Application of Automatic Code Generation in Software Development of Tractor AMT Control System

Liyou Xu, Jingyun Zhang, Zhili Zhou, Xianghai Yan

1Vehicle & Motive Power Engineering College, Henan University of Science & Technology, Luoyang, Henan Province, China, xlyou2002@sina.com
2Vehicle & Motive Power Engineering College, Henan University of Science & Technology, Luoyang, Henan Province, China, zhangjingyun6832@163.com
3Vehicle & Motive Power Engineering College, Henan University of Science & Technology, Luoyang, Henan Province, China, zzli@haust.edu.cn
4Vehicle & Motive Power Engineering College, Henan University of Science & Technology, Luoyang, Henan Province, China, yanxianghai6093@163.com

Abstract

To solve the problems of many errors, low efficiency and massive work during manual programming, a software development method for automated mechanical transmission (AMT) control system based on Simulink/Embedded Coder is proposed in this paper. On the basis of the analysis of control principle of tractor AMT, the automatic shift control algorithm model is established in Simulink. The AMT control system code model which takes TMS320F28335 DSP as the processor is developed in Embedded Coder. Based on the above work, the software code of tractor AMT control system is generated and loaded in the controller. Automatic shift of tractor is realized by semi-physical simulation. The simulation results show that the tractor AMT software development method determined in this paper is feasible.

Keywords: Tractor, Automatic Code Generation, Embedded Coder

1. Introduction

The traditional software development of automated mechanical transmission (AMT) is divided into demand analysis, detailed design and specific implementation. These three stages are finished by different technical staff, and each staff is responsible for different but interrelated work [1-5]. Because many people participate and their development platforms are different, the integration work later is complicated. Especially, in the specific implementation stage, the manual programming is difficulty, efficiency is low, lots of mistakes appear, and requirement is high to technical person [6-7]. With the rapid development of electronic technology and control technology, the requirement on tractor performance increases, and the code volume of tractor AMT control system grows. The traditional software development mode cannot satisfy the developing situation. Compared with the traditional software development mode of AMT control system, software development based on model makes every development stage of AMT system in a unified platform. The AMT control system model which is established in the control prototype development stage is taken as a dynamic executable specification. The transition from “detailed design” to “specific implementation” is realized by automatic code generation tool. In this way the workload for software developers is reduced [8-9].

At present, the software development method which is on the basis of model and takes software similar to Matlab/Simulink as a platform is established in foreign countries, and this method is also increasingly used in development of vehicle electronic control system [10-11]. The purpose of this paper is to solve the problems of many errors, low efficiency and massive work of manual programming of tractor AMT software on the basis of proposing a software development method which uses Simulink/Embedded Coder.

2. Development Process of AMT Automatic Code Generation

In this paper, the AMT code is generated based on Matlab. The Simulink model of tractor
AMT control system is generated into embedded real-time standard C code by the real-time embedded code generation tool Embedded Coder, in order to provide the design input for the semi-physical simulation. Only the goal setting of target hardware is needed, the executable code of AMT control system corresponding to the hardware platform is generated on the basis of the Simulink model.

The development steps (Figure 1) of tractor AMT automatic code generation are designed based on model. The code generation of tractor AMT is mainly divided into three stages [12-13]: control prototype development stage, algorithm implementation stage and algorithm verification stage. The control prototype development of tractor AMT is accomplished in Simulink. The Simulink model which reflects the control algorithm and control strategy of automatic shift must meet the requirement of the tractor AMT system. The algorithm simulation should be completed in this stage. If the simulation results are incorrect, the system algorithm model needs to be modified. The control prototype development stage is not over until right simulation result is gathered. The simulation test makes technical staff find problems and errors in initial stage of AMT system software development. The correct Simulink model of tractor AMT is used as a dynamic executable standard, and the later work is based on this model. The algorithm implementation stage is completed in Simulink /Embedded Coder and CCS. The code model of tractor AMT is established and the software code is generated automatically based on the Simulink model. The AMT code is built and loaded into the target hardware TMS320F28335 DSP. This stage is the key step to realize the research from control algorithm into code. The code verification stage is the last stage of AMT software development based on model. When a problem is discovered, the Simulink model is modified directly to ensure the synchronization between the AMT automatic shift control model and the executable code.

