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On Encoding of Position Information in Inter-Vehicle Communications

Yoshito GOTO†* *and* **Takaaki HASEGAWA**†, ***Regular Members***

SUMMARY This paper discusses encoding of vehicular position information using predictive algorithms in inter-vehicle communications (IVC) from the viewpoints of source coding and noisy channels. Two vehicular driving models are assumed; one is the 15-mode as a suburban rapid transit driving pattern, the other is called calming mode as a street-driving pattern. Three types of schemes are compared; a pulse code modulation (PCM) scheme, a predictive coding (PC) scheme, and the variable interval prediction (VIP) scheme that is proposed here. This paper assumes that precise position information is got from a positioning system, and that all the transmitters and receivers have common predictors. Performance comparisons of the three types of schemes are carried out both of noiseless and noisy channels. Results show that the VIP scheme is superior to any other scheme.
key words: *ITS, inter-vehicle communications, predictive algorithms, position information, source coding*

1. Introduction

Recently, ITS [1], which aim at making safety, pleasant, and efficient transportation by solving traffic accidents, traffic jam, environmental pollution, and energy problems, have attracted the attention of the world.

Inter-vehicle communication networks (IVCN) [2] support safety and automatic driving. In IVCN, each vehicle exchanges its state, for example, position, velocity, acceleration, ID and so on. These are necessary to keep safety, and should be exchanged precisely in real time. In particular, if surrounding vehicles' position information can be recognized, although a driver has to depend on the one's vision and experience in the present systems, it is possible to drive more safety and efficient. However, in the situation of transmitting position information got from a positioning system, for example, the GPS, the PN coded magnetic markers positioning system [3] and so on, the amount of transmission data becomes enormous with increasing the number of vehicles. Therefore, when traffic is heavy, information could not be got successfully by interference. Accordingly, safety may be reduced because of lack of the surrounding information.

There have been many studies on IVC until now. For example, channel access schemes [4]–[7], the effects of IVCN [8], [9]. Also, the vehicle-to-vehicle communication and ranging system using spread spectrum (SS) Techniques called SS boomerang transmission [10], the hierarchical vehicle position encoding scheme in IVCN [11] and the scheme of surrounding vehicles' positions recognition and IVC without signal collision, called V-PEACE (Vehicle Position Environment Acquisition and Communication Evolution) [12] and Modified V-PEACE [13]. On the other hand, a study on reducing communication traffic and improving safety by using predictive information [14] from the viewpoint of the characteristic of a vehicular driving pattern was already investigated.

This paper aims at traffic reduction by efficient encoding in IVCN. Redundancy was defined by Shannon [17], and data compression has been utilized not only in multimedia communications but also electrocardiogram (ECG) encoding and so on [18]–[22].

However, encoding of position information in IVCN has been insufficiently discussed yet. This paper proposes a new position encoding scheme using predictive information, and compares the proposed scheme with PCM and PC schemes.

This paper is organized as follows. we begin in Sect. 2 by describing IVCN and encoding of position information in IVC. In Sect. 3, an applied predictive coding scheme and a proposed VIP scheme are presented. In Sects. 4, 5, and 6, three schemes; a PCM scheme, a PC scheme, and the VIP scheme are compared both of noiseless and noisy channels. Section 7 is for conclusions.

2. IVC

2.1 IVCN Model

The characteristics of IVCN, which consist of IVC, are different from those of usual cellular personal communication networks. The IVCN's characteristics are explained as follows:

1. No base station like ad-hoc networks:
   - IVCN have characteristics of autonomous distributed networks.
2. Dynamic configuration:
   - IVCN are ad-hoc and change rapidly.
   - Network moves for itself.

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†The authors are with the Department of Electrical and Electronic Systems Engineering, Saitama University, Saitama-shi, 338–8570 Japan.
*Presently, with the Matsushita Communication Sendai R&D Labs, Co., Ltd., Japan.

