Middle East Journal of Applied Sciences, 4(4): 1000-1006, 2014
ISSN: 2077-4613

Modeling and Simulation of Gear-Shift Controller for Automated Manual Gearbox Based on Neuro Fuzzy Control Logic

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ABSTRACT

Gear shift control of automated manual transmissions (AMT) has many advantages in terms of improvement of driving comfort, reduction of fuel consumption and shifting quality. This paper aims to present a mathematical model, simulation, for gear-shift controller of automated manual gearbox (AMG) using neuro fuzzy approaches. The neuro fuzzy control is used for shift decision making at maximum torque, which will be correspond to the best shift. The mathematical and the control logic for the model have been developed using Matlab/Simulink software tool.

***Key words**:* Automated manual transmission, Automated manual gearbox, Gear shifting mechanism, Neuro fuzzy control logic.

Introduction

The development of automotive transmissions are improving driving performance, increasing driving comfort, reliability and service life, reducing installation, costs, fuel consumption and pollutant emissions space, raising efficiency levels (Kuchle *et al.* 2010). According to previous survey, there are several types of transmissions such as the manual transmissions (MT), automated manual transmissions (AMT), dual clutch transmissions (DCT), conventional automatic transmissions (AT), continuously variable transmissions (CVT) and hybrid drives (Cho *et al.* 2000). The automated manual transmission (AMT) is designed and applied to make an intermediate technological solution between the manual transmission and the automated transmission as it combine the best features in the manual and automatic transmissions. Automated manual transmission develops the manual transmission to automatic transmission by breaking the operating chain at one point and inserting hydraulic, pneumatic or electric automatic actuators (Zhong, Lv, and Kong 2012). AMT has become successful, because it combines the best features in the manual and automatic transmissions. Moreover, it is more compact and reliable aggregates (Kuchle *et al.* 2010).

Automated Manual Gearbox (AMG) is one of the basic components of the automated manual transmissions system. AMG could be introduced as add-on solution that increases driver driving comfort especially in countries where manual transmission is more popular. In addition, its low production cost, ease of use and especially due to the new restricted pollution and fuel economy legislations for new vehicles (Haggag and Omran 2014). Bansbach (1998), used electromechanical actuators under microprocessor control to describes the modification of a rear wheel drive manual transmission for the purpose of shifting. Sakaguchi *et al.* (1999) developed an algorithm for the calculation of the combinations between the engine torque and CVT ratio in order to achieve the highest overall efficiency for the engine and transmission system. a continuous-time model and controller for the drivetrain dynamics and hydraulics governing the dynamics ratio of a metal V-belt continuously variable transmission was developed by Foley *et al.* (2001). Lucente *et al.* (2007) introduced simplified hybrid model of an Automated Manual Transmission system with servo-actuated clutch and gearbox. The gear upshift request is performed with locked clutch and achieving the synchronization of the requested gear by exploiting engine cut-off and properly controlling the engine and the gearbox. Chenglin *et al.* (2004), presented new shift control algorithm without clutch operation for reducing the shift shock and improving accelerating ability of a parallel hybrid vehicle with an automated manual transmission.

The current research is concerning on the control of clutch, gearshift, and engine using different algorithms such as fuzzy control, pattern recognition, self-learning algorithm and sliding mode control etc. Jo *et al.* (2000), proposed an advanced shift control algorithm for a parallel hybrid drivetrain system with automated manual transmission (AMT). Jacobson *et al.* (2003), used the dynamic programming technique to set up an analytical tool for determining the optimal gear-shift sequence applicable to any given vehicle and driving situation. An optimal control approach for gear shift operations in automatic transmissions was proposed by Haj-Fraj and Pfeiffer (2001). Tan *et al.* (2007), used the Neural network to describe the torque and fuel consumption characteristics of engine under non-stable work conditions, and the automatic gear-shifting decision. Liu *et al.* (2014), presented the shift control strategy and the related experiments for dry dual clutch

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transmissions (DCT). The gearshift processes, upshifts and downshifts, have been analyzed by model simulation. The control strategies for both the torque phase and the inertia phase of both clutches were proposed during the shift process respectively.

