European Journal of Molecular & Clinical Medicine
ISSN 2515-8260 Volume 7, Issue 4, 2020

An Analysis of Different Watermarking Schemes for Medical Image Authentication

Lalan Kumar, *Kamred Udham Singh
Graphic Era Hill University, Dehradun, India. Email: lalankumar100@gmail.com
Graphic Era Hill University, Dehradun, India. Email: kamredudhamsingh@gmail.com

Abstract:
These days enormous amounts of information are at almost everyone's disposal with a single click of a button, and that too on a hand-held device. Data can be present in various forms like still images and slides of pictures like a video or GIF, over various websites present on the Internet. Because of the excessive use of this data, it also becomes important to secure it as it can be duplicated, transformed, stolen, tampered or misused pretty easily. Recently, there has been a spike increase in the use of medical images in various E-health applications. In order to counter these potential threats, a number of watermarking techniques are being developed. A watermark is embedded in an image in the form of some pattern that can be used to authenticate the integrity of the image. This paper deals with the various algorithms that have been developed, proposed and utilized in recent years to solve the highly complex problems that have been faced while trying to secure the medical images from different kinds of threats. Alongside the survey of the techniques, this paper also goes through the concept of watermarking, properties of watermarking, various challenges faced by watermarking for medical images and the summary of different techniques for watermarking.

Keywords: Watermarking, Spread Spectrum, DCT, DWT, Least Significant Bit

1. Introduction:

In the present digital era, with the introduction of affordable hand-held devices and with the advancement of communication and modern technologies, it is easier than ever to make digital content. This content is then shared over the internet among different communities. In order to protect this content which is essentially intellectual property over the internet where anyone can access your data, various techniques are implemented e.g. steganography, cryptography and watermarking [1]. Watermarking is different from techniques like steganography as it doesn't use hidden messages without the knowledge and consent of the end-user to implement the security. Though there are some watermarking techniques that aren't perceivable by end-users. Digital watermarking can be unique to each copy or can be shared by a group of copies. Digital watermarking technique is employed to insert the information(watermark) into the image. The image here acts as a container for the information.
[3] Watermarking is preferred over similar encrypting/data hiding techniques. Watermarking is comparatively more robust for the medical images. Watermarking can be used to embed the hospital's logo, as well as the user's details into the medical image when needed [3] [10]. These other techniques can be used in combination with the watermarking technique in case of highly sensitive data to increase efficiency.

Watermarking can be used to trace illicit distributions. In the past, large scale copyright infringements were limited due to costs involved in large scale photocopying and redistribution physically but now it is easier than ever to do so using the modern technologies like the internet and hand-held devices which come with their own high-quality cameras. Hence, watermarking has become more important than ever to prevent copyright infringements.

2. Watermarking and Its Types:

Digital watermarking technique is employed to insert the information (watermark) into the image and image acts as a container for the information [3]. Watermarking is preferred over similar

encrypting/data hiding techniques. Digital watermarking is used for authentication, copyright protection, medical images, and other applications.

