Practice of Model-based Development for Automotive Engineers

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This study presents the practical results concerning model-based development educational practices implemented by Hiroshima University and Mazda Motor Corporation, an automobile manufacturer, and the consequent educational effects. In recent years, diversification and complexity of product structures have become prominent. Simultaneously, there is an increasing demand for short-period development with limited resources to promptly respond to customer needs. In order to efficiently proceed with the aforementioned development, model-based development employing computer simulation is considered effective. Model-based development is performed according to a development process called the "V-type development process (V-process)." This process includes the operations of model in the loop simulation and hardware in the loop simulation. However, several professional engineers involved in automobile development have insufficient experience in conducting model-based development. In this study, the authors propose a program that allows these professional engineers to learn the V-process using a motor control system via a hands-on approach. The program is implemented to target 159 professional engineers belonging to Mazda Motor Corporation. In the learning program, exercises for motor control system using "MATLAB/Simulink" are performed. Additionally, hardware in the loop simulation exercises using a simple simulator exclusively developed for this purpose, and control experiments with an actual motor control system are conducted. From the questionnaire surveys taken by the learners, it is revealed that the V-process exercises considerably contribute to the self-efficacy of the learners for operational performance using model-based development.

I. INTRODUCTION

Customer needs for products have become more diversified and complex over the years. Companies must promptly respond to such demands. Moreover, the cost and time required for manufacturing must be reduced to the maximum extent possible owing to the intense international competition currently. Given this background, importance of model-based development (MBD) [1]–[3] has increased. The automotive industry has proactively adopted MBD for product development [4]. However, there are only few professional engineers involved in automobile development having sufficient experience for performing MBD.

The "Hirojiren" (i.e., Hiroshima Council for the Promotion of Collaboration among Government, Academia, and Automobile Industry) was established in June 2015 in Hiroshima Prefecture in regard to the "Industry-Academia-Government Collaborative Vision 2030." The Hirojiren, comprising of three committees and four expert committees, undertakes relevant activities. The expert committee for MBD established "Fundamentals of MBD Laboratory (MBD lab)" in Hiroshima University in 2016, Hiroshima University and Mazda Motor Corporation, the Japanese automobile manufacturer, played a central role in the establishment of this lab. An MBD education program that would allow for educational effects with the learners being beginners and the implementation period as constraints was proposed for the MBD lab. Such a program was implemented for 159 people for 4 months. According to the above-mentioned program, control experiments based on physical modeling and motor control systems, as well as basic exercises using MATLAB/Simulink were performed. Moreover, in order to learn HILS via a hands-on approach, a simple hardware in the loop (HIL) simulator using Arduino was developed, which was then utilized for practical training. The questionnaire surveys implemented for each lecture revealed that several learners gained confidence for operational performance via MBD before and after participating in the learning program. In this study, changes of the educational effects on the learners will also be analyzed based on the changes in the results of the questionnaires.

Importance of MBD has been recognized by the educational processes of universities. Program proposals and practices mainly targeting undergraduates have been reported [5]–[7]. However, to the best of our knowledge, the number of studies that have reviewed proposals for MBD educational programs targeting professional engineers involved in automobile manufacturing and the educational effects based on such programs is small. Thus, this highlights beneficial case examples for fostering MBD professional engineers in companies.

II. MODEL-BASED DEVELOPMENT LEARNING PROGRAM

A. Model-based Development

MBD is performed in line with the development process named, the V-process. The V-process varies depending upon the number of items according to the degree of details for the descriptions. Briefly, this is described as per Fig. 1. According to model in the loop simulation (MILS), first the requirements for an intended system operations are determined. The combination of components and parameters necessary to satisfy the aforementioned requirements is verified and designed via simulation using a simulation block. In such a case, feasibility for intended specifications may be also reviewed and modifications may be added. According to HILS, controller algorithms designed through MILS are implemented for actual ECUs, and operation verifications are performed by using a HIL

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TABLE I
QUESTIONNAIRE SURVEY ITEMS.

Question Number	Question	Evaluation Item
Q1	Are you capable of explaining MBD (i.e., Model-Based Development)?	Knowledge
Q2	Are you capable of explaining the V-Type Development Process?	Knowledge
Q3	Are you capable of explaining the significance of the modelling?	Understanding
Q4	Are you capable of modelling with the use of these software, such as Matlab and Simulink?	Skills
Q5	Are you capable of explaining MILS (Model in the Loop Simulation)?	Knowledge
Q6	Are you capable of explaining simulation based on MILS through the use of software, such as Matlab and Simulink?	Skills
Q7	Are you capable of explaining HILS (Hardware in the Loop Simulation)?	Knowledge
Q8	Are you capable of performing a simulation based on HILS by the using a software, such as Matlab and Simulink?	Skills
Q9	Are you capable of explaining the necessity for MBC (Model-Based Calibration)?	Understanding
Q10	Are you capable of explaining the operational performance based on the v-type development process or are you confident in the performance?	Self-efficacy

