On the Enhancement of Unequal Error Protection Performances in Images Transmission over Time-Varying Channels

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Summary
In this paper, we dealt with an unequal error protection (UEP) solution for visual-based quantized JPEG images coded and transmitted over time-varying channels by focusing our purpose on the question of how to improve the total rate-distortion performances of a given UEP scheme. In consequence, over an UEP scheme, a packet transmission solution is proposed with a retransmission protocol using rate-compatible punctured convolutional codes (RCPC codes). The simulated time-varying channel is a Rayleigh fading type where the transmitted packets do not always experience the channel distortion with the same intensity. Attractive results are issued from our simulations.

Key words:
ARQ/FEC, JPEG images, RCPC codes, time-varying channels, UEP.

Introduction

Joint source-channel coding approach for digital data communications, mainly for information sources like images and video, has registered a great success and is more and more passing to be conventional nowadays. Many are the interesting results published on the topic to highlight the stake of building communication systems based on some of its methods including unequal error protection (UEP). Aiming a judicious use of an a priori knowledge of the source significance information, UEP aims at bringing the necessary protection need to each information bits to be transmitted and so that to reduce the required bandwidth per user. The literature on UEP is abundant and includes works reported in [1], [2], [3] and [4] where better performances of UEP than EEP (equal error protection) are somehow reported.

Thus, one constructer would like to base his solutions of images communication systems on the UEP technique. The most common way of doing it, in practice, will be to choose a fixed number of channel codes with different correction capacities, for example the RCPC codes (rate compatible punctured convolutional codes), and to adapt to a transmission environment where good qualities of transmission are obtained. One question is that, whenever UEP is done with data presenting different levels of protection requirements, whenever the transmission environment may be time-varying and a return channel available (for example in High Speed Downlink Packet Access (HSDPA) systems), why not take the risk – under the bounded limits of the channel codes chosen for UEP - of protecting slightly the data to be sent and if not received correctly proceed by transmitting incremental redundancy until the received data recover from errors when passing through the channel decoder. For example, in an UEP scheme using a RCPC code of rate 8/14 for a level1 of source data significance and 8/18 for level2, we would like to have the code, effectively used, varying in the range [8/9, 8/14] for level1 and [8/9, 8/18] for level2. In the worst case the additional redundancy bits transmitted will induce a channel cost equal to the one given by the fixed channel code for each level of protection (8/14 for level1 and 8/18 for level2).

The solution that we propose to this question is to adapt a modified type II ARQ/FEC protocol - described by J. Hagenauer in [5] - in UEP schemes based on a DCT (Discrete Cosine Transform) source significance information structure [4]. Source data are coded and transmitted by packets with a mechanism of reliability control. The last packet (which size varies following the source data rate) of each significance level of the DCT image (a DC packet or an AC packet) is sent following the classical UEP scheme with the appropriate channel code adopted for the level of protection requirement to which the packet belongs. Moreover, when a packet has to be transmitted more than one time, only additional bits which were previously punctured are transmitted to help the initial packet to recover from errors.

Details of our proposal start with section 2 for the coding and transmission system description; then continue with a visual based-quantization, an overview of the channel protection methods and tools, respectively presented in sections 3 and 4. We present the proposed protocol in section 5 and the illustrations of experimental results in section 6.

2. Overview of the Image Coding and Transmission System

The fig. 1 depicts the image coding and transmission system. The original image is source coded following the JPEG standard. The quantization matrix (Q_{HVS}) [6] exploits the human visual system (HVS) properties and provides several source entropies. Entropic coding is done using the algorithm of Huffman (Huff).

At the output of the JPEG coder, DC and AC bits stream are processed successively. The paquetization module has the role of splitting each AC or DC bits into packets which follow either **(a)** for common UEP and EEP or **(b)** for the proposed processing integrating a reliability control algorithm over UEP schemes. As for the RCPC coder, it performs the channel coding to bring the necessary protection to the packets. When running an UEP scheme, the packets carry the source significance information (DC or AC). The block labelled π represents a convolutional interleaver.

As for the modulation block several options are available for the mobile radio channels. In [7], J. Proakis makes a comparative study of Frequency Shift Keying (FSK), Phase Shift Keying (PSK) and Differential Phase Shift Keying of alphabet size 2 (2-DPSK) modulators performances.

