TCU Based Fast Testing Platform for Automated Manual Transmission

[1]Tapas Ranjan Mahapatra, [2]Biswa Ranjan Swain

Abstract--- *To lower the time of development cycle and transmission controlling unit (TCU) cost for automatic manual transmission (AMT), a "rapid testing platform (RTP)" in light of the idea of hardware loop simulation is presented and executed in this paper. The proposed RTP highlights that the vehicle parts in reproduction are on the whole model-based. Torque characteristics for the engine, the mechanical quality of the DC engine, and the torque moving trait of grip are talked about. By numerical demonstrating, simulators of vehicle movement, clutch, actuators, engine and gearbox that form the RTP for TCU are created. Through the technique of signal processing, those simulators have been embodied in an embedded system with functioning networks. Experiments with an outcome of TCU are conceded and simulating outcomes shows that RTP is capable of simulating the vehicle conditioning and behaviour approx. well.*

Index Terms--- *Hardware loop, Simulation, Rapid Testing Platform, TCU, AMU, Model-based.*

I. INTRODUCTION

Because of its low creation cost and incredible mileage, "automated manual transmission (AMT)" has been playing a progressively significant role in commercial vehicle showcase than different kinds of automatic transmission. To acquire better move quality and system dependability, TCU (Transmission Control Unit) is required to participate and impart data to EMS (Engine Management System). Increasingly modern control system including a versatile control rationale, self-demonstrative and self-ensured calculations are applied in the embedded programming of TCU. For the most part in the improvement technique, various capacities are independently tried and checked and coordinated at last[1].

Practical and improved software is from refinements and multiple tests. Progressively intricate control system implies longer and increasingly broad testing of TCU. Locally available tests in vehicles are not adequate and ought to never be the first option, on the grounds that the potential mistake in the control programming may cause mechanical damage to the powertrain and safety issues to the analyser and driver. Further, the parameters of the test condition (motor speed, drive design, and so on.) cannot be subjective and precisely rehashed[2]–[5].

To decrease the improvement process duration and cost, equipment on the up and up reproduction (HILS) is for the most part utilized. This method enables the engineer to work in a virtual domain to reproduce test conditions and vehicle conduct, testing the control programming without the interest of the genuine vehicle. For the most part, just not many of the vehicle parts (motor, transmission, actuators, sensors, and so on.) are model-based and running for all intents and purposes in the earth, for example, Simulink/State flow/RTW from Math works on a (PC), different parts are on the whole genuine equipment on the up and up. This sort of HILS doesn't lessen a lot of cost of work and consumption, and

Department of Electronics and Communication Engineering, Siksha 'O' Anusandhan (Deemed to be University), Bhubaneswar
tapasmohapatra@soa.ac.in, biswaranjanswain@soa.ac.in

Received: September 2019 | Revised: October 2019 | Accepted: November 2019

furthermore has dangers of mechanical harm. To the furthest reaches of HILS, models can be build-up for all the vehicle parts aside from the test target[6]–[8].

Be that as it may, running every one of the models in PC, at least one DAQ (Data Acquisition) sheets and correspondence links, (for example, CAN-to-USB) are expected to move and trade information between the test target and the PC. Advancement of the information interface between installed system and PC is a tiring activity as a result of the varieties of sign's attributes and the contribution of Windows API. Additionally, keeping every one of the models and the test target running synchronously progressively needs a few abilities, and a few sensors' flaws are difficult to be mimicked in light of the fact that all are virtual[9]–[11].

II. TECHNIQUE FOR RAPID TESTING

All things considered, to test the control rationale and not the control execution of TCU, the exact scientific models of the vehicle parts are not required. Some confusing systems can be linearized and improved to run in an embedded system. Since TCU is an embedded system, if the entire vehicle is virtualized in another embedded system, the signal moving and preparing will be significantly more helpful. The significant expense DAQ sheets and PC are not required[12].

The quickening agent pedal, brake pedal, move the switch, street express, sensors' issues can be discretionary set and effectively re-enacted with potentiometers & switches. Signal of the analog sensors are simulated with DAC (Digital-to-Analog Converter), and the lobby sensor signals are simulated with the compare/capture module of the microprocessing unit in the embedded system. The running state of an actuator, speed of motor and speed of the vehicle are imagined with LEDs. By comparing scientific models running inside, this embedded system has the capacity to recreate the vehicle conduct and structures an RTP for TCU of AMT[13].