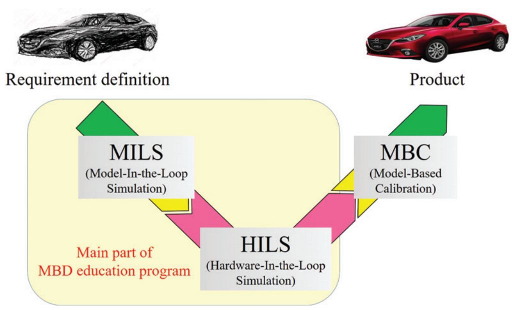

Fig. 1. V-Type Development Process.

simulator. After the aforementioned designing and verification, a model-based calibration (MBC) that allows for satisfaction of various requirements relating to mass production, such as vehicle performance and law adaptation, is performed for the combined use of actual components and models. The final products are completed after relevant products are tested. In regard to the learning program, MILS and HILS which are particularly important operations described on the left-hand side of Fig. 1, the V-process will be primarily examined.

B. Learners

159 professional engineers of Mazda Motor Corporation undertook the basic course of MBD. The program was implemented for 4 classes (i.e., a single class comprised 40 professional engineers (and 39 professional engineers for some classes)). The learners undertook the learning program concurrently with their operations. Therefore, a 4-day (i.e., 6 h a day and 2 days a week) implementation period for the program was set in advance. Many learners were primarily responsible for operations for vehicle design, vehicle equipment, electrical equipment, and vehicle analysis, instead of development of the control algorithm. Therefore, it could be inferred that such learners were not very familiar with the MBD development process accompanying the controller development. The questionnaire survey shown in TABLE I was provided to the learners prior to implementation of the learning program in order to evaluate their knowledge and predict the degree of understanding of MBD as well as the degree of motivation for MBD operational performance. In relation to all the question items, the learners selected the correct answer

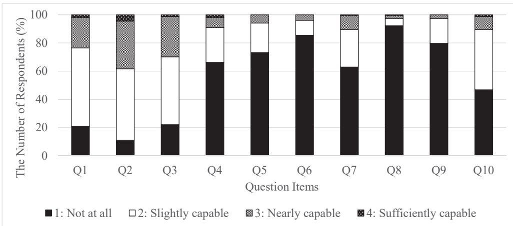

Fig. 2. Questionnaires Prior to Implementation of the Program.

TABLE II
MBD EDUCATION PROGRAM

Day 1	MBD overview and MATLAB/Simulink exercises
Day 2	First-principle modeling (examples of the spring mass damper system)
	Basics of Laplace transform (first-order lag system)
Day 3	V-Type development process exercises (MILS)
Day 4	V-Type development process exercises (HILS and actual-machine experiment)

from 4 choices of "1: Not at all," "2: Slightly capable," "3: Nearly capable," or "4: Sufficiently capable" using a 4-point scale. Fig. 2 shows the distribution of responses by the learners prior to implementation of the program. It is observed that although several learners had knowledge about MBD to some extent, they did not have skills or were not confident in the performance of MBD (the details thereof will be discussed in Section 4). Moreover, questionnaire surveys with the same content as that mentioned above were implemented on all 4 days of the lectures. The changes thereof were surveyed as well. The survey results will be discussed in Section 4.

C. Organization of the Learning Program

According to the educational program, the following educational objectives have to be achieved: (i) the learners understand the positioning of their own duties relating to MBD after implementation of the program, (ii) they will become interested in proactive use of MBD, and (iii) they will become confident in implementing MBD. In the light of the outline of MBD and the situation of the learners described above, the program is organized as per TABLE II. On the first half of the 1st day, overview of MBD was provided, which motivated the learners to learn. In the second half of the 1st day, exercises using simulation blocks allowed the learners to understand the basic method for using MATLAB/Simulink. On the 2nd day, physical modeling was performed based on differential equations for a basic learning of plant modeling, which was inevitable for MBD. Learning regarding the Laplace transform and transfer function as a separate method for expression of plant models was performed. The learners understood that there existed various methods for plant expressions. Moreover, establishment and execution of the aforementioned models via MATLAB/Simulink could lead to the effect of repetitive learning with the methods available with the software. On the 3rd day, application of the knowledge gained thus far allowed modeling of the motor control system. Explanations of the details of the motor control system will be provided in the following section. In here, the entire motor (and the load), sensor, actuator, interface (AD/DA converters), and control logic (Proportional-Integral-Derivative (PID) Controller [8]) are described as simulation blocks. Thereby, simulation could be conducted. Moreover, the learners adjusted PID parameters included in the control logics so that such parameters could satisfy the requirements specifications (i.e., settling time and overshoot) defined by the learners. On the 4th day, real-time simulation was conducted using a simple HIL simulator. Explanations regarding the details of the simple HIL simulator will be provided in the following section. Through this process, the learners were able to discover failures (i.e., response to noises etc.) that they could not notice through parameter adjustments for MILS anew, and readjust the parameters. In this way, the learners were able to learn that a method for development in line with the V-process could resolve problems relating to failures urgently through a hands-on approach. Furthermore, the learners implemented controllers obtained through the HILS operations as controllers for experimental devices, and found that results equivalent to those regarding HILS could be obtained. Thereby, the learners were able to achieve success using the V-process.