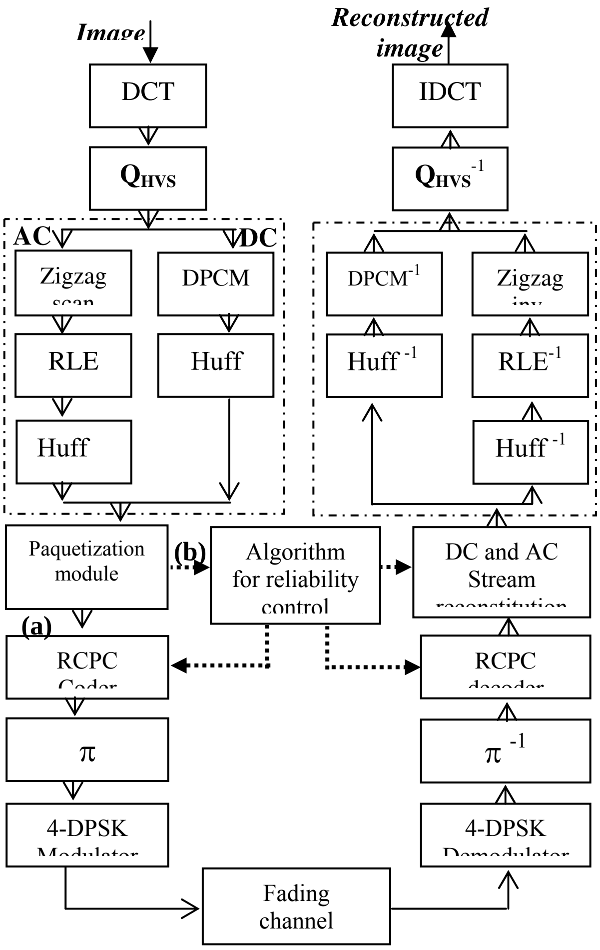

Fig. 1. Block-diagram of the image coding and transmission system.

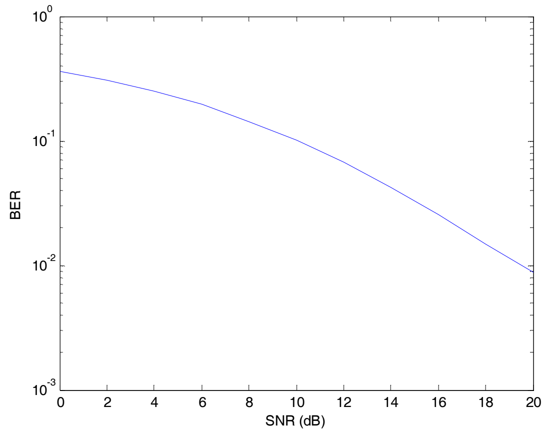

Fig. 2. Bit error rate versus signal to noise ratio on the simulated Rayleigh fading channel with a 4-DPSK modem. 200000 bits are transmitted and an average minimum number of 1700 errors are observed.

Specifications (http://www.umtsworld.com/technology/wcdma.htm) of the WCDMA standard for UMTS recommend a QPSK modulator. J. Hagenauer [8] makes a 4-DPSK modulation for speech transmission over a Rayleigh fading channel. Here a 4-*DPSK* modulator is experienced.

Dealing with the physical channel we focus our transmission environment on a frequency-flat time-varying Rayleigh fading channel [9] where the mobile antenna velocity is assumed to induce a Doppler shift of 150 Hertz. Moreover, many of the channel properties are chosen in accordance with the WCDMA standard for UMTS. The global noise model is completed with an Additive White Gaussian Noise (AWGN) and the induced bit error rate (BER) distortion is characterized by the curve plot in fig. 2.

Since the quantization is based on a HVS approach, the distortion performances are evaluated using a visual representation of the peak signal to noise ratio (PSNR) measure, named weighted PSNR (wPSNR) [10], and calculated in the DCT domain following the formula (1):

$$wPSNR = 10\log_{10}\left(\frac{255^2}{wMSE}\right) \qquad (1)$$

where *wMSE* is the weighted mean square error given by

$$wMSE = \frac{1}{N^2}\sum_{u=1}^{N}\sum_{v=1}^{N}\left(H^2(u,v)\left(x(u,v)-\hat{x}(u,v)\right)^2\right) \qquad (2)$$

and H is the weighted matrix, x is the DCT output and $\hat{x}$ the output of the quantization inversion (Q_{HVS}^{-1}).

