Restart Marker Regulation Technique for Progressive JPEG Image Coding in Mobile Communications

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***Abstract*—In this letter, an error-robust and JPEG compliant progressive image compression scheme over wireless channels is presented. The use of restart markers in the JPEG standard provides the resynchronization function for error handling. Unfortunately, misinterpreted markers may cause serious error damage due to the error propagation. Therefore, a restart marker regulation technique is proposed here to preprocess restart markers at the decoding end. All erroneous restart markers are corrected and rearranged in the correct order. After decoding, isolated erroneous restart intervals are detected and further processed by the error concealment to reduce image degradation. The simulations demonstrate that the proposed scheme does significantly improve the image quality in error-prone environments.**

***Index Terms*—Error compensation, image coding, mobile communication, synchronization.**

I. Introduction

With the development of mobile communications, multimedia transmissions over wireless channels are getting increasingly popular. There mainly exist two problems in current wireless communications, the relatively high error rate and the limited bandwidth. Thus, the error-robust transmission is expected in an error-prone environment while the limited bandwidth makes the progressive coding attractive. Two complementary progressive procedures, spectral selection and successive approximation, which are defined in Annex G of the JPEG standard, are suitable for interactive image communications over band-limited channels. In spectral selection, the DCT coefficients of each block are segmented into different frequency bands and the bands are coded in separate scans. In successive approximation, the precision of the DCT coefficients is reduced through divisions by a power of two, i.e., the point transform, prior to coding. After the first scan, the precision of the DCT coefficients is increased by one bit in each subsequent scan [1].

Because of using the variable length coding, the bit streams generated according to the DCT-based JPEG standard are very sensitive to channel errors. This is mainly caused by the loss of synchronization in the decoder. Several techniques have been developed to enhance the error protection and error correction capability for the sequential JPEG [2]–[4]. In the JPEG standard, restart markers are available to help the resynchronization of the decoder. Jaehan In *et al.* proposed a rate-distortion optimized JPEG compliant progressive encoder [5]. The Independent JPEG Group (IJG) also provided a default resynchronization method for the error recovery assuming the decoder is unable to back up [6]. Moreover, the restart markers have been studied to improve the error robustness for the H.263 video [7], [8]. Those works mainly investigated on the positioning of markers, however, the marker error itself is not considered. Since the error in markers produces more serious quality degradation than the DCT coefficients, the restart marker regulation is very important for mobile communications.

In this work, we present a progressive and standard-compatible solution to reinforce the wireless image transmission. Basing on the observation that separate scans have different error tolerance capabilities, we insert different numbers of restart markers in accordance with the JPEG standard into separate scans to isolate erroneous blocks. If errors occur in restart markers, the proposed regulation preprocessing approach, which allows look-ahead in a scan, can resist such severe error damage effectively. At last, the corresponding error concealment techniques are applied to the detected erroneous restart intervals to further improve the reconstructed image quality.

II. Resynchronization and Restart Marker Regulation

In JPEG, the erroneous compressed data before the next resynchronization point, i.e., the next restart marker, usually cannot be decoded correctly. Thus, the restart markers play an important role for the error detection and error recovery in error-prone environments. These two-byte long byte-aligned markers are inserted between entropy-coded data segments (ECS), ranging from one marker after every minimum coded unit (MCU) to one marker after an integer number of MCU's. For gray-level images, the size of a MCU is a single 8×8 block. For color images, the number of blocks in a MCU is determined by the chrominance sub-sampling factors.

