Development of low cost inspection module for manufacturing process

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Abstract

As for the market of a car infotainment product which is one of DENSO TEN's main products, the lowering of price and the multiple functionalization of products are proceeding due to the increased competition by the entry of new manufacturers and the change of customer needs. Under the circumstances, we immediately need to reduce the cost for assembly and inspection in production considering the cost increase in accordance with the multiple functionalization.

Focusing on the equipment cost among the inspection cost, we have continuously worked on the reduction of the equipment cost, however, our efforts do not keep up with actual cost until now because of the increase of inspection items resulting from the multiple functionalization. Therefore, we aim to realize reduction of equipment cost by replacing with the low-cost measurement equipment (inspection module) which has been developed under the unprecedented idea using the circuit of DENSO TEN's products instead of third party's measurement equipment that comprises a large part of the equipment cost.

We introduce the outline of this inspection module in this paper.

1. Introduction

A car infotainment (hereinafter “CI”) product which is one of DENSO TEN's main products is proceeding to the multiple functionalization, but the lowering of price is proceeding. In production, the manufacturing process tends to increase responding to the multiple functionalization. Especially, weight of the inspection process increases and it is an important issue how we reduce the inspection cost.

Previously, we have proceeded with the reduction of the inspection cost by efforts of automation and high-speed operation of the inspection. Focusing on the equipment cost among the inspection cost as the further measure for the improvement of competitiveness, we worked on development for the reduction of the equipment cost.

2. Current situation of inspection process and direction of development

In the inspection process of CI products, we implement the measurement of output signal of products and the inspection of operation to aim for assurance of the required performance and confirmation of all functions of products. **(Fig. 1)**

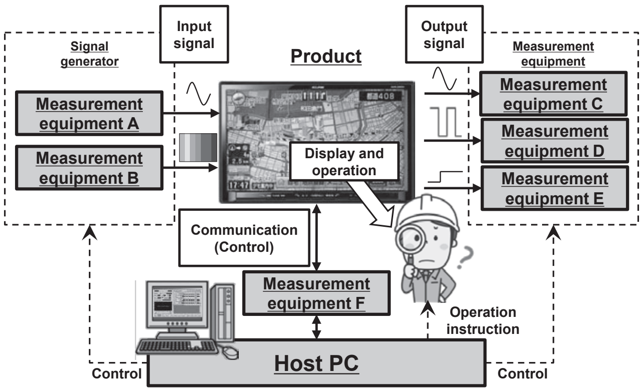


Fig. 1　Outline of Inspection

There are about 300 inspection items. We reduce the equipment cost by allocating the inspection items to the plural processes considering the measurement equipment for inspection, the production number and the inspection time. If we cannot allocate the inspection items, we secure production capacity by installation of equipment as required. **(Fig. 2)**

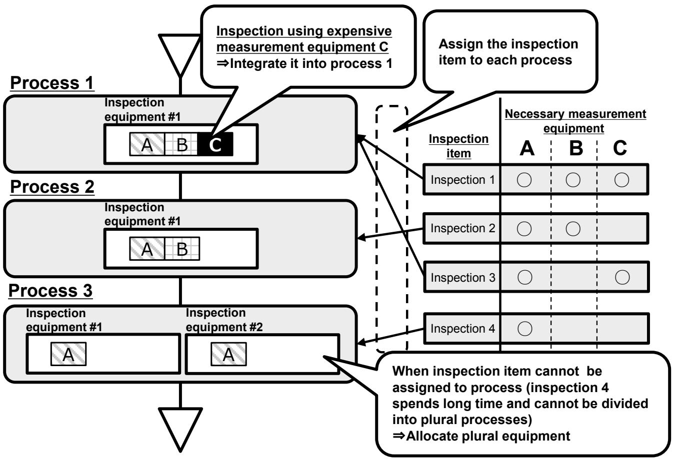


Fig. 2 Outline of Inspection Process

As mentioned above, we have worked on the reduction of the equipment cost by devising process design. However, our efforts have not kept up with actual cost because of the increase of inspection items resulting from the multiple functionalization of products. Then, we investigated details of the equipment cost for the inspection process, and we found that cost for purchased measurement equipment comprises a large part of the equipment cost. Therefore we settled the target to reduce this measurement equipment cost.

DENSO TEN has selected the measurement equipment used for the inspection with the prospect that the equipment can be widely used for the inspection of various products. Therefore, we selected the marketed products which have rich functions. As the result, the price of measurement equipment tended to increase. Also, we studied cost reduction by in-house manufacturing of the marketed measurement equipment, however, we could not implement it because of poor cost advantage considering the development cost. However, in the process of inspection technical development, we found the unprecedented idea to use the circuit of DENSO TEN's products as the measurement equipment. Also, we had developed embedded software for product control focusing mainly on minimum device control with single task operation (without OS) to aim for effective inspection. We thought that we could perform in-house manufacturing with low cost by utilizing this embedded software technology. We elaborate our efforts for the cost reduction by in-house manufacturing from the next section.