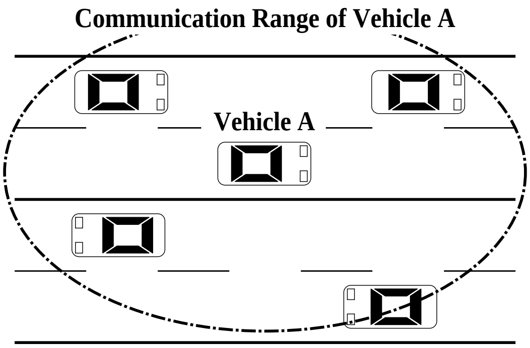


Fig. 1 An image of IVCN.

3. Different QoS requirements from usual networks:
   - Position information is vital for safety.
   - Real time communications and high quality information are required. Moreover, surrounding vehicles' information is more important than far vehicles' information.
   - There is little possibility of sudden motion change of vehicles.

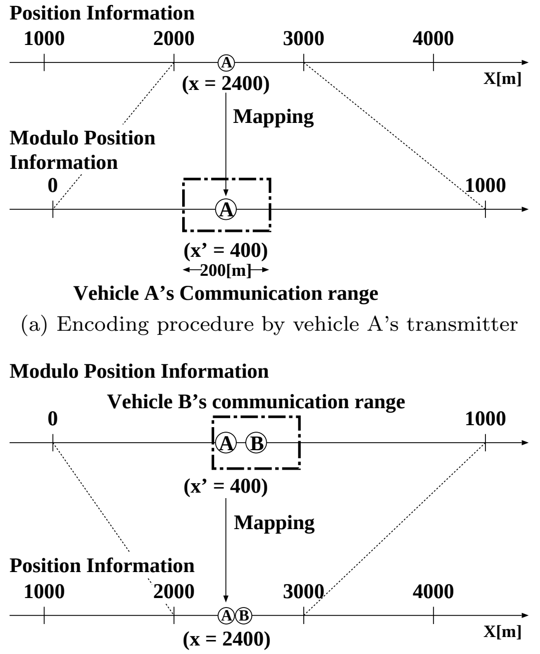
Figure 1 shows an image of IVCN. It is assumed that each vehicle can communicate vehicles within the vehicle's communication range. The contents of exchange information in IVCN are classified into two categories. One is the information that directly relates to vehicle driving and controlling such as position, velocity, acceleration and so on, so called "front-seat information." The other is called "rear seat information" (e.g., tourism information, weather information, web information). This paper treats the front-seat information, and it is assumed that each vehicle gets relative position information by communicating position information.

2.2 Description of Position Information in IVC

This section explains description of position information in IVC. This study is based on the following assumptions about vehicles that communicate each other.

Since the velocity and acceleration information can be calculated using position information in the case of a short sampling period, this paper deals with only position information assuming as follows:

1. One-dimensional position information along the lane is exchanged.
2. It is possible to get precise position information from a positioning system, for example, the GPS, the PN coded magnetic markers positioning system and so on.
3. To obtain near vehicles' position information in IVC, modulo information instead of absolute position information is sufficient and exchanged to determine positions.



(a) Encoding procedure by vehicle A's transmitter

Ⓐ: Vehicle A Ⓑ: Vehicle B
(b) Decoding procedure by vehicle B's receiver

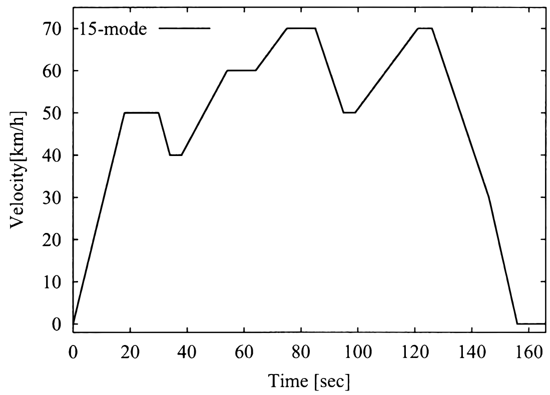
Fig. 2 An example of mapping of position information and modulo position information.