AMT comprises of the gearbox, multiple actuators that change the gears and disengage/engage the grip, and a TCU. TCU screens the driver's aim (quickening or braking), speaks with EMS through CAN bus for sharing data and controlling the torque of the engine, and drives the actuators in closed-loop control to execute the automated movements. Figure 1 shows the system block diagram and the major information flow.

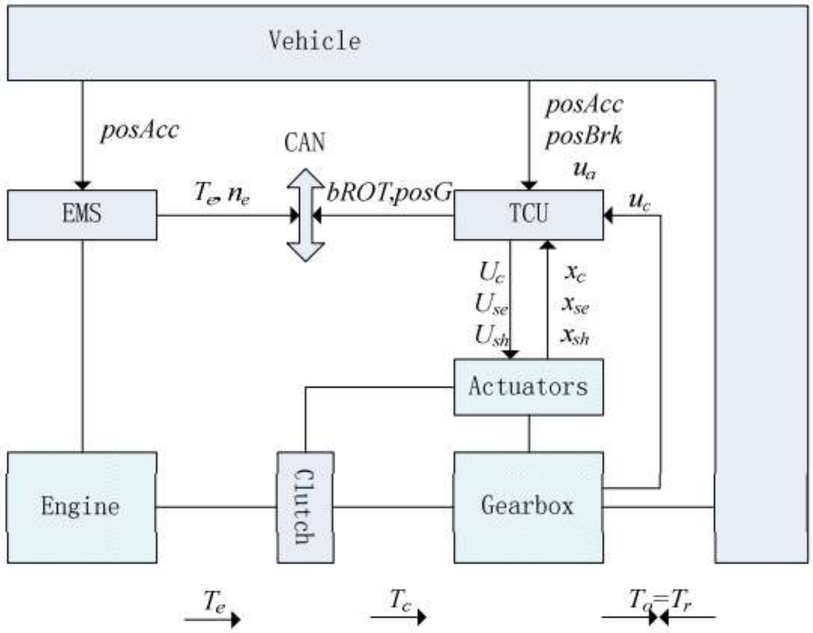

Fig 1: Information flow and Block diagram of the AMT system

- posAcc: depth of accelerator pedal
- Te: engine output torque ne: engine speed
- bROT: request of torque decrease or torque increase by TCU
- posG: gear position (neutral/reverse/1,2,…)
- posBrk: depth of brake pedal
- ua: vehicle velocity
- uc: input speed of gearbox (clutch speed)
- Uc, Use, Ush: pulse width modulated (PWM) voltage signal to drive the clutch actuator, gear selecting actuator and gear shifting actuator respectively
- xc, xse, xsh: sensor feedback signals to indicate the position of the clutch actuator, gear selecting actuator and gear shifting actuator respectively
- Tc: torque transferred by the clutch
- To: gearbox output torque
- Tr: equivalent torque of all driving resistance including acceleration, braking, etc.

As it can be observed from fig 1, clutch, engines simulator, actuators, gearbox, and vehicle develop the rapid testing platform[14]–[19].

III. SIMULATOR'S DESIGN

III.I. Vehicle Motion Simulator

The key role of the vehicle motion simulation unit is for providing tester for simulation of driving intention such as braking and accelerating, and for computing real-time of the state of motion[20].

Through the mechanical analysis on the vehicle, driving formula is stated below:

$$(T_C(t)\, i_g\, i_o\, \eta_T)/ r = F_f(t) + F_W(t) + F_i(t) + F_b(t) + \delta_m \{(du_a(t)/dt)\} \quad (1)$$

where Tc(t) is the transferred torque through grip, ig is the transmission gear proportion of gearbox, i0 is last decrease gear proportion, ηT is transmission effectiveness, r is wheel range, Ff(t) is moving opposition, Fw(t) is wind obstruction, Fi(t) is tough obstruction, Fb(t) is braking power, ua(t) is vehicle speed, δ is pivot mass transformation factor, m is vehicle mass.

To improve the model, the braking power is considered as relative to the profundity of the brake pedal, which is set by the analyzer during recreation. The moving opposition and tough obstruction are comparative with the street slant, which is additionally set by the analyzer. The breeze opposition is relative to the square of vehicle speed. In like manner, given Tc(t), ua(t) can be determined. The torque moved by grip is from the motor and changes nonlinearly while grasp is drawing in and separating[21]–[23].

