Video Compression Technology for In-vehicle Image Transmission: SmartCODEC

● Jun-ichi Odagiri ● Yasuhiko Nakano ● Shigeru Yoshida

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Next-generation vehicles will require multiple video channels for safer and more enjoyable driving. Digital video data from, for example, cameras positioned around a vehicle, a navigation system, and a DVD, will be transmitted over an in-vehicle LAN. Currently, the in-vehicle LAN standard with the widest bandwidth is IDB (ITS Data Bus)-1394. However, because it has insufficient bandwidth for multiple video channels, a data compressor-decompressor (codec) will be needed to multiplex the video data so the LAN bandwidth is used more effectively. The compression technology for in-vehicle video must implement minimal delay and a high image quality at low cost. This paper describes Fujitsu's SmartCODEC technology, which was specially developed to transmit video data in vehicles to meet these requirements.

1. Introduction

Recently, cars are being equipped with multiple channels for transmitting video data. For example, car navigation systems are used for driver assistance and digital TVs and DVD players are used for amusement. Additionally, cars are being equipped with cameras for monitoring the left side and rear blindspots.[1)] Next-generation vehicles will be able to transmit videos to monitors at the rear seats so passengers can watch DVD and car navigation images. They will also have a multi-camera system for displaying outside images to a monitor by the driver's seat. In the future, vehicles will have more and more imaging devices as standard equipment.

However, if each image is transmitted over its own dedicated cable using analog signals, the wiring will become complicated as the number of channels increases [**Figure 1 (a)**]. It is therefore better to use a single in-vehicle LAN[2)] to transmit images over multiple channels using digital multiplexing [**Figure 1 (b)**]. Currently, the in-vehicle LAN standard with the widest bandwidth is IDB (ITS Data Bus)-1394, which has a 400 Mb/s nominal bandwidth and a 320 Mb/s effective bandwidth. This standard is sufficient for one or two 640 × 480-pixel VGA cameras, which require a bandwidth of 147 Mb/s each. However, it is not sufficient for a car equipped with a 640 × 480-pixel VGA camera (147 Mb/s), DVD (165 Mb/s), and car navigation system (415 Mb/s), which would require a total bandwidth of 727 Mb/s.

There is therefore increasing demands for a LAN that has a built-in video compressor. To meet this demand, Fujitsu Laboratories has developed the SmartCODEC[3)] in-vehicle compression technology.

This paper describes the requirements and problems of in-vehicle video compression and then describes the development and performance of SmartCODEC.

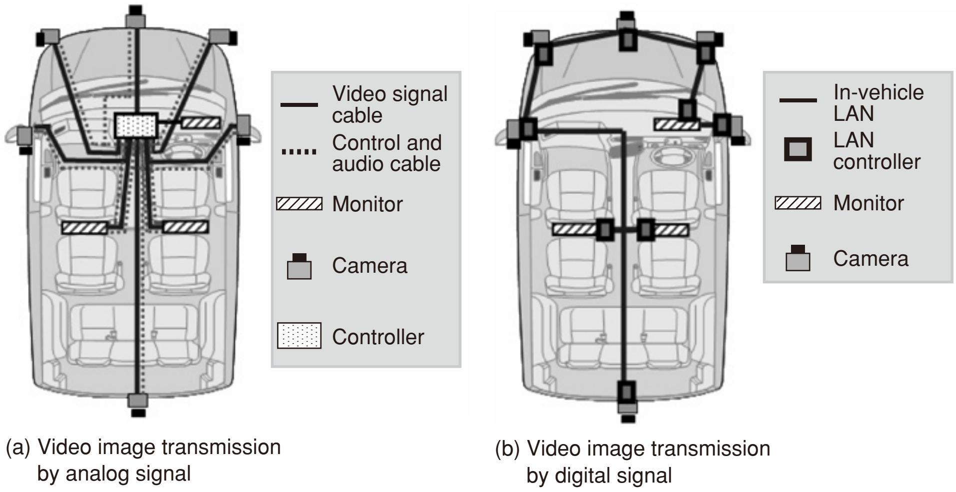

Figure 1
In-vehicle video transmission systems.