Table 1 Specification of encoding by PCM.

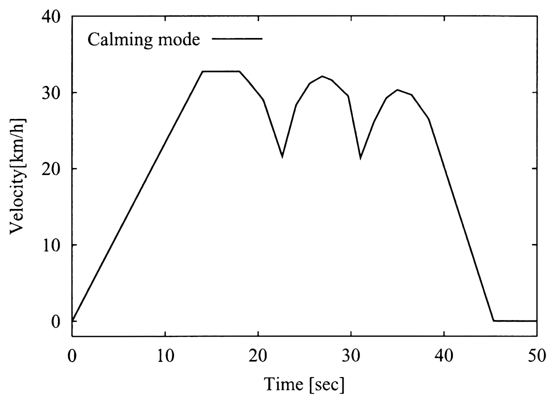
Encoding resolution	0.01 m
The bits of modulo position information	17 bits

In Fig. 2, an example of mapping of position information and modulo information is drawn. It is assumed that each vehicle can get position information or modulo position information from a positioning system, and that modulo position information is transmitted. In this figure, it is assumed that the period of modulo is 1000 meters and that the communication range is 200 meters (communication radius is 100 meters) [8]. Figure 2 (a) shows encoding procedure of position information by vehicle A's transmitter. Vehicle A substitutes modulo position information (x' = 400) for position information (x = 2400) by the modulo rule, then the modulo information is transmitted. Figure 2 (b) shows decoding procedure of the position information sent from vehicle A in vehicle B's receiver. If vehicle A is driving within the vehicle B's communication range, vehicle B receives modulo information x' = 400 from vehicle A, and recognizes that vehicle A is driving at x = 2400.

Table 1 shows specification of encoding by ordinary PCM Position information, which is encoded to one of 131072 symbols if the position encoding is carried out from 0 meters to 1310.71 meters every 0.01 meters; this requires 17 bits.



(a) 15-mode



(b) Calming mode

Fig. 3 Change of the velocities of the 15-mode and the calming mode.

2.3 Vehicular Driving Modes

In this paper, two vehicular driving pattern models are examined. One is the 15-mode [23] that assumes a suburban rapid transit driving pattern, the other is called the calming mode [24] that assumes a street-driving pattern. The 15-mode is combined by 15 kinds of driving way, that is, idling, speeding up, slowing down and so on. This pattern is used for estimation of the fuel consumption provided by the Ministry of Land, Infrastructure and Transport in Japan. The calming mode is a speed profile model examined by traffic calming schemes. Figure 3 shows each driving mode.

3. Encoding Methods in IVC

3.1 A PC Scheme

Figure 4 shows a PC scheme. Input original position data is assumed as precise analog data. In this paper, we consider quantization noise of the differential data and channel noise and ignore any error associated with the predictive calculation. In the predictive coding, after position data is predicted by the transmitter's predictor, the difference between the actual position and

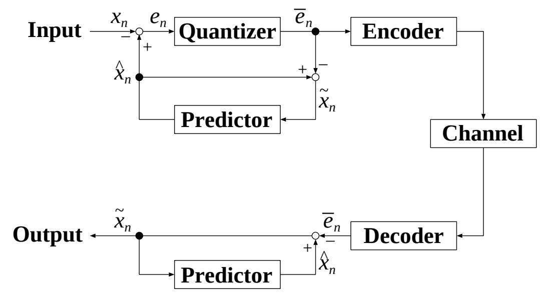


Fig. 4 Predictive coding.

the predicted position is quantized and transmitted. Since the receiver's predictor is the same as the transmitter's predictor, the decoded positions are obtained without loss of information except quantization noise.

Linear predictors predict the next data by linear operation of previous samples. In this paper, the first-order prediction that considers vehicle's velocity is discussed.

In IVC, all the transmitters and receivers have the same predictors. In this scheme, present position information is calculated from past position information, and then the differential information between the predicted and the actual position is encoded and transmitted every sampling period that is 20 ms here.

