Protection and Authentication of Dubai Digital Elevation Model using Hybrid Watermarking Technique

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***Abstract*—Nowadays, with the availability of digital images and models at no cost on the World Wide Web, the need to provide copyright protection of multimedia data arises. Hence, digital watermarking products have been in high demand. Digital watermarking essentially embeds information into data in such a way that data usage is not affected, and it simultaneously protects and authenticates the data. This research paper deals with the development and evaluation of a watermarking technique for protection and authentication of Dubai Digital Elevation Model (DEM) provided by United States Geological Survey (USGS). The technique uses a hybrid combination of Discrete Cosine Transform (DCT) and Discrete Wavelet Transform (DWT), and it is implemented for the protection of DEM by embedding the ownership information in hybrid DCT-DWT domain and for checking the integrity of the elevation model by embedding hash-key information in the spatial domain. The proposed watermarking technique causes minimal distortion to the DEM and the performance is assessed by using Peak Singal-to-Noise Ratio (PSNR), Wavelet Signal-to-Noise Ratio (WSNR), and Structural Similarity Index Measurement (SSIM). The results show promising performance with strong robustness of watermark information ownership for many intentional and non-intentional attacks, in addition to precise detection of localized modified areas on tampered DEM.**

***Index Terms*—Digital Elevation Model, Digital Watermarking, Discrete Cosine Transform, Discrete Wavelet Transform, Hash Function**

I. Introduction

Digital Elevation Model (DEM) is one typical type of Digital Terrain Model (DTM). These models are a gridded digital representation of the terrain, where each pixel value corresponds to an elevation above a datum [1]. DEM data is an important part of the geospatial data infrastructure, as it imposes a vital role for many scientific researches and applications [2], [3]. Hence, it is essential to protect DEM data against illegal data usage [4]. Digital watermarking is the process of undetectable modifying of image data to embed watermark information either in the space domain or the transform domain [5]–[9]. Many research papers have studied and discussed copyright protection and integrity authentication of DEM data using digital watermarking. For example, Zhou et al. [10] presented a zero watermarking algorithm based on the edge length characteristics for the Triangulated Irregular Network (TIN) DEM data. The authors only use TIN DEM data to construct the watermark from the characteristics of the edge length and register it in the third-party Intellectual Property Rights (IPR) repository instead of being embedded in the TIN DEM data. Thus, the data quality is maintained to the greatest extent and there is no degradation to the TIN DEM data. Some researchers focus on digital watermarking using frequency domain analysis. In [11], the authors derived an adaptive watermarking method based on Discrete Cosine Transform (DCT) to protect the copyright of DEM data. The proposed methodology provides near-lossless DEM and the watermarking embedding strength can be decided automatically by the quality demands of the slope and the aspect. The proposed watermarking model is robust against various JPEG compression and cropping attacks. Another example of using frequency domain analysis is presented in [12], where the authors proposed a digital watermarking technique using the stationary wavelet transform algorithm to embed the watermark within a DEM and extract the watermark from the watermarked DEM image. Depending on the characteristics of a DEM, the selection of the ideal position for embedding the watermark is chosen where the DEM's slope is relatively gentle. The embedding intensity is important to the precision of the data and the robustness of the watermark. The selection of the embedding intensity can be modeled as an optimization problem. The optimization model was used to optimize the embedding intensity, of which the objective function can be defined as the similarity between the original watermark and the extracted watermark. The model is then resolved with ant colony optimization algorithm to guarantee the precision of DEM data and watermarking robustness. The performance of the algorithm is tested and the results show that the distortion in DEM data is less than 5% and the distortion of the image is indistinguishable by human eyesight. In [13], the researchers developed another technique for constructing an enhanced protection model of DEM data by combining fragile digital watermarking with robust digital watermarking in file filter encryption driver. Fragile watermarking is very sensitive and it is designed to detect every possible change in the data to verify DEM data integrity, while the robust one's