2. Requirements and problems of in-vehicle video compression

We decided to base our in-vehicle LAN video compression technology on the IDB-1394 LAN standard. The compression ratio was fixed to 1/3 so that videos from several 320 × 240-pixel QVGA cameras, a DVD player, and a car navigation system could be multiplexed. We identified three main goals for this development environment:

1) The size and cost of the circuit must be minimized because each terminal requires its own chip. To achieve this, we decided the circuit should be built into the LAN controller and have no external frame memory.
2) The processing time for compression and decompression must be short so the outside environment can be monitored in real time. Therefore, the maximum transmission delay should be 30 ms so the delay is less than the display period for a single frame.
3) The system must be able to display high-quality natural images (camera/DVD images) and line drawings (car navigation graphics) on a rear seat monitor.

3. General configuration of video compression method

Before starting the development, we selected the compression method because it determines the compression ratio, circuit size, and maximum delay time. Generally, higher compression ratios can be obtained as the size of the processing unit is increased. For example, MPEG-2, which processes from 1 to more than 12 frames at a time, has a compression ratio of 1/20 or higher and JPEG, which processes an 8 × 8-pixel block at a time, has a compression ratio of approximately 1/10 (**Figure 2**). However, a larger processing unit requires a larger circuit, a larger memory, and more time to process, which can easily increase the processing delay. Therefore, because our goal was fast processing for real-time monitoring by a lightweight IDB-1394 controller chip, we decided to use predictive coding, which processes a single pixel at a time.

Predictive coding is based on the fact that a pixel's value is usually near the values of its neighboring pixels. It predicts the value of the next pixel to be processed from the values of the previously processed neighboring pixels and then encodes the difference between the predicted

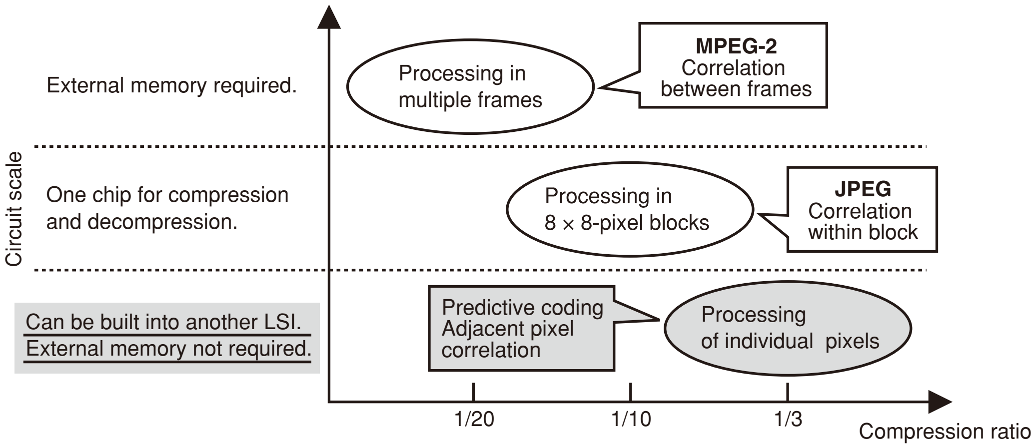

Figure 2
Relationship between circuit scale and compression ratio of video compression methods.

value and the actual value. Only the memory for one scan line is required to store the pixels needed to make the predictions. Therefore, it is easy to downsize the circuit. Additionally, encoding and decoding a single pixel at a time enables fast processing. However, it is difficult to simultaneously achieve an adequate compression ratio and image quality, especially for complicated images. To address this problem, we developed a new codec algorithm called SmartCODEC that preserves the detail of high-quality camera/DVD images and navigation graphics. The following section describes this technology.

4. SmartCODEC

In SmartCODEC processing, the pixel value to be input next is predicted in the scan direction and then quantized and encoded. In the quantization process, the tone numbers of the difference between the predicted value and the actual value is thinned out. In the encoding process, pixel information with a higher occurrence ratio is given a shorter code in order to compress it. We developed a new technique for the predictor and quantizer used to improve the quality of camera/DVD images and navigation graphics (**Figure 3**).