In the present works, the mathematical model, Simulation, and the gear shift control algorithm of automated manual gearbox are presented by using neuro fuzzy control. Matlab/Simulink is used as a simulation software tool to develop the mathematical model and control logic for the integrated vehicle powertrain model.

Mathematical Model

In this section, the mathematical proposed model derived. Figure 1 shows the system is modeled as an integrated two-degree-of-freedom engine and clutch inertia at the engine flywheel and vehicle chassis equivalent inertia at vehicle wheel in which each element is a lumped mass model. By applying Newton's second law, the equation of motion of the engine is:

$$T_e(\beta, \theta_e) - T_c = J_{eq}\,\ddot{\theta}_e \quad (1)$$

Where J_{eq} is the equivalent inertia of the engine and its fly wheel inertia, $\ddot{\theta}_e$ is engine angular velocity, T_e is the engine torque which is assumed to be function in the throttle opening β and the engine speed θ_e , T_c is the clutch transmitted torque.

When the clutch is engaged, the equation of motion of the clutch as:

$$T_c = k(\theta_e - \theta_g) + C(\dot{\theta}_e - \dot{\theta}_g) \quad (2)$$

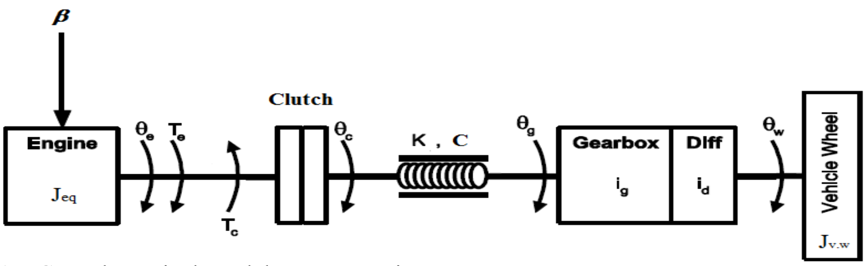

Fig. 1. AMG Mathematical Model Representation

Where θ_g is the gearbox input shaft angle of rotation, k is clutch equivalent stiffness coefficient, and C is the clutch equivalent damping coefficient. The input speed of the gearbox and the output speed of the final drive (differential) could be easily related by the following equation:

$$\theta_g = i_g\, i_d\, \theta_w \quad (3)$$

$$\dot{\theta}_g = i_g\, i_d\, \dot{\theta}_w \quad (4)$$

Where, θ_w vehicle wheel angular position, i_g is the gearbox shift reduction ratio, and i_d is the differential reduction ratio.

Automated Manual Gearbox Simulation Model

In this section, the simulation model of the automated manual gearbox system is carried out by using MATLAB software ver. 8.3 (R2014a). The main simulink model, illustrated in figure 2 to figure 5, which consists of four subsystem blocks; engine, clutch and gearbox, vehicle body, and shifting logic block. Figure 2 represents the engine subsystem block, which used to solve the engine differential equation (1). The clutch transmitted torque is calculated based on the clutch disk angular stiffness and damping, while the gear selector selects the desired gear shift which depends on the selected gear from the fuzzy logic block. The clutch and gearbox are presented in figure 3.

Figure 4 shows the vehicle body subsystem block, which equivalent to the vehicle wheel inertia (which represented the vehicle body) and the rolling resistances were considered as system friction. Fuzzy logic controller is responsible for the shift decision making depending on two parameters as inputs which are the throttle opening and the vehicle wheel revolution per minute (rpm) to reach the desired output gear shift to reach the maximum performance. The shifting logic controller is presented in figure 5.

In order to reach the maximum performance; a robust control system was designed. It uses neuro fuzzy control for the shift decision making at maximum torque which will correspond to the best shift. This shift decision making system uses the trained shifting data stored depending on two parameters as inputs which are the vehicle wheel rpm and the throttle opening to reach the desired output gear shift, as shown in figure 6.

