Experimental Automatic Gear Shifting for a Combustion Race Car

Varun Mamtani
School of Electrical Engineering
Vellore Institute of Technology
Vellore, Tamil Nadu, India

Sarthak Agrawal
School of Electronics Engineering
Vellore Institute of Technology
Vellore, Tamil Nadu, India

Manas Utkarsh Malviya
School of Electronics Engineering
Vellore Institute of Technology
Vellore, Tamil Nadu, India

Sumit Kumar Jindal
School of Electronics Engineering
Vellore Institute of Technology
Vellore, Tamil Nadu, India

***Abstract*— Automatic gear shifting is a process in which an electronic hardware system is installed in the vehicle and the gear shifts automatically when it moves, without the need for any person to manually shift it. This automation is accomplished through the use of a microcontroller as well as the necessary sensors. The automatic gear shifting system is designed to keep the engine running at optimal revolutions per minute (RPM). The transmission must automatically up-shift as the engine revolutions rise above the top limit. This results in the efficient working of the engine, also increasing its longevity making the task of the driver easier. The microcontrollers communicate with the control systems and other components in the car using the Controller Area Network (CAN) protocol. This work discusses the algorithm involved, the sensors used to achieve the perfect output and safe transmission. Comparing the graphs of the manual transmission and automatic transmission. The proposed work also allows shifting from AMT to manual mode with the use of a simple button controlled using the micro-controller. Finally, the modifications required on the existing car models to achieve higher speeds at a shorter period of time and the improvements in a car after the implementation of the concept.**

Keywords—Micro-controller, Embedded Systems, Actuators, Engine Control Unit, Driver assistance, Electro-pneumatic Control, Automated Manual Transmission(AMT)

I. INTRODUCTION

Automation is developing automatic solutions for various tasks that have been carried out manually in the past with the aid of multiple sensors, controllers, and processes to accomplish the optimal operation. Automated Transmission is built from electrical sensors and different types of actuators one of which is an electro-pneumatic system for clutch actuation and gear shifts. Without the requirement of any modification to the sequentially geared engine. Gear transmission is done electro-pneumatically like a human driver does, by comprehending the RPM of the vehicle making the gear shifting process effortless to an extent.

Whenever the RPM of wheels of the vehicle goes up or down in comparison to the previously determined RPM for a specific ratio of gear, the embedded controller transmits a signal to the pneumatic valves through its output pins which further actuate clutch and shift the gear. The clutch and the gear are actuated by the microcontroller-based control system which helps in maintaining the car's steady performance.

A lot of research is done recently in the domain of transmission frameworks which had started as an establishment for research in the field of automatic gear shifting. This was done by replacing the methods previously being used from the foregone times and introducing new methods that involve embedded electrical and electronics systems which include both digital software programs and hardware machinery too and hence developing more efficient and reliable systems. The model in this research work functions on electro-pneumatic gear shifting strategy. This model was presented by QIN Da-tong et al in 2004. [1]

Kei-Lin-Kuo proposed the process of automatic transmission shifting which involves joint components such as the clutch and bands, linking gear sets to create a fixed gear ratio. Since these ratios differ between gears in a transmission with a fixed gear ratio, the vehicle's motion may suddenly change during the shifting process. [2]

Meng et al. in 2015 mentioned that the gear transmission is made up of majorly three stages which are the fill stage, the torque stage, and the inertia stage. Someone who’s driven a car can easily understand these three phases. In the first stage when the clutch is actuated, its chamber fills and there is a lot of pressure in it, it could be a hydraulically controlled clutch chamber. Next is the torque stage in which the gear actually changes and the transmission occurs and a sudden jerk occurs while driving. The third is the inertia stage, in which the clutch is released slowly and the vehicle moves forward freely. [3]

Ahmed F et al. mentioned that in an automatic gear shifting system, the decision of when to shift the gear is made through the microcontroller, in which an embedded microcontroller determines the gear shifting process in accordance with the speed of the wheels of a vehicle without the requirement of any human getting involved in it. [4]

Ngo et al. in 2013 presented that the selection of the optimal gear ratio for the reliability of the gear shifting system is one reason for the use of automatic transmission control. The appropriate choice of the transmission ratios corresponding to the demand for velocity and torque is made keeping in mind the efficiency and reliability. [5]

Mairal A. A. et al. presented a deep understanding of when the speed of the vehicles changes beyond a pre-defined range of values, the control mechanism in accordance with the microcontroller actuates both the clutch and the gear to ensure a smooth operation of the vehicle. The gear shifting system works with the help of a solenoid actuator which is further based on a spring related mechanism. There is a DC motor that controls the clutch. These systems are operated with the help of the microcontroller designed to process output from the wheel speed sensor. [6]

