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Image Fusion in the JPEG 2000 Domain

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Abstract— **This paper presents a novel approach to image fusion in the JPEG 2000 domain. In this scheme, compressed images are fused without the need for full decompression. The proposed method can be integrated with the existing JPEG 2000 tools. It offers several benefits: it avoids error propagation, allows for the development of error correction and protection mechanisms and reduces computational effort. This paper also presents a comparison with commonly used algorithms for image fusion and studies their performance in the presence of compression and transmission losses. The results show that the performance of the proposed method is superior to currently available techniques under noisy conditions.**

I. INTRODUCTION

Image fusion is increasingly being applied in areas such as medical imaging, remote sensing or military surveillance. Due to the characteristics of the communication channel, many of these applications demand highly compressed data combined with error resilient coding. In this respect, JPEG 2000 has many advantages over previous image coding standards [1], [2], [3], [4], [5].

This paper presents a new approach to image fusion, which exploits the characteristics of JPEG 2000 to perform image fusion in the compressed domain. A new utility function has been added to the reference software, Kakadu, in order to achieve this.

In our experiments, different wavelet bases have been considered for compression and fusion purposes: Cohen, Daubechies and Feauveau 9/7 irreversible transform (CDF I9/7) and the reversible spline 5/3 transform. The results are compared with three representative image fusion algorithms: Contrast Pyramid (CP), Discrete Wavelet Transform (DWT) and Dual Tree-Complex Wavelet Transform (DT-CWT).

The rest of this paper is organised as follows: Section II gives a brief overview of the JPEG 2000 standard. Section III introduces the idea of image fusion in the compressed domain. Section IV studies the influence of transmission losses on different fusion methods. Finally, conclusions are drawn in Section V.

II. JPEG 2000 COMPRESSION STANDARD

JPEG 2000 is a new coding standard, which fulfils requirements of progressive coding while providing error control mechanisms. JPEG 2000 [6] performs well at low bit-rates, with less distortion and better subjective quality ratings than previous standards [3]. Comparisons between different compression standards have shown that JPEG 2000 outperforms JPEG in computational complexity and subjective ratings tests [4], [5].

The encoding scheme consists of a forward wavelet transform, followed by quantization and bitplane entropy coding by the Embedded Block Coding with Optimal Truncation (EBCOT) algorithm. This coding and ordering technique is based on the concept of a scalable image compression algorithm introduced by Taubman [7]. The encoder is able to produce a fully embedded codestream, which is optimal in a rate-distortion sense. The decoder reconstructs the image by inverting the steps of the encoder.

```
for tiles
    open tile_1, open tile_2
    for components
        open component_1, open component_2
        for resolutions
            open resolution_1, open resolution_2
            for subbands
                open subbands_1, open subbands_2
                for code-blocks
                    open code-block_1, open code-block_2
                    fused-code-block = fuse(code-block_1, code-block_2)
                    close fused-code-block
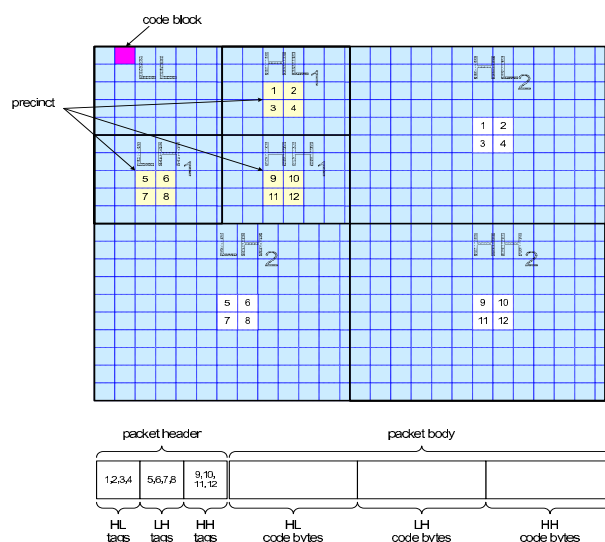```

TABLE I

PSEUDO-CODE FOR FUSION IN THE JPEG 2000 DOMAIN



Fig. 1.    JPEG 2000 partitions and packet structure.

