

# Survey on Development of Fail Safe Feature for Automated Manual Transmission

Uthara R<sup>1</sup>, Natarajan V<sup>2</sup>, Ranganathan L<sup>3</sup>

<sup>1</sup> Postgraduate student, Mechatronics Engineering, Jeppiaar Engineering College, Chennai, India

<sup>2</sup> Head of Department, Department of Mechanical Engineering, Jeppiaar Engineering College, Chennai, India

<sup>3</sup> Professor, Department of Mechanical Engineering, Jeppiaar Engineering College, Chennai, India

## Abstract

Transport is an integral part of our day-to-day lives. There has been a lot of advancements in the way we view this and also the way in which these systems have been developed. Comfort and fuel economy coupled with less emissions have been the focus for the last few years and a lot of research has been focused on it. Improvements in the transmission system have been at the focus for most of the research purposes. Automated Manual Transmission (AMT) is one such technology which has become more popular in the recent years. Being such a complex system, there are bound to be a lot of faults and failures that can happen in these systems. In such a scenario, a fail-safe feature becomes vital. This survey reviews some of the notable research done regarding AMT and its component systems.

**Keywords** - Automated Manual Transmission (AMT), Comfort, fail-safe, fuel economy

## I. INTRODUCTION

Automated manual Transmission has become one of the most sought after transmission systems for commercial vehicles due to its ease of use and increased fuel economy. These systems can be either semi-automatic or fully automatic. Another advantage over other transmission systems is that AMT does not need a radical makeover in the clutch and gear setup. However, faults are prone to happen in this too and pose a challenge to overcome. This paper describes some of the research which has been conducted regarding AMT and associated technologies.

## II. LITERATURE SURVEY

Zongxuan Sun and Kumar Hebbale discuss about the various automotive transmission systems and the advantages and limitations of the same. Many automotive transmission systems have come into use with the aim of improving fuel economy, reduce emissions and improve driving performance. Some of them include Continuously Variable Transmission (CVT), Automated Manual Transmission (AMT) and Electrically Variable Transmission (EVT). Common transmission systems in the market include traditional Automatic Transmission (AT) and Manual Transmission (MT). In many of the new automatic transmissions (AT), clutch-to-clutch shift is adopted.

This eliminates the shifting valves, accumulators thus making it more mechanically simple. On the other hand, the absence of these components makes the control of the clutch-to-clutch shifts a challenge.

The clutch fill process is a huge uncertainty in the traditional control system of an automatic transmission. Commanded fill pressure and commanded fill time are important parameters in order to achieve a smooth transmission [1]. Small errors in these values can lead to lot of issues. Special algorithms can identify the end of the fill but they are not reliable enough.

Most clutch-to-clutch production transmissions use a combination of open loop control, event-driven control and feedback control schemes. The potential use of Automated Manual Transmissions is limited in North America due to the torque interruption during the shifts. However, a variant of AMT known as Dual Input Clutch Transmissions (DCP) can overcome this challenge [1]. They have two input clutches thereby transmitting torque continuously during the shift.

In a Continuously Variable Transmission (CVT), the engine can operate in a wide range of speed and load conditions independent of the speed and load requests of the vehicle. Since the engine can function in the optimal region irrespective of the vehicle speed, it increases the fuel economy. Maintaining an optimal clamping force to prevent slipping is a major challenge.

Electrically variable transmissions offer advantages such as greater flexibility, controllability and performance. Speed ratio coverage of these systems are minimal. Different planetary gear train arrangements are under research to overcome this issue.

An increase in functionality and number of electric components increases the complexity of calibrating the system. The complexity increases as the system should also be coordinated with the engine and other components. Fuzzy logic has been vital in shift scheduling algorithms to promote smooth driving patterns. Fig. 1 shows the same [1].

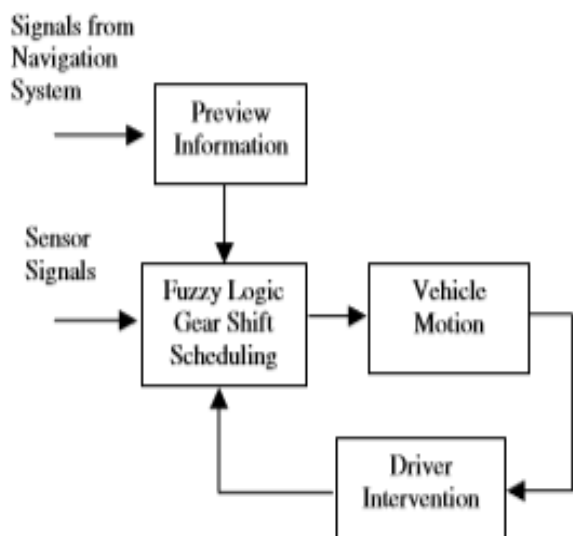


Fig. 1. Gear Shift Scheduling Algorithm block diagram

Transmission control hardware has changed due to the ever-increasing demand for computational power. These changes have occurred at the sensing level, actuation level and the system level. Piezoresistive sensors pose an alternate for the pressure sensors. Variable Bleed Solenoid (VBS) valves have replaced Pulse Width Modulation valves because of their better controllability. But VBS valves suffer from hysteresis and hence other types of valves are required [1]. More research and development in control software and algorithms are required to meet the ever increasing demand for better performance and fuel economy.