**Figure 1.** Flow Chart of AMT Control System Automatic Code Generation

- MATLAB/Simulink
  - AMT Control Prototype Development
  - Embedded Coder
  - Automatic Shift Algorithm Implementation
  - Semi-physical Simulation
  - AMT Software Code Verification
  - Establish AMT automatic shift control model
  - Simulation correct
    - Executable specification
    - Establish AMT code model
    - Automatic code generation
    - Executable code
    - Code verification
    - Right
    - Over

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3. Tractor AMT Control System Model

3.1. AMT Control Principle

Tractor AMT takes transmission control unit (TCU) as the core of system. According to the actual working condition of tractor, the TCU conducts the clutch engagement/disengagement and transmission shift by hydraulic actuating mechanism, and controls the throttle opening by stepping motor. The working principle of shift hydraulic system is presented as Figure 2. In Figure 2, the hydraulic pump provides energy for the hydraulic system. The accumulator which stores all of the hydraulic oil for the hydraulic system has good steady effects on the pressure. Mv1 and Mv2 compose the control valve unit for clutch hydraulic cylinder. Mv3 and Mv4 compose the control valve unit for shift hydraulic cylinder 1. Mv5 and Mv6 compose the control valve unit for shift hydraulic cylinder 2. Mv7 and Mv8 compose the control valve unit for shift hydraulic cylinder 3. The relief valve is used to avoid the overload of the oil circuit. When the engine is idling or the tractor stops, the hydraulic system does not work, and the three shift hydraulic cylinder pistons are all in the intermediate position of the shift hydraulic cylinders. When a gear change is required, the TCU lets Mv1 open, and oil flows into clutch hydraulic cylinder. When receiving complete separation signal of the clutch that sent by clutch position sensor, the TCU gives orders to Mv3/Mv4 or Mv5/Mv6 or Mv7/Mv8. Once the shift hydraulic cylinder piston position sensors send the information that tractor has been in target gear to the TCU, Mv2 is opened. The oil in clutch hydraulic cylinder returns, the clutch engages, and the gear shifting is achieved.

3.2. Tractor AMT Automatic Shift Control Model

For starting, accelerating, idling and other working conditions of the tractor, the AMT TCU sends instructions to control the output signals in accordance with the input signals and feedback signals. Thus, the clutch actuator, shift actuator and throttle actuator act, and the automatic gear shifting of tractor is realized. Only then can the tractor works at optimum condition, and the advantage of AMT system be exerted. As tractor often works in the field, the slide rate of driving wheel of tractor reflects the change of road running status and traction load. The running speed loss of tractor work unit decreases with the slide rate of driving wheel decreases. When the slide rate of driving wheel decreases, the traction load should be increased and the transmission should be shifted into a higher gear. When the slide rate of driving wheel increases sharply and exceeds one value, the running speed and drive efficiency of tractor decreases rapidly. At this moment, the traction load should be decreased and the transmission should be shifted into a lower gear. The AMT of this research is processed based on the mechanical transmissions of Dongfanghong MG series tractors. The automatic gear shifting model of
tractor AMT which takes tractor speed $v$, throttle opening of engine $\alpha$ and slide rate of driving wheel $\delta$ as the control parameters is the basis of automatic code generation. The automatic gear shifting control model of tractor AMT in Simulink is shown in Figure 3. In Figure 3, the handle position HP, brake pedal position BPP, driving mode, throttle opening of engine $\alpha$ are treated as the input signals of the AMT system. The default state of the system is power shift mode $P$. When pushing the Mode Switch button, the switch signal 1 is sent to the TCU and the tractor runs at the economic shift mode. The clutch engagement position CEP, three shift hydraulic cylinder piston positions CPP1, CPP2 and CPP3, tractor speed $v$, rotary speed of driving wheel $n_k$, engine rotary speed $n_e$ and transmission input shaft speed $n_{e_{in}}$ are treated as the feedback signals of AMT system. The control signals of eight high-speed solenoid valves Mv1-Mv8 and a stepper motor are taken as the outputs signals. When the driver chooses forward gear $D$, the tractor AMT shifts automatically according to the shift rules of Auto_D Controller module in Figure 3. The automatic control algorithms for the handle at N and R positions are contained in Auto Controller.

Figure 3. Automatic Gear Shifting Control Model of Tractor AMT in Simulink

4. Automatic Generation of Tractor AMT Code

4.1. AMT Code Model

In order to simplify and speed up DSP development, Math Works converts the peripheral units into Embedded Coder toolbox by using Simulink language. The rational use of Embedded Coder toolbox can instead of complex manual programming. The tractor AMT model for code automatic generation is
presented in Figure 4. The code model which is established by Embedded Coder toolbox contains the following modules.