3. Cost Reduction Measure by in-house manufacturing of measurement equipment

As for in-house manufacturing of measurement equipment, we extracted the universal function with the cost advantage among the measurement function group used for the inspection process considering the return on investment, and we aimed to reduce the cost by the development of the measurement equipment in which those functions were integrated.

Fig. 3 shows the outline of in-house manufacturing of the measurement equipment. Conventionally, each measurement equipment A, B, C and D are assumed to be used for inspection in process 1, 2, 3 and 4. Focusing on the measurement equipment B and C, 75% of all functions of the measurement equipment for the inspection are used in process 1, however, in process 2, 3, and 4, only 25% of all functions are used. This means that we bother to purchase the measurement equipment B and C which are required for 25% of all functions in process 2 to 4. Then, we build the in-house manufacturing equipment that includes the 25% of all functions of measurement equipment B and C, and replace it with the measurement equipment B and C. Since the measurement equipment B and D have partially the same circuit, the function of measurement equipment D can be realized with low cost by adding a few parts to the measurement equipment B. Then, the in-house manufacturing equipment includes the function of measurement equipment D, too. As the measurement equipment A is used only in process 1, we continue to use it.

As the result, we can realize cutdown of eight pieces of measurement equipment in process 2 to 4 by replacing them with the in-house manufacturing equipment which equipped with the function of measurement equipment B, C and D. We call this in-house manufacturing equipment an inspection module, and elaborate the outline in the following section.

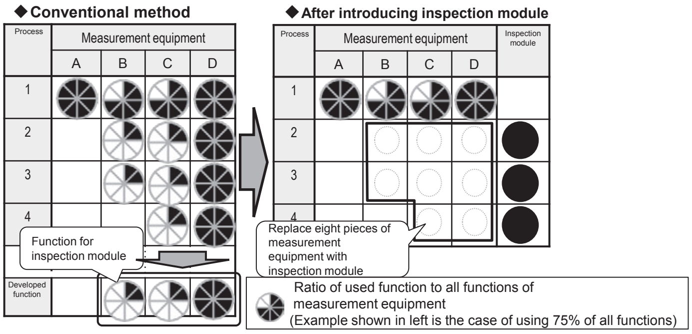


Fig. 3　Outline of In-house Manufacturing of Measurement Function

4. Development of Inspection Module

4.1 Outline of hardware and software

4.1.1 Hardware (Circuit block)

The hardware block diagram is shown in **Fig. 4**. As for the development, the hardware consists of signal generator block, measurement block, in-vehicle LAN block and digital signal input / output block (DIO) centering on SoC (System on Chip) which controls each block in order to realize the integrated module. The basic circuit of these hardware is the circuit of DENSO TEN's products because of the viewpoint of reduction of parts cost and development man-hour, however, we proceeded with development considering the circuit structure and terminal assignment of IC while re-considering the necessity of the circuit.

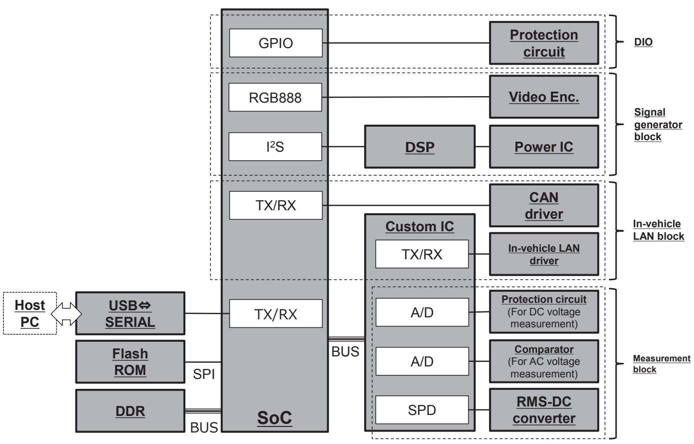


Fig. 4　Hardware Block Diagram

4.1.2 Software

The inspection module software is designed centering on the main block which works on the communication to the host PC which executes an inspection scenario. **Fig. 5** shows the work flow of the main block. The main block executes the targeted measurement function responding to the command data from the host PC and returns the executed result to the host PC.