3. Human Visual-Based Quantization

Several researchers have dealt with human visual system (HVS) including Mannos and Sakrison [11] or Daly [12]. Based on Daly's contribution with his contrast sensitivity function described in (3), Ching-Yang *et al.* [6] proposed a human visual frequency weighting matrix *H(u,v)* and a quantization table for the baseline JPEG in (4). The parameter q is an indicator of quality which variation gives several rates at the source coder output.

$$H(p)=\begin{cases}2.2\left(0.192+0.114\tilde{f}(p)\right)\exp\left(-\left(0.114\tilde{f}(p)\right)^{1.1}\right) & \text{if } \tilde{f}(p)\succ f_{\max} \\ 1.0 & \text{otherwise}\end{cases} \quad (3)$$

where p is a point of coordinates *(u,v)* in the block 8×8, $\tilde{f}(p)$ is the radial spatial frequency in cycles/degree and $f_{\max}$ is the frequency of 8 cycles/degree at which the exponential peak is.

$$H(u,v)=\begin{bmatrix}1.0000 & 1.0000 & 1.0000 & 1.0000 & 0.9599 & 0.8746 & 0.7684 & 0.6571\\ 1.0000 & 1.0000 & 1.0000 & 1.0000 & 0.9283 & 0.8404 & 0.7371 & 0.6306\\ 1.0000 & 1.0000 & 0.9571 & 0.8898 & 0.8192 & 0.7371 & 0.6471 & 0.5558\\ 1.0000 & 1.0000 & 0.8898 & 0.7617 & 0.6669 & 0.5912 & 0.5196 & 0.4495\\ 0.9599 & 0.9283 & 0.8192 & 0.6669 & 0.5419 & 0.4564 & 0.3930 & 0.3393\\ 0.8746 & 0.8404 & 0.7371 & 0.5912 & 0.4564 & 0.3598 & 0.2948 & 0.2480\\ 0.7684 & 0.7371 & 0.6471 & 0.5196 & 0.3930 & 0.2948 & 0.2278 & 0.1828\\ 0.6571 & 0.6306 & 0.5558 & 0.4495 & 0.3393 & 0.2480 & 0.1828 & 0.1391\end{bmatrix}$$

$$Q_{HVS}(u,v)=\frac{q}{H(u,v)}, \text{ for } 0\le u,v\prec 8\,, \quad (4)$$

4. Common Equal/Unequal Error Protection with RCPC Codes

To protect source coded information bits against errors occurred during transmission through the channel, equal error protection (EEP) uses a given single channel code with its fixed error correction capacity to protect all the source data bits to transmit. This way of doing has been proven not optimal with joint source channel coding theory and practice through the example of unequal error protection (UEP).

Unequal error protection (UEP) gets the advantage of being more judicious for, bringing the necessary protection to each information data bits according to their significance so that useless additional protection can be avoided. UEP is generally leant on a defined source significance information (SSI) structure.

Source Significance Information (SSI), so called by J. Hagenauer in [5], is a way of partitioning data of a same information source (image, video, speech, etc.) in different levels of importance according to some objective criteria. The interest of the SSI is to define different error protection requirements for the source coded data. The literature relates various SSI designs. In [1], Zhenzhong Chen, King N. Ngan and Chengji Zhao exploit different error sensitivity of video macroblocks as a SSI for UEP. Chung-Lin Huang and Sling Liang [2] do achieve a SSI design of MPEG-2 video for UEP transmission. For JPEG images, very few works have concerned the design of a SSI. However, examples of published works are reported in [3] and [4].

In the present application of UEP, the SSI considers DC data to be more significant than AC's as done in [4]. RCPC codes are then used to provide unequal protection.

As far as rate compatible punctured convolutional codes (RCPC codes) are concerned, let's notice that the pioneers in puncturing convolutional codes are Cain, Clark, and Geist [13]. Furthermore, Yasuda *et al.* [14], [15] found a family of $(N-1)/N$ codes by puncturing a 1/2 code for N up to 14, and built selectable rate coders and Viterbi decoders. J. Hagenauer [5] introduces rate-compatible punctured convolutional codes by designing a family of codes with a rate-compatibility restriction to the puncturing rule based on a traditional $1/N$ convolutional code called mother code.