Process monitoring and diagnosis receive a lot of attention in the current scenario of automobile technologies. Current troubleshooting methods can only utilize static data like engine revolutions per minute and temperature. Hence, traditional Monitoring and Fault Detection (MFD) becomes more difficult to develop and maintain. Modern techniques deal with either analytical model-based MFD techniques or by data-driven techniques. These techniques are used to determine the error between the model estimate and measurements known as the residual signal [2].

A parity space framework of residual signal generation is addressed for dynamic MFD of Automated Manual Transmission systems. Though accurate, these systems have an increased difficulty in modelling and calibrating large amounts of parameters in the clutch, gearbox, wheels and so on. Hence, it is difficult to perform a reliable MFD system for AMT. Apart from the modelling-by-design strategy, a new method known as Subspace Identification Method (SIM) may be a viable alternative [2]. Most existing data-driven approaches focus on the linear time invariant systems. These systems do not actually exist in practice. The proposed data-driven scheme can be applied for a

MFD system of AMT vehicles. Future work requires its implementation to a real vehicle.

An AMT is developed from a manual transmission by breaking the operating chain and introducing hydraulic, pneumatic or electrical actuators and other components. Though this has a lot of advantages, the engine speed control during the gear shift process is difficult. The engine system is highly non-linear and time dependent. Hence, a high level of control is required for this. A PID control algorithm is very simple and can work even with uncertain mathematical models. A Bang-Bang algorithm can be used to monitor the speed. Integration of these two algorithms can lead to very good results.

A driveline scheme of the powertrain model is required. The engine speed control should happen when it is in a non-loaded condition. Fig. 2 shows the same [3].

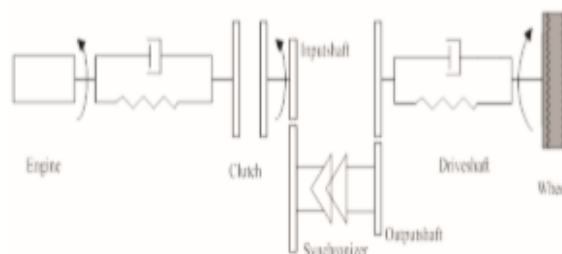


Fig. 2. Driveline scheme

The most direct way to reduce the engine speed is to adjust the engine torque. The speed difference is different during upshift and downshift and hence two different algorithms are required. During up-shift, the engine speed is to be reduced to the target speed within a specific period of time. CAN communication is an effective way to reduce the engine torque to zero and can take over the engine torque control from the Engine Control Unit (ECU) to Transmission Control Unit (TCU). A combination of PID and Bang-Bang algorithm is used here [3]. During downshift, the engine speed has to be increased to the target speed. Increasing the engine output torque is an easy way to achieve this and a PID control algorithm can fulfil it. Field experiments show that this process is an efficient way for controlling the engine speed during shifting in an AMT.

As mentioned earlier, gear shifts represent an important operation in an AMT. The clutch is used to connect to rotating masses, namely the flywheel and transmission shaft, rotating at different speeds in order to transmit the torque. An automatic setup should satisfy these. During engagement and lock-up, the engine and clutch speeds play an important role. Though there have been various models provided for the smooth operation of these components, some research still needs to be done. Some areas of interest include the role of speed feedback loops in the clutch engagement control, the robustness of the solution with respect to clutch ageing and uncertainties in the

clutch characteristics [4]. For the new gearshift solution, models of the driveline, dry clutch and closed-loop electrohydraulic actuator are considered. Five different operating phases of operation of the AMT have been classified according to the engine speed and clutch speed signals during the gearshift. They are engaged, slipping-opening, synchronization, go-to-slipping and slipping-closing. Fig. 3 shows the five operational stages of an AMT [4].