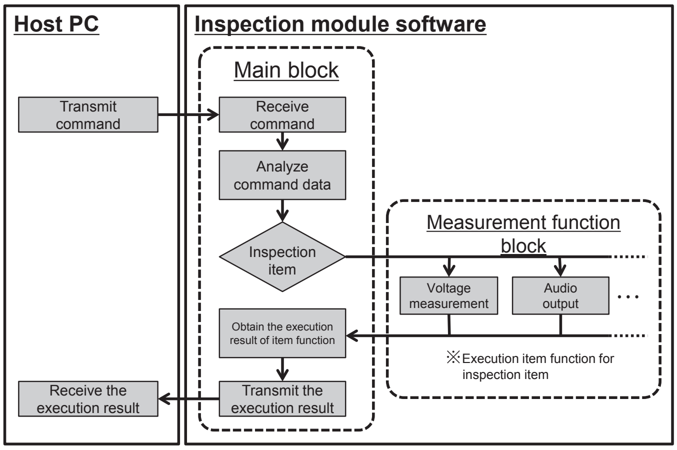


Fig. 5　Work Flow of Main Block

4.2 Measurement Functions

The functions of the inspection module are shown in **Table 1**.

Table 1　Functions of Inspection Module

Function	Ch	Function	Ch
Audio signal output	4ch	IEBus communication	1ch
Video signal output	1ch	CAN communication	1ch
Test square wave output	4ch	UART communication	2ch
AC voltage / frequency measurement	1ch	Digital signal output	Max 300ch
DC voltage measurement	10ch	Digital signal input	Max 48ch

We describe the representative functions among the functions in detail in the next section.

4.2.1 Audio Signal (Sine wave) Output

This is the function to output audio signal (sine wave) which is specified by user. Normally, the trigonometric function which is necessary for audio data calculation can be used likely as the standard. However, our software developmental environment doesn't have mathematical functions like this, and it takes long time to add them later. Therefore, we designed the function by ourselves using approximation of the trigonometric function by Taylor expansion. **(Fig. 6)**

$$\sin(x) = \sum_{n=0}^{\infty} \frac{(-1)^n}{(2n+1)!} x^{2n+1} \fallingdotseq x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \frac{x^9}{9!} - \frac{x^{11}}{11!}$$

Fig. 6 Sine Approximation by Taylor Expansion

Created audio data is output to DSP with I2S format through the audio function of SoC, and DAC port of DSP outputs it as analog audio. **(Fig. 7)**

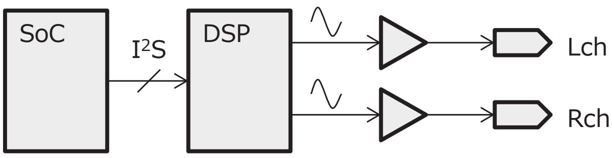
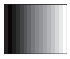


Fig. 7 Block Diagram of Audio Signal Output

4.2.2 Video Signal (NTSC) Output

This is the function that outputs the color pattern shown in **Table 2**. Firstly, we adopted the method to store the image data to the software as the image file as it is. However, the start-up time was longer because of a large size of software. Then, we changed the method to dynamically create the data by calculation, and we succeeded to reduce the size and the start-up time. The created data is output from video IP of SoC, which is output as NTSC signal via video encoder. **(Fig. 8)**

Table 2 List of Color Pattern

Pattern name		Pattern name	
Raster (Specified RGB value)		Full color bar	
16 gradation Gray scale		SMPTE color bar	
Lamp		SMPTE color bar + characters	

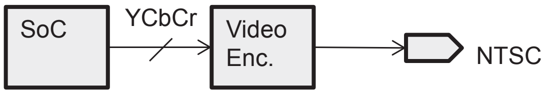


Fig. 8 Block Diagram of Video Signal Output

4.2.3 IEBus Communication (In-vehicle LAN)

This is the function to communicate to products. Previously, the cost of the entire equipment was high because we used the marketed products, which were expensive. On the other hand, as for the inspection module, we realized reduction of the parts cost by replacing the function of marketed products with the circuit designed with the low-cost parts based on the circuit of products. **(Fig. 9)**

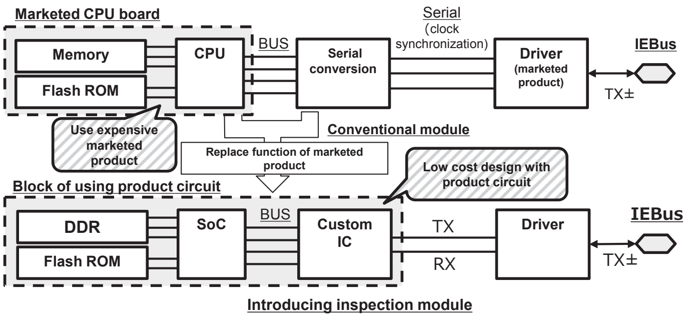


Fig. 9 Block Diagram of IEBus Communication Function

As for the software, we devised the software so as to divert the conventional application layer by designing the software structure of which the middle layer absorbs the change of driver layer associated with the change of device framework. As the result, we maintained compatibility with the conventional equipment and reduced the development man-hour.

