Modified Data Aggregation for Aerial ViSAR Sensor Networks in Transform Domain

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Abstract – In this paper, some developments of a new data hiding technique entitled interpolation-based reversible watermarking with greedy weights quartered interpolator (IBRW-GWQI) for data aggregation in video synthetic aperture radar (ViSAR) sensors are presented. In order to modify the basic data hiding technique, combinational forms based on decomposition transforms are used. Our results show that wavelet-based combination is the best approach to increase the embedding capacity in ViSAR networks.

Keywords: Interpolation-Based Reversible Watermarking with Greedy Weights Quartered Interpolator (IBRW-GWQI), Video Synthetic Aperture Radar (ViSAR), Wavelet, Discrete Cosine Transform, Histogram Shifting.

1 Introduction

Video synthetic aperture radar (ViSAR) is a new imaging mode of SAR to generate video sequences [1]-[2]. ViSAR is currently used for aerial remote sensing imaging with air-borne radar platforms. Despite conventional SAR sensors for capturing still images, communication data rate needed for ViSAR sensors is extremely more of which the current implemented systems mostly do not send their acquired data through wireless communication links. In fact, they have to store the data into memory and after landing, data is transferred physically to remote sensing surveillance centers to be analyzed. This shortfall is caused by two reasons, at first, frame formation process (like SAR image formation) is a relatively complex and time-consuming procedure. So, once the imaging system in ViSAR mode has to generate for example 16-24 frames per second, this issue would be a big challenge. Researchers who are working on ViSAR imaging techniques have a substantial focus on this point that computational complexity must be reduced alongside improving the frame acquisition process. In addition, using powerful computers, high-performance hardware implementation (instead of software-based processing or middleware) and benefits of parallel programming can speed up the formation process. The second issue can be noted is to have a large data size for video frames (including processed frames from raw data and other related data for control, management, etc.) that should be compressed, aggregated or integrated to be transferable before wireless transmission on a low-bandwidth link. Otherwise, we have to use the ViSAR technology just for non-real-time applications whereas the main idea behind ViSAR is to apply it for real-time monitoring and surveillance in remote sensing, smart cities, civil and military applications all the time and all weather. For example, natural hazards and traffic control even in dark night without any light source. Here, we don't work on efficient image/frame formation because it is a problem for signal processing experts to process raw data of radar sensing. Instead, we try to aggregate relevant administrative data and embed it into the video frames considering specific features of SAR videos. This can reduce the data size considerably and is indeed a process like compression.

Therefore, in order for ViSAR data to be communicated between two aerial radar platforms or an air-borne imaging radar and a ground control station (they can be consumed a ViSAR sensor network), we should use such compression or aggregation techniques to reduce remote sensing data size. In details, remote sensing data always includes some payload information about geographic systems, control data and so on, in addition to the main images and videos. Because of the low-bandwidth in radar communication systems, there is no alternative except to apply lossy/lossless data aggregation techniques to integrate the payloads and radar data (raw data or processed videos). On the other hand, sending compressed raw data is difficult and not sufficiently effective for real-time systems, so our preference is to convert raw data into formed video frames and then to compress and transmit the frames along with some payloads aggregated in them. As a consequence, the main aim of this research is ViSAR payload communication through data hiding-based aggregation. For integrating a general bit-stream data and video frames, a recently proposed reversible watermarking scheme is selected as base-line to embed bit stream into ViSAR frames. Although the selected basic method is really powerful for quasi-sparse image data like ViSAR frames, however, we wish to improve its embedding capacity while keeping the final imaging quality as much as possible. This technique is named interpolation-based reversible watermarking with greedy weights quartered interpolator (IBRW-GWQI) [3] and does watermarking based on an...
interpolator and error histogram computation [4]-[5]. We combine it with some transforms to change error histogram in order to find more suitable places in the frames to add bits. The proposed technique can be used for lossless payload aggregation or even (low-rate) near-lossless video coding in ViSAR sensors. This paper is organized as follows. The 2nd section presents the proposed approach, the 3rd section is about simulation results and the 4th section is conclusions.