III. LEARNING MATERIALS (MOTOR CONTROL SYSTEM)

Fig. 3 shows the external appearance of the motor control system for the experiment, which was used for exercises on the 3rd and 4th days. Three aluminum disks having diameters different from those of the pulley were connected to the motor shaft. Such disks were connected by a pulley (connected to the dynamo-shaft) and belt. Moreover, the Arduino Mega 2560, motor driver, tachometer, and current sensor were mounted integral to the housing. In the exercises, controlling of rotational speed was set as an assignment. Control parameter adjustment and verification of the controller safety performance were performed via MILS and HILS. Brief explanations of MILS, HILS, and an actual experiment are presented as follows. However, the detail explanations of them are presented in a presentation due to the limitation of the paper.

A. Model in the Loop Simulation (MILS)

In MILS, learners design a block diagram of the motor system shown in Fig. 4 by using MATLAB/Simulink. The learners adjust PID parameters in a controller by using the Simulink model.

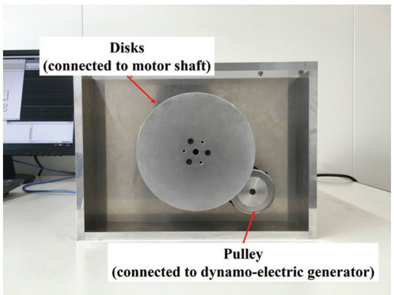

Fig. 3. Motor Control System (on the Load Side)

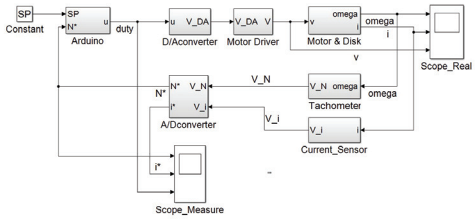

Fig. 4. Simulink model for the motor control system

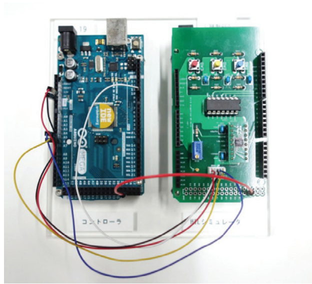

Fig. 5. Overview of the HILS System (Left Side: Controller; Right Side: HIL Simulator)

B. Hardware in the Loop Simulation (HILS)

In HILS, a PID controller designed via MILS was mounted to Arduino Mega 2560 as a type of micro controllers and operation verifications thereof were performed by using a HIL simulator shown in Fig. 5.

C. Actual-machine Experiment

Control of the actual motor control system was achieved by using the controller whose safety was verified via HILS. The control results of an actual machine with the same PID controllers as those used for MILS and HILS are shown in Fig. 6. Upper, middle, lower row of the figure indicate the number of rotation of the disk, the current in the motor, and duty ratio to the motor that is a control input outputted from the controller. From Fig. 6, the good control performance is obtained by only one actual experiment.

IV. RESULTS OF THE QUESTIONNAIRES AND EDUCATIONAL EFFECTS

In this section, educational effects from the learning program will be identified. Furthermore, based on the results

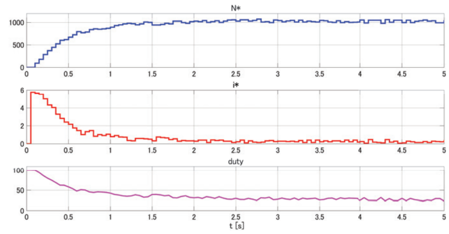

Fig. 6. PID Control Results of the Motor Control System

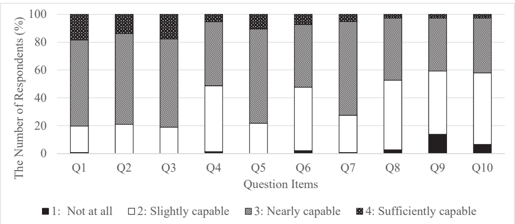

Fig. 7. Results of Questionnaires following Implementation of the Program

of the answers of the questionnaire surveys tallied for each lecture, changes of self-efficacy by those who took the course will also be discussed.