The calculations are as follows:

The velocity at t is calculated from position at t and $t - \Delta t$ as follows.

$$v(t) = \frac{x(t) - x(t - \Delta t)}{\Delta t} \tag{1}$$

The acceleration at t is got from velocity at t and $t - \Delta t$ as follows.

$$a(t) = \frac{v(t) - v(t - \Delta t)}{\Delta t} \tag{2}$$

The displacement of acceleration at t is obtained from acceleration at t and $t - \Delta t$ as follows.

$$\Delta a(t) = \frac{a(t) - a(t - \Delta t)}{\Delta t} \tag{3}$$

The predictive position at $t + \Delta t$ is calculated as follows. In the case of the prediction using two position information.

$$\begin{aligned} \hat{x}(t + \Delta t) &= v(t) \cdot \Delta t + x(t) \\ &= 2x(t) - x(t - \Delta t) \end{aligned} \tag{4}$$

In the case of the prediction using three position information.

$$\begin{aligned} \hat{x}(t + \Delta t) &= a(t) \cdot \Delta t^2 + v(t) \cdot \Delta t + x(t) \\ &= 3x(t) - 3x(t - \Delta t) + x(t - 2\Delta t) \end{aligned} \tag{5}$$

In the case of the prediction using four position information.

$$\hat{x}(t + \Delta t)$$

$$\begin{aligned} &= \Delta a(t) \cdot \Delta t^3 + a(t) \cdot \Delta t^2 + v(t) \cdot \Delta t + x(t) \\ &= 4x(t) - 6x(t - \Delta t) \\ &\quad + 4x(t - 2\Delta t) - x(t - 3\Delta t) \end{aligned} \tag{6}$$

The difference between the predictive position and the actual position is calculated as follows.

$$e = \hat{x}(t + \Delta t) - x(t + \Delta t) \tag{7}$$

$\Delta t = 20$ ms and t is arbitrary time.

In a PC scheme, the difference information is encoded every sampling period. Then, efficient utilization of 17 bits and minimization of quantization errors are desired for the encoder. We examine two types; one is a floating-point number type, the other is a fixed-point number type. In the former, the differential information is expressed as a floating-point number, and then, its mantissa and exponent are transmitted. In the latter, the differential information is expressed as a fixed-point number.

3.1.1 A Floating-Point Number Type

Figure 5 shows bit allocation of the differential information for a floating-point number type in the case of 850 bps. 12 bits from the MSB express its exponent, and 5 bits express its mantissa.

3.1.2 A Fixed-Point Number Type

If the differential information is expressed N bits, it is encoded within $-2N - 1 \sim +2N - 1 - 1$ as a decimal number. Table 2 and Fig. 6 show the range of the differential information in case of 850 bps.

3.1.3 Resetting in the PC Scheme

How to reset is explained here. If bit errors occur in a channel, errors are accumulated in the predictors, and the calculated position in the transmitter and that in the receiver become largely different. Consequently, it is necessary to reset appropriately, that is, to transmit true position information to the receiver. Table 3 shows several kinds of resetting conditions by a PC scheme. In this paper, the regular period of resetting is 5 seconds [15], [16], for the purpose of preventing the error from accumulating. Whenever position information is received, the receiver calculates the velocity at that time. If the computed velocity exceeds the predetermined velocity condition by transmission errors, the receiver requires to reset of transmitter's actual position, and then reset all over again. This paper considers velocity condition as follows.

Eeven if the above-mentioned velocity condition is satisfied, computed errors accumulate when small errors occur. That case may cause to calculate an inherently impossible position for a vehicle. Therefore, when computed velocity does not satisfy the velocity condition Eq. (8), resetting is done.

$$-20 < \text{computed velocity [km/h]} < 180 \tag{8}$$

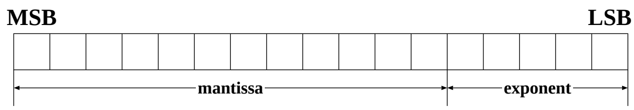


Fig. 5 Bit allocation of the differential information for a floating-point number type in case of 850 bps.