1) Development of high-performance predictor

In predictive coding, the compression and image quality can be improved by making the predictions more accurate. However, when the source images are interlaced, the reference pixels are two lines away from the pixel being processed. As a result, the prediction accuracy and compression ratio of the conventional predictor are low for interlaced images.[4)]

To improve the prediction accuracy, the virtual pixel values of the skipped lines are obtained by virtual interpolation. We evaluated the peak signal-to-noise ratio (PSNR) for eight types of ITE images,[5)] which are used as standard evaluation images. We chose these images because there are relatively large differences in the values of neighboring pixels in these images, which makes them very difficult to predict. The PSNR is a measure that indicates the coincidence between an image and its de-compressed form. Higher values mean a higher coincidence between images. Most people cannot distinguish between images having a PSNR of 35 dB or more. Compared to the conventional predictor, our predictor improved the Y component from

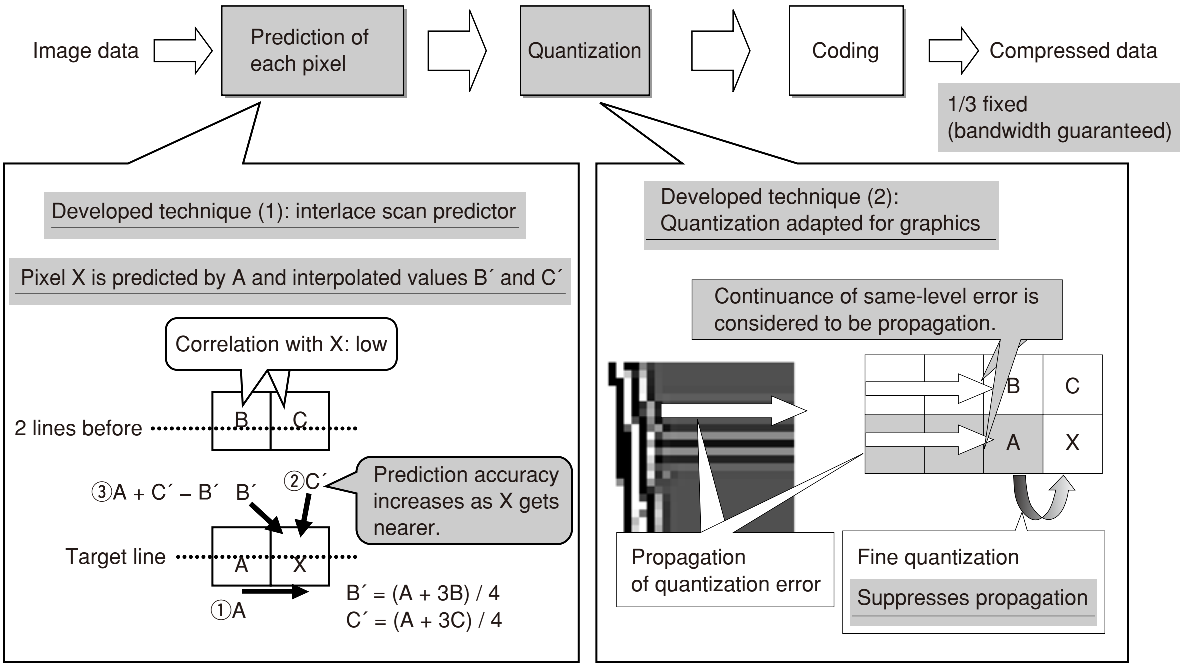

Figure 3
Quality improvement of camera/DVD and graphics images.

35.5 dB to 35.8 dB (up by 0.3 dB), the U component from 39.1 dB to 39.9 dB (up by 0.8 dB), and the V component from 40.1 dB to 40.9 dB (up by 0.8 dB). This technique improved the prediction accuracy and compression rate, resulting in a higher image quality.

2) Adaptive control of quantizer

In the predictive coding method, prediction and quantization are performed in the scanning direction. Therefore, prediction and quantization are different for each line. As a result, quantization errors among lines are sometimes highly visible. This phenomenon is especially noticeable in navigation images because the letters of, for example, the names of cities and roads, have a significant tone difference from their backgrounds, which degrades the prediction accuracy. The information amount is reduced by thinning out the tone numbers in the quantization process. However, if the prediction accuracy is low, to maintain a compression ratio of 1/3, the tone must be coarsely thinned out, resulting in a large quantization error. If the coarse thinning-out is repeated in the scanning direction, lines that do not exist in the images before compression will be stretched in the scanning direction and appear as a significant degradation.