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used for the purpose of ownership protection and identifying whether the data files are protected files or not. The proposed technique has shown strong abilities in protecting the integrity of DEM files and it is robust against various attacks. A new lossless watermarking technique has been presented in [14] for protecting the DEM data using the directional wavelet and generalized histogram shift. This approach can be used to authenticate the DEM data, as it is safe, difficult to detected, and it can restore DEM data without any loss. Luo et al. [15] proposed a visible 3-D watermarking technique to protect DEM data. The watermark is embedded by modifying the generalized histogram of the DEM data and the original data can be restored easily without any loss. The proposed methodology shows satisfactory results and can effectively protect the copyright of DEM data. To ensure the copyright protection and the integrity of satellite imagery, several studies [16], [17] discussed using the secure hash algorithm (SHA-512) to verify authenticity of the image and precisely locating the tampered area. The main contribution of this research is developing a new hybrid DCT with Discrete Wavelet Transform (DWT) watermarking technique for embedding QR code watermark information and SHA-512 hash-key authentication information into DEM. The new watermarking algorithm has been successfully tested on DEM image for Dubai city area and the invisible distortions were assessed based on SSIM, PSNR and WSNR. The SHA-512 hash-key watermarking is highly sensitive to small modifications to the DEM and it is capable of verifying the authenticity of the DEM and precisely locating the tampered area. Consequently, the hybrid DWT and DCT watermarked QR code is robust against many intentional and non-intentional attacks. The remainder of this paper is organized as follows. Section II describes the study area. Section III explains the methodology used, including watermarking technique, embedding authentication key, and QR code extraction and authenticity verification of Dubai DEM data. Section IV discusses the results obtained from the proposed methodology. Finally, Section V summarizes the paper and draws the future direction of this study.

II. Study Area

The area of interest in this study is Dubai area, as shown in Figure 1. Dubai is one of the seven emirates of the United Arab Emirates (UAE), located at 25.2697°N 55.3095°E, and covers an area of 4,110 km^2 at the southeast coast of the Arabian Gulf [18]. Shuttle Radar Topography Mission (STRM) DEM of spatial resolution 30m is used in this study. The DEM data is obtained from the United States Geological Survey (USGS) earth explorer [19].

III. Methodology

The following subsections explain the different components of the proposed watermarking algorithm.

A. QR Code and Authentication Key Embedding Algorithm

This algorithm consists of embedding both the watermark and authentication key in the DEM image, and it is described as follows:

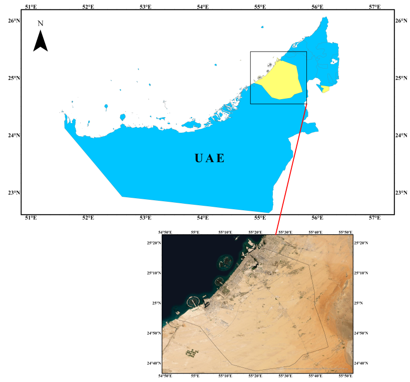


Fig. 1. Study area map.

- **Step 1:** Finding the DWT of Dubai DEM, which is performed by decomposing the DEM image into sub-images with different frequency components; Low-Low (LL), Low-High (LH), High-Low (HL), and High-High (HH). The first sub-band, LL, is a low resolution copy of the original image, and the remaining sub-bands, horizontal (HL), vertical (LH), and diagonal (HH), contain information about the details of the image. DWT is widely used in image compression and scaling tasks, and it is also adopted for watermarking and copyright protection purposes [20]. In this study, 2D-Daubechies 1 (db1) wavelet [21] is used. Only the first level of decomposition is considered.
- **Step 2:** Dividing LL sub-band into $N \times N$ sub-blocks and each sub-block is transformed by DCT.
- **Step 3:** Embedding QR Code watermark information into the selected DCT coefficients of sub-block.
- **Step 4:** Dividing the watermarked DEM into non-overlapping blocks, where some of them will be used to generate keys and others will be used to hide keys using random selection pattern algorithm [22]. Blocks used to generated keys will be referred to as Key Generate Blocks (KGBs). Blocks used to hide keys will be referred to as Key Hide Block (KHBs).
- **Step 5:** Embedding the generated hash-key from KGB into KHB in the Spatial domain.

