Data Recording Technology for Autonomous Driving/Advanced Driver Assistance

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Abstract

For autonomous driving and advanced driver assistance system (hereinafter, "AD & ADAS") that have been rapidly developed in recent years, evaluation and verification of applied technology and algorithm are very important for ensuring the reliability of the system, which is a very time-consuming process at the same time.

As the development period is required to be shortened, the development style, which performs functional verification and system evaluation by simulation using a large amount of data obtained in advance as a solution, is being established. However, the data which is used for the simulation is required to be extremely high in both quantity and quality due to the advancement of AD & ADAS.

The technology for its solution is described in this article.

1. Introduction

For autonomous driving and advanced driver assistance system that have been rapidly developed in recent years, evaluation and verification of applied technology and algorithm are very important for ensuring the reliability of the system, which is a very time-consuming process at the same time.

As the rapid spread of technology in market and the shortening of development period are required, the development style, which performs functional verification and system evaluation by simulation using a large amount of data obtained in advance, is being established.

However, requirements of data which is used for the simulation become stricter not only for quantity but also for quality every day, escalating to the point where a conventional data logger and the like cannot meet this demand.

Thus, the technical issues in these circumstances and our approach are described in this article.

2. Data Logger for AD & ADAS Development

First, an overview of the data logger which was developed as an approach to solving technical issues for AD & ADAS development is explained in this chapter, and then the technical issues and solutions are described in the subsequent chapters.

As for AD & ADAS development process which was described at the beginning, we, DENSO TEN Limited, advance the development in the following procedure **(Fig. 1)**.

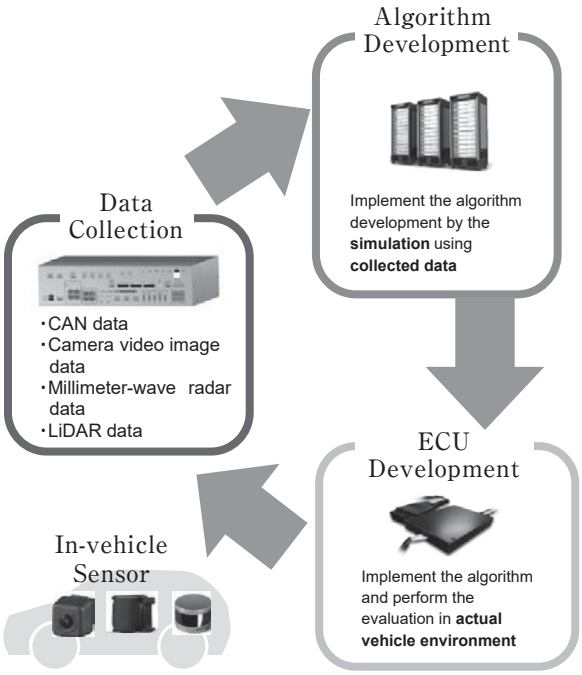


Fig. 1　AD & ADAS Development Process

①Install a sensor on the vehicle and acquire primary data.
②Perform the simulation using the collected data and develop the algorithm.
③Install the algorithm completed to a certain extent on actual ECU.
④Acquire data according to actual movements in the vehicle.
⑤Use the collected data again to perform the simulation for improving the algorithm.
⑥Subsequently, repeat steps from ③ to ⑤ to ensure reliability and quality.

Among the above, a device which is used at the time of collecting data is the data logger for development described in this article. The role of the data logger for development is as follows.

・Acquire sensor data which is required for AD& ADAS simulation.
・Acquire data for reference (hereinafter, "reference data") which is capable of verifying the validity of AD & ADAS operations at the same time as acquisition of the above sensor data.
・Record the situation when acquiring the above two types of data. (driving position, vehicle running status, etc.)

As can be seen from the above, the more complex the system is, the more massive data is required. Simultaneously, if there is a deviation in the measurement timing between these data, sufficient accuracy cannot be ensured in the subsequent simulation because the exact situation cannot be reproduced.

Accordingly, recording a large amount of data at the same time as performing the accurate timestamp is the role of the data logger for AD & ADAS development.

Fig. 2 shows I/O block diagram of the newly developed data logger. As can be seen in the figure, it has a large number of I/F as input, and the data which is necessary for AD & ADAS development shall be secured by recording data collected from these I/F on five HDD.