In this paper, we work with a family of RCPC codes deriving from a convolutional mother code $1/N \equiv 1/3$, of memory M=6, and a generator given, in octal notation, by G= [133 171 145]. The puncturing period P is 8. The different codes of the family are of rate given by $P/P+l$, $l=1,2,4,6,..,16$, representative of respective rates 8/9, 8/10, 8/12, 8/14…8/24. These codes performances are reported in [5] where they are moreover proven non catastrophic.

5. The Proposed Protocol of Packets Retransmission over UEP

In [5], J. Hagenauer presented the RCPC codes and their applications for UEP and ARQ/FEC. When applying UEP, RCPC codes provide a set of rates with the same encoder structure to satisfy different protection requirements to source information bits. Following the context, two or more RCPC codes are used for that purpose and only one per level of protection requirement at once. What we propose here is unequal error protection of images source coded bits. In addition to the assumed fixed RCPC codes per level of significance (level of protection requirement) of the source information, we adapt a modified ARQ/FEC type II protocol proposed by J. Hagenauer in [5] to enable the use of several RCPC codes per level of protection requirement and that at once per image packet transmission. Since images are coded and transmitted packet per packet through a time-varying channel, all the packets do not experience the same intensity of the channel distortion. The interest of doing so is that, whenever a return channel is available in wireless environments and that the option of using UEP as a solution for data transmission is made, significant improvements can be brought in reducing the channel bandwidth per user.

Details of the proposed protocol, a modified version of the one proposed by J. Hagenauer [5], are in the following algorithm:

Initialisation and variables:

XC_code_index represents either a DC RCPC code index (l) or an AC RCPC code index. There are set to initial index values in accordance with the UEP scheme adopted for the transmission. For example, *AC_code_index=6* and *DC_code_index=10* correspond respectively to the RCPC codes of rates 8/14 and 8/18. k is the size of the information packet fixed equal to 1000. p is the number of parity bits fixed equal to 28; ($k+p$) is the size of the CRC codeword; $M=6$ is the memory of the RCPC 1/3 coder. *current_code_index* is the current RCPC code index for a packet of length k being coded. This variable takes its value in the range [1, *XC_code_index*].

For each AC or DC packet *pqt* coming from the source coder output, its length is either equal to 1000 or maybe smaller. In this last case, the packet is the last of the DC or AC bit stream and does not always follow the ARQ/FEC due to the fact that it is not sure to find a compatible generator polynomial for data of various lengths. The following instructions are performed for the packet coding and transmission.

if length (pqt) <1000
  perform (&)
else
  perform (β)
endif

(&): *ordinary UEP coding and transmission running*

Step1: add M zeros to properly terminate the coder memory.

Step2: code with the RCPC code associated to *XC_code_index*.

Step3: send the packet and proceed to the decoding at the receiver.

(β): *UEP with retransmission*: *the steps 1 to 5 are followed while transmitting a packet.*

Step1: add p parity bits by coding a cyclic code $C(k+p, k)$.

Step2: add M zeros to properly terminate the coder memory.

Step3: set *current_code_index* to 1. Code with the RCPC code by using the puncturing matrix associated to *current_code_index*. Send through the channel and decode the RCPC code, then the cyclic code and check for errors.

Step4: *while* errors are detected
  increment *current_code_index*
  if current_code_index >XC_code_index
    break;
  endif
  send bits of additional redundancy in the RCPC codeword produced by the code with *current_code_index* (already incremented); combine them with the initial packet, then decode the RCPC code and check for errors by decoding the cyclic code.
endwhile

Step5: the packet is either free of errors or the *break* instruction is met within the loop block. An acknowledgement is sent to the receiver and the decoded packet is store in a buffer. While AC and DC are separately source-coded the JPEG decoding can be processed as soon as all the DC or AC packets are received.

In *step 4*, the initial packet that we are about is the packet sent while attempting a packet transmission for the first time. When unsuccessfully decoded, it's not thrown away, but is stored and updated with the additional bits to come with the possible retransmissions. In [5], additional redundancy bits are transmitted following a conceptual arrangement of the bits in a matrix. In our simulations we manage differently although the goal is the same.