Meng et al. proposed that the pressure control systems that function automatically uses a device which is called a proportional solenoid valve. In this work, the authors investigate the results of a simulation for this valve taking into consideration many different factors. [7]

Hyeoun D et al. proposed that Pneumatic servo-systems are used to implement pneumatic transmission shifting. This system is both mechanically and automatically controlled transmission systems that use a pneumatic gear shifting strategy which is developed from sensors for both lengthwise and crosswise shifts. The regulation of pressure is synchronized with the change of gears. [8]

Martin Sommerville presented a deep understanding of the use of solenoid valves and a pneumatic based throttle actuator used as a to-and-fro control system. The author has provided a relation between the performance model and the input model of the control system with designs based on various self-derived equations. [9]

Wang et al. proposed an innovative dynamic model for Variable force solenoid (VFS) and clutch circuit explaining the outcome of a pressure range directed by relaying shifting system, with final models verified by SIMULINK modeling and data is validated CD4E transaxle. The final model suggested the use of a conventional PID controller for minimum error and maximum accuracy.[10]

F. Baronti et al. presented a creative thermal and a dynamic model for voice-coil actuators for a manual transmission Formula Student Racecar. A detailed description of the gear control unit interfaces with hardware and software. CAN communication protocol is implemented making their work easier and making the troubleshooting easier. With various input sensors and real-time validation, the authors also presented a validation model for their findings. [11]

Tao et al. proposed a model for functions of a pneumatic system for AMT to generate adequate pressure for shifting clutch and quality control. Based on the hydraulic system model simulated on AMESim, a simplified setup is designed. The results of this research were validated using an energy-based model and activity index analysis. [12]

Zhigang Yang et al presented a technique of a learning algorithm to predict optimal shifting. The method used to simulate driver's intentions and thinking in predicting the change in gear ratio in AMT, the learning algorithm is hence used to schedule the shifting in an optimum and accurate manner in order to achieve perfect shift timing. [13]

L. Xi et al. proposed a method for data acquisition by MATLAB programming of an optimized dynamic 3-parameter automatic 8-speed transmission gear-shift algorithm. On the basis of MATLAB / SIMULINK, a simulated model of a gear-shift algorithm is developed. A generator, a hydraulic torque converter, a gearbox, a gear-shift algorithm, and a vehicle body dynamic system are included in the model for vehicle system integration.[14]

B Mashadi et al. presented that the controlling parameters for gear shifting in AMT are considered and hence, based on these benchmarks the working conditions of the engine and the driver are defined. The strategy of gear shifting was designed with the application of a fuzzy control method, taking into account the effects of these parameters. [15]

C. Li et al. proposed a data acquisition model with automated transmission research, using NI's acquisition and CAN card. Test data can be used to obtain the automatic transmission shift control strategy and oil pressure characteristics of the clutch or brake, the solenoid duty ratio, and the CAN message issued by the automatic transmission and engine control unit. [16]

II. Theory

The Honda CBR600RR engine utilizes a sequential transmission, which means that the gears are shifted only in either ascending or descending order and they can't be skipped. The vehicle is facilitated with an electro-pneumatic gear shifting system. Previously, paddle shifters were used for gear shifting, but because of the new automatic gear shifting system, there is no need for paddle shifters or manual shifting. For the whole mechanism, four 5 by 2 pneumatic valves fitted with solenoids are used with an air cylinder in the pneumatic cylinder unit as shown in Fig 1. The data is transmitted from the sensors to the Engine Control Unit (ECU) and then to the microcontroller through a Controller Area Network (CAN) protocol. The control is mediated from the algorithm fed to the microcontroller, commanding the H-bridged L293D IC to actuate the specific valve.

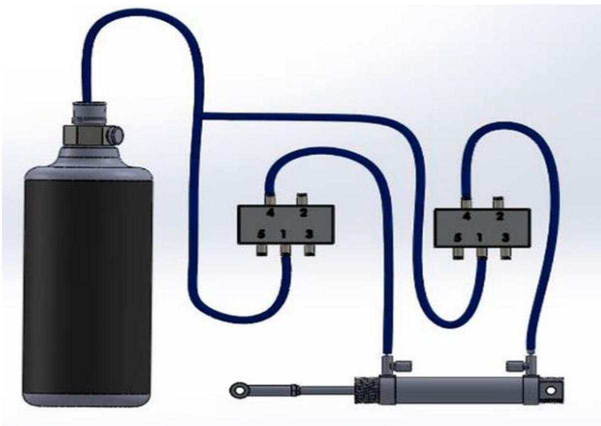

Fig. 1. Compressed gas cylinder, 5/2 valves, and the actuator comprising of the whole pneumatic shifting system.