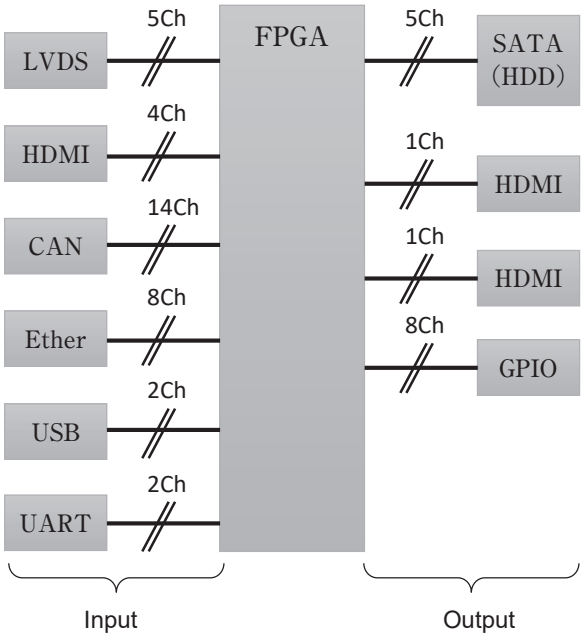


Fig. 2　Data Logger I/O Block Diagram

3. Issue on Data Logger When Developing AD & ADAS

The requirements for the data logger for AD & ADAS development were defined as follows.

・Timestamp accuracy of data to be recorded shall be completely synchronized at 1ms or less.
・Data to be recorded shall be 30ch or more.
・All data shall be recorded on HDD.

The following three development issues were extracted from requirements.

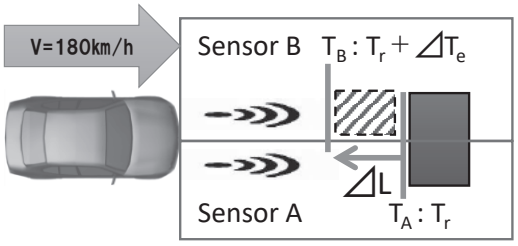
- Time control in the system by 1μs to ensure the timestamp accuracy of 1ms.
- Parallelization of all data processing
- Optimization of HDD writing

Due to space limitation, the necessity of timestamp accuracy from the above issues is described in this chapter.

The timestamp accuracy is directly linked to information accuracy in a vehicle which is constantly driving because recent AD & ADAS combines information from multiple sensors (hereinafter, "Fusion") and processes them.

Therefore, the timestamp accuracy is a primary key factor for the data logger.

For example, when timestamped data is simultaneously compared by two types of sensors which measure distance to the forward target, if they are completely synchronized, the difference in its distance is a deviation purely caused by the accuracy of sensors. However, since there is an actual difference in the processing until the data of each sensor is timestamped, the difference occurs in the time given to the data. **(Fig. 3)**



T_A : Time of sensor A
T_B : Time of sensor B
T_r : Absolute time measured by sensor A
ΔT_e : Clock error of sensor B

Fig. 3 Issue of Timestamp Accuracy

From the above issues, since the output delay time until the data which results from the processing in the sensors is output and the transfer time for transferring the data through a communication path cannot be controlled by the logger, they were excluded from consideration.

In the example above, when the time to be timestamped on each data is deviated by ⊿Te in the data from sensor A and sensor B, the magnitude L of the deviation from the actual position of the vehicle is as follows if the speed of the vehicle (hereinafter, "vehicle speed") is V (km/h).

$L = V \times \Delta T$

As can be seen from this formula, this is not a problem when the vehicle speed is slow at the time of moving in a parking lot or others. However, this ⊿T cannot be negligible when the vehicle speed is high on an expressway or the like. In a situation where the vehicle is driven at 100km/h on an expressway in Japan, a travel distance of the vehicle within 1ms is deviated by about 3cm. Assuming the vehicle travels at 180 km/h, just like on an overseas expressway, the distance will be deviated by about 5 cm. On the other hand, if deviation in distance of the sensor data is ⊿L to facilitate the measurement value matching processing between sensors in the verification work, the timestamp error can be ignored in the case of ⊿L=5cm or less. Therefore, the issue is to ensure the timestamp accuracy of 1ms or less for data.

4. Approach to Improvement of Timestamp Accuracy

For a general data logger, processing which is performed by CPU is adopted for use in timestamp for data.

