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Control Algorithm Development for Electric Vehicle Residual Driving Distance Based on V Model

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***Abstract*—Marketing for electric vehicle is one of the solutions for solving the environment pollution and energy consumption problem. The powertrain control software of electric vehicle as one important core technology gets the attention and investment from main OEMs. The V model development flow is one mainstream software development flow. The steps, advantages and tools, development software for this development flow are introduced here. One important sub function of powertrain control software of electric vehicle, remain driving distance calculation was developed and validated based on this development flow. The tested data can show that, this EV remain driving distance algorithm can calculate accurate value all the time. This value can be a valuable reference for driver to manage route and driving method.**

Keywords—V model development flow; electric vehicle; remain driving distance

I. INTRODUCTION

Environment pollution and energy consumption issues followed the rapid development of Chinese economy these days. For fulfilling the targets of low carbon, environment friendly and sustainable development, Chinese government released a series of rules and standards to set the limitation for emission and fuel consumption of vehicles. For example, Limits and measurement methods for emissions from light-duty vehicles (CHINA 6, GB18352.6—2016[1]). The forth phase of passenger car fuel consumption standard (GB 19578-2014 and GB 27999-2014) [2]. At the same time, Chinese central government and local governments released a series of policies to propel the marketization process of new energy vehicle, including battery electric vehicle (BEV), plug-in hybrid electric vehicle (PHEV) and fuel cell electric vehicle (FCEV). With the positive factors (spur policies from government, charging piles and based facilities rapid construction and rapid progress of battery technology), the development and marketization of electric vehicles have been kept continuous progressing. [3]

Vehicle control technology is one of the three big electric technology (motor control, battery management system and electric control), OEMs regard it as the core technology, put money and resource to develop it. The V model development process based on models is now the mainstream powertrain system control software development process. Residual driving distance is one important module in electric vehicle powertrain control function, it influence the usage feeling of customers directly. [4,5] The main content of this article includes the application of V model development process based on models in BEV vehicle control software development, the residual driving distance function development with this process.

II. INTRODUCTION OF V MODEL DEVELOPMENT PROCESS BASED ON MODELS SECTION HEADINGS

The common software development processes include, Build-and-Fix Model, Waterfall Model, stagewise model, Incremental Model [6] , V model etc.

Because the V model development process has the obvious advantages comparing to other development processes, it becomes the mainstream development process for vehicle powertrain system control software. The main phases of V model process are showed in Figure I, include function requirement, software architecture and requirement, SW algorithm development and modeling, model integration, rapid code generation, unit test, integration test, function validation and calibration.

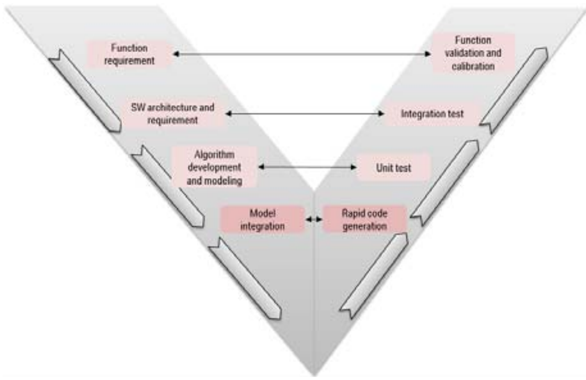

FIGURE I. THE MAIN PHASES OF V MODEL PROCESS

The description of these phases is as follows:

Function requirement. All the functions of vehicle control software are confirmed based on vehicle design requirement, powertrain system design requirement, E/E architecture, function and interface of relative components (High voltage battery, traction motor, on board charger).

Software architecture and requirement. The software architecture is defined based on the function requirement, the main task includes, distributing control software into several sub-modules, defining the signal interface of these sub-modules, the specific requirement of software design is defined.

Software algorithm development and modeling. Software is developed mainly based on model now, the algorithm of sub-modules is designed based on the software architecture and requirement, the control models are designed using model develop tools.

Model integration. All the models of sub-modules are integrated into a whole control model based on the defined software architecture. The application software and low level software are integrated based on interface provided by low level software.

Rapid code generation. The integrated model is transferred to C code and machine code of target controller using complier.

Unit test. The models of sub-modules are tested to ensure the logical correctness. The common test methods include MIL (Model In Loop) and SIL (Software In Loop).