III.II. Simulator of Engine

The engine is an extremely confounded system and its attributes are affected by numerous components, for example, fuel infusion and ignition. Nonetheless, in out re-enactment system, no need to think about these components. The motor test system has two principal capacities. One is to compute motor yield torque (Te) and motor speed (ne) as per the profundity of quickening agent pedal and burden; the other is to reaction the solicitation of torque reduction or torque increment by TCU. The motor model can be constructed dependent on its enduring state trademark.

Working in the consistent express, the yield torque of the motor can be communicated as a component of throttle opening (θ) and motor speed[24].

$$(T) = f(\theta(t), n_e(t-1)) \quad (2)$$

In the simulation, the opening of the throttle can be expected as drawing nearer to the profundity of the quickening agent pedal rapidly. Te(t) can be acquired by turn upward and insertion to the engine torque steady-state mapping. Figure 2 shows the case of such a guide.

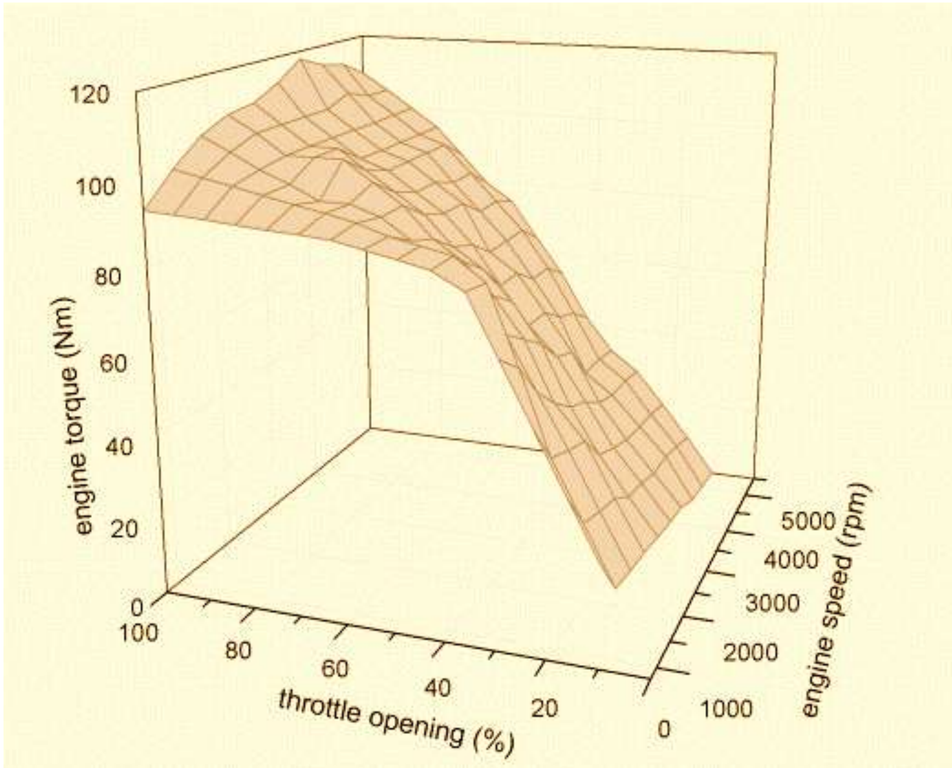

Fig 2: Engines map on steady-state torque.

Where Je is engine's moment of inertia, ωe is the engine's angular speed. It is important that, from articulation, if the torque moved by grip is considerably less than the yield torque of the motor, what will happen when the grasp is withdrawn or transmission in nonpartisan rigging, the precise speed of the motor will increment rapidly. To maintain a strategic distance from this, the motor test system likewise capacities to change the throttle opening naturally in such cases.

III.III. Actuators' Simulators

The actuators' test systems are to collaborate with TCU and give a re-enactment of DC engines and mechanical parts. It is the key point in the plan of the RTP. For the engine driving AMT, there are three actuators: rigging choosing actuator, gear moving actuator and grasp actuator. The driving sign is all of the PWM designs that are delivered by the H-connect drive circuits of TCU. The voltage between the two yield shafts of H-connect drives circuit shifts from –BAT to +BAT, in which BAT is the battery voltage, normally +12V or +24V. The actuators' test systems utilize operational enhancer circuits to change the voltage from [–BAT, +BAT] to [0, 5], which is appropriate for sign handling in a chip. As per the driving voltage, the actuators' test systems go about as DC engines and ascertain the removals of the actuators[25].