4.1 Problem of CPU Processing

In the case of the processing which is performed by a general CPU such as x86 processor or ARM processor normally used, 1ms is the limit in terms of processing cycle even for RTOS (Real Time Operating System), otherwise 10ms or more when using OS such as Windows.

Also, in the case of processing multiple data simultaneously, there is only one data for which the timestamp processing can be performed at a certain moment per CPU core. Therefore, when the timestamp processing is performed for multiple (in this case, 30ch or more) data simultaneously, the processing is inevitably performed off and on. In other words, the timestamp cannot be performed at the same time,

resulting in deviation of timestamped time **(Fig. 4)**.

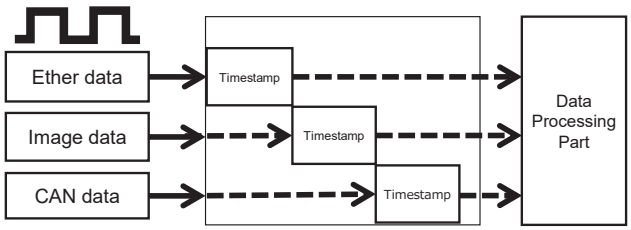


Fig. 4　Problem of CPU Processing

4.2 Implementing Timestamp Processing in Hardware

Since the timestamp by CPU processing cannot meet the requirements in the first place, we determined that the timestamp processing needs to be implemented in hardware.

Considering the number of loggers to be manufactured and the development period, FPGA (Semiconductors for which circuits can be configured freely) was adapted because a dedicated semiconductor couldn't be developed.

In order to ensure the timestamp accuracy given to the data as 1ms, the required timestamp accuracy was prescribed by the following concepts.

- Ensure accuracy in the system level by increasing the number of digits for the time accuracy at each stage of processing in sequential order.
- Consider the necessity for time synchronization between different devices as well.

This time, due to the limitations of development period, the timestamp processing shall be implemented in hardware except for TCP communication requiring data reconstruction from multiple packets.

4.3 Confirmation of Effect of Implementing the Processing in Hardware

After constructing a logic in FPGA and verifying the timestamp accuracy, it was found that it did not reach the expected accuracy **(Fig. 5)**.

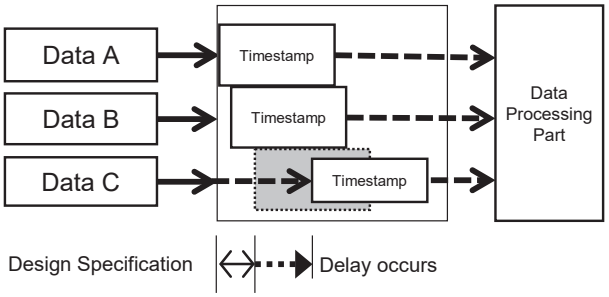


Fig. 5 Verification Result of Implementing the Processing in Hardware

As a result of simulating data input and observing the data simultaneously, about several tens of μs of random deviations were observed between I/F on the device. In the design stage, we assumed that the deviation would be limited within a few μs.

Furthermore, as a result of the cause analysis, it was found that a delay occurred when competing for the access to RTC (Real Time Clock) in FPGA to obtain time information. Due to the access conflict for time correction processing from ARM core in FPGA and for time acquisition processing from multiple I/F functional blocks, which occurs to this RTC, we found that delay occurred in the case of simultaneous access conflict **(Fig 6)**.

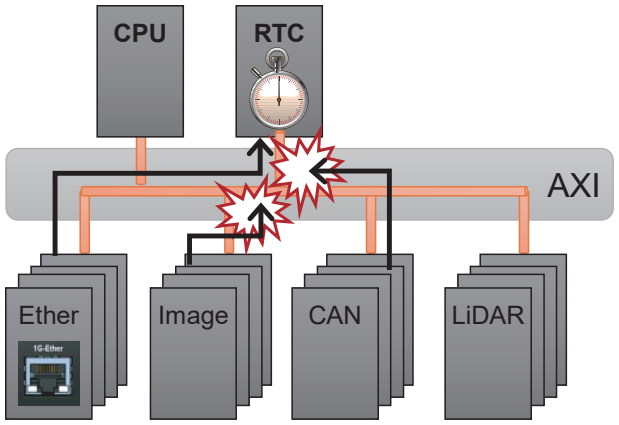


Fig. 6　Access Conflict to RTC

4.4 Resolution of Access Conflict to RTC

Fig. 7 shows the improved/simplified architecture diagram, which was implemented in FPGA.