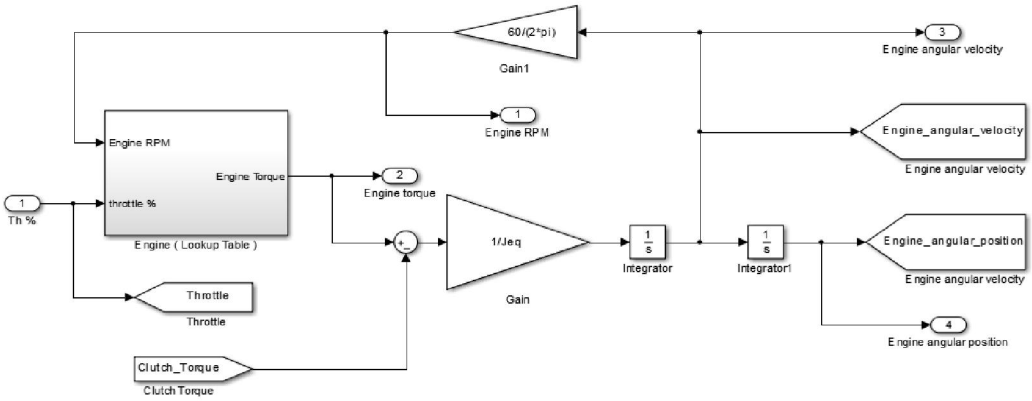

Fig. 2. Engine Subsystem Block

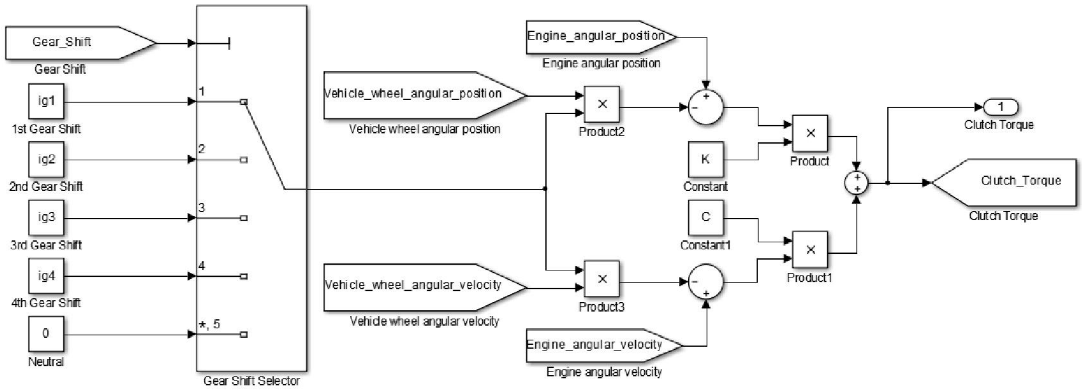

Fig. 3. Clutch and Gearbox Subsystem Block

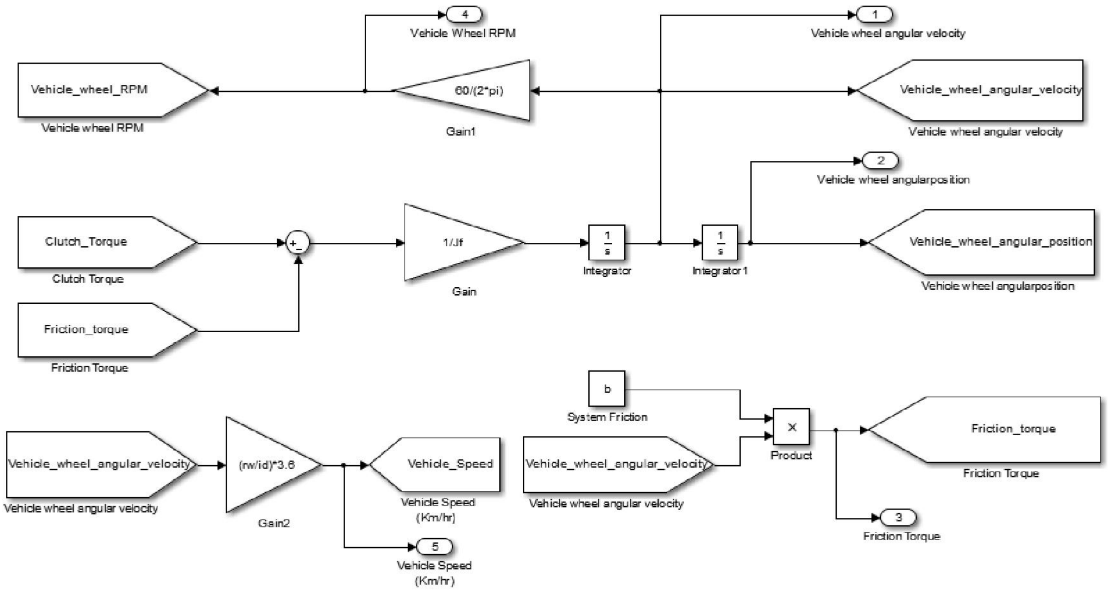

Fig. 4. Vehicle Body Subsystem block

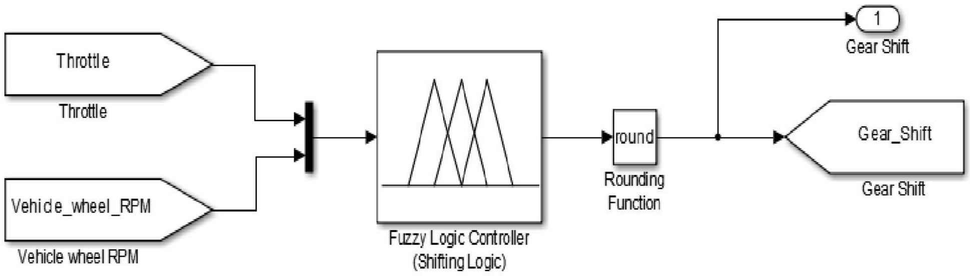

Fig. 5. Shifting Logic Subsystem block

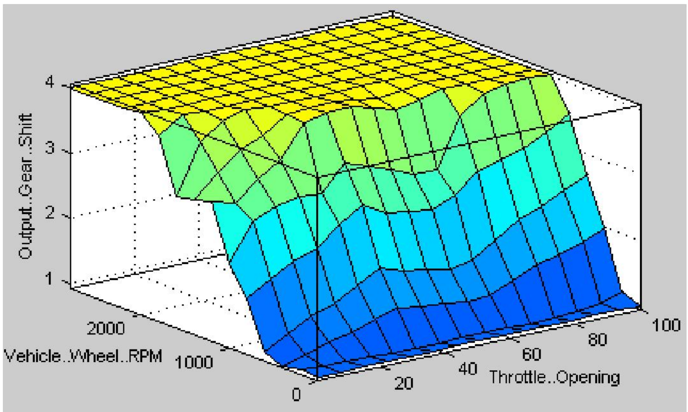

Fig. 6. The trained shift control surface

Simulation Results

In order to characterize the performance of the simulated automated manual gearbox system, different operating conditions with different throttle valve positions were applied to the Matlab-Simulink model. Figure 7 shows the results of the gear shifting time of an automated manual gearbox consisting of four shift gears. Figure 7(a) shows an applied throttle opening set at (0.66% per sec) slope for 150 sec. Figure 7(b) shows the gear shifting time from 1st to 4th gear. The vehicle speed is shown in figure 7(c). The results for gear shifting time for an applied throttle value of 1% per sec slope and 100% throttle opening are shown in figure 8 and figure 9 respectively. Moreover, we can see in figures 7(a) and 7(b) the gear shifting time is consistent with the throttle opening.

It is observed that, when the throttle opening rate is increased the gear shifting time decreases accordingly to the change in the throttle opening rate as shown in figures 8 and 9 respectively. The least gear shifting time is obtained when the throttle opening is set to 100% and maximum velocity is obtained in a much lesser time.

