A Development of the Validation System of Indirect TPMS

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Abstract. Indirect tire pressure monitoring system (ITPMS) uses only the software which is embedded in the electronic stability control (ESC) to determine whether the low-pressure of the tire. Because they do not use a sensor, unlike the direct TPMS, there are advantages that can greatly contribute to cost reduction and weight reduction of the vehicle.

ITPMS uses a radius analysis and frequency analysis to determine whether the low-pressure of the tire. In case of the radius analysis, the relative change is measured in the radius of the running of the tire according to the change in pressure. Thus, in the case of 1-3 low pressure of the tire, which is accompanied by the wheel difference, it is possible to detect a low pressure. On the other hand the case of the low pressure four wheels, all four wheels cannot be detected by the low pressure conditions using the radius. To overcome the disadvantages of this radius analysis method, we use a frequency analysis.

Because of the above-described technical features, ITPMS can only determine whether the low pressure when the vehicle is driving and receives a great influence on the tire and the driving environment. As opposed to using the hardware in the loop simulation (HILS) to verify the effect of the plant and the environment for a typical chassis system, because making the tire model to simulate the non-linear characteristics and the frequency characteristics according to the driving mode of the tire is difficult, the implementation of HILS is not easy.

In this study, we introduce the verification system for verifying effectively on the process of developing ITPMS. We'll investigate developments such as the process of converting to the verification data by using the data measured via actual vehicle traveling, building test data management system to systematically manage the data, building model in the loop simulation (MILS) environment using a parallel processing system for verifying the developed software, simulators for verifying ITPMS performance on the hardware. We can develop ITPMS effectively through the Verification Process on the basis of the above.

Keywords: Indirect Tire Pressure Monitoring System, MILS, Simulator, Test Data Management

International Congress of Automotive and Transport Engineering, CONAT 2016
Transilvania University of Brasov, 2016
ISSN 2069-0401

1 Introduction

By recall cases of Firestone tires and Ford, the US government mandated that ensure the stability of the tire with a tire pressure monitoring system (TPMS) in the car [1]. TPMS legislation of the US government made TPMS legislation of countries such as EU, Korea legislated. The China government also plans to be a duty on vehicles equipped with TPMS [2]. Because appropriate air pressure of the tire is significantly affect the fuel economy of the vehicle in order to improve fuel economy [3], vehicles must inform the air pressure to the driver for maintaining properly the air pressure of the tires. By the two reasons described in the above, in original equipment manufacturing (OEM) it is a trend that vehicles are equipped with TPMS mandatorily [4]. TPMS technique is divided into direct method that uses a sensor and indirect method that does not use a sensor. Since it is getting competitive in the automotive market, OEM want to lower the cost of a vehicle equipped with indirect TPMS on vehicles of less than C segment [5]. Hyundai Autron, Hyundai Mobis and Hyundai Motors did a mass product by developing ITPMS. This paper introduces the equipment and validation process to establish effective verification of ITPMS in the process of developing indirect TPMS and to explain the effect.

2 Related Work

2.1 Indirect TPMS

ITPMS is only software that is embedded in ESC for monitoring the air pressure of the tire without any machine or electronic components.

The car mounted with ESC has a wheel speed sensor to measure the wheel speed of each wheel. ITPMS checks the air pressure of the tire using wheel speed sensors value that is the input data of the radius analysis and frequency analysis [6]. In case of the radius analysis, the relative change is measured in the radius of the running of the tire according to the change in pressure. Thus, in the case of 1-3 low pressure of the tire, which is accompanied by the wheel difference, it is possible to detect a low pressure. There are two kinds of methods for the radius analysis such as using the difference in wheel speed [7], creating a dynamic model of the vehicle with the adaptive filters [8]. On the other hand the case of the low pressure four wheels, all four wheels cannot be detected by the radius analysis that uses the relative changes. To overcome the disadvantages of this radius analysis method, we use a frequency analysis.