There is such a relationship as articulation (4) between the rotational speed of the DC engine and the driving voltage[2]–[5], [26].

$$n_m = (U-IR)/(C_E\varphi) = (4)$$

Where nm is the rotational speed of DC engine, U is driving voltage, I is armature current, R is armature obstruction, CE is EMF steady, φ is excitation transition. Modifying the rotational speed of DC engine by controlling the driving voltage, such quality of smooth parallel bends can be attained as illustrated in figure 3, where y-hub is the rotational speed of DC engine, x-pivot is the heap torque of DC motor.

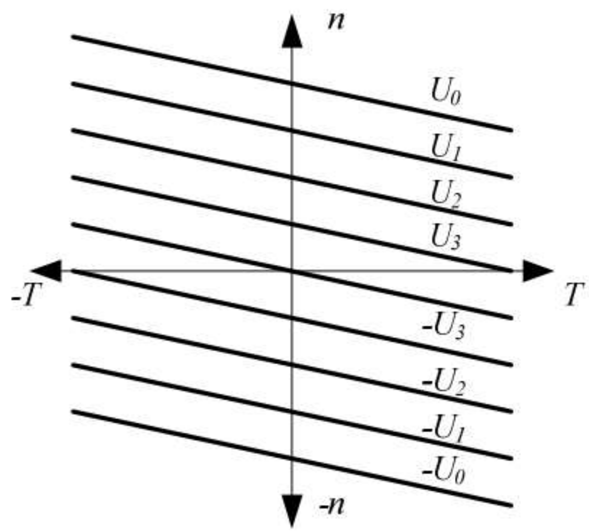

Figure 3: DC motor characteristics by the change in voltage.

For rearrangements in recreation, the heap of the actuator is accepted as steady, in this way the rotational speed of the engine is relative to the driving voltage.

To take note of that, the recurrence of the PWM driving sign from TCU is normally higher than a few kilohertz. To lessen the chip's computational weight, the test system won't compute the rotational speed in each PWM sign cycle. As a matter of fact, the computational cycle is set as 5 to 10 milliseconds. The dynamic normal driving voltage during each computational cycle is determined and used to figure the rotational speed. As appeared in figure 4, a hinder will be created and time ticked by the chip's catch module at each rising edge or falling edge of the information PWM signal. The obligation cycle of the PWM sign is determined as[27], [28]:

$d_1= (T_2-T_1)/ (T_3-T_1)$,

$d_2= (T_4-T_3)/ (T_5-T_3)$,

And the active average voltage U_d will be

$U_d=U_0(d_1+d_2+\ldots+d_n)/n$

Or

$U_d =U_0 ((T_2-T_1) + (T_4-T_3) +\ldots (T_{2n}-T_{2n-1})) / (T_{2n+1}-T_1)$

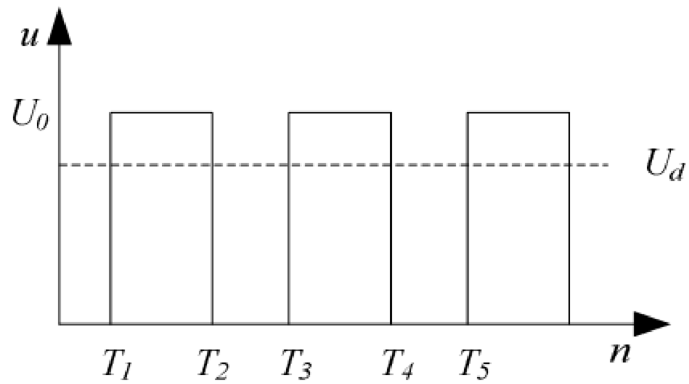

Figure 4: Waveform of the PWM signal

After the rotational speed of the engine is registered by utilizing Ud, the uprooting of actuator x (t) is got from articulation (5):

$$x(t) = x(t-1) + c_a n(t) \Delta t \quad (5)$$

Where ca is the transmission coefficient from the engine to the actuator, Δt is the period between two computation steps. This uprooting of the actuator is encouraged back to TCU as a genuine sensor's simple sign after it is prepared and smoothed by the DAC module of the system. The sensor's issues can be effectively simulated in the manner. For example, to reproduce the mechanical square, the test system yields an equivalent estimation of the relocation of the actuator in obliviousness of the contribution of changing driving voltage.