(a) Input Image A
(focus on the right)

(b) Input Image B
(focus on the left)

(c) Corrupted Image A

(d) Corrupted Image B

(e) Fused image after full
decompression

(f) Fused image in JPEG 2000
domain

(g) Fused image in JPEG 2000 domain
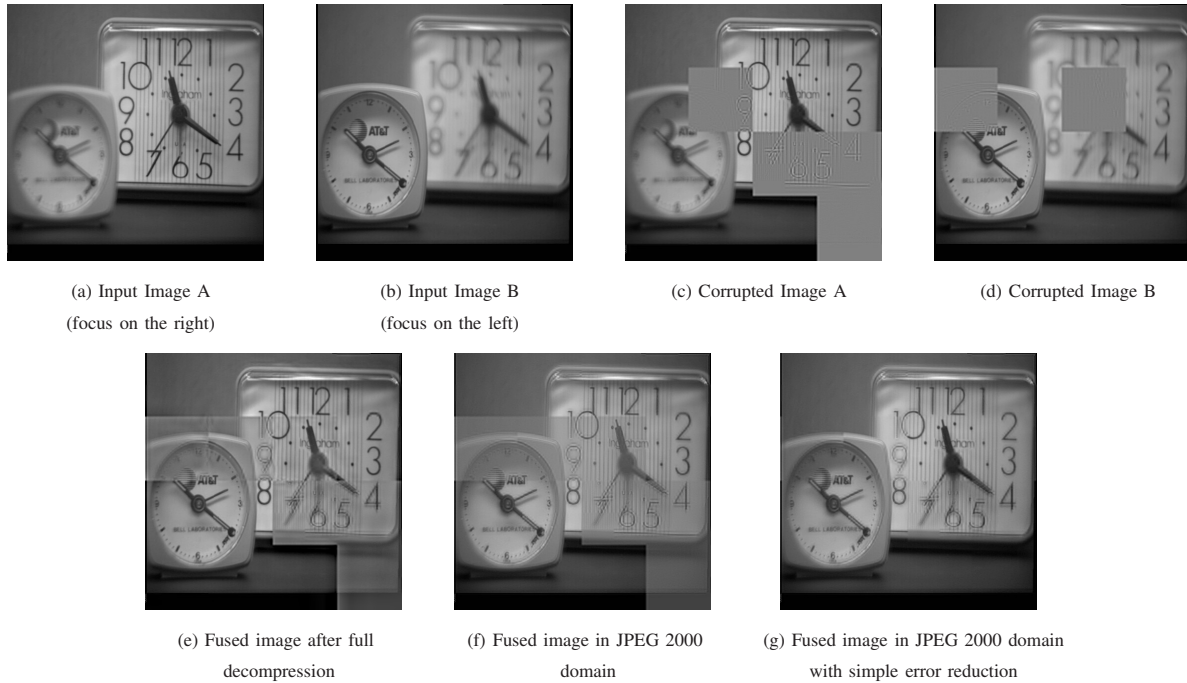with simple error reduction

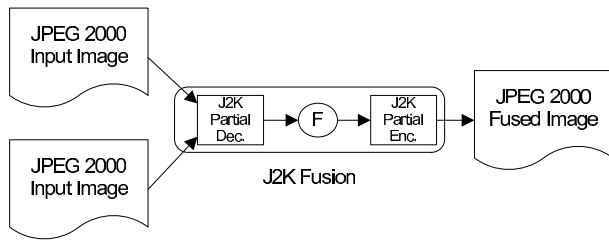Fig. 2.    Comparison of different fusion approaches
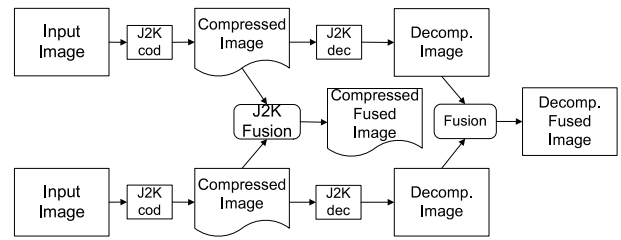


Fig. 3.    JPEG 2000 Fusion.



Fig. 4.    JPEG 2000 Fusion vs. standard fusion

Scalable compression refers to the generation of a bitstream which contains embedded subsets, each of which represents an efficient compression of the original image at a reduced resolution (spatial scalability) or increased distortion (SNR scalability).

Other advantages of this standard include the posibility of defining a Region of Interest (ROI), the capability of lossless and lossy compression and robustness to bit errors.