The frequency analysis determines whether the low pressure by detecting a frequency variation of the tire caused by the pressure difference. In other words, the frequency is lower than normal pressure balloon tire. Therefore, frequency analysis unlike the radius analysis can easily detect low pressure four wheels. Frequency analysis method is how to extract the frequency range of interest by using the fast Fourier transform (FFT) [9], making the tire model with adaptive filter [8] and zero crossing algorithms for counting whether to change the code after passing through the signal processing [10]. (Fig. 1) shows the ITPMS main concept.

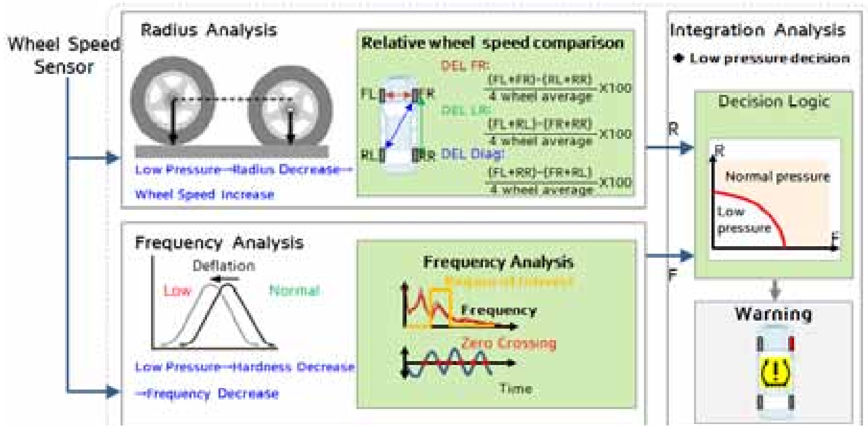

Fig. 1. ITPMS Main Concept

2.2 ITPMS evaluation equipment

ITPMS evaluation equipment is divided in two methods such as using the plant model of the vehicle and the tire, using the data acquired from the actual vehicle. The method using the plant model of the tire and the vehicle has the advantage of being able to try a variety of driving environments for validation [11]. However, there is a disadvantage of less validity for vehicles and tires from the actual vehicle development stage. Therefore, in the actual vehicle development step it is required to be the operation for acquiring the verification data from the actual vehicle and the tire. But there are few related researches.

3 Structure of the Paper

In Chapter4 we brief overview about the process and equipment to verify the ITPMS. Chapters 5 is to learn the system for managing obtained data from the vehicle and in chapter 6, by using the acquired data, we look at the server-based verification and MILS environment for the tuning method. In chapter 7, by using the obtained data, we investigate the simulator to verify ITPMS on the actual hardware. Finally, chapter 8 shows a tool to support ITPMS verification process and the reliability test result.

4 ITPMS Verification Process and Equipment

4.1 Process

ITPMS is operated based on the vehicle driving data. Analyzing the test results or actual data need no distortion to the experiment, and also requires a lot of time. An effective development process is necessary in order to develop in a short time. We made a process and conducted developing according to the process (Fig. 2). ITPMS is developed and validated in three stages:

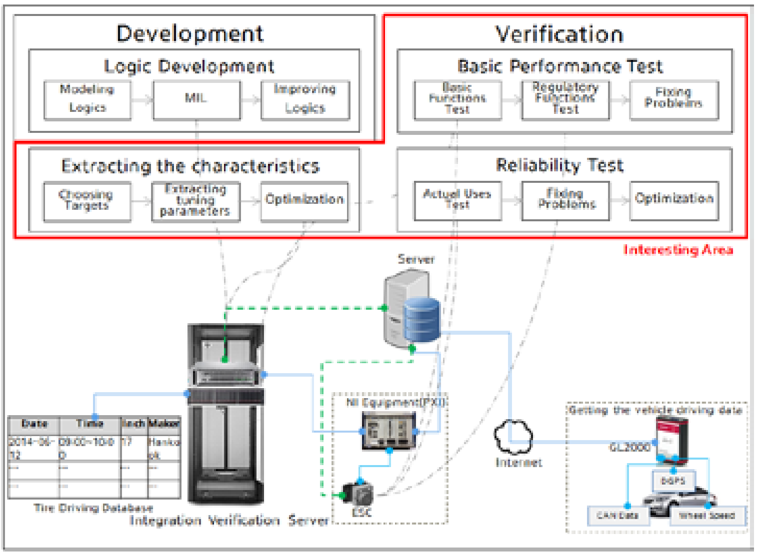

Fig. 2. ITPMS Development & Verification Process

- Extracting the characteristics: In the test for extracting the characteristic values of the tire, we extract the tuning parameter for all tires mounted on a vehicle. The tuning parameter is used to calibrate the threshold of low pressure decision. For example, if the A vehicle can be equipped with the five kinds of tires, we measure the data from the vehicle through the test mode by mounting each tire in a vehicle to extract the characteristic of the tire. By using the measured data, the tuning parameter optimization based on the verification server to be described later is performed.
- Basic Performance Test: Once extraction is complete, to confirm the basic performance and regulatory performance a real vehicle test is conducted. Not to test all tires, we choose edge-tiers that mean having insensitive or sensitive characteristics and test them. The test can be performed for all tires mounted on the vehicle. However, because of many resources and time consuming, the test cases are made with respect to the peculiar tire characteristics. If a problem occurs in the basic performance testing, tuning operations carried out again.
- Reliability test: After the basic performance is secured, considering the variety of actual use in real road conditions, we conduct a test for reliability verification. If a problem occurs similarly in this case, we solve the problem through the tuning. It is difficult to carry out the test again when problems occur because of a lot of resources and time consumption. For this reason, we acquire the vehicle data from each test. If problems occur, using the acquired data without performing again the test is repeated by using the simulator described later and the verification server.

4.2 Equipment

ITPMS verification equipment is consisted of three modules. The first is a data acquisition device attached to the vehicle which transmits data of the vehicle to the server. The second is to manage the data collected by the data acquisition device as ITPMS verification server, and performs tuning and verification based on the data obtained and ITPMS model. Finally ITPMS simulator that uses the obtained data is performed for the verification on the ITPMS hardware.

5 The Data Acquisition Device

ITPMS necessary data is a counter value of the wheel speed sensors, vehicle driving information(Brake signals, acceleration, engine torque, Yawrate etc.), global positioning system (GPS) information. We use vector GL2000 to obtain all of above information. GL2000 is equipment that can have CAN channel, GPS signal. The driving information of the vehicle is acquired through the CAN, and the wheel speed sensors of the vehicle are obtained at ESC controller via a high speed CAN. Data acquisition is completed and is transmitted to the ITPMS verification server using the long term evolution (LTE) modem.

6 ITPMS Verification Server

6.1 Data Management Environment

The data from the obtaining apparatus is collected by ITPMS verification server. The collected data with the test information which tester made is recorded into the database. CAN data which has driving information and the wheel counter value of the vehicle after the reading is completed, is respectively converted into a data format that can be performed in the data format that can be implemented with the simulator and the verification server.

6.2 Verification Server Environment

ITPMS verification server is made of the parallel computing environment to perform the tuning parameters and verify ITPMS functions. The work environment is consisted of MATLAB and Simulink of MathWorks. In case of a need to use all of the acquired data to perform a tuning or verification, because car data is so much larger data capacity, the efficient parallel processing is required to perform the tuning and verification. For such parallel processing in hardware the verification server is composed of one server and four workstations that perform the verification practically and by using the parallel tool box of MathWorks performs parallel processing in software.

6.3 Tuning and Verification

As it described in process, we extracts the necessary data by using the test data to extract the characteristic of the tire. The data to be extracted is a reference value for determining the low pressure and a corrected value that is used in the radius analysis.

We obtain the respective data by each tire and set a representative value that can covers the tire to be mounted on the vehicle by using a statistical technique. In this way using the parameters and the acquired data, the basic performance and the reliability test is performed for verifying that the ITPMS accurately determines the low or normal condition. At this time, using the receiver operating characteristic (ROC) charts we track whether MISS ALARM and FALSE ALARM appear in ITPMS.

7 ITPMS Simulator

7.1 Scope of the Simulator

When verifying ITPMS with the 20 ~ 30 thousand km driving data, using the parallel computing takes about 3 hours. Therefore, even when the tuning parameters or ITPMS software is changed, by using the verification server, there is no great burden.

