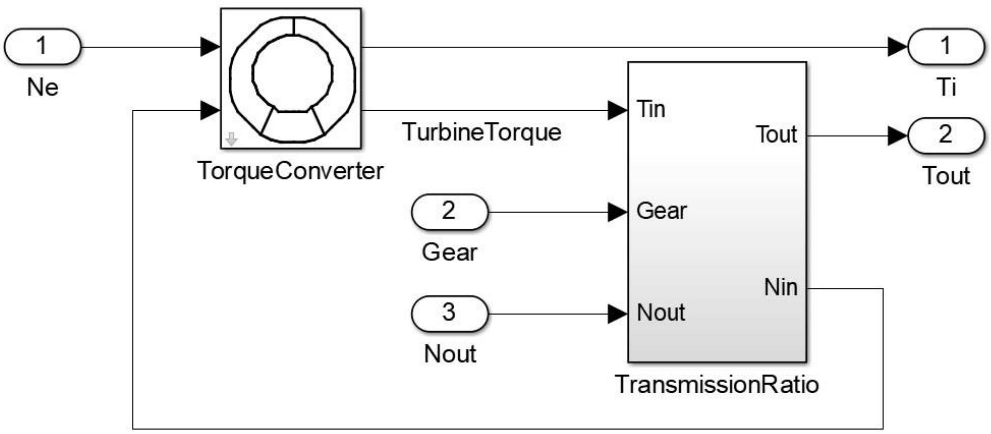

Figure 4. Modeling of transmission parts

2.5. Vehicle dynamic modeling and angle control system

Vehicle dynamic has three subsystems, namely end drive array systems, inertia, and dynamically varying loads. Equations 8 and 9 are used to determine the vehicle inertia and wheel speed. Where I_v denotes vehicle inertia, N_w is the wheel speed (rpm), R_{fd} is the final drive ratio, and T_{load} is the load torque, including road load and brake torque.

$$I_v \cdot N_w = R_{fd}(T_{out} - T_{load}) \quad (8)$$

$$T_{load} = f_5 \cdot N_w \quad (9)$$

Road load is the sum of the friction losses and aerodynamics. Where mph is the linear vehicle velocity, T_{brake} is the brake torque, T_{load} is load torque, and R_{load0} and R_{load2} are the friction and coefficient drag, as formulated by Equation 10.

$$T_{load} = \text{sgn}\ (mph)(R_{load0} + R_{load2}mph^2 + T_{brake}) \quad (10)$$

To design the angle control system using a multilevel system, the road's slope angle is recognized by the signal generated by the accelerometer sensor. The signal generated is analog, while the angle control system works to provide information on transmission based on information from the accelerometer sensor.

2.6. LPG dynamics modeling

LPG dynamic described the flow of LPG in the fuel system and applied to the 1998 cc engine. It also presents the vd engine volume (m^3), ma airflow in the intake manifold (g/s), nv volumetric efficiency, ρa air density (kg/m^3). The LPG that enters the intake manifold is controlled by an engine control unit (ECU), which works based on input from various sensors [12]. The formulation process is shown in Equations 11, 12, and 13. The air entering the engine is assumed to be 1.2 kg/m^3. The determination of volumetric efficiency refers to a study carried out by Masi [13].

$$m_a = \frac{\eta_v.\rho_a.V_d.N}{12.10^7} \tag{11}$$

$$m_L = \frac{m_a}{AFR} \tag{12}$$

$$AFR = \frac{m_a}{m_L} \tag{13}$$

3. Results and Discussion

The automatic transmission modeling test is operated at the throttle valve opening from 0 to 58%, which was linearly performed for 30 seconds, as shown in Figure 5a. Furthermore, the engine speed simulation results are shown in Figure 5b. In the second, the speed decreased from 2700 rpm to 2300 rpm due to a gear shift from 1 to 2. In the 4^{th} second, the engine speed decreased from 2800 rpm to 2400 rpm, and automatic transmission experienced a further shift from gear 2 to 3. While in the 8^{th} second, the engine speed fell from 3000 rpm to 2500 rpm due to a shift in speed from gear 3 to 4.