### III.  FUSION IN JPEG 2000 DOMAIN

Most image fusion algorithms are based on multi-resolution decompositions. These range from pyramid decomposition (Laplacian, Contrast, etc.) to more sophisticated wavelet based methods. (See [8] for a more comprehensive review).

The JPEG 2000 compression standard is based on the wavelet transform. JPEG 2000 Part 1 includes only two different wavelet kernels: the CDF I9/7 [9] and the reversible spline 5/3 transform. However, Part 2 supports reversible and irreversible transformations with a large class of wavelet kernels. It also provides the capability of defining customised kernels.

The approach presented here has been to perform image fusion by combining two, or more, different JPEG 2000 code-streams into a single stream, thus avoiding full decompression. This has been implemented via a new utility ('kdu_fuse') for the JPEG 2000 reference software Kakadu.

Table I depicts the pseudo-code for fusion in the compressed domain. Compressed images are partially decompressed in parallel, by first accessing the tiles one by one, followed by the different colour components. At this stage the internal data representation is as shown in Fig. 1. Each frequency resolution is then accessed starting from the lowest frequency band, which comprises a single subband, LL. In higher frequency bands, the subbands are accessed in the following sequence order HL, LH and HH. Note that up to this point, there is no significant extra computational effort.

Code-blocks are accessed by pairs (one from each image), decoded and de-quantized. The subband samples are then available to apply the appropriate fusion rule, creating a new set of samples that are then quantized and encoded to generate the target code-block.
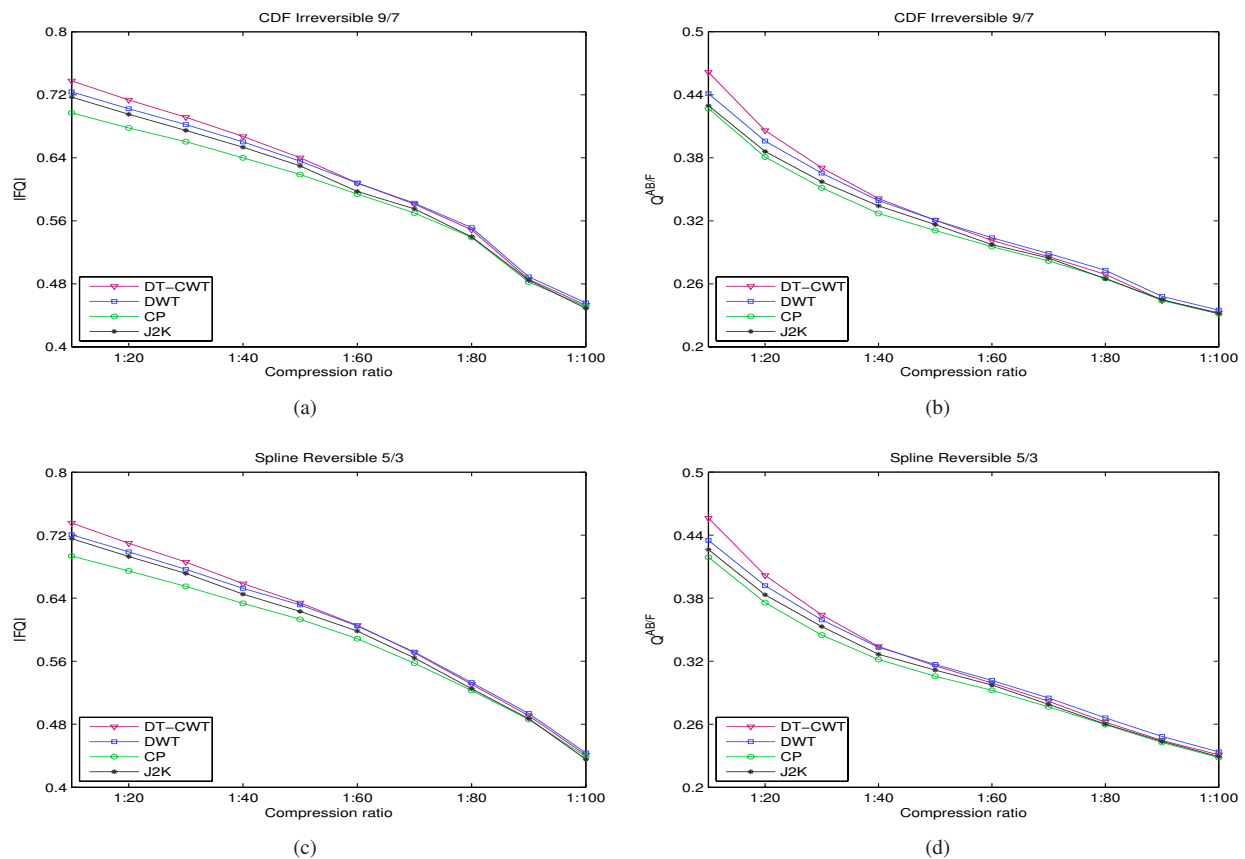
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Fig. 5.    Fused images quality evaluation

In this algorithm, it is assumed that both input images have identical compression parameters such as: wavelet kernel, tiling structure, decomposition levels, code-block size and ROI definition if any. Some parameters that could differ are: bit rate, quality layers or number of components (colour images can be fused with gray scale images).