2 Proposed Method

In order to extend the IBRW-GWQI algorithm, we use three frequency domain/multi-resolution decomposition transforms to change the error image histogram in the basic algorithm. One of the most popular ways to modify interpolation-based reversible watermarking (IBRW) techniques is to use a better interpolator or histogram modification through histogram shifting, histogram adjustment, etc. As IBRW-GWQI is a new version of these techniques that uses a novel interpolator along side a histogram modification process [3], we wish to combine this method with another process based on fast Fourier transform (FFT), discrete cosine transform (DCT) and discrete wavelet transform (DWT) to improve its performance. In this regard, we use the magnitude information of FFT as an image to embed data using IBRW-GWQI, and name it FFT-based IBRW-GWQI. Another way, is to use standard DCT with patch size of 8×8 similarly to make another combinational approach entitled DCT-based IBRW-GWQI. Our experiments show medium-sized patches are more effective, so 8×8 has been selected. And the last approach is DWT-based IBRW-GWQI which uses a discrete Haar wavelet in 1-level to make a transformed image like other transforms. If a transform is able to create a quasi-sparse image with less zero pixels, it is probably able to improve IBRW-GWQI in ViSAR frames. As we know, the mentioned transforms can be invertible generally, but in use of them to make transformed images, we have to scale and quantize the coefficients matrix, so after re-scaling, a loss may be seen because of the quantization. However this loss does not affect the watermark/embedded data, but the final data hiding approach might be non-reversible. Among these watermarking techniques, only near-lossless approaches will be acceptable. Particularly, because FFT uses complex values, removing all the phases makes it highly lossy, so this approach cannot be acceptable in general form. In the next section, we see the results and will discuss about the superiority of all the proposed versions of IBRW-GWQI.

3 Results and Discussion

These are two 440×440 sample ViSAR frames for this paper, as seen in Fig. 1. The ViSAR frames are very low energy with a histogram near to zero. So, these frames have a different behavior in comparison to ordinary images. They may be according to Markov random field (MRF) neighborhood system, and with some textural features [7]-[9]. We compare all three proposed approaches to the basic IBRW-GWQI algorithm and all results are given in Tables 1 and 2, for frame 1 and frame 2 (in Fig. 1), respectively. The quality assessment metrics of PSNR, SSIM and EPI [2]-[3], [6] are used. EPI is applied to see how embedding process affects the frames’ edges. Capacity is the main factor which we aim to increase it. All running times are presented to find out more things about computational complexity of methods.

The simulation results clearly show FFT-based approach has recorded the weakest results compared to the base-line method, so this can be the second reason to not consider it as a good approach (the first reason was a huge loss in FFT). The DCT-based approach can be notable for frame 1 compared to the base-line, but is not winner for frame 2. The best performance belongs to the DWT-based combination which outperforms all other combinational approaches and also the base-line method in terms of capacity. Its PSNR is better than the base-line, its SSIM and EPI is very close to the base-line method and so this 3rd approach is the best case. It is noticeable that all combinational methods are more complex than the base-line because two image transformation steps (direct + inverse) should be done in them, in addition more time is needed to find suitable places for injecting bits because their histograms are possibly more complex. However, this more execution time of DWT-based IBRW-GWQI is a cost for having better performance. Another cost is a little loss in combinational approaches which would be acceptable and optimized in most of real-world applications [10]-[11].

<table>
<thead>
<tr>
<th>Data Hiding Methods</th>
<th>Payload Capacity (bit)</th>
<th>PSNR (dB)</th>
<th>SSIM</th>
<th>EPI</th>
<th>Time (s)*</th>
</tr>
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<tbody>
<tr>
<td>FFT-based IBRW-GWQI</td>
<td>6172</td>
<td>48.41</td>
<td>0.9998</td>
<td>1.02</td>
<td>13.61</td>
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<td>DCT-based IBRW-GWQI</td>
<td>79854</td>
<td>51.06</td>
<td>0.9994</td>
<td>1.04</td>
<td>12.16</td>
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<td>DWT-based IBRW-GWQI</td>
<td>92591</td>
<td>49.93</td>
<td>0.9998</td>
<td>1.11</td>
<td>13.37</td>
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<tr>
<td>IBRW-GWQI [3]</td>
<td>59791</td>
<td>48.86</td>
<td>0.9982</td>
<td>1.11</td>
<td>11.87</td>
</tr>
</tbody>
</table>

* Excluding the time elapsed for image transformation. All methods have been simulated by the same hardware.

4 Conclusions

This paper presented some novel extensions of IBRW-GWQI algorithm for ViSAR data. Among the proposed structures, DWT-based approach is the best case which can be widely used in ViSAR sensor networks.
Figure 1. Data-set used.
(Data has been provided by Sandia National Laboratories)

Table 2. Results for ViSAR frame 2.

<table>
<thead>
<tr>
<th>Data Hiding Methods</th>
<th>Payload Capacity (bit)</th>
<th>PSNR (dB)</th>
<th>SSIM</th>
<th>EPI</th>
<th>Time (s)*</th>
</tr>
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<td>51.22</td>
<td>0.9991</td>
<td>1.04</td>
<td>11.23</td>
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<td>DWT-based IBRW-GWQI</td>
<td>117466</td>
<td><strong>50.10</strong></td>
<td>0.9995</td>
<td>1.17</td>
<td>13.47</td>
</tr>
<tr>
<td>IBRW-GWQI [3]</td>
<td>107676</td>
<td>49.54</td>
<td>0.9961</td>
<td>1.17</td>
<td>10.89</td>
</tr>
</tbody>
</table>

* Excluding the time elapsed for image transformation. All methods have been simulated by the same hardware.

References