B. QR Code Extraction and Authenticity Verification

The second part of the proposed methodology is used to retrieve the QR code from the watermarked DEM image and checking the authenticity of the DEM image. The steps of applying this algorithm are as follows:

- **Step 1:** Dividing the watermarked DEM into 100×100 non-overlapping KGBs and KHBs in order to check the authenticity of the DEM image.
- **Step 2:** Extracting the SHA-512 hash-key from the KHBs using Least Significant Bit (LSB) method and comparing it with the regenerated hash-key from the KGBs. Matching keys indicate that the key sub-block (100×100) is authentic and not tampered.

- **Step 3:** Extracting the QR code information from the watermarked DEM is performed by finding the DWT decomposition of the watermarked DEM using db1 wavelet.
- **Step 4:** Dividing LL sub-band into $N \times N$ sub-blocks and finding their DCT.
- **Step 5:** Extracting QR Code information from selected $N \times N$ DCT coefficients of the low frequency block LL components using the scaled odd/even extraction technique, as given in (1) [22].

$$a = Q\left(\frac{DEM_k(u,v)}{Scale}\right), \quad (1)$$

where Q indicates the quantization to the nearest integer value. $w(i,j)$=1 indicates that a has an odd values, and $w(i,j)$=0 indicates an even values, where w stands for the extracted QR code watermark information.

The workflow diagram that describes the encoding parts of the watermarking technique is shown in Figure 2. The decoding part is the inverse operation of the encoding one.

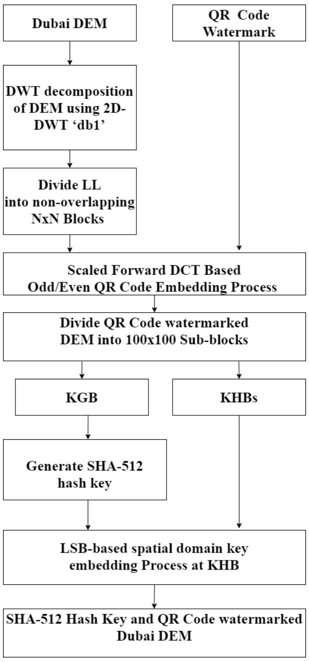


Fig. 2. Workflow of the hybrid DWT-DCT watermark encoding scheme.

C. DEM Slope Estimation

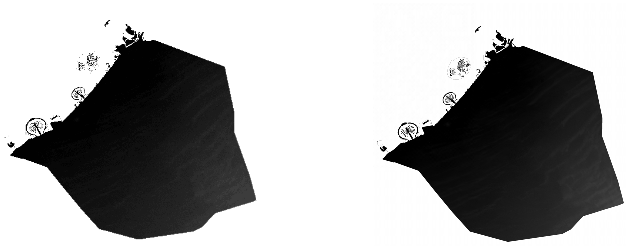
Slope is an essential DEM parameter that represents the rate of change in the elevation of each cell in DEM. The slope of DEM can be defined as a function of gradients in the X and Y directions, as given in (2) [23]:

$$Slope = \arctan\sqrt{(f_x)^2 + (f_y)^2}\ , \quad (2)$$

where f_x and f_y are the gradients in X and Y directions, respectively. There are different methods to determine f_x and f_y. The one used in this study is the four cell method introduced by Zevenbergen and Thorne [24]. The slope of the original Dubai DEM is $0.92°$. Any changes to the slope after watermarking will be observed in the results section as an indication of any distortions caused by the algorithm.