The advantage of this new fusion approach, apart from the obvious computational effort reduction, is the possibility of including error protection and/or correction in the fusion process. A simple example is illustrated in Fig. 2, where two input images (Fig. 2(a), Fig. 2(b)) are affected by transmission losses (Fig. 2(c), Fig. 2(d)). Fig. 2(e) shows the result of fusing these images after decompression with the DT-CWT fusion method. Fig. 2(f) corresponds to the image obtained by fusion in the JPEG 2000 domain without any error correction. Finally, the best result is obtained with fusion in the JPEG 2000 incorporating a simple mechanism of error reduction (Fig. 2(g)).

Before assessing the performance of the fusion process in the presence of noise or losses, it is interesting to compare its quality with other 'more traditional' fusion methods under ideal conditions. Fig. 4 shows the procedure followed diagrammatically. A number of input images were compressed with different compression ratios. These images were then, either fused in the JPEG 2000 domain or decompressed and then fused with other widely used methods (CP, DT-CWT or DWT). Quality values for the fused images were

computed using Piella's metric: the Image Fusion Quality Index (IFQI)[10], and Petrovic's metric [11] (see [1] for a review on these metrics).

The images were compressed with the two wavelet transforms available in Part 1 of the standard: CDF I9/7 (Fig. 5(a-b)) and spline 5/3 reversible transformation (Fig. 5(c-d)). It can be observed that the metric values for these methods (CP, DWT and DT-CWT) do not differ significally from the JPEG 2000 domain fusion. DT-CWT is as expected the best method, but JPEG 2000 fusion provides similar quality. Regarding the wavelet kernel used for compression, CDF I9/7 appears to perform the best of the two.

## IV. INFLUENCE OF TRANSMISSION LOSSES

Wireless image transmission has been a very demanding feature in recent multimedia communications. However, a wireless environment is very prone to the fading leading to a high error rate channel. This condition, if not handled properly, may badly affect the transmitted image quality leading to a catastrophic degradation.

The main influences of noisy channels and congested networks on image transmission are bit-errors, block de-synchronisation, packet loss, packet delay, latency and jitter, and packet intrusion [12].

A number of mechanisms have been devised in the past for combating these transmission errors. These can be categorised into three groups [13]:
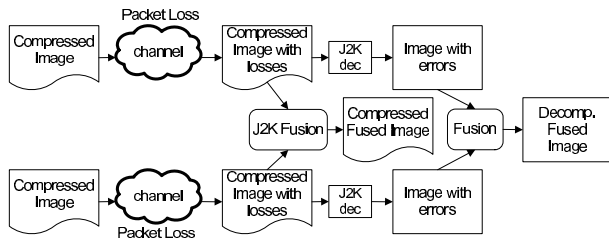
**349**

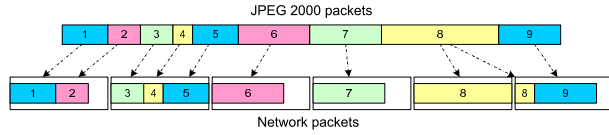Fig. 6. Effect of losses on image fusion evaluation system



Fig. 7. Packetisation of JPEG 2000 code-stream packets into network packets

- *Error Resilient Encoding*: In this approach, the encoder operates in such a way that the transmission errors on the coded stream will not affect the decoder operation and lead to unacceptable distortion in the reconstructed image.
- *Decoder Error Concealment*: in this approach, it is the decoder that estimates or predicts the information lost due to transmission errors.