4.2.4 Digital Signal Input / Output（DIO）

This is the function to be mainly used for the equipment control.

We can easily realize DIO function using GPIO port of SoC. However, the number of SoC port is not enough for the requirement. Therefore, we determined to extend the port using the IO expansion IC. We needed to modify the software because IO expansion IC was controlled by I^2C communication. Finally, the port can be extended to the maximum 256 ports. **(Fig. 10)**

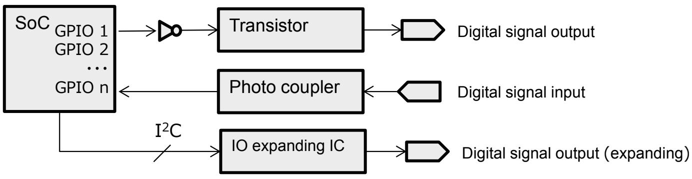


Fig. 10　Block Diagram of Digital Signal Input / Output

5. Additional functions to Host PC

In association with the development of inspection module, we added the functions to the host PC.

Previously, the host PC controlled each measurement equipment via individual I/F. However, this method cannot be used this time because the control I/F for the inspection module is one. Then, we added a mechanism that assigns the process per control function to the host PC, which resulted in the realization of the control of plural functions with one I/F without large change of the structure of conventional inspection software. **(Fig. 11)**

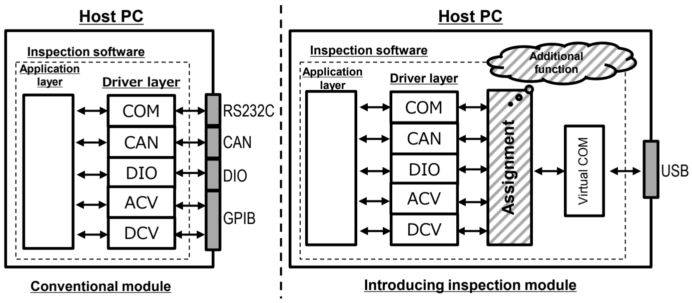


Fig. 11　Additional Function to Host PC

6. Introduction Effect

Fig. 12 shows the appearance of the developed inspection module. This inspection module has universal functions for inspection, but its size is compact, nearly equal to B5 size. Also, we expect cost reduction by about 20% of the entire process by introducing the inspection module.

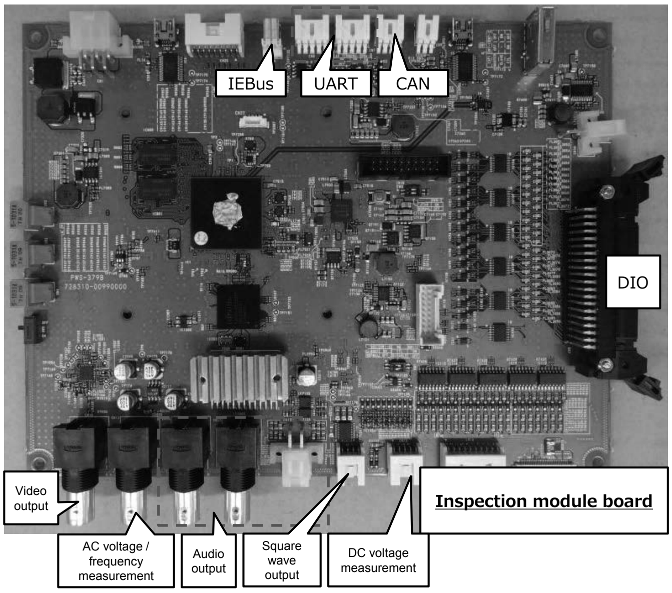


Fig. 12　Appearance of Inspection Module

7. Conclusion

Through these efforts, we have developed the low-cost inspection module which is generally used in our inspection process. With utilization of this experience, we will work on the development of measurement function for digital video transmitting in future, which is not included this time.

DENSO TEN also aims to realize the self-checking function, which is a function that the product checks itself, as the future target. If this self-checking function is realized, simpler structure of the inspection equipment is expected, which results in further cost reduction of the equipment. This time, we have had prospect for solutions to the technical issues through the development of the inspection module. In future, we will work on the realization of this self-checking function.

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