In its initial version, the modified ARQ/FEC type II protocol as proposed by J. Hagenauer can perform the packet retransmissions until the use of the most powerful of the RCPC codes and if the packet remains with errors several possibilities can be a matter of recourse for the reliability purpose. Hereby we do not, because of the joint source-channel coding philosophy aimed through an UEP method. For this reason, we limit retransmissions to the RCPC codes accommodated with the UEP scheme; that means that, even if errors are still detected, no other mechanism of recovering from errors is handled and the packet is passed to the JPEG decoder.

6. Experimental Results

Simulations have concerned the coding and transmission of the well known images "Lena" and "Barbara" both of size 512×512 pixels. They are source coded at rates in the range [0.44 bpp, 0.96 bpp] for Lena, and for Barbara in the range [0.47 bpp, 0.98 bpp]. Coded images with corresponding source rates, transmitted and successfully reconstructed are presented in figures 3, 4, 5 and 6.

The total bit rate (TBR) is the transmission cost and is representative of the total bits per pixel cost after source and channel coding. The variation of the total bit rate is got by varying the source coder quantization matrix as indicated in formula (4). Images are so coded at a given source rate and transmitted through the fading Rayleigh channel at a given total rate.

Simulating transmission at a given rate, different signal to noise ratio (SNR) values are experienced to find the minimum SNR at which the Viterbi algorithm runs successfully. The reason of doing so is the application of a packet retransmission algorithm which aims the reliability. At the end, for the whole range of source rates involved in the simulations, we are about (see table 1) an average

Fig. 3. *Lena source coded at 0.44 bpp and reconstructed with a wPSNR=36.2 dB.*

Fig. 4. Barbara source coded at 0.47 bpp and reconstructed with a wPSNR=32.1 dB

minimum SNR (AMSNR) to characterize the average SNR at which "total rate-distortion" performances are reported. Over a given AMSNR value, performances are maintained for EEP and UEP and are expected to be improved again for the proposed idea in this paper.

Two schemes of channel coding are distinguished:

- Scheme 1, the first, is characterized by an EEP with a RCPC code of rate 8/16 and an UEP with RCPC codes of rate 8/18 for DC and 8/14 for AC.
- Scheme 2, the second, is characterized by an EEP with a RCPC code of rate 8/22 and an UEP with RCPC codes of rate 8/24 for DC and 8/20 for AC.

Fig. 5. *Lena source coded at 0.96 bpp and reconstructed with a wPSNR= 41.3 dB.*

Fig. 6. Barbara source coded at 0.98 bpp and reconstructed with a wPSNR=38.1 dB.

The proposed solution over UEP using packets retransmission does not (by its principle) work at a fixed RCPC code rate. Nevertheless, the RCPC codes rates to use are limited not to be powerful than the one used for the common UEP of scheme 1 or scheme 2.

Reported results (figures 7 - 10) show that a great gain of "total rate-distortion" performances makes the proposed coding and transmission scheme more advantageous than the common UEP and EEP schemes.

Table 1: Sample of comparative parameters when coding and transmitting Lena 512×512 at indicated source coding rates. MSNR (Minimum SNR), AMSNR (Average MSNR) are in decibels (dB) units whereas Source rate and TBR (total bit rates) are in bits per pixel (bpp).

	Source rate	TBR	MSNR	AMSNR
EEP (8/22)	0.44	1.22	14	15.14
	0.52	1.45	14	
	0.61	1.69	15	
	0.70	1.93	15	
	0.79	2.18	16	
	0.88	2.42	16	
	0.96	2.67	16	
UEP (8/20, 8/24)	0.44	1.15	14	15
	0.52	1.35	14	
	0.61	1.58	15	
	0.70	1.80	16	
	0.79	2.03	15	
	0.88	2.25	15	
	0.96	2.47	16	
Proposed solution based on UEP (8/20, 8/24)	0.44	0.52	14	15
	0.52	0.62	14	
	0.61	0.72	15	
	0.70	0.82	16	
	0.79	0.92	15	
	0.88	1.02	15	
	0.96	1.13	16	