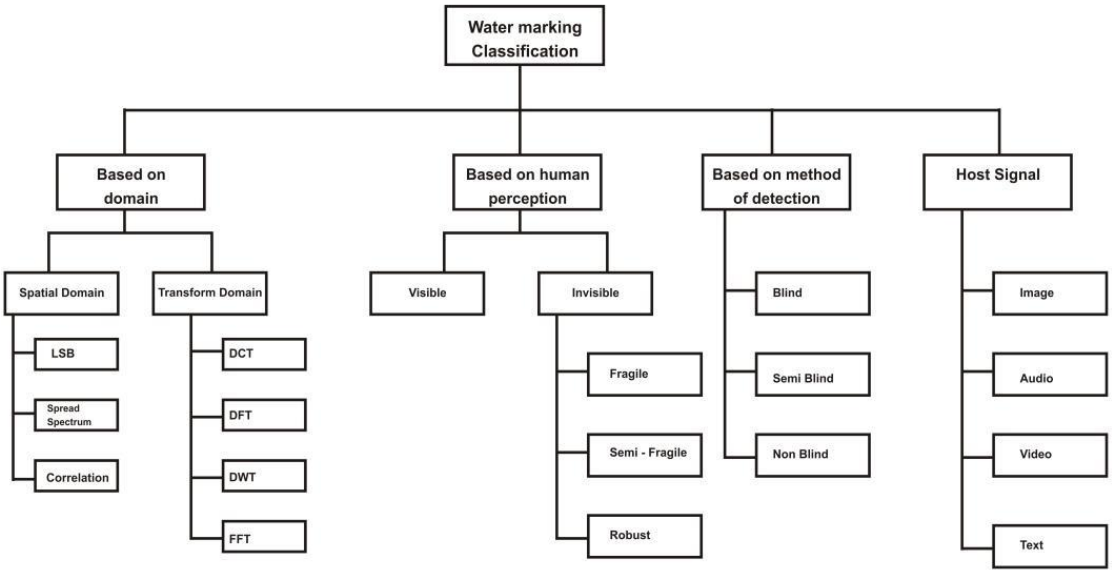

Fig1: Classification of Watermarking Technique [4]

2.1 Watermarking is of the following two types based on human perception.

2.1.1 Visible watermarking:

The watermarking technique that leads to visible watermarks on the content like stamping the name of the original creator on the work or embedding some kind of logo on the content which the end user can perceive is known as visible watermarking. E.g. television networks like CW and ABC, NETFLIX embed their logos on the corner of the images, videos that are the intellectual property of the network.

2.1.2 Invisible watermarking:

This technology aids the creator to embed patterns/ information in his/her work that cannot be seen but can be decrypted with the use of the needed software product. Using this technique cannot prevent the actual theft of the image but it can help prove that the stolen image originally belonged to the creator.

2.2 The watermarking techniques are classified into various types; taking **frequency domain into the consideration**, some of them are: [4]

2.2.1 Discrete Cosine Transform (DCT):

Discrete Cosine transform like Discrete Fourier Transform, converts a signal into elementary frequency components [5]. DCT is a robust watermarking technique compared to the other techniques that are prevalent (In spatial domain)

The watermark is inserted into the component with lower frequency to make the watermarking process and result more robust. As a side effect, it becomes harder to hide the watermark. Inserting a watermark in the higher frequency component on the other hand, results into a less robust but much easier to hide image [6].

2.2.2 Discrete Wavelet Transform (DWT):

Wavelets are discretely sampled when it comes to discrete wavelet transform. Unlike the Fourier transform it captures both the frequency as well as location information. The image is split into four bands namely LL, LH, HL and HH. The LL band is more perceptible to the human eye but still is more robust. The HH band offers good imperceptibility but at the same time is less robust [7].

2.3 Spatial domain techniques:

In the spatial domain techniques, the watermark is directly inserted in the host image by modifying the pixels as well as properties of the image. The combination with the host signal in the pixel domain is based upon the use of simple operations. Imperceptibility is maintained in this image. The Least Significant Bit (LSB) algorithm is the most employed algorithm in the spatial domain [8].

2.3.1 Least Significant Bit Algorithm:

Watermark information is inserted in Least significant bit of the pixel, least significant bit algorithm calculates significance of each bit of the image and thus differentiates between different areas of the image. Some areas of the image are busier where users focus more of their attention while some areas of the images are less busy which attract less attention from the users as well [8].

2.3.2 Correlation-based techniques:

In correlation-based watermarking techniques, the similarity between the altered image after the watermarking process and the pseudo-random code that must be inspected for the existence of the watermark is computed. The accuracy of this technique depends on the properties of the host image. A. Miyazaki presented [9] that a certain image can lead to errors while detecting watermarks. They have proposed an improved version of the embedding process for the watermark to avoid such scenarios from occurring. This improvement includes using a whitening filter while employing a non-linear programming algorithm.