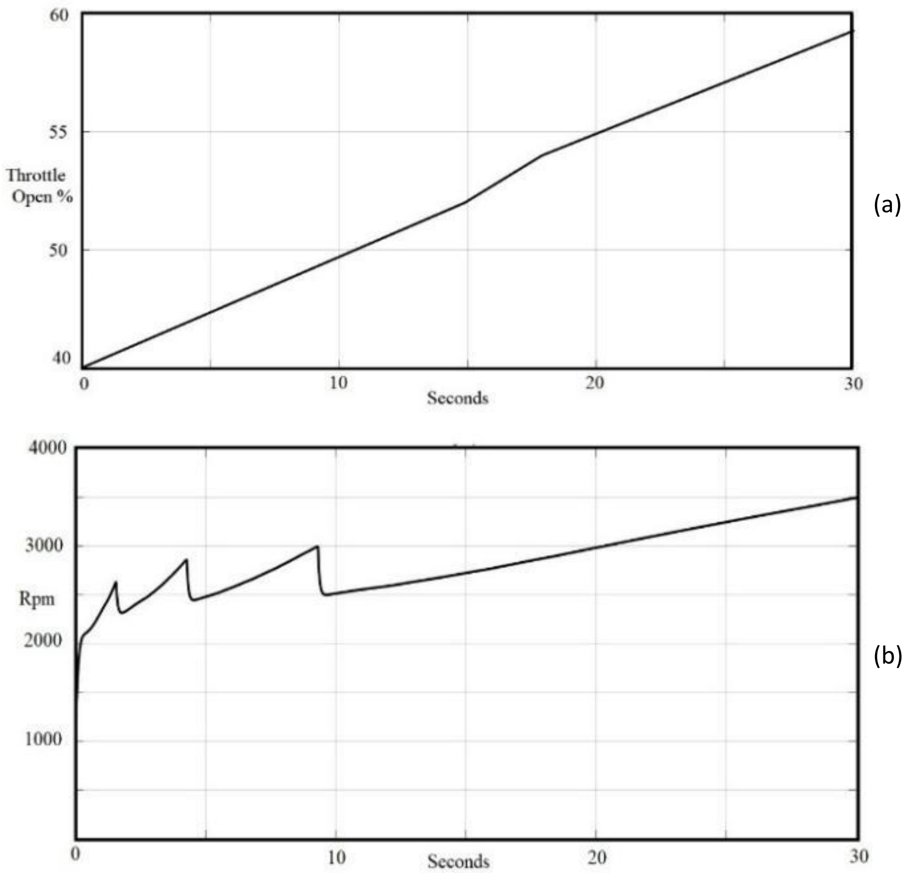

Figure 5. Opening throttle valve (a) and simulating engine speed (b)

The LPG Air to Fuel Ratio (AFR) simulation has a range of 15.6 when the speed gear shift occurs, which has a slight change in the AFR LPR value. When a speed gear shift occurs, the AFR decreases by about 1-5, as shown in Figure 6b. The LPG flow simulation underwent several changes in the 2^{nd}, 4^{th}, and 8^{th} seconds, with gradual fluctuations. LPG flow dynamics are shown in Figure 6a.

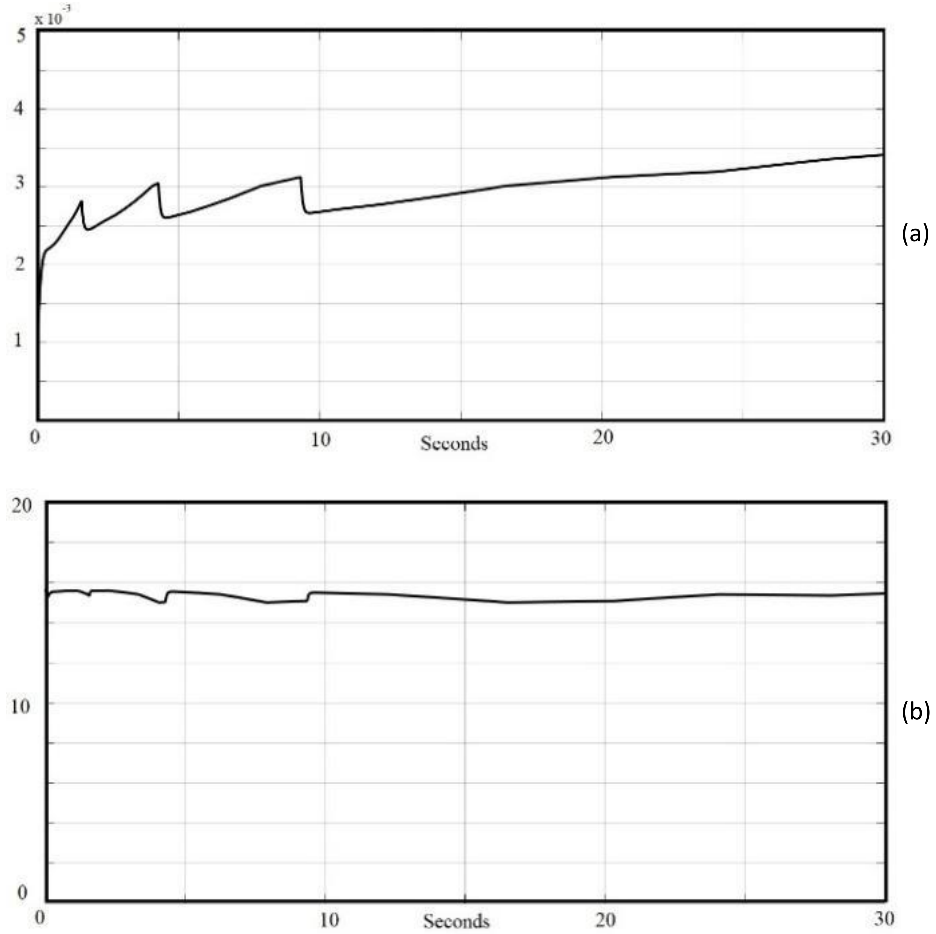

Figure 6. Simulation of LPG flow (a) and AFR LPG (b)