Table 2 The range of the differential information in case of 850 bps.

Mode	The range of the differential information
PC (fixed-0)	Five figures to 4 decimal places
PC (fixed-1)	Five figures from 1 to 5 decimal places
PC (fixed-2)	Five figures from 2 to 6 decimal places
PC (fixed-3)	Five figures from 3 to 7 decimal places
PC (fixed-4)	Five figures from 4 to 8 decimal places

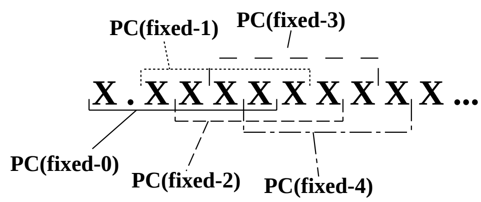


Fig. 6 The range of the differential information in case of 850 bps.

Table 3 Kind of resetting conditions by a PC scheme.

Kinds of reset	Decision of reset	
	Transmitter	Receiver
Time (5 seconds)	Do	Do
Velocity condition when position information is received	Don't	Do
Velocity condition during calculating	Don't	Do

3.2 The Proposed VIP Scheme

In this section we propose the VIP scheme, which aims at reducing communication traffic by using predictive information, considering the viewpoint of the characteristic of vehicular driving pattern. The way of calculating predictive information is the same as the PC scheme. Transmitters and receivers, which have the same predictors, calculate the difference between the predictive information and the position information every sampling period. Only when the difference exceeds a predetermined error range, called Reset Decision Error (RDE) here, the transmitter sends position information. If the difference does not exceed the RDE, the transmitter does not transmit position information and goes on predicting by using the predictive information.

Figure 7 shows the VIP scheme that uses three position information. In this figure, an example of a position sequence at every sampling time is as the same way

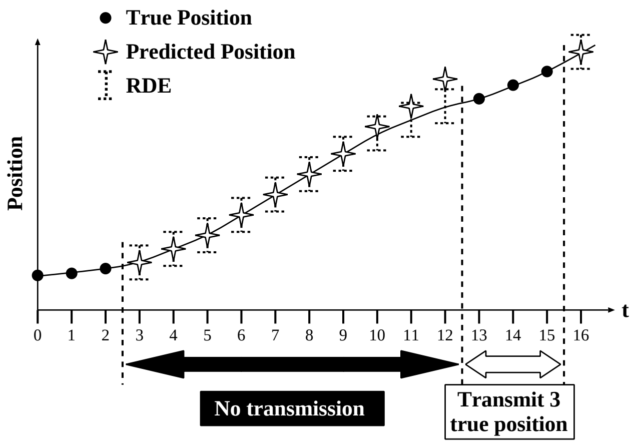


Fig. 7 The VIP scheme.

as Ref. [22]. The transmitter sends the modulo position information at $t = 0$, 1, 2. When $t = 2$, the transmitter predicts the predictive position information at $t = 3$. Then, when $t = 3$, the difference between the predictive information and the position information is calculated. If the difference does not exceed the RDE, the transmitter does not transmit position information and goes on predicting the predictive position information of $t = 4$ by using the predictive information. Prediction will be repeated until the difference exceeds the RDE in the same way. Therefore, during the predictive calculation ($t = 3 - 12$), the transmitter does not send position information. When $t = 12$, the difference exceeds the RDE. So, the transmitter sends the modulo position information at $t = 13$, 14, 15 and the transmitter predicts the predictive position information again.

3.2.1 Resetting in the VIP Scheme

How to reset in the VIP scheme is explained here. Table 4 shows several kinds of resetting conditions in the VIP scheme. In this paper, 0.10 meters [15], [16] as the regular period of resetting is examined.

3.3 Conditions of Performance Evaluations

Predictive algorithms are optimized for performance evaluations [15], [16]. We examined the 2nd, 3rd and 4th order prediction.