However, in order to verify ITPMS on the hardware, because the simulator has to enter the data in real-time, it cannot be verified for all the input data as ITPMS verification server. In case of using ITPMS simulator, we make test cases using a limited ITPMS data to verify the malicious running mode or fault diagnosis and verify them.

Fig. 3. ITPMS Simulator

7.2 Configuring Simulator

The ITPMS simulator (Fig. 3) was configured using PCI extensions for instrumentation (PXI) of National Instrument (NI). It can perform a simulation with up to two ECUs. Using the digital board to simulate the wheel speed sensor input data, and uses the CAN card and a digital input/output card to simulate the CAN and IG ON / OFF, Brake signal. The simulator carries out in the fault diagnosis mode and the verification mode for verifying the general performance.

8 Control Tool and Experiment

We can proceed according to the simulator control, data management, test cases generation, validation result management by a tool to support the ITPMS development process.

In the data management mode, it transforms the raw data acquired in the vehicle to the data format for the test environment and stored in the database. Based on the stored data and generates a test case for the test purpose. Test cases written in the script form can dynamically have a variety of test items. Once the verification is complete, the report documents are automatically generated and the generated document is written to the database easier to manage history. Because of the difficulty of the same experiment in the vehicle, a simulator is extremely useful. However, if the results are different, the simulator cannot be used. We compared to the output of the vehicle and performed a test of repeatability in order to verify that the output values are same. Fig. 4 shows that the wheel speed value of vehicle and simulator is same.

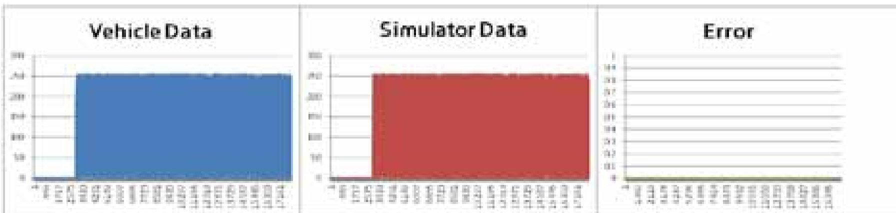

Fig. 4. Comparing the wheel speed value of ITPMS simulator and a vehicle

According to the test results, it was confirmed that the simulator outputs the same result. However, even though we control with the same clock, as a physical limitation between the simulator and the ECU, an error occurs in the portion where the pulse occurs at the same time. It was confirmed that the range of small errors that do not affect the result. The following is a data comparing the results of testing important factors for determining the low-pressure value.

Table 1. Errors between a vehicle and a simulator

	Del FR	Del LR	Del Diag	Fre FL	Fre FR
Vehicle	0.36	0.36	0.19	36.5	44.16
Simulator	0.36508	0.35186	0.20016	36.4827	44.131
Error	0.00508	0.00814	0.01016	0.0173	0.029

Table 2. Errors of repeatability tests

	Del FR	Del LR	Del Diag	Fre FL	Fre FR
Average	0.36508	0.35186	0.20016	36.4827	44.131
Standard deviation	0.006356	0.002447	0.005914	0.021302	0.033516
Error(100%)	1.741197	0.695535	2.95513	0.05839	0.075947

Del FR, Del LR and Del Diag represent the difference of the left/right, front/rear and diagonal of each wheel. Fre FL/FR indicates the frequency value of the front wheel. By relative standard deviation (RSD) method, factor analysis results show the RSD values of Del FR, Del LR, Del Diag is less than 3%, RSD value of Fre FL/FR that needs for precise comparison is less than 1% (Table 2). It means that there is no problem as the performance evaluation simulator.

9 Conclusions

By the above construction of process and verification equipment, we can effectively do the ITPMS development and validation. If we received a simple change requests from OEM or tier1, it takes more than a month without building the verification process and equipment. We can reduce the development period to a week by the solution about the process and equipment. Also by utilizing the existing accumulated data, the quality of ITPMS was a remarkably improved by performing verification for the modified software.

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