In this architecture, RTC is accessed from multiple

functional blocks through the AXI bus, and also a bus contention and wait state for exclusive processing occur because the access is concentrated on a specific functional block (in this case, RTC) on individual buses, causing the delay.

Therefore, a circuit which was capable of simultaneous access to the RTC ("Delegate RTC" and "designated bus" in **Fig. 7**) was built and mounted so that the time could be obtained at the same delay time (about 50ns) for all functions accessed simultaneously.

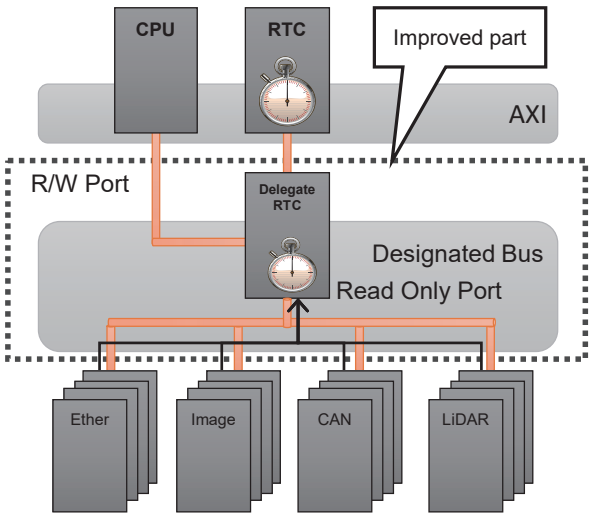


Fig. 7 Improvement of Architecture

As a result, the accuracy of 1μs became capable of being ensured in all time acquisition processes. **Fig. 8** shows the final timestamp deviation, which indicates that the accuracy of ±6μs was achieved by actual measurement for the targeting accuracy guarantee of timestamp accuracy of 1ms for the data.

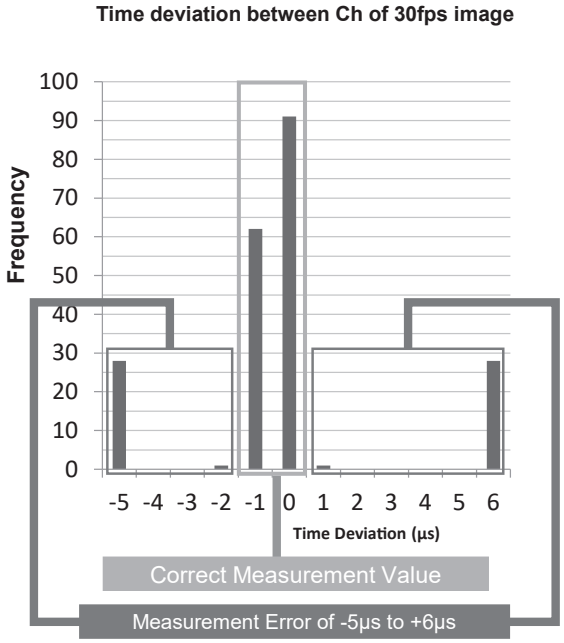


Fig. 8 Measurement Result of Timestamp Accuracy

5. Response to Mass Data Processing

When assuming autonomous driving, the amount of data to be handled is about 1.2 GB per second due to a large number of images and a large amount of LiDAR information. This chapter explains issues and solutions in the case of handling this large amount of data.

5.1 Issue on Existing Logger

As seen on TV or other information media, a vehicle for which the autonomous driving system was developed was equipped with sensor group installed on a roof as well as a large number of PC installed in a trunk.

The reason why PC occupies a large amount of equipment in the trunk is because the architecture based on an embedded system which is usually installed in a vehicle doesn't have the capability to handle an enormous amount of data to be required in the first place. Thus, a high-performance CPU or GPU is required to process a large amount of data.

On the other hand, although the logger requires a certain level of arithmetic capacity in images and data compression processing, most importantly, parallelism which can process a large amount of data

simultaneously is required.