- *Encoder and Decoder Interactive Error Control*: a feedback channel is set up from the decoder to the encoder so that the former can inform the latter about which part of the transmitted information is corrupted by errors, and the encoder can adjust its operation correspondingly to suppress the effect of such errors.

The following work will focus on the issue of packet loss. Packets may be lost due to bit errors in the address field, network congestion or buffer overflow. Several approaches have been suggested to overcome this problem. For example concealment (spatial or temporal reconstruction) can be used to minimise the degradation due to packet loss. This exploits the high correlation between the lost block and its neighbours [14], [15]. Another approach is layered coding. The basic idea is to separate information into the Most Significant Parts (MSP) and the Least Significant Parts (LSP) and allocated different transmission priorities [16], [17], [18]. In this way, only the LSP packets should be discarded in a congested network scenario.

However, all these methods rely on the hypothesis of a single data source. Image fusion applications, on the other hand, support multiple data sources and facilitate exploitation of their redundant information. This section focuses on the impact of packet losses on image fusion.

### A. Experimental Framework

Fig. 6 depicts a block diagram representation of the experiments performed to evaluate the performance of a fusion system where images are captured, compressed and then transmitted over a noisy channel. The received images are then fused in the JPEG 2000 domain, as described in



(a) Decompressed image



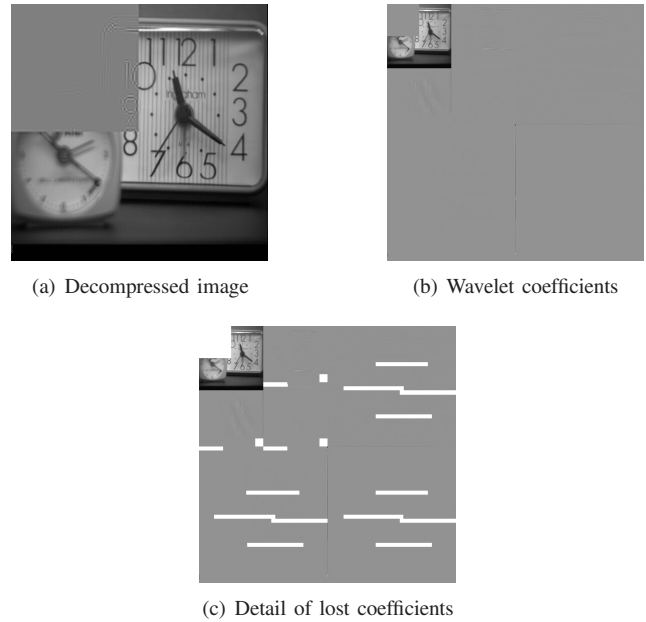(b) Wavelet coefficients



(c) Detail of lost coefficients

Fig. 8. Example of errors caused by packets being dropped

Section III, or decompressed first and then fused with any other fusion method.

In these experiments, the packet loss model used was based on a simple uniform distribution with three different network packet sizes (1024, 512 and 256 bytes) and three possible packet loss probabilities ($5\%$, $10\%$ and $20\%$). At this point, it is important to distinguish between network packets and packets from the JPEG 2000 code-stream. The latter are packetised into the former avoiding truncation when possible as shown in Fig. 7. Hence, when a network packet is dropped during transmission, one or more code-stream packets will be lost.

None of the error resilient or concealment mechanisms described above have been used to protect the data in these experiments. However, the reference JPEG 2000 decoder (Kakadu) has some error resilience capabilities. By default (no resilience), if a packet is missing in the code-stream the decoder will return an error message and abort the decompression. On the other hand, when the resilience option is enabled, if information of any given codeblock is missing, the wavelet coefficients affected are switched to zero. Fig. 8 shows an example of an image affected by losses (Fig. 8(a)), the wavelet coefficients extracted by the decoder (Fig. 8(b)) and finally a detail of the coefficients that have been lost and therefore converted to zero (white boxes in Fig 8(c)). Note that zero is the mean value in JPEG 2000 data representation, since the dynamic range goes from $-0.5$ to $0.5$. Decompression is not possible when the main header or a tile header is lost, in these cases the decoder will abort the process.