IV. Results and Discussion

The proposed new hybrid DWT-DCT watermarking algorithm is tested with DEM using QR Code and SHA-512 hash-key. A sample result is shown in Figure 3. Scaling factors 4, 8, 12, 16, 20, and 24 are used to control watermark strength with DCT block sizes 4, 6 and 8. SHA-512 hash function is used to generate a unique 512 bits hash-key. The distortions caused by the watermarking to the DEM are assessed by using Structural Similarity Index Measurement (SSIM), Peak Signal to Noise Ratio (PSNR), and Wavelet-based Signal-to-Noise Ratio (WSNR). A summary of the results of the hybrid DCT-DWT watermarked Dubai DEM is shown in Table I. The WSNR of the watermarked DEM remains greater than 60dB even at a high scaling factor of 24, where the QR Code watermark is invisible and not easy to detect. Similarly, PSNR and SSIM maintain high values that do not decrease below 53dB and 0.9967, respectively. Figure 4 illustrates the effect of increasing the scaling factor on PSNR and WSNR. It is worth mentioning that the slope of the DEM slightly increases with the increase of the scaling factor, but overall shows negligible changes that do not exceed $0.23°$ under all scaling factors, which is a testament to the resilience of the watermarking algorithm.



(a) Original DEM (b)Watermarked DEM

(c) QR code

Fig. 3. Watermarking the DEM (a) with the proposed hybrid DWT-DCT algorithm using QR code (c) shows no visual distortions in the resultant watermarked DEM (b).

V. Conclusion

This paper presented a hybrid DWT-DCT watermarking technique for embedding QR code watermark information and SHA-512 hash-key authentication information in the DEM image. The new watermarking algorithm was successfully tested on Dubai DEM and the invisible distortions caused were assessed by using SSIM, PSNR, WSNR, in addition to

TABLE I
PERFORMANCE EVALUATION OF THE WATERMARKED DEM WITH DIFFERENT SCALE FACTORS AND DCT BLOCK SIZES.

DCT Block	Scale	Evaluation Metric			ΔSlope(°)
		SSIM	PSNR(dB)	WSNR(dB)	
4	4	0.9991	60.42	72.19	0.12
	8	0.9989	58.90	67.55	0.15
	12	0.9986	57.72	66.12	0.16
	16	0.9986	57.53	64.97	0.17
	20	0.9980	55.55	61.95	0.19
	24	0.9975	54.54	61.10	0.21
6	4	0.9991	60.41	72.38	0.12
	8	0.9990	59.47	69.01	0.14
	12	0.9988	58.64	67.85	0.15
	16	0.9985	57.03	64.33	0.18
	20	0.9982	55.59	61.70	0.19
	24	0.9974	53.84	60.00	0.23
8	4	0.9992	60.67	73.31	0.11
	8	0.9987	58.75	68.39	0.15
	12	0.9985	58.06	66.89	0.15
	16	0.9979	56.27	64.32	0.19
	20	0.9976	55.64	63.69	0.19
	24	0.9967	54.13	61.34	0.23

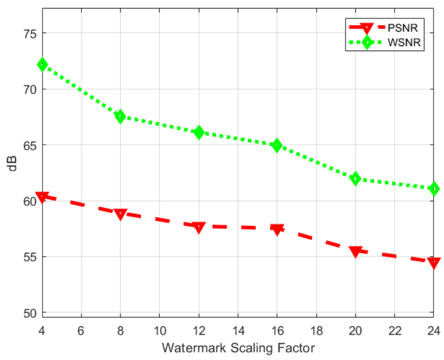


Fig. 4. Plot of PSNR and WSNR versus the watermark scaling factor for DCT block 4.

observing slope changes. The SHA-512 hash-key watermarking is very sensitive to modifications to the DEM and it is capable of verifying the authenticity of the DEM and precisely locating the tampered area. Furthermore, the proposed hybrid DWT-DCT watermarked QR code is robust against different intentional and non-intentional attacks.

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