In the PC schemes, in the case of a floating-point number type, influence of the incorrect exponent is serious. In the fixed-point number type, if the quantized error is too small, overflow happens. On the other hand, if the quantized error is large, bits of the differential information are not used efficiently. However, if bits of the differential information are used efficiently, a fixed-point number type is superior to the floating-point number type. Moreover, position errors accumulate every sampling time in transmission if transmission errors occur. A degree of accumulation becomes large with increasing order of prediction. Therefore, the prediction using two positions information is the most effective in the three types of PC schemes.

In the VIP scheme, if transmission errors do not occur, the precision of prediction depends on the order of prediction. In this paper, both driving modes are limited to uniform acceleration motion. Therefore, the prediction using three position information is most effective in VIP schemes.

Table 5 shows conditions of simulations in Sects. 4, 5 and 6. PC-L (Linear) stands for a PC scheme using two samples. VIP-Q (Quadratic) stands for a VIP scheme using three samples. Table 6 shows PC-L's modes of simulations in Sects. 4, 5 and 6. In this paper, we do not consider directly error correction. Althogh noisy channels are treated in Sects. 5 and 6. Two vehicular driving models are assumed; one is the 15-mode as a suburban rapid transit driving pattern, the other is called Calming mode as a street-driving pattern.

Table 4 Kind of resetting conditions by the VIP scheme.

Kinds of reset	Decision of reset	
	Transmitter	Receiver
RDE (0.10 meters)	Do	Do
Time (5 seconds)	Do	Do
Velocity condition when position information is received	Don't	Do
Velocity condition during calculating	Don't	Do

Table 5 Conditions of simulations.

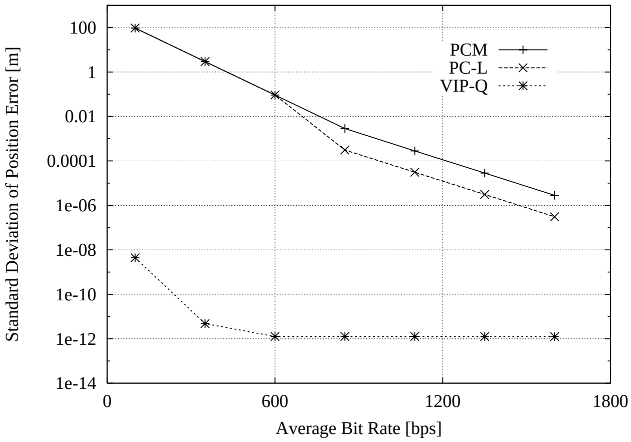
The order of prediction by a PC scheme	Prediction using two samples (PC-L)
The order of prediction by the VIP scheme	Prediction using three samples (VIP-Q)
Errors in a channel	Random errors
The period of sampling [ms]	20
Period of module [m]	1310.71
The period of reset [sec]	5
The range of RDE [m]	0.10
Velocity condition [km/h]	$-20 < v < 180$

Table 6 PC-L's modes of simulations.

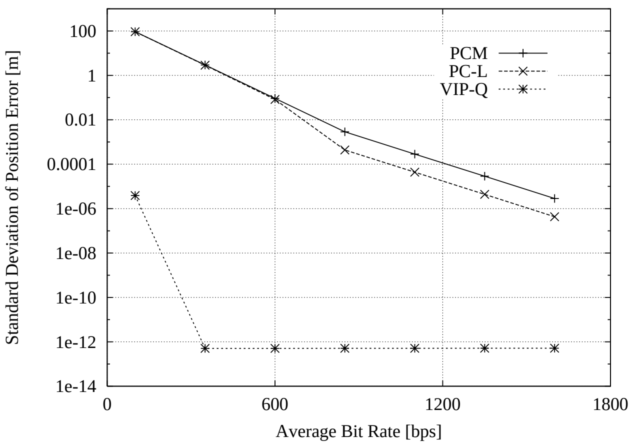
bps	Mode
100	PC (fixed-0)
350	PC (fixed-1)
600	PC (fixed-1)
850	PC (fixed-3)
1100	PC (fixed-5)
1350	PC (fixed-7)
1600	PC (fixed-8)