As for a system which is generally available, even a high-performance PC which seems to have the highest processing capacity at present may lack its data processing capacity. This is because the bus is used for the connection between CPU and a chipset in all data transfer processing, and that part becomes a bottleneck. (issue ①)

Furthermore, as for image data, in consideration of the data accuracy which is required for the simulation, lossy compression which is represented by H264 or the like cannot be adopted. Accordingly, the amount of data is very large even for data from one sensor, resulting in insufficient performance even for writing to a storage to record data in a general file system. Therefore, it is necessary to handle this point as well. (Issue ②)

5.2 Parallelization of Processing (response to issue ①)

For the purpose of improving the timestamp accuracy, implementing parallelization of processing as measures against mass data was considered at the stage where we decided to introduce FPGA.

Specifically, the design was performed according to the following policy.

- Processing logic is made into the functional block for each data type.
- The functional block ranges from data input I/F to molding function for output.
- Each functional block is implemented for each 1ch input data.
- Output data I/Fs from multiple functional blocks are unified so that it can be easily collected with the storage export function at the later stage.

Under the above policy, the system was configured like the structure shown in **Fig. 9**. An overload test was conducted with the logger actually constructed, and it was confirmed that data could be processed without any problems even if data exceeding the expected 1.2 GB/s was input.

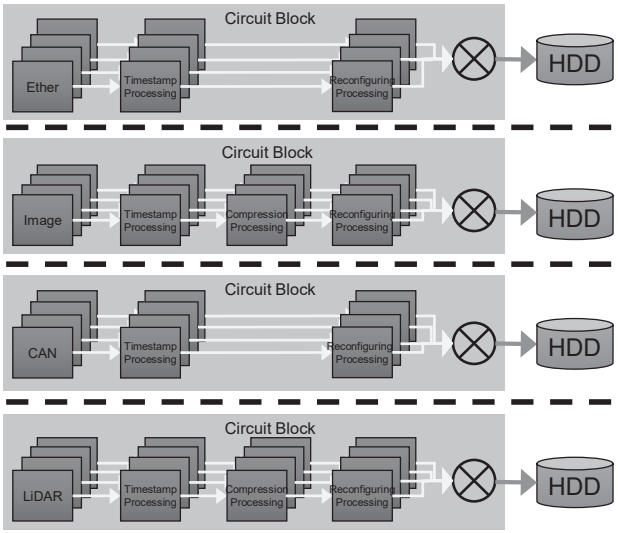


Fig. 9 Parallelization of Processing

5.3 Optimization of Writing ⇒ Large Amounts of Data Export (response to issue ②)

Data which includes images is very large. In the case of a so-called Full-HD resolution of 1920 x 1080 (Pixel), the original data amount can be reduced to only about 50% in size. when compressed with lossless compression. Thus, when recording the data for a long time, a large-capacity storage is required.

Also, when acquiring data, the vehicle often travels for a long time so that various situations can be obtained to perform an efficient operation. Therefore, it is required that data can be recorded for about 16 hours per day. These days, although SSD is capable of high-speed writing along with the expansion of data capacity and lowering prices, it couldn't be adopted because of the lack of absolute capacity at the moment. Thus, a writing method with HDD was considered.

We have been dealing with this problem since 2015 and have established a technology using HDD in RAW format writing as a function for exporting data from FPGA.

Concretely, writing has been realized at the speed close to a theoretical limit of HDD writing speed by not seeking the HDD head as much as possible.

Accordingly, this allows continuous writing while maintaining the speed of about 90% or more of the HDD's theoretical writing speed.

6. Future Prospect

Various technologies which were established as the data logger for development this time are also required for autonomous driving system and advanced safe driving assistance system. In future, we consider that adapting this newly developed technology to those for mass-produced cars is indispensable in order to install a more reliable system in the vehicle.

Simultaneously, as we respond to the new use of a vehicle including MaaS, various data collected from the vehicle are beginning to have commercial value. For commercial use of data, not only protection of personal information, but also data format and accuracy need to be standardized to ensure portability and versatility.

Therefore, we will continue to apply the asset, which was built this time, to products in future in parallel with the incorporation of new technologies such as response to personal information protection and data standardization.

7. Conclusion

Although the automobile industry is said to be "a big transition for the mobility business once in 100 years," its core is CASE (Connected/Autonomous/Shared/Electric), among which the technology related to AD & ADAS corresponding to A is extremely important.

In such a situation, while promoting not only AD& ADAS but also response to CASE centering on Vehicle-ICT as a member of the DENSO group, we aim to "contribute to the realization of a free and comfortable mobility society by connecting people and cars, and society and cars." In addition to the technology which was introduced in this article, we will promote the technology development to provide a new value to the mobility society.

Acknowledgements

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