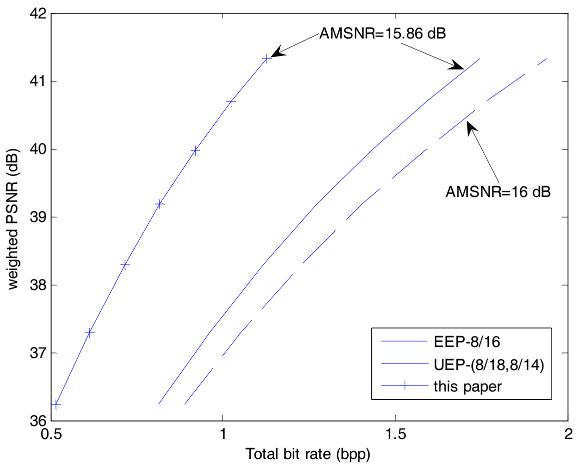

Fig. 7. Lena->Scheme 1: Total rate-distortion performances.

Conclusion

Through this paper, we make a comparative study of total rate-distortion performances of methods aiming at protecting images information bits that one would like to transmit over a noisy time-varying wireless channel. We have proven as already done by several authors that the

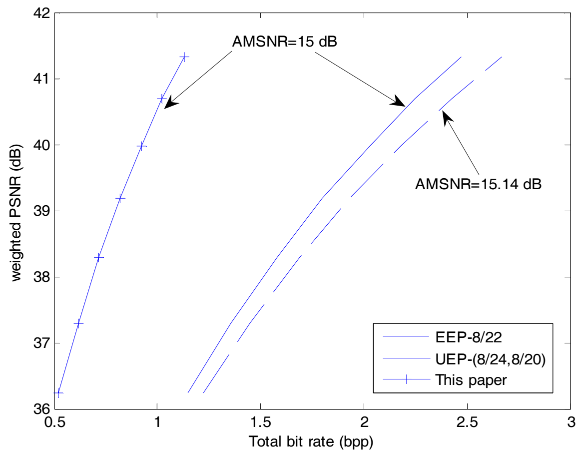

Fig. 8. Lena->Scheme 2: Total rate-distortion performances.

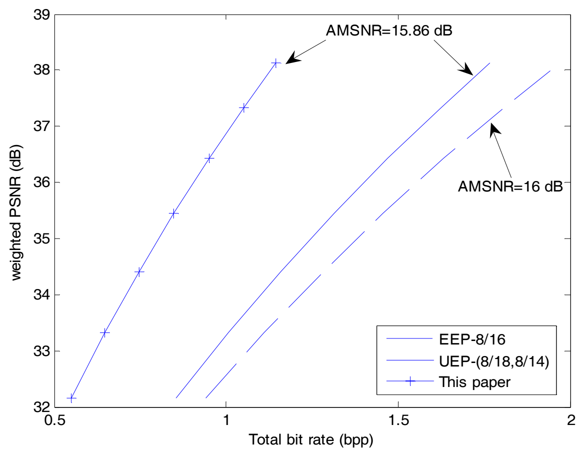

Fig. 9. Barbara->Scheme 1: Total rate-distortion performances.

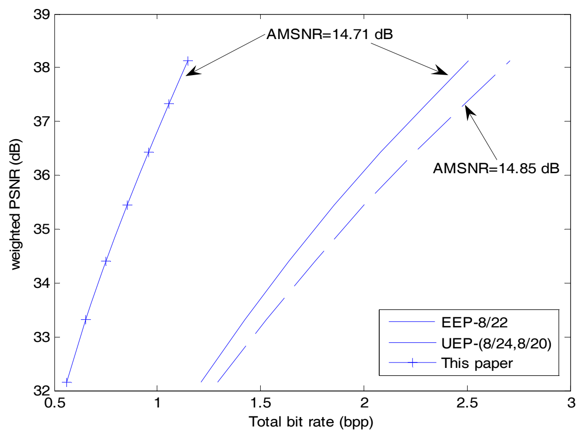

Fig. 10. Barbara->Scheme 2: Total rate-distortion performances.

joint source-channel method of UEP can provide better performances than the classical equal error protection of data. Upon this, we mainly think about a solution to get profit of some specific situations that it's possible to encounter in mobile environments: the time-varying property of the channel, the possible existence of a return channel for retransmission. Thus we run upon ordinary UEP schemes, a protocol of packet retransmission. Total rate-distortion performances are evaluated attractive. However, it is not obvious that the proposed solution match very well with real time applications.

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