To achieve good error robustness, it is necessary to frequently use restart markers to constrain the error propagation areas. Accordingly, there exists a tradeoff in choosing the frequency of restart markers. The fewer the restart markers are used, the broader the errors are propagated. However, frequent using of restart markers results in the substantial overhead in the bitrate. The probability of errors occurring in markers is also increased. A misinterpreted restart marker generally causes much more serious image degradation than the error within the ECS does. Consequently, we develop a restart marker regulation scheme functioning before decoding the bit streams. In the encoder, the eight unique restart markers in sequence from 0 to 7 (RSTn, $n = 0, 1, \cdots, 7$) are periodically inserted into the ECS. In the decoder, each scan of the compressed bit

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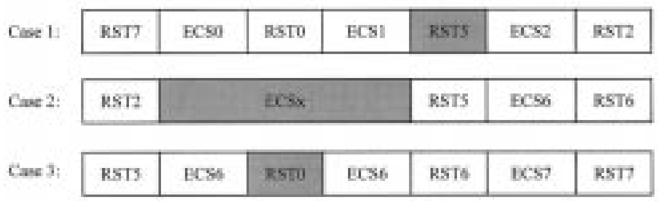
	RST0	RST1	RST6	RST3	RST4	RST5	RST7	RST0
Step 1:	C	E	E	E	C	E	E	C
Step 2:	C	C	E	E	C	C	E	C
Step 3:	C	C	E	C	C	C	E	C

(a)



(b)

Fig. 1. Examples of restart marker regulation: (a) Three steps of erroneous restart marker allocation, (b) three cases of erroneous restart marker rearrangement.

streams is preprocessed to search all restart markers before being decoded. Then the following three steps are executed to allocate the erroneous markers.

- *Step 1:* If the number of a restart marker is in the consecutive order with both neighbors, it is classified as a correct marker. Then, the rest of found markers are labeled as corrupt ones.
- *Step 2:*If the preceding marker of a defined erroneous marker is correct and consecutive, the erroneous marker is redefined as a correct one.
- *Step 3:* If the subsequent marker of a defined erroneous marker is correct and consecutive, but the preceding marker is erroneous, the erroneous marker is redefined as correct.

Fig. 1(a) illustrates the erroneous restart marker allocation. Three restart markers are labeled as correct (C) in Step 1, and the others are erroneous (E). In Step 2, restart markers RST1 and RST5 are redefined as correct. In Step 3, restart marker RST3 is redefined as correct at last.

After the erroneous marker allocation, the number of detected corrupt markers between two correct markers is set as N_{found}; the number of desired consecutive markers between two correct markers is N_{need}. Each segment with erroneous markers is classified as one of the following three cases and the corresponding rearrangement procedure is carried out.

- *Case 1:* Forced Marker Assignment ($N_{\text{found}} = N_{\text{need}}$). All erroneous markers are forcibly changed into the corresponding correct restart marker numbers.
- *Case 2:*Lost Marker Reconstruction ($N_{\text{found}} < N_{\text{need}}$). The lost restart markers are reconstructed by searching the erroneous restart intervals for the 2-byte patterns with the minimum Hamming distances to the correct markers.
- *Case 3:*Extra Marker Erasure ($N_{\text{found}} > N_{\text{need}}$). Two possibilities are taken into considerations. If $N_{\text{need}} < N_{\text{found}} \leq N_{\text{need}}+4$, the markers with the minimum Hamming distances to the desired ones are forcibly changed into the correct ones. Then the rest are erased from the bit streams. If $N_{\text{found}} > N_{\text{need}} + 4$, one additional period of restart markers, i.e., 8, should be added to N_{need} and this rearrangement procedure beginning from the comparison between N_{found} and N_{need} is repeated again.

TABLE I
SIMULATION RESULTS FOR TRANSMISSIONS OVER DECT CHANNELS: (a) SCAN PROFILE (b) RESTART MARKER ERROR PROBABILITIES AND OCCURRENCE RATIOS (c) AVERAGE PSNR VALUES (dB)

Spectral Selection	1	2	3	4
Ss-Se	0-0	1-4	5-11	12-63
Ah-Al	0-0	0-0	0-0	0-0
Encoded bytes	3398	8875	9936	9704
Encoded bytes with restart markers (Restart interval, Ri)	6195 (4)	10163 (8)	10575 (16)	10025 (32)
PSNR (dB)	25.18	28.67	32.27	37.74

Es/No (dB)	26	28	30
Error probability of restart markers	.00398	.00253	.00165
Occurrence ratio of Case 1	26.2%	24.4%	26.4%
Occurrence ratio of Case 2	66.4%	67.9%	66.2%
Occurrence ratio of Case 3	7.4%	7.6%	7.3%