(1) Processor Module and Watchdog Module.
Different DSP hardware platform can be chosen in Target Preferences. In this paper, TMS320F28335 is chosen and the system clock is set at 150MHz. With the interference of external electromagnetic fields, DSP program may fleet and the system may enter dead circulation. The watchdog is used and the reset time is designated as 2ms to avoid this problem.

(2) Signal Input Module.
The signal input module is composed of CAP module, Digital Input module, ADC module and eCAN Receive module. A pulse can be captured in the CAP module. As the change of pin value is captured and recorded into FIFO cache memory, the capture unit is designed to collect the transmission input shaft speed \( n_{\text{e,in}} \) and rotary speed of driving wheel \( n_k \). In Digital Input module, the GPIO is designated as input state and is used to gather switching signals such as handle position HP, mode switch and so on. In ADC module, the analog signals are captured and digitized, and the results are saved in ADResult. The cascade sequence sampling is chosen and the sampling time of tractor AMT is set to 500Hz. The function of serial communication is achieved in CAN Receive module. The AMT TCU receives the engine rotary speed and the throttle opening information which is sent by the engine ECU through CAN mailboxes. When the new message arrives, the port f() can be used to call a subsystem.

(3) Signal Processing Module and System Control Module.
In Figure 4, Digital filtering of the software, function expanding of the DSP GPIO and the conversion between result register values (binary) and the inputs of AMT Controller module are accomplished by Signal Conversion module. The real-time monitoring of the input signals and feedback signals are achieved in AMT Controller module. According to control strategy and the real-time monitoring results, the actions of gear shifting are completed by AMT Controller module. In the model, the control flow changes depending on the handle position. The final control targets are eight high-speed solenoid valves in the AMT Controller module. The change among these control flows is accomplished by “switch” module in the last section of the AMT Controller module.

(4) Signal Output Module.
Signal output module consists of eight PWM modules. The on-off time of the high-speed solenoid valves is controlled by the PWM duty cycles.
4.2. Fixed point model of AMT

As the fixed point model has advantages of small size, high speed of calculation, low power consumption, the data of code model of tractor AMT is processed by fix-point processing. According to each variable’s possible size, its data length and data range are arranged to obtain sufficient calculation accuracy and to ensure that there is no overflow in the computational process.

4.3. Code Generation Process

After the above process, the parameters for code generation are set by Simulation→Configuration→Parameters. In Hardware Implementation, TMS320F28335 is chosen. In Code Generation, idelink_ert.tlc/idelink_grt.tlc is chosen according to the DSP platform. Then, the parameters for simulation, optimization and self-diagnosis are set depending on the requirements of AMT system. After clicking the Build button, the executable file for CCS is generated. During the generation process of AMT code, the information in MATLAB is drawn up as Figure 5.
5. Semi-physical Simulation Analysis

On the basis of the above work, the generated executable code is loaded to the DSP. The AMT controller communicates with PC through the standard serial port. The semi-physical simulation system is made up of the controller, engine simulation model and tractor simulation model which are established in PC. According to the test results of engine performance and the bilinear interpolation fitting method, the engine simulation model is established by using Look-up module in Matlab/Simulink. The engine rotary speed $n_e$, slide rate of driving wheel $\delta$ and transmission output torque $M_{e_{out}}$ are treated as the input parameters of the tractor simulation model. Transmission gear, tractor speed $v$ and transmission output shaft speed $n_{e_{out}}$ are taken as the output parameters. The parameters in Simulink are set to make the Simulink model and DSP hardware in synchronous operation so as to ensure the real-time simulation.
The semi-physical simulation platform is set up based on the above method, and the simulation results are shown in Figure 6. It can be seen that from Figure 6, the economy shift speed of tractor is lower than the power shift speed of tractor. From figure (a) and (b), (c) and (d), when the slide rate of driving wheel $\delta$ is certain (0.041, 0.11), the shift speed of tractor increases with the throttle opening increases. From figure (a) and (c), (b) and (d), when the throttle opening $\alpha$ is certain (30%, 60%), the shift speed of tractor decreases with the slide rate of driving wheel $\delta$ increases. Tractor AMT semi-physical simulation results are in consistent with the requirements of the three parameters automatic gear shift rules.

6. Conclusions

On the basis of the analysis of control principle of tractor AMT, the automatic shift control algorithm model is established in Simulink. The AMT control system code model which takes TMS320F28335 as the processor is developed in Embedded Coder. Based on the above work, the software code of tractor AMT control system is generated and loaded in the controller. Automatic shift of tractor is realized by semi-physical simulation. The simulation results show that the tractor AMT software development method determined in this paper is feasible.

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8. References