III.IV. The test system of Gearbox and Clutch

In view of the determined dislodging of actuators, the test system of gearbox and grip mimics the rigging movements and movements of grasp and decides their relating state: in nonpartisan apparatus or in different riggings, grasp withdrawing or connecting with, and separated or locked in.

The torque moving qualities of grip around agree to the accompanying articulations [7]:

$$T_c(t) = \begin{cases} 0 & , \quad x_c(t) \le i_m \lambda_0 \\ Z f_c R_c C_z \left(\dfrac{1}{i_m} x_c(t) - \lambda_0 \right) & , \quad i_m \lambda_0 \le x_c(t) < i_m(\lambda_0 + \xi) \\ T_e(t) & , \quad x_c(t) \ge i_m(\lambda_0 + \xi) \end{cases} \quad (6)$$

Where Z is the number of grinding surfaces, fc is the grating coefficient, Rc is the normal span of rubbing plate, Cz is a steady controlled by the structure of grip and got by analyzing, im is the influence coefficient of stomach spring, xc is the dislodging of grasp which is determined by the actuators' test system, λ0 is the free travel of grasp plate, ξ is the most extreme distortion of grip plate. After Tc(t) is registered, the vehicle speed ua(t) can be accomplished by utilizing articulation (1). By making a decision about the condition of grasp and gearbox, the information speed of gearbox uc(t) is likewise assessed. Estimations of both speed sign are handled by the chip and sent to TCU in a heartbeat sign example[21].

IV. RESULTS

The created test systems are typified in an implanted system with a 16-piece microchip. To assess the fast testing stage, a checked result of TCU is utilized for the test. Adjacent to watching the stage for its running status, a PC is associated with the TCU to get extra data of the vehicle running state. Figure 5 outlines the technique of one programmed change from gear 2 to outfit 3. In this figure, "move current pos" signifies the present situation of rigging moving actuator, and "select current pos" means the present situation of apparatus choosing actuator. These two signs are recreated by RTP and sent from RTP to TCU. The objective places of actuators and the objective apparatus are determined by TCU.