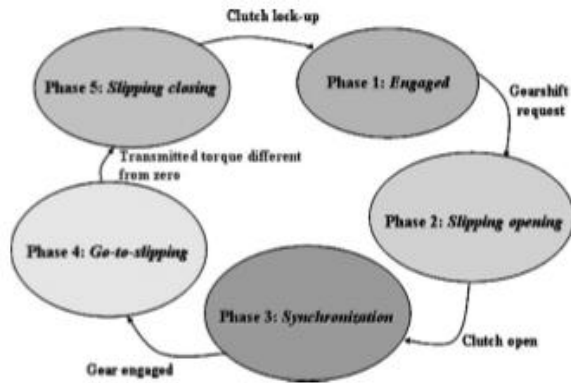


Fig. 3. AMT operating phases

Based on the hierarchical approach with decoupled and cascaded feedback loops based on measurements of clutch speed, engine speed and throwout bearing position, the controllers are designed. The driveline model and the controllers of different AMT operating phases are imported into Matlab for simulation. The results show the effectiveness of the controllers [4]. Because of the low computational load, the controllers can be implemented in the ECU of commercial vehicles.

Another novel approach for the gearshift system of an AMT is based on introducing an electromagnetic actuator in order to increase transmission efficiency and improve shift quality. Currently, hydraulic and electrohydraulic actuators are used in AMT for its higher density. On the other hand, hydraulic systems can have up to 50% losses in their systems [5]. Electrohydraulic systems too have the same problem. They are also complex in nature. Electromechanical actuators provide an alternative for this problem.

The entire gearshift process is divided into two phases namely the non-synchronization phase and the synchronization phase [5]. Extended State Observer (ESO) based Inverse System Method (ISM) can eliminate the nonlinearity of the actuator and estimate and compensate the uncertainties, parameter variations and external disturbances. The Active Disturbance Rejection Controller (ADRC) is used to improve the tracking accuracy of the synchronization process. Existing synchronization process methodologies when the clutch is disengaged is not diverse and robust enough for wider applications in AMT. A gearshift system based on direct-drive actuator can be a viable solution. It uses an improved direct-drive electromagnetic rotary linear actuator (EMRLA) as a gearshift actuator [5]. It has a very

simplified construction with very less number of components. There is no reduction gear and motion conversion linkage and hence reduces mechanical hysteresis and backlash. It also has a faster dynamic response. A test bench is developed to test and verify the gearshift system. The test bench consists of an actuator, transmission, sensors, variable frequency motor, control system and other assisting mechanisms. The variable frequency motor represents the engine output. The results show that the maximum degree of impact and synchronization time are smaller with ADRC control.

The AMT is a complex system comprising of many components such as a clutch, gearbox and TCU. Malfunctions in any actuator will lead to the failure of the AMT. The Fault Detection and Isolation (FDI) systems play an important role in identifying the problem and assist the on-board system to warn the driver about the potential problem [6]. Therefore, fault modelling of actuators assumes an important role. A structural analysis can help in obtaining a set of sensors which can detect and isolate the critical faults in an AMT actuator.

The shifting actuator under consideration is an electro-mechanical system used in EcoCAR2. It consists of a DC motor and other drive chains such as geartrains, lead-screw drive, push/pull cable and revolutes levers. The same is shown in Fig. 4 [6].

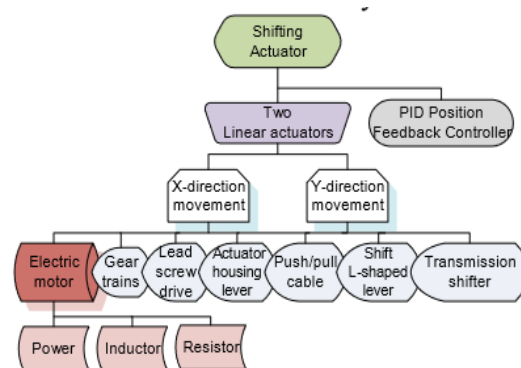


Fig. 4. Shifting actuator composition

The faults which are critical to the actuator include the motor faults, push/pull cable faults and the transmission shifter faults. Structural model of the actuator is then created in order to judge if system faults can be detected and identified for a given system. This is followed by the generation of residuals for fault diagnosis. MATLAB models of the shifting actuator model can be used to verify if the residuals can detect and isolate the necessary faults [6]. The results show that the transmission lever displacement sensor and current sensor have maximum detectability and isolation capacities. The simulations were in line with these results.

Most studies tend to consider the reduced order driveline models and the clutch and gearbox dynamics have usually followed a similar pattern. A physically based non-linear model of the electro-