A. Algorithm

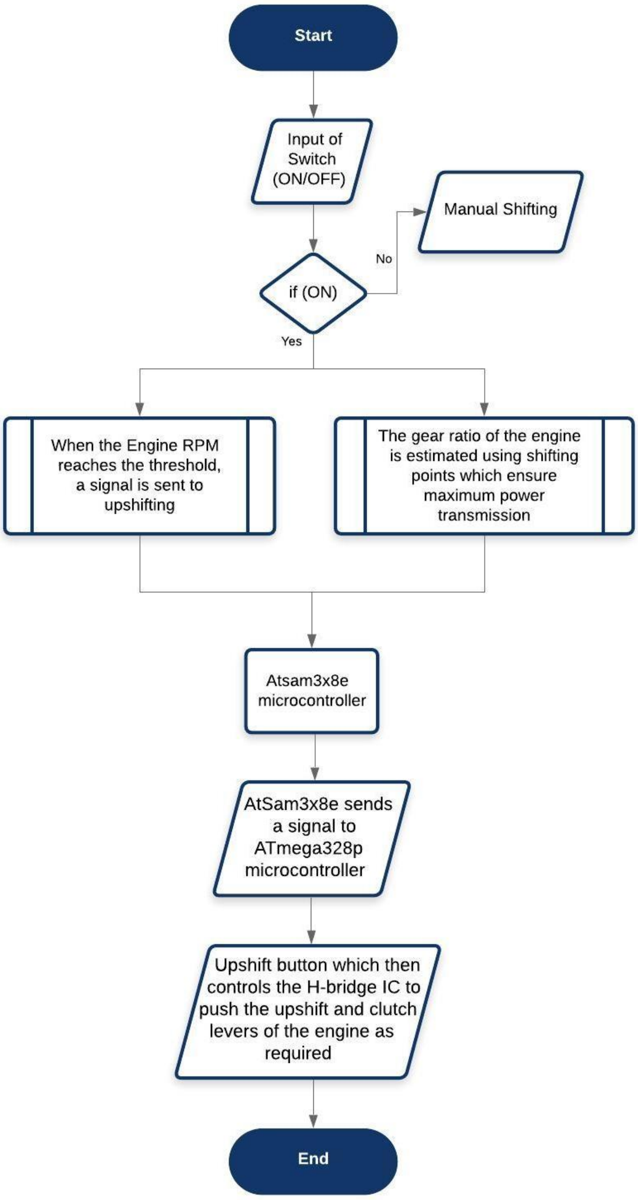

Fig. 2. Algorithm of the codebase

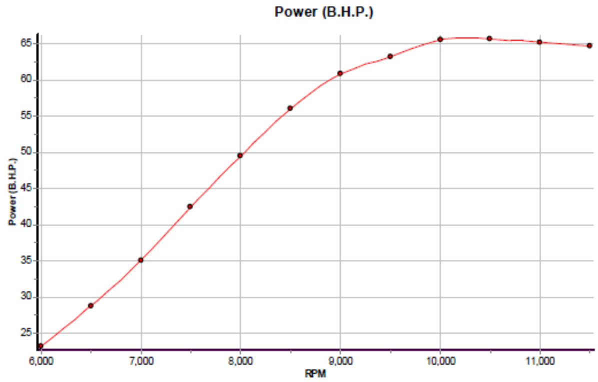

Fig. 3. Power vs RPM graph obtained from the dyno

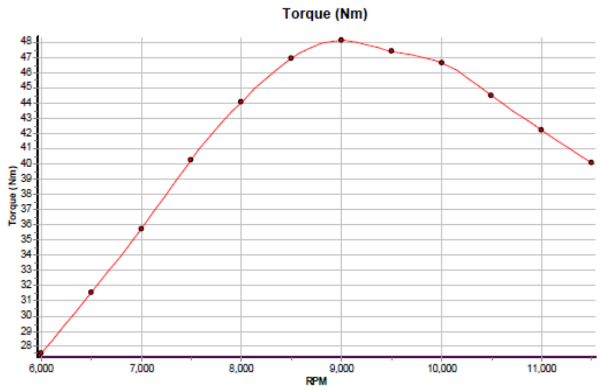

Fig. 4. Torque vs RPM graph obtained from the dyno

III. EXPERIMENTAL SETUP

As the system is facilitated with an electro-pneumatic gear shifting system, a threshold needs to be set at which the car will increase or decrease its gear. The threshold selected in the code for the car was determined using Fig. 3 and Fig. 4 which were obtained when the engine was taken to the dyno for engine tuning. The conclusion after seeing these two graphs is that the maximum torque and power are obtained at 9,000 RPM. This RPM value is further useful for determining the range in which the gear should shift. The limits to upshift or downshift were set according to the RPM, when the gear ratio to shift to the next gear is adequate then the vehicle is made to upshift, and while the RPM decreases the engine is shifted to a lower gear to give enhanced drivable experience.