Integration test. After the unit test, the integration test will be carried out to validate the logic correctness of sub-modules in the whole model, the connection correctness of sub-modules, data transferring correctness. The common test methods include MIL (Model In Loop) , SIL (Software In Loop) and HIL (Hardware In Loop).

Function validation and calibration. The task of this phase is mainly carried out on the test bench and vehicle. Verifying whether the whole control software can meeting the software requirement. To meet the target of vehicle performance, drivability and system protection via calibration and optimization.

The main advantages of V model development process based on models are as follows:

- The whole development mode is obvious to team members, easier communication is in the development team. It's suitable to the control software development which needs cooperation.
- The structure of development process is excellent, every phase can be carried out based on the output and detailed record of previous phase.
- The quality assurance activities is accompanied with software development process, that means the development and validation process start nearly at the same time. The two parallel dynamic process can decrease the bug and error dramatically, avoiding the disastrous result because the big problem is found at the later stage.
- The software development efficiency can be improved dramatically by using relative tools and software.

III. The Tool Chain for V Model Development Process Based on Models

As introduction before, the efficiency of software development can be improved dramatically if the relative software and tools are equipped. The mainstream software and tools are listed in Table I.

TABLE I. SOFTWARE AND TOOLS FOR V MODEL DEVELOPMENT PROCESS

Development phase of V model process	**Mainstream software and tools**
Function requirement	IBM DOORS[7]
SW algorithm development and modeling	Mathworks MATLAB/Simulink/Stateflow, ETAS ASCET, dSPACE Mirco Autobox[8], Woodward Mototron[9].
Rapid code generation	Mathworks Embedded coder, dSPACE Target Link, Green Hills.
Unit test	TraceTronic ECU TEST[10]
Integration test	dSPACE Simulator, ETAS LABCAR.
Function validation and calibration	ETAS INCA, Vector CANoe, CANanalyzer, CANape, ATI VISION.

A. Developing the Electric Vehicle Residual Driving Distance Using V Model Development Process Based on Models

Developing the electric vehicle residual driving distance using V model development process will be introduced in this paragraph. For the residual driving distance function is one sub-module of electric vehicle powertrain control software, only the relative work for developing this function, including algorithm design, modeling and unit test will be mentioned here.

1) Function description of electric vehicle residual driving distance:

For electric vehicle, the driving distance in one charging period is somehow short because of the current battery technology limitation. The SOC (state of charge) of high voltage battery pack on electric vehicle is only relative to the residual driving distance, the specific residual driving distance cannot be evaluated by the driver based on this value. So the vehicle control system of electric vehicle should provide residual driving distance, drivers can get accurate residual driving distance information real-timely. It can help drivers to manage the driving route, avoid of the residual driving distance anxiety.By analyzing the searched document, the residual driving distance of electric vehicle calculation method described in these document [11]~[15] cannot provide the whole, suitable for engineering solution.

2) Requirement analysis for residual driving distance of electric vehicle:

Based on the whole vehicle design requirement, common residual driving distance control function analysis, relative engineering experience, the key requirements of this residual driving distance function are as follows:

The average electricity consumption in the future is estimated by the electricity consumption in previous driving distance. The driving style will influence the average electricity consumption in the future.

The average electricity consumption in the history should be stored, this value is the initial average electricity consumption value at the beginning of every key cycle. The initial residual driving distance is calculated by the SOC of high voltage battery and this value.

If there is special operation, e.g. driving mode (ECO, Sport) changing, AC system on/off, the residual driving distance should be changed in defined time.

3) Algorithm development of electric vehicle residual driving distance:

Based on analysis of function requirement, software architecture and analysis of software requirement, the defined algorithm of residual driving distance is as follows:

Calculate the useable energy of high voltage battery pack, the formula is: Residual useable energy of high voltage battery pack=*(SOC1-SOC0× Total.* useable energy of high voltage battery pack SOC1 is current SOC value provided by battery management system, SOC0 is lowest useable SOC value.

Estimate the average electricity consumption in the future based on historic average electricity consumption. Set up n storage areas. Calculate the average electricity consumption value in defined driving distance and save it in the first storage area. The next average electricity consumption value is saved in the second storage area if the driving distance reaches setting value. To use an analogy, replace the old average electricity consumption with the new one.