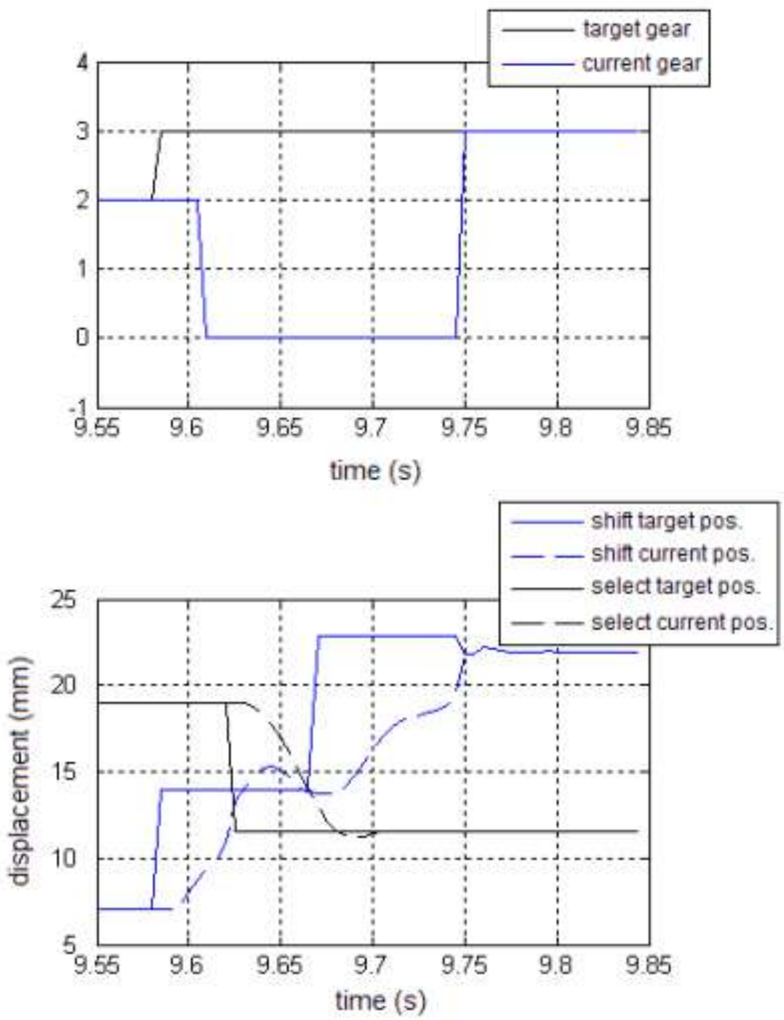

Figure 5. The technique of one programmed move

By looking at the two arrangements of the sign, it is anything but difficult to draw the accompanying surmising's:

- The analyzer's quickening goal was recognized by RTP and vehicle's running state was all around simulated to trigger TCU's upshift choice;
- RTP mimicked the actuators' activities near the genuine as indicated by the PWM driving signal from TCU;

- The calculations and simulations merged and are kept stable toward the finish of the upshift. From the test outcome, it can be presumed that the created RTP can around pursue the analyzer's driving aim and execute the best possible apparatus moves in collaboration with TCU.

V. CONCLUSION

In this paper, a fast testing stage for TCU is presented and satisfied. The mechanical qualities of the vehicle parts for AMT are talked about. The recreation models of vehicle movement, motor, actuators, grip and gearbox for AMT are created and actualized in an installed system. The accentuation in the usage is the structure of the actuators' test system. The simulation technique and handling strategy for the trading sign are proposed. By explores, different avenues regarding a demonstrated result of TCU, the elements of RTP are tried and the outcome shows that the RTP can simulate the vehicle conditions around well, along these lines making the testing of TCU quicker and more secure all through the entire advancement process. The improvement technique of the RTP is nonexclusive and can be applied for different systems. With suitable recreation models of actuators set up with those talked about in this paper, the RTP can be created to test the TCU of twofold grip transmission.

REFERENCES

[1] H. Naunheimer, B. Bertsche, J. Ryborz, W. Novak, and P. Fietkau, Automotive transmissions: Fundamentals, selection, design and application. 2011.
[2] M. Jiang, W. Chen, Y. Zhang, and L. Chen, "Multi-domain modeling and simulation of AMT based on modelica," in SAE Technical Papers, 2011.
[3] C. Ding, Z. Xu, Y. Zhang, and Q. Tao, "Multi-domain modeling and simulation of vehicle thermal system based on modelica," in SAE Technical Papers, 2014, vol. 1.
[4] J. Li, Y. Zhang, and W. Chen, "Multi-domain modeling and simulation of automotive air conditioning system based on modelica," in Lecture Notes in Electrical Engineering, 2013, vol. 196 LNEE, no. VOL. 8, pp. 1337–1350.
[5] J. Liu, G. Wang, and Y. Luo, "Multi-Domain Modeling Based on Modelica," in MATEC Web of Conferences, 2016, vol. 77.
[6] H. Naunheimer, B. Bertsche, J. Ryborz, and W. Novak, Automotive Transmissions. 2011.
[7] N. Zaman, Automotive Electronics Design Fundamentals. 2015.
[8] V. D. Ngo, T. Hofman, M. Steinbuch, and A. Serrarens, "Gear shift map design methodology for automotive transmissions," Proc. Inst. Mech. Eng. Part D J. Automob. Eng., vol. 228, no. 1, pp. 50–72, 2014.
[9] A. F. Ergenc, A. Ergenc, C. Erdogan, and A. Dumanli, "A New Control Scheme for Automated Manual Transmission with Electromagnetic Powder Clutch," SAE Tech. Pap., vol. 2015, 2015.
[10] N. Srinath, A. Shashidhar, P. G. Shanthamurthy, V. Reddy, and H. Bhadana, "Smart Clutch: An automated clutch that can be used in manual transmission driven vehicles," in ASME International Mechanical Engineering Congress and Exposition, Proceedings (IMECE), 2016, vol. 14.
[11] A. Ranjan, S. Prasanth, F. Cherian, and P. Baskar, "Design and control of electromagnetic clutch actuation system for automated manual transmission," in IOP Conference Series: Materials Science and Engineering, 2017, vol. 263, no. 6.
[12] T. S. Nguyen, J. Song, L. Yu, S. Fang, Y. Tai, and Z. Lu, "Design and development of a real-time simulation and testing platform for a novel seamless two-speed transmission for electric vehicles1," in Journal of Dynamic Systems, Measurement and Control, Transactions of the ASME, 2019.
[13] C. Y. Kim, S. Rho, N. Lee, C. K. Lee, and Y. Sung, "Semi-automated counting method of axons in transmission electron microscopic images," Vet. Ophthalmol., 2016.
[14] Z. Zhou and M. Huang, "Regenerative braking algorithm for the electric vehicle with a seamless two-speed transmission," Proc. Inst. Mech. Eng. Part D J. Automob. Eng., vol. 233, no. 4, pp. 905–916, 2019.
[15] Y. Wang and X. Qu, "A novel real-time simulation platform for testing control algorithm," in Proceedings of the 2015 27th Chinese Control and Decision Conference, CCDC 2015, 2015, pp. 4748–4750.