3. Watermarking Review

Medical data can be watermarked for security by implementing the reversible watermarking technique, [11]. In this technique, a hash value based on the MD5 checksum of the image is extracted first and R-S vector is determined and then Huffman's algorithm is implemented to compress the R-S vector which is then used alongside the hash value and patient ID to create a watermark value, which can be inserted using AES encryption technique. This technique boasts a BER of 0, SNR value of 53 dB, MSE of 0.12 and a standard deviation of 0.02 respectively. Therefore, it can conclude that the inserted watermark doesn't alter the host picture a lot. The high PSNR value (57 dB) shows that the watermark is essentially imperceptible [11]. Nested Quantization Index Modulation (NQIM) based another technique has been proposed for watermarking of medical data. This technique can increase the capacity of the embedded watermark by taking the aid of its nested structure. It also increases the capability of exactly recreating the original image which makes it desirable for medical image watermarking [12]. A hybrid of DCT and DWT has also been proposed for watermarking of the medical data. In this method, the confidential EPR data is inserted into the NROI region and the less confidential data like the logo is inserted into the ROI region [13]. The watermark in the ECG data can be embedded into the low-frequency coefficients. This method has better robustness as well as SNR value [15]. A hybrid of Zero watermarking and reversible watermarking can also be used to watermark medical data [14]. The average PSNR value obtained from using this method is between 81 and 105. A block-based fragile watermarking technique has been proposed that can help in the detection of tampering in the host picture as well as help in recovering the host picture. This method can detect the modified blocks in the ROI as well as taking them back to their original state [16].

FDCT-based reversible watermarking is an algorithm that can be used to increase the transparency of the final image, it can fully recover the original image [17]. Pinned sine transform PST has been proposed to selectively authenticate information inside of the digital pictures. This method can detect even the minute modifications in the texture of a given image. This scheme is found to be very robust at the same time 98% detection rate for the modifications [18]. Image bit depth plane digital image watermarking is another technique that can help to increase data security. This method has the

capability of maintaining the originality of the image as long as it is on the internet [20]. Watermarking ROI in the spatial domain while Watermarking RONI with a DWT-SVD hybrid transform can meet the expectation as far as the security in medical watermarking goes [19]. This algorithm uses a series of fragile local watermarks at random to detect the tampered blocks. A combination of Daubechies and PSO based transformation [21] can be employed on the original image. Later DCT is used on the watermark that is going to be inserted in the original host image. This watermark can then be incorporated into the PSO based coefficients. Another algorithm proposed for medical data is a dynamic block-based watermark algorithm. After the decomposition of the wavelet, the algorithm analyzes the characteristics of the coefficients then the insertion of watermark is done in original image. The intensity of the insertion is found to be inversely proportional to the quality of the image as determined by the PSNR value [22]. This algorithm has also been found to be immune to the spatial alterations in the data. In another approach based on the Weber Excitation Deferential descriptor to created watermark to be inserted in host image by using linear interpolation [23].

A watermarking technique coupled with fuzzy matrix composition can be used to hide watermarks efficiently though author insert text watermark of up to 30KB [24]. A hybrid technique with digital signature approach and the fragile watermark can be used to yield pretty good results [25]. Combination of genetic algorithms with other existing schemes can increase the efficiency of the watermarking technique significantly [26]. A combination of permutation transform, and chaotic map can be used together to act as an efficient and fast watermarking technique [27]. A texture masking based perceptual model can adapt to each block and choose the watermarking strength for each block to increase the robustness of the watermarking technique. Flexibility as well as security of the image can be increased by adding multiple watermarks into the host image [28]. Various nature-based algorithms are based upon the behavior of various living algorithms to apply watermarking i.e. Firefly and modified firefly algorithm, bat algorithm, cuttlefish algorithm, seed-based algorithm and artificial bee colony algorithm etc. [29]. In [30], Multi-resolution Wavelet transform has been used alongside the Genetic algorithm to implement a efficient watermarking algorithm. Author [31] proposed, a hybrid technique based on Constraint Difference Expansions and Haar Wavelet