4. Performance Evaluations from the Source Coding Viewpoint

In this section, performance evaluations are carried out assuming noiseless channels, that is, source coding. The transmitter encodes and sends position information every sampling period. No transmission errors occur in a

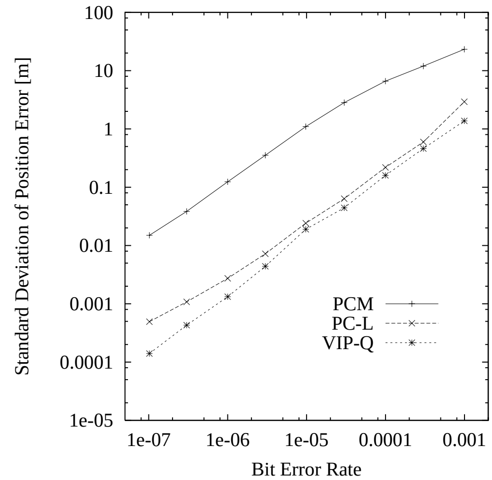


(a) 15-mode

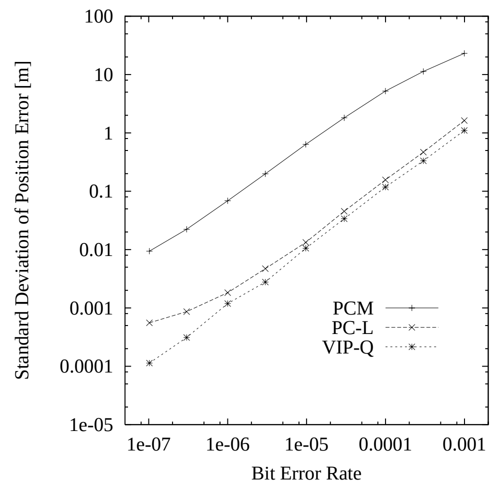


(b) Calming mode

Fig. 8 Average bit rate vs. position error.



(a) 15-mode



(b) Calming mode

Fig. 9 Bit error rate vs. position error.

channel. The receiver decodes received position information. Therefore, the decoded position errors caused by only quantized errors.

Figure 8 depicts performance comparisons of the three types of schemes. The average bit rate varies from 100 bps to 1600 bps. The quantization error becomes small with increasing bit rate. PC-L is superior to PCM because the quantized error of the differential position information is smaller than that of the position information. Both in PCM and PC-L, the lower the rate is, the larger the position error is. On the other hand, the VIP-Q's position errors are extremely small, and show floors. This reason is that a number of bits can be assigned when the transmitter sends position information because the transmission interval of prediction is long, and the floors are caused by computational precision. (64 bits floating type calculation is assumed in the predictor.)

Consequently, VIP-Q is superior to PCM or PC-L.

5. Performance Evaluations on a Noisy Channel

In this section, we evaluate performances under the assumption of noisy channels. Bit errors occur in such channels. Therefore, the decoded position errors caused by quantized errors and bit errors.

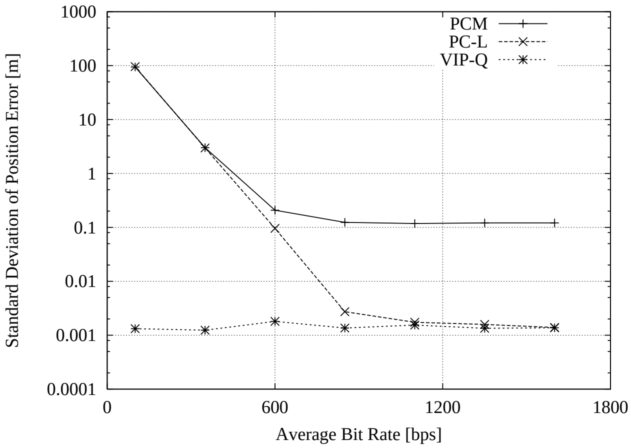
Figure 9 illustrates performance comparisons of the three types of schemes. We evaluate under the condition that the average bit rate is 850 bps. The BER (Bit Error Rate) varies from 10^{-3} to 10^{-7}. The position errors of PC-L can be suppressed about 1/50 in comparison with PCM. Moreover, those of VIP-Q are about 1/2 in comparison with PC-L.