[16] M. S. Rahimi Mousavi and B. Boulet, “Modeling, simulation and control of a seamless two-speed automated transmission for electric vehicles,” in Proceedings of the American Control Conference, 2014, pp. 3826–3831.
[17] A. Sorniotti et al., “A novel seamless 2-speed transmission system for electric vehicles: Principles and simulation results,” SAE Int. J. Engines, vol. 4, no. 2, pp. 2671–2685, 2011.
[18] S. Fang, J. Song, H. Song, Y. Tai, F. Li, and T. Sinh Nguyen, “Design and control of a novel two-speed Uninterrupted Mechanical Transmission for electric vehicles,” Mech. Syst. Signal Process., vol. 75, pp. 473–493, 2016.
[19] M. S. R. Mousavi, A. Pakniyat, and B. Boulet, “Dynamic modeling and controller design for a seamless two-speed transmission for electric vehicles,” in 2014 IEEE Conference on Control Applications, CCA 2014, 2014, pp. 635–640.
[20] X. Y. Song, Z. X. Sun, X. J. Yang, and G. M. Zhu, “Modelling, control, and hardware-in-the-loop simulation of an automated manual transmission,” Proc. Inst. Mech. Eng. Part D J. Automob. Eng., 2010.
[21] H. Huang, S. Nowoisky, R. Knoblich, and C. Gühmann, “Multi-domain modelling and simulation of an automated manual transmission system based on Modelica,” Int. J. Simul. Process Model., vol. 10, no. 3, pp. 253–264, 2015.
[22] Q. Liu, M. A. Silva, M. R. Hines, and D. Da Silva, “Hardware-in-the-loop simulation for automated benchmarking of cloud infrastructures,” in Proceedings - Winter Simulation Conference, 2012.
[23] Y. Z. Fan and F. C. Jiang, “Hardware-in-the-loop simulation of electronic control unit used on automated mechanical transmission,” in ICCET 2010 - 2010 International Conference on Computer Engineering and Technology, Proceedings, 2010, vol. 3.
[24] H. Huang, S. Nowoisky, R. Knoblich, and C. Gühmann, “Modeling and simulation of an automated manual transmission system,” in 7th Int. Conference on Integrated Modeling and Analysis in Applied Control and Automation, IMAACA 2013, Held at the International Multidisciplinary Modeling and Simulation Multiconference, I3M 2013, 2013.
[25] Q. Huang, J. Song, and L. Li, “Research on rapid testing platform for TCU of automated manual transmission,” in Proceedings - 3rd International Conference on Measuring Technology and Mechatronics Automation, ICMTMA 2011, 2011.
[26] Y. Sun, W. Chen, Y. Zhang, and L. Chen, “Multi-domain modeling and simulation of hydraulic power steering system based on Modelica,” in SAE Technical Papers, 2010.
[27] J. Singh, A. Balpande, A. Verma, R. Kunal, and L. Batra, “Servomotor controlled standard automated manual transmission for rapid smooth shifts,” in SAE Technical Papers, 2013, vol. 11.
[28] W. D. Grimes, T. Vadnais, and G. A. Wilcoxson, “Acceleration Testing of 2016 Kenworth T680 with Automated Manual Transmission in Auto Mode,” in SAE Technical Papers, 2017, vol. 2017-March, no. March.