For the whole mechanism, four 5 by 2 pneumatic valves fitted with solenoids are used. Two of these valves are deployed for the upshift and downshift control while the other two manage the clutch lever. The gear shifting operation is started when the lever is turned in the control valve. There are two pneumatic cylinders for engaging the gear in the construction, consisting of pistons on each side of the vehicle pedal. All of them are given a common ground from the car's chassis. When the H-bridge IC relays the 12V power supply to the corresponding solenoid, it is actuated and the corresponding lever is pushed by the CO2 gas stored in a cylinder close to the valve as shown in Figure 2. The cylinders are operated with the help of pressurized air coming from the compressor and it is controlled by a Microcontroller. Previously paddle shifters were used for gear shifting, but because of the new automatic gear shifting system, there is no need for paddle shifters or manual shifting.

The most important part of the system is the data being transmitted from the sensors to the Engine Control Unit (ECU) and then to the microcontroller through a CAN protocol. A CAN is a standard vehicle bus interface designed to enable microcontrollers and devices to communicate with each other without a host data processor. As it proves to work efficiently in different electrical environments and certifies noise-free communication.

The idea behind the system is to provide drivers an efficient and better response due to better acceleration in events. This automation ensures that the driver's focus is not shifted. To achieve this, previous data of the engine and the gear ratios of the engine are used.

With the help of RPM data and the gears, the gear ratios were calculated and hence defined the shifting point at each gear. The current system is equipped with a gear position sensor and a crankshaft position sensor. With the help of these sensors, the RPM and the gear data are sent through the CAN bus to the ECU and the ATsam3x8e microcontroller inside the steering wheel as shown in Figure 5.

The ECU smoothens the data and then it is relayed to the microcontroller where all the calculations and the algorithm runs. Using a self-developed code base, the car is made to shift. The limits to upshift or downshift were set according to the car's RPM, when the gear ratio to shift to the next gear was adequate then the car was made to upshift, and while the RPM fell the engine was shifted to a lower gear to give enhanced drivable experience.

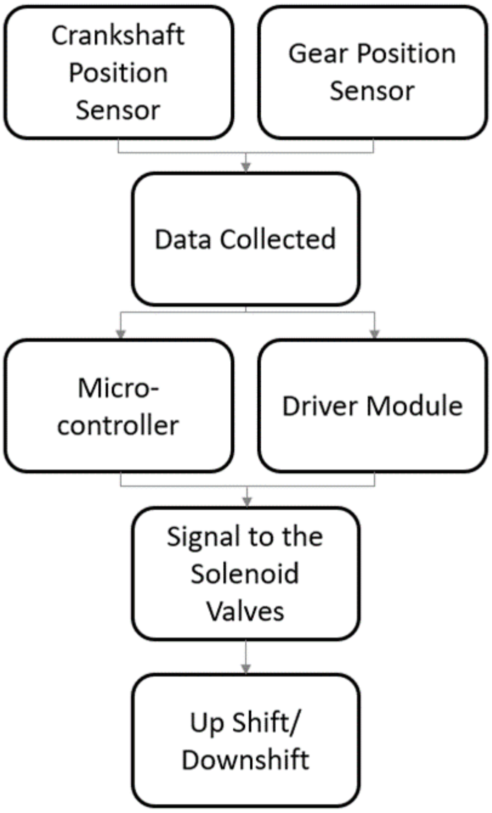

Fig. 5. System Logic

IV. Result

It can be inferred that the presented work has obtained outstanding performance. Through driver feedback and testing results, it was found that the total time required for a gear shift has reduced compared with the previous gear shifting methods. Previously, the gear shifted in 0.6 seconds but now the time has been reduced to 0.365 seconds with the introduction of automatic gear shifting.

This can be illustrated by the following graphs of automated gear shifting before and after implementation. This data is sensed in real-time and the gears are automatically shifted based on the values previously derived.

Before Implementation of Automatic Gear Shifting:-

Fig. 6. Speed vs Time and RPM vs Time Graphs:-

After Implementation of Automatic Gear Shifting:-

Fig. 7. Speed vs Time and RPM vs Time Graphs

V. Conclusion

The presented work included the development and implementation in the Formula Student Racecar of automatic gear shifting without any driver intervention. The project proved to be reliable, cost-effective, improved performance and had a lightweight packaging with the capability to withstand harsh racing environments. Using the microcontroller and the required hardware enables to convert the previous semi-automatic gear shifting mechanism to a fully automated one. When the gear is changed to a higher or lower gear, it is verified whether the gear shifting system is behaving logically or not. As this mechanism changes the gear at the perfectly optimum RPM, it increases the engine's longevity and overall there is less consumption of fuel too. All of this allows the rider to ease the process of driving and maintain the efficiency of the engine.

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