The fusion rule applied for JPEG 2000 domain fusion is to average the values from the lowest frequency band and to select the maximum absolute value in the other bands. If a block is empty or missing in one of the input images, the
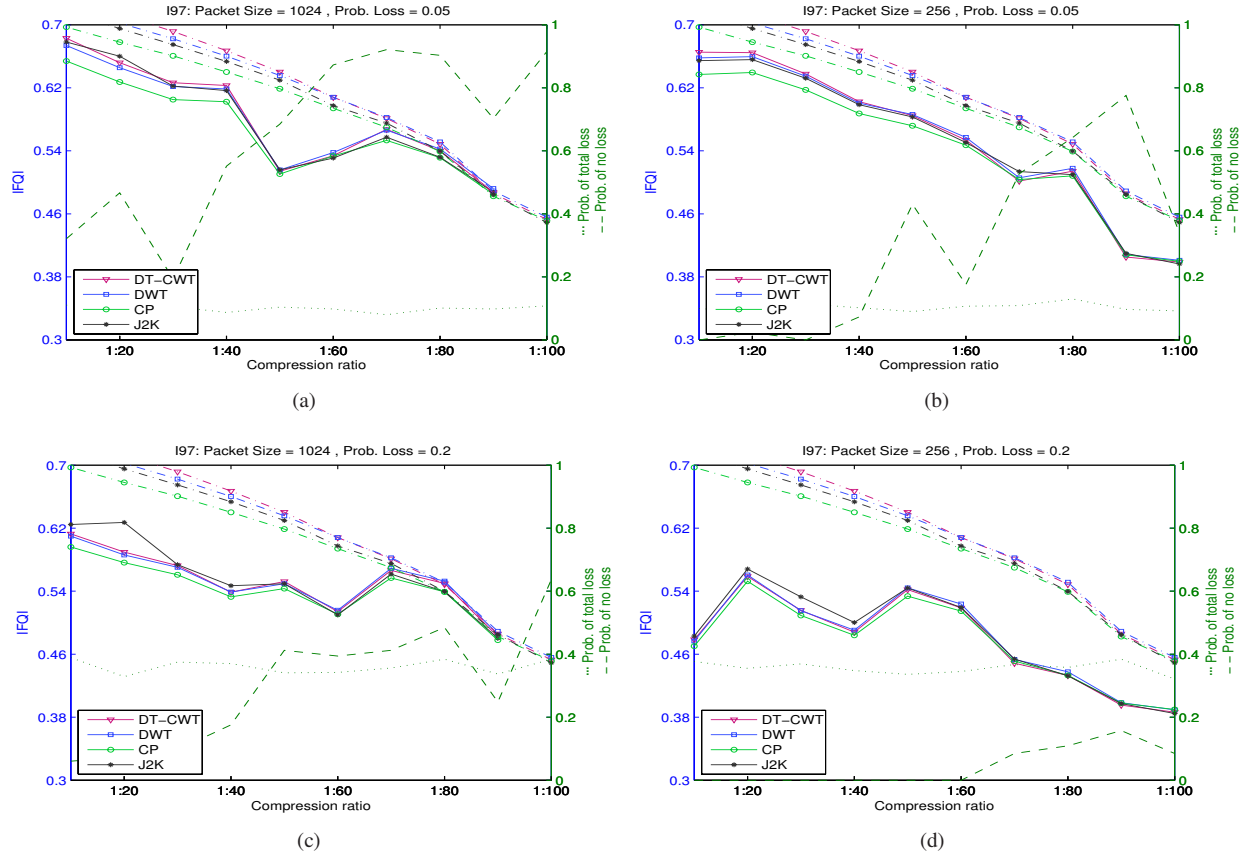
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Fig. 9. Transmission losses results: (a-b) $P_{packet\ loss} = 5\%$, (c-d) $P_{packet\ loss} = 20\%$

corresponding block from the other images will be copied into the fused image.

The other fusion methods tested (CP, DWT and DT-CWT) follow a similar fusion rule: averaging in the lowest frequency and maximum absolute value selection in the other bands. In these cases it is not possible to check whether a block is missing or empty. Therefore, if a packet is empty due to an error, this will inevitably lead to error propagation during decompression.

### B. Experiment Results

Piella's metric (IFQI) and Petrovic's metric ($Q^{AB/F}$) were used again to assess the influence of losses. Fig. 9 illustrates some of the results obtained with IFQI (solid lines), by averaging the values obtained from 8 different sets of images (infrared and visible), which were run 50 times each. It can be observed that, according to this metric, DT-CWT is the best method among the traditional ones. However, JPEG 2000 domain fusion provides similar quality and is sometimes better in the presence of losses, especially at low compression ratios. Regarding the wavelet kernel used for compression CDF I9/7 seemed to perform better than spline 5/3, confirming the results obtained in section III.