Method \ Es/No (dB)	26	28	30
IJG	28.41	30.78	32.79
RMR	31.68	33.31	34.69
RMR + EC	33.94	35.00	35.99

Fig. 1(b) offers examples of the erroneous restart marker rearrangement. In Case 1 ($N_{\text{found}} = N_{\text{need}} = 1$), marker RST5 should be changed to marker RST1. In Case 2 ($N_{\text{found}} = 0, N_{\text{need}} = 2$), the lost markers, RST3 and RST4, are searched in the entropy-coded data segment x (ECSx) by comparing the 2-byte patterns with the minimum Hamming distances to RST3 and RST4, respectively. In Case 3 ($N_{\text{found}} = 1$, $N_{\text{need}} = 0$), marker RST0 should be erased.

III. Error Concealment

After the regulation process of restart markers, each restart interval is identified. Nevertheless, errors may still exist in the ECS. A corrupted restart interval can be detected by the decoder via three events: premature end of data segment, extra codewords before next marker, and invalid variable length codes [6]. Accordingly, the error concealment should be performed on the MCU's in the corrupted restart intervals to improve the image quality.

For spectral selection, errors will propagate in certain bands of coefficients in the corrupted restart interval. The error concealment is carried out for each erroneous band by using the average coefficients of the same band from both the upper and bottom MCU's. For successive approximation, erroneous MCU's are replaced by the estimates from the point transformed coefficients of the upper and bottom MCU's. Note that only the first scans of DC and AC coefficients need to perform the error concealment for the sufficiently good recovery of the reconstructed image quality. Errors existing in the scans of AC refinements are ignored. Both the proposed resynchronization regulation and error concealment techniques, which only need simple arithmetic operations, show very low complexity for real-time implementation.

(a)

(b)

ca)

Fig. 2. Performances of various resynchronization approaches over a correlated Rayleigh fading model in DECT system: (a) IJG default method (28.95 dB) (b) RMR method (33.43 dB) (c) RMR+EC method (35.23 dB).

IV. Simulation Results

The gray-level image *Lenna* (512×512) is tested in the simulations. That the headers of the image scans are correctly received is pre-assumed. Retransmission is within the consideration because of the relative small size of the header and the catastrophic effects of errors in the header. The DECT (Digital European Cordless Telecommunications) system over a correlated Rayleigh fading model at 14-km/h speed is used [9]. The simulation results for a four-scan spectral-selection progressive JPEG are shown in Table I, which lists the scan profile, restart marker error probabilities and occurrence ratios of the three cases, as well as the average PSNR values over 1000 iterations of simulations. It should be noted that, due to the use of DPCM coding, the first scan, i.e., DC coefficients, is the most essential to the visual quality but inherently is very susceptible to the channel disturbances. Therefore, restart markers are frequently added to the first scan and then decreased in the following scans, shown as the restart interval (Ri) in Table I(a). We observe that the restart marker regulation (RMR) achieves 1.9 to 3.3 dB PSNR gains over the IJG default method and a further improvement of 1.3 to 2.3 dB can be obtained by performing the error concealment (EC). Besides, the image quality improvement of the proposed scheme is more significant at higher error rates. The cost for preprocessing the RMR is only a buffer storing maximally one scan of the received image data and the corresponding delay. Fig. 2 shows an example of the same scan file with that of Table I simulated at Es / No $=$ 26 dB. Fig. 2(a) is the resultant image processed by the IJG strategy. It is found that most errors in the decoded images disappear in Fig. 2(b) through the RMR. A further image quality improvement can be efficiently achieved by the EC, shown in Fig. 2(c).

V. Conclusion

We have proposed a restart marker regulation technique with the error concealment for the progressive JPEG image compression over wireless channels. Although the proposed scheme does not guarantee to correct all errors in restart markers, and occasionally it may even bring errors by making wrong decisions, it is still able to correct most errors statistically and yield significant image quality improvements. In addition, this coding scheme, which complies with the standard, presents low complexity for real-time implementation.

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