Consequently, VIP-Q is superior to PCM or PC-L.

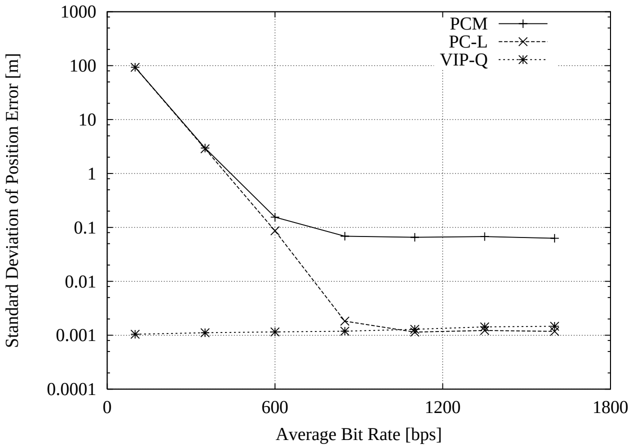
6. Performance Evaluations about the Amount of Transmission Data

In this section, we evaluate bit rate properties under the assumption of noisy channels. Bit errors occur in such channels. Therefore, the decoded position errors caused by quantized errors and bit errors.

Figure 10 shows performance comparisons of the three types of schemes. Average bit rate varies from



(a) 15-mode



(b) Calming mode

Fig. 10 Average bit rate vs. position error.

100 bps to 1600 bps. The BER is 10^{-6}. The position error of VIP-Q can be suppressed 1/100 in comparison with PCM or PC-L at 600 bps.

Consequently, if the amount of transmission data is little, VIP-Q is most effective in three schemes.

7. Conclusions

In this paper, we have proposed encoding of vehicular position information using predictive algorithms in IVC. Assuming two vehicular driving models, computer simulations have been carried out to compare performances of three types of schemes.

Performance evaluations from the viewpoint of source coding and noisy channels show that the VIP scheme is effective as a coding scheme in IVC.

In this paper, we investigated well-known and typical two driving pattern modes. In particular, other actual vehicles' speed profiles should be examind. Further works include examination using real vehicles' speed profiles, investigation of other front-seat information, and relationship between IVC coding and safety.

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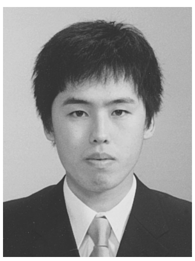

Yoshito Goto received his B.E. and M.E. degrees in Electrical and Electronic Systems Engineering from Saitama University in 2000, and 2002, respectively. He joined the Matsushita Communication Sendai R&D Labs, Co., Ltd.. His research interests include inter-vehicle communication networks and vehicular position encoding systems on Intelligent Transport Systems (ITS).

Takaaki Hasegawa received his B.E. and M.E. and Ph.D. degrees in Electrical Engineering from Keio University in 1981, 1983, and 1986, respectively. He joined the Faculty of Engineering at Saitama University in 1986. He has been an Associate Professor since 1991. During 1995–1996 he was a visiting scholar at The University of Victoria. His research interests include Intelligent Transport Systems (ITS), human machine interfaces (HMI), human communications (HC) and Spread Spectrum (SS) communications. He is the author of the book Primary C Language Note (Japanese, HBJ, 1989), a co-author of the books: Fundamentals and Applications of Spread Spectrum Communication Technologies (Japanese, Triceps, 1987), Application Technologies of Spread Spectrum Communications (Japanese, Triceps, 1992), and Personal Communications and Consumer Communications (Japanese, Baifukan, 1994), Mobile Computing Textbook (Japanese, ASCII, 1998). He is a member of IEEE, and SITA (The Society of Information Theory and its Applications, Japan).