The results of the questionnaires for the learners after implementation of the learning program are shown in Fig. 7. In relation to the items of the questionnaire surveys shown in TABLE I; Q1, Q2, Q5, and Q7 represent the items pertaining to knowledge about MBD; Q4, Q6, and Q8 represent the items on skills necessary for MBD performance; Q3 and Q9 represent the items on understanding the connection between the questions and MBD, and Q10 represents the item on confidence gained through learning (self-efficacy).

First, the results of the questionnaires prior to implementation of the program shown in Fig. 2 are discussed. Based on the results of answers regarding Q1 and Q2, the number of persons who answered that no explanations could be provided regarding MBD or the V-process accounted for less than 21% of the total (Q1: 32 persons (20.9%) in maximum). Therefore, it can be inferred that the MBD method is recognized internally to some extent even when the learners were in charge of operations other than those relating to controller designing. Moreover, the answer distributions of Q1 and Q3 are remarkably similar. Therefore, even when some learners were beginners, it is revealed that recognition to the effect that simulation models were necessary for MBD has been gained to some extent. In contrast, in addition to specific explanations regarding MILS and HILS that make up the V-process, more than 60% of the learners gave the answer ”1” (Not at all) regarding the items on skills using MATLAB/Simulink (Q8: 142 persons (92.2%) in maximum). Given such a situation, despite the fact that the relevant learners had knowledge of MBD, they were not able to understand the entire picture of how MBD is performed because they have not had any experience in development in line with the V-process (or even when they are in charge of some operations in the V-process, they do not recognize so). Consequently, as they had little operational experience (or successful experience) with V-type processes, it can be assumed that their self-efficacy in being capable of carrying out MBD operations is low. Next, educational effects from the learning program are discussed based on a comparison of Figs. 2 and 7. In relation to the question items Q1 - Q8, less than 3% of the learners gave the answer ”1” regarding questions on using MATLAB/Simulink (Q8: 4 persons (2.63%)). Based on this result, high educational effects can be recognized. Additionally, in relation to Q9, despite the fact that no treatment was made through the learning program, the answer results are improved. Thus, it can be assumed that a knowledge transfer has been made based on the understanding of the content of the V-process. Moreover, based on the result of Q10, understanding of the content of learning and successful experience via exercises have led to confidence gained by the learners for their operational performance. Thus, educational effects from the learning program have been recognized.

V. CONCLUSION

The MBD education program was proposed to 159 professional engineers who belonged to Mazda Motor Corporation, and as such the program was implemented. Observation was made regarding educational effects from the program based on the results of the questionnaires for the learners. First, prior questionnaire surveys were given to the learners, and situations for acquisition of knowledge, understanding, skills, etc. regarding MBD were understood. The learning program was organized under the constraint of the schedule for program implementation. Furthermore, the motor control system and simple HIL simulator were developed for exercises and the resultants were used thereof. As a result of the questionnaire surveys following implementation of the program, exercises regarding the V-process significantly urged the learners to understand MBD. We would like to progress observation on a method for objective evaluation regarding skills of learners in the future.

ACKNOWLEDGMENT

This work was supported by JSPS KAKENHI Grant Number JP17K12803.

REFERENCES

[1] H. Ogata and T. Katayama, “Skill standards for model based development engineers in the automotive industry,” vol. 8, no. PART 1, 2009, pp. 240–244.

[2] G. Singh, “Experiential learning with respect to model based design applied to advanced vehicle development,” 2014. [Online]. Available: http://hdl.handle.net/10012/8138

[3] F. Franco, G. D. Stella, J. H. Neme, M. M. D. Santos, S. L. Stevan, and J. N. H. Rosa, “Teaching model-in-the loop: A case study for controller of distributed dashboard in a road vehicle,” in *2016 IEEE 25th International Symposium on Industrial Electronics (ISIE)*, 2016, pp. 863–868.

[4] J. Reedy and S. Lunzman, “Model based design accelerates the development of mechanical locomotive controls,” in *SAE Technical Paper*. SAE International, 10 2010.

[5] S. Prabhu, L. Callanan, Z. Chambers, and M. Herniter, “Development of model based design curriculum,” 2007.

[6] B. Yang and C.-Y. Chen, “Development of a robotic platform for teaching model-based design techniques in dynamics and control program,” 2011.

[7] K. Lano, S. Yassipour-Tehrani, and H. Alfraihi, “Experiences of teaching model-based development,” vol. 1555, 2015, pp. 43–54.

[8] A. Visioli, *Practical PID control*. Springer Science & Business Media, 2006.