The vehicle speed simulation is shown in Figure 7. In the initial position, the vehicle was simulated on a slope inclined at an angle of 5°, and in 5th, 10th, 15th, and 20th seconds, its moving speeds were 66 km/h, 84 km/h, 90 km/h and 110 km/h. In the next process, the vehicle was simulated on a slope inclined at an angle of 15° and in 5th, 10th, 15th, and 20th seconds, its moving speeds were 65 km/h, 76 km/h, 83 km/h, and 86 km/h. In the final process, the vehicle was simulated on a slope inclined at an angle of 25°, and in 5th, 10th, 15th, and 20th seconds, its moving speeds were 63 km/h, 73 km/h, 79 km/h and 82 km/h.

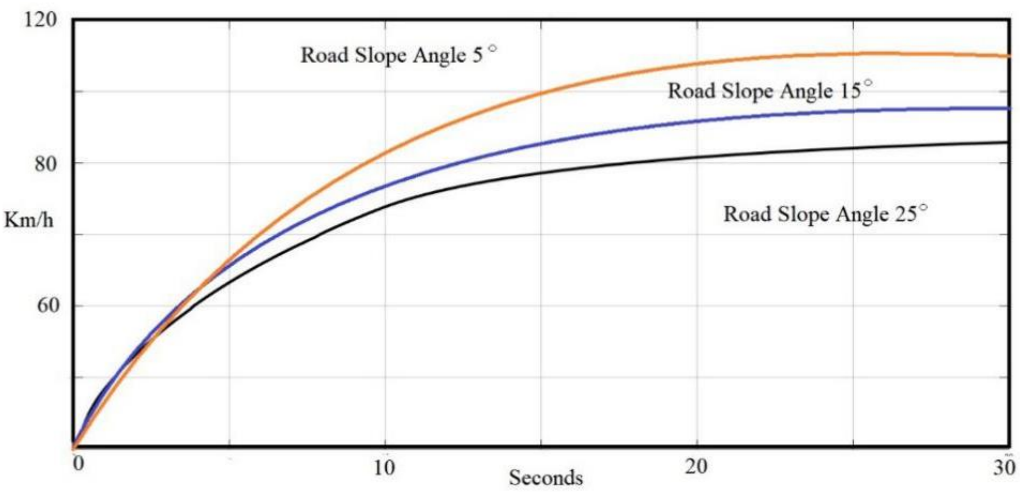

Figure 7. Result simulation vehicle speed with angle position controller

The simulation results from the road slope angle of 5°, 15°, and 25° have different decreases in speed. The change comparison in vehicle speed to the road slope angle is shown in Table 1. The speed of the vehicle decreases with an increase in the tilt angle of the vehicle. The largest and smallest decrease in vehicle speed occurs at slope angles of 25° and 5°.

Table 1. Change comparison in vehicle speed to the road slope angle

No.	Time (second)	Vehicle speed (km/h) based on the road slope angle			Decrease ratio of vehicle speed (km/h)		
		5°	15°	25°	Between 5° and 15°	Between 5° and 25°	Between 15° and 25°
1.	5th	66	65	63	1	3	2
2.	10th	84	76	73	8	11	3
3.	15th	90	83	79	7	11	4
4.	20th	110	86	82	4	28	4

4. Conclusion

Based on the simulation of automatic transmission performance, it can be concluded that the control system can regulate the speed gear following the road angle. The vehicle speed changes in accordance with the road's tilt angle. It can be seen when the vehicle is simulated at a road angle of 5°. The vehicle speed in the 5th period (seconds) is at 66 km/h, while in the 20th period (seconds), the automatic control system regulates the vehicle speed at 110 km/h according to the throttle valve position opening and vehicle load. However, when the vehicle is simulated at a road angle of 25°, the developed automatic control system directly regulates the gear speed at a lower shifting scheme even though the throttle valve opening, and vehicle load are in the same condition. Then in the 5th period (seconds), the vehicle speed is reduced to 63 km/h, while in the 20th period (seconds), the vehicle speed is reduced to 82 km/h. Therefore, based on these conditions, this control system can be applied in real condition.

Acknowledgments

The authors are grateful to the Kemenristek for funding this study in the 2020 fiscal year and the Universitas Muhammadiyah Magelang for support in the administration of this research.

Authors' Declaration

This research was supported by:

KEMENTERIAN PENDIDIKAN DAN KEBUDAYAAN

Universitas Muhammadiyah Magelang unimma

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

Funding - This study was supported by the Ministry of Research and Technology, Republic of Indonesia. Grant scheme: *Penelitian Terapan Unggulan Perguruan Tinggi* – PTUPT, 2020.

Availability of data and materials - All data are available from the authors.

Competing interests - The authors declare no competing interest.

Additional information - No additional information from the authors.

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