To reduce the magnitude of this problem, we developed a technique for performing a minute quantization immediately after detecting a repetition of the same quantization. For example, when the same level difference occurs continuously between lines, the quantization errors propagate or gaps occur. In this case, a fine quantization can safely be used because there is little probability that actual gaps will continue to occur. Therefore, we developed and adopted a mechanism that counts the number of times the same level difference occurs between lines and performs a minute quantization immediately after this number exceeds a specified threshold. **Figure 4** shows post-decompression images with

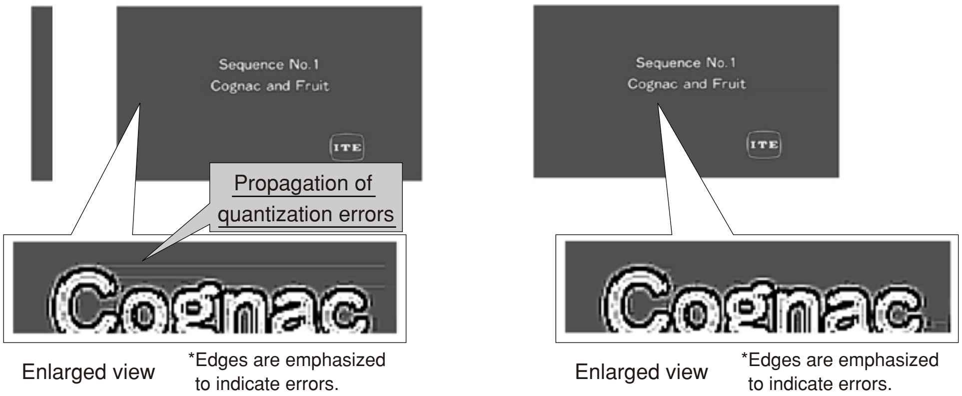

Figure 4
Improvement of quantization method.

and without adaptation control of the quantizer. In the image obtained without adaptation control, significant linearly-arranged errors in the horizontal direction on the background can be found. On the other hand, in the image obtained with adaptation control, the propagation of quantization errors is completely suppressed.

5. Performance of technology

We have developed a video compression technology for transmitting high-quality images for in-vehicle use with just a line memory. This technology is based on the predictive coding method, which can reduce the circuit size and achieve negligible processing delays. It allows 800 × 480, RGB 4: 4: 4, progressive scanning, 60 fps navigation images to be transmitted over an IDB-1394 network for the first time in the world. The major characteristics of this technology are as follows:

1) Small circuit size

The circuit can be built into an IDB-1394 LAN controller using a single chip. No external frame memory is required.

2) Minimal delay time

Data is compressed and transmitted via an IDB-1394 network. Data is compressed and decompressed within 2 to 3 ms.

3) High image quality

The technology enables the transmission of high-quality camera/DVD images and navigation graphics.

6. Conclusion

To make driving safer and easier, there are growing demands for a technology that can transmit videos from multiple cameras over an in-vehicle LAN. In this paper, we described the development of a compression technology for transmitting digital video over multiple channels for next-generation vehicle equipment. This technology satisfies the circuit scale, processing speed, and image quality that are required for in-vehicle applications. It is also compatible with the compression technology of the 1394 Trade Association (TA) standard for transmitting video via an IDB-1394 network, which the TA developed in cooperation with Fujitsu. In the future, we will build this technology into an IDB-1394 LAN controller LSI and then commercialize the LSI.

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Jun-ichi Odagiri, *Fujitsu Laboratories Ltd.*
Mr. Odagiri received the B.S. degree in Electrical and Electronic Engineering from Tokyo Institute of Technology, Japan in 1996. He also received the M.S. degree in Geosystem Engineering from the University of Tokyo, Japan in 1998. He joined Fujitsu Laboratories Ltd., Japan in 1998, where he has been engaged in research and development of image processing technology, image compression technology, and XML data processing technology. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan.

Yasuhiko Nakano, *Fujitsu Laboratories Ltd.*
Mr. Nakano received the B.S. degree in Electrical Engineering from Kumamoto University, Japan in 1988. He was a visiting scholar at California University at Berkeley from 1993 to 1994. He joined Fujitsu Laboratories Ltd., Japan in 1988, where he has been engaged in research and development of data compression technology for still color images and files. His current interest is human sensing systems and evaluation of image quality technology. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan.

Shigeru Yoshida, *Fujitsu Laboratories Ltd.*
Dr. Yoshida received the B.S. and M.S. degrees in Electronics Engineering from Iwate University, Japan in 1973 and 1975, respectively. He also received the Ph.D. in Information Networks from Graduate School of Information Systems at the University of Electro-Communications, Japan in 2006. He joined Fujitsu Laboratories Ltd., Japan in 1975, where he has been engaged in research and development of data compression technology for facsimiles, newpapers, still color images, and files. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan and a member of the Institute of Image Electronics Engineers of Japan (IIEEJ).