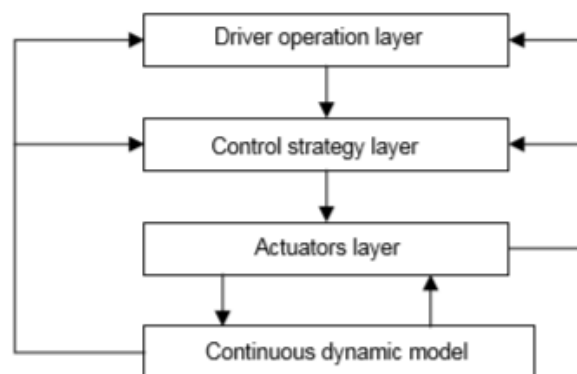
hydraulic gearbox and clutch actuators are a welcome change from the aforementioned shortcomings [7]. The actuator dynamics are highly interconnected with the driveline dynamics. An overall driveline model can hence be obtained by combining the actuator model with the transmission shaft model. The drivetrain is divided into three sub-systems namely the transmission shafts, electro-hydraulic gearbox and clutch. The gearbox actuator model is a higher order, highly non-linear model which takes into account the electromagnetic, hydraulic and mechanical dynamics of the actuator. Singular perturbation is applied to obtain a reduced order model of the hydraulic gearbox actuator. The clutch actuator model is as refinement of the electro-hydraulic model and then these models are combined together with the dynamics of the transmission shafts. The model is then validated with respect to the experimental data. The dynamical properties of the gearbox actuator are examined with the help of tests performed on a laboratory test-bench. Then the overall model is validated in MATLAB. The results show that the model can accurately reproduce the gearbox dynamics during gearshifts, making it an ideal tool for further research purposes.

On-board fault diagnosis occupies an integral part in an AMT system. The fault diagnosis of control systems can be divided into physical redundancy methods and the analytical redundancy methods [8]. The analytical redundancy methods do not increase the number of components required and are profitable for maintaining the system costs. The vehicle systems are non-linear in nature and hence were difficult to model. The control devices are also small in size and hence found it difficult to undertake complex computing algorithms. As a result, such systems become unfavourable for using analytical redundancy models. During operation, the subsystems in a powertrain can either be engaged or disengaged. Hence, local structure models and local time models are ideal to represent such a system. They are also very precise in these operations. Even though the engine system is non-linear, if the input varies only within a small range, then these models can be considered as linear. To get a single-input-single-output model, a SISO CARMA (Single-Input-Single-Output Controlled Auto-Regressive Moving Average) model is used [8]. The gearbox and clutch models are then generated. The model results show that it can accurately find a single fault at a time. When multiple faults are involved, the system shows the first fault which it could detect. Hence, the system is useful for single fault detection at a given time without any additional hardware required.

On-board testing of the Transmission Control Unit (TCU) or any other system is not preferable. It should have been thoroughly tested beforehand for all possible faults before being fit into the vehicle system. This may also cause damage to the vehicle when carried out in a real system first-hand. Hardware-in-

the-loop (HIL) simulations are generally used to overcome these problems. However, these do not reduce the costs involved significantly and can still cause damage to the parts involved. Data Acquisition Boards (DAQ) and communication cables needed increase the complexity and costs further. In order to test the control logic, precise mathematical models are seldom required. Linearized and simplified models can be utilized under the right conditions for the same purposes [9]. As the TCU is an embedded system, the whole vehicle system can be assumed to be in another embedded system thereby making the processing easier. Accelerator pedal, brakes, shift lever can be set with the help of potentiometers and switches. Analog sensor signals can be simulated with the help of a Digital-to-Analog Converter (DAC) and the hall sensor signals can be simulated with the help of a microprocessor. LEDs can represent the state of the engine and vehicle speed. These form a Rapid Testing Platform (RTP) for the TCU. Factors such as fuel injection and combustion are ignored in the simulation. A steady state model is built for the system. The actuators involved include the gear selecting actuator, gear shifting actuator and the clutch actuator. Load acting on the actuators is assumed to be constant. This data is used to simulate the gearshifts and the clutch [9]. The testing results show that the RTP can follow the instructions set and can execute gearshifts along with the TCU.

MATLAB is an important tool for simulating a continuous hybrid system along with Simulink and Stateflow [10]. A hybrid system method is usually used to describe a dynamic system which has a Continuous Time System (CTS) and Discrete Event System (DES). A vehicle dynamic system and its automatic control represent the same. When the CTS is running, a discrete event is generated. This will trigger new control parameters which can be kept track of. Hence, the CTS and DES continuously exchange information. The vehicle auto-shift process represents a discrete event. The different events can be classified into the driver operation layer, control strategy layer and the actuator layer [10]. These are differentiated by means of their priority.



**Fig. 5. Vehicle hybrid system hierarchy**

Fig. 5 shows the vehicle system hierarchy [10]. The simulated models are then compared with actual road tests on a prototype vehicle. The results show that the model can verify and optimize the control strategy based on the surrounding conditions. It will also lead to reduction in developing costs. Further research can be done to test the model in a HIL environment.

### III.CONCLUSIONS

Recent advancements have improved the overall performance and efficiency of the transmission systems. Even so, there is much scope for improvement in the same. AMT's are viable and competent systems which have the potential to incorporate automation and reduction in costs. Ongoing research in these systems offer a promising picture. Some of those studies were looked upon in this survey and they give a good account of the possibilities and challenges in this promising system.

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