Fig. 9 also shows the influence of packet size for different probabilities of loss, 5% and 20%, measured with the IFQI and using CDF I9/7 as compression method. In each figure the top four curves represent the zero error condition for comparison. In the first case ($P_{packet\ loss} = 5\%$), it can be seen that the biggest packet size (1024 bytes) has better results at very high and low compression ratios, while the smallest packet size (256 bytes) has better results in the middle of the compression range. Table II summarises these results, and shows how JPEG 2000 fusion is the most robust method against losses and DT-CWT the most sensitive one.

For a $P_{packet\ loss} = 10\%$, a packet size of 1024 bytes is still the best solution for very low and high compression

|  | Packet size | $P_{packet\ loss}$ | | |
|---|---|---|---|---|
|  |  | 5% | 10% | 20% |
| DT-CWT | 256 | **− 6.12%** | **−8.92%** | **−14.22%** |
|  | 512 | −5.80% | −8.24% | −13.49% |
|  | 1024 | −5.06% | −6.82% | −8.57% |
| DWT | 256 | −5.88% | −8.56% | −13.71% |
|  | 512 | −5.61% | −7.99% | −13.07% |
|  | 1024 | −4.54% | −6.25% | −7.87% |
| CP | 256 | −5.09% | −7.38% | −12.00% |
|  | 512 | −4.96% | −7.28% | −12.15% |
|  | 1024 | **−3.99%** | **−5.59%** | −7.20% |
| JPEG 2000 | 256 | −5.38% | −7.71% | −12.69% |
|  | 512 | −4.66% | −6.87% | −11.32% |
|  | 1024 | **−4.03%** | **−5.62%** | **−6.78%** |

TABLE II
PERCENTAGE QUALITY LOSS (IFQI)

ratios, while in the rest of the range a packet size of 512 bytes seems to be the best option. Finally, for a $P_{packet\ loss} = 20\%$ (Fig. 9.(c-d)), the biggest packet size (1024 bytes) gives the best result in all the compression range.

These plots also present information about the probability of no loss ($P_{no\ loss}$, dashed line) and the probability of total loss ($P_{total\ loss}$, dotted line). These two measures could also be computed theoretically. The probability of total loss is the probability of losing the packets containing the header for one or both input images. Given the size of network packet used in these experiments, it can be assumed that the header will fit in a single packet. Therefore the probability of total loss is simply the probability of packet loss ($P_{packet\ loss}$) multiplied by two, since there are two input images:

$$P_{total\ loss} = 2 \times P_{packet\ loss} \qquad (1)$$

In a similar way, the probability of no loss is equal to the probability of receiving all the packets. If an image fits in $n$ network packets, then the probability of no loss for a single image $a$ will be:

$$P^a_{no\ loss} = (1 - P_{packet\ loss})^n \qquad (2)$$

and for two images:

$$P^{ab}_{no\ loss} = P^a_{no\ loss} \times P^b_{no\ loss} = (1 - P_{packet\ loss})^{n+m} \quad (3)$$

where $m$ is the number of packets needed for image $b$.

These equations confirm the data obtained empirically, which suggest that the probability of total loss is, in this case, independent of the network packet size. As mentioned before, this is true only if the size of the network packet is bigger than the size of the code-stream header (In these experiments, the size of the header was 222 bytes). On the other hand, the probability of no loss decreases with the size of the network packet as expected. However, the impact of a packet lost is obviously greater with bigger packet sizes. This is a trade-off that would require further study.

## V. CONCLUSIONS

This paper has presented a novel approach to image fusion in the JPEG 2000 domain. It compared commonly used algorithms for image fusion and studied their performance in the presence of compression and transmission losses.

The results show that the quality of JPEG2000 domain fusion is comparable to that of the standard methods, while considerably reducing the computational load. The performance of this new method has been found to be more robust to transmission losses than others. Furthermore, it offers higher possibilities of including error protection and concealment mechanisms.

Future work should include a study on the effects of loss under realistic network conditions. This research could also benefit from the study of current techniques for error protection and concealment and their application to JPEG

2000 compression data. More sophisticated image fusion rules could also be implemented in this standard, to improve robustness against transmission errors.

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