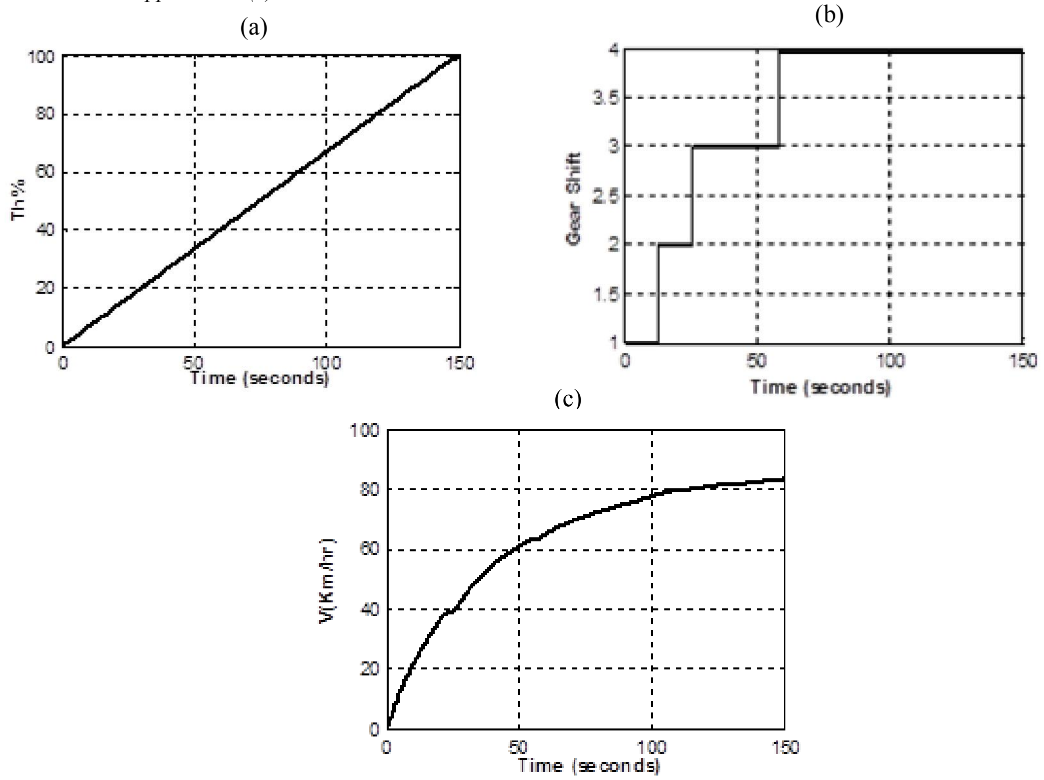

Fig. 7. Simulation results for throttle valve position set at 100% ramp with (0.66% per sec) slope for 150 sec