Initialize the average electricity consumption in n storage areas. In one key cycle, the initial values of average electricity consumption in n storage areas should be set during the control software initializing period. The calculation formula of average electricity consumption initial value is:

$$P_o = a \times P_p + b \times P_h \tag{1}$$

Po is the initial values of average electricity consumption, Pp is average electricity consumption in pervious key cycle, Ph is average electricity consumption in the whole time. a and b are weight coefficients:

$$a + b = 1 \tag{2}$$

The sum of the average electricity consumption values in n storage areas is divided by n, the result is the average electricity consumption in the future which is used for estimating the residual driving distance.

The formula for calculating the residual driving distance is as follows: Residual driving distance = Residual usable energy of high voltage battery ÷ average electricity consumption in the future.

4) Model design for residual driving distance sub-module:

Design the control model using MATLAB/ Simulink/ Stateflow development tool software based on defined algorithm of residual driving distance. The models can be found in Figure II and Figure III, Model in Figure II. is the main model of this function, includes average electricity consumption in the future calculation model and final residual driving distance model. Model in Figure III is the detailed model for final residual driving distance.

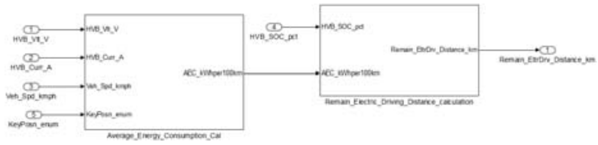

FIGURE II. THE MAIN MODEL OF RESIDUAL DRIVING DISTANCE CALCULATION SUB-MODULE

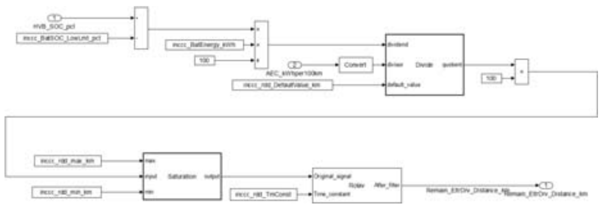

FIGURE III. RESIDUAL DRIVING DISTANCE CALCULATION MODEL

5) Unit test:

The unit test model based on MATLAB/Simulink is showed in Figure IV, The unit test requirement and test cases are designed based on control function and model of this sub-module. The test cases run in this unit test model, carry out the model tuning, bug finding and fixing, verifying the logic correctness.

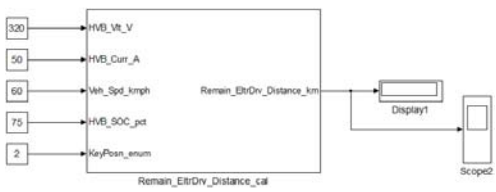

FIGURE IV. MODEL FOR UNIT TEST

6) Test and validation of this function:

This function sub-module is used on the vehicle control software of one electric vehicle. The model integration, rapid code generation, integration test are carried out after the unit test. The function is tested and validated on the vehicle at last. The analysis of recorded data on the vehicle is showed in Figure V, the upper curve is SOC of high voltage battery, the middle curve is driving mode selection, the lower curve is residual driving distance. At the starting time, the residual driving distance is initial value based on historic average electricity consumption. Then the residual driving distance is a reasonable value based on SOC and driving style. At 800s point, the driving mode changes from sport mode to economic mode, residual driving distance responses rapidly. This function can be proved to meet the function requirement definition based on above data analysis. This function can send out an accurate and reasonable residual driving distance in real time, it can give drivers a reliable basis to manage the driving style and route.

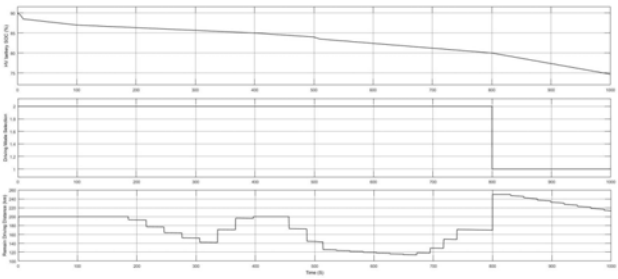

FIGURE V. RECORDED DATA ANALYSIS

IV. SUMMARY

The V model development process based on models for vehicle powertrain control software development, the tool train for this process are introduced in this article. One important control function (residual driving distance calculation) in vehicle control software of electric vehicle is developed based on this process. The algorithm design, modeling and unit test are introduced. This function can fulfill the function requirement after the validation on the vehicle. This article can be a useful reference for relative developers and engineers.

ACKNOWLEDGEMENT

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