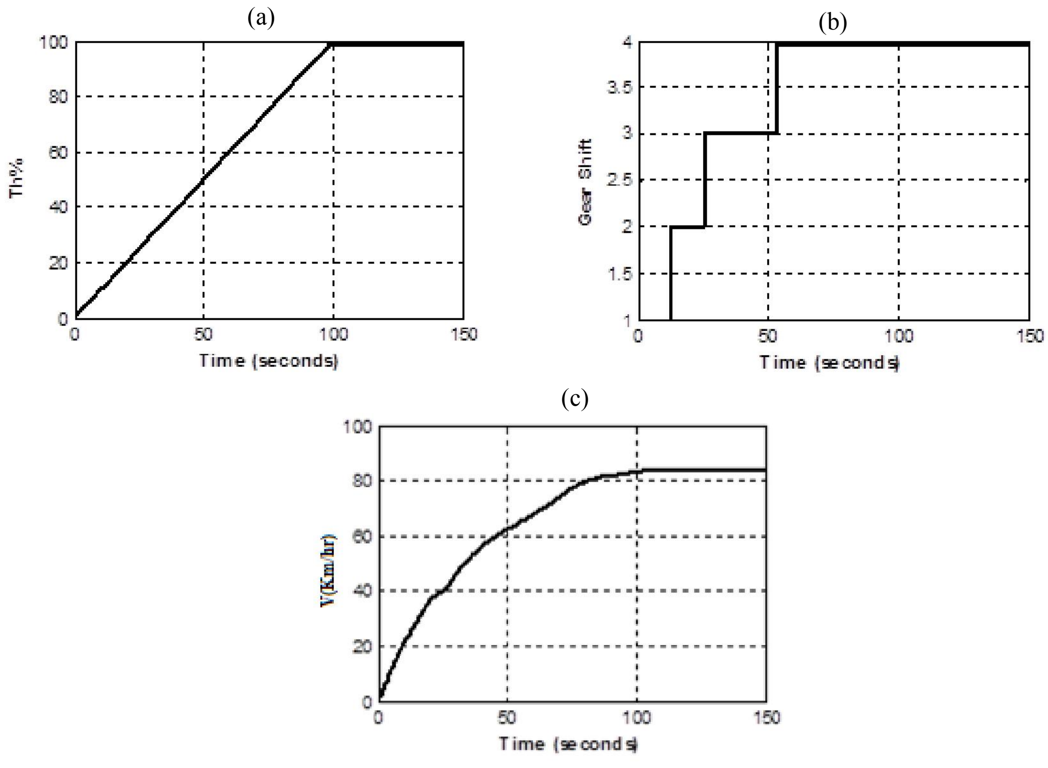

Fig. 8. Simulation results for throttle valve position set at 100% ramp with (1% per sec) slope up to 100 sec than stay constant for 150 sec

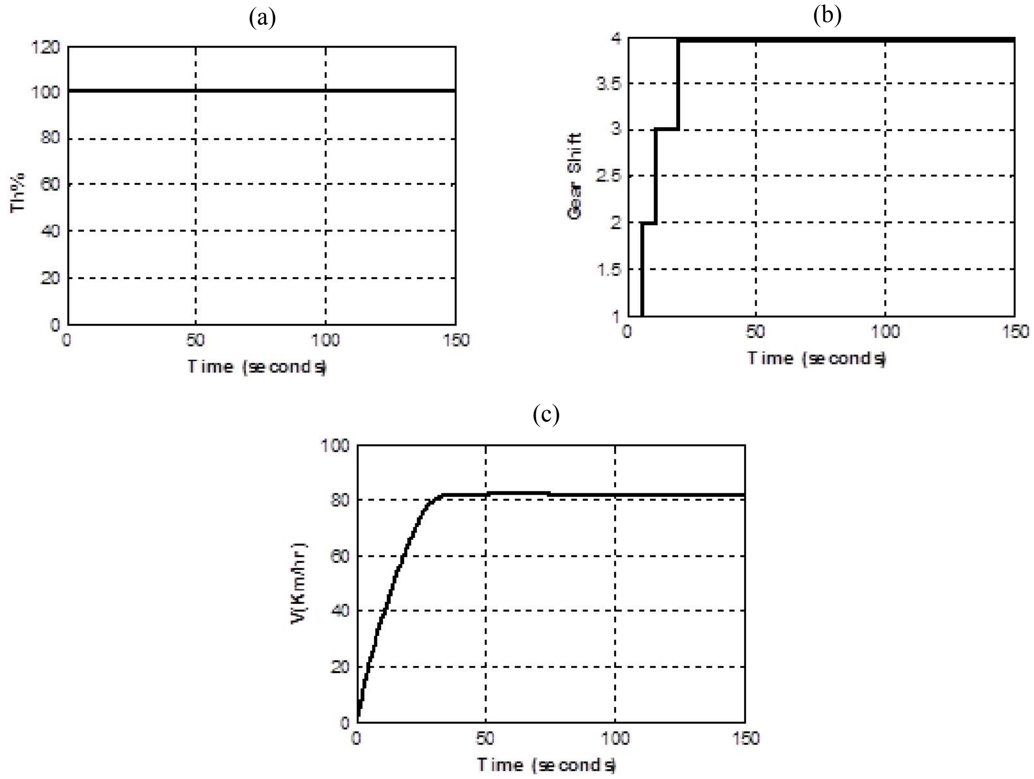

Fig. 9. Simulation results for throttle valve position set at 100% at full engine load for 150 sec

Conclusion

The simulation and mathematical model of the gear shift control algorithm of automated manual gearbox were presented in this paper. Neuro fuzzy control was used for the shift decision making at maximum torque which will correspond to the best shift through Matlab/Simulink software tool. The simulated result indicates that the developed system can predict the gear-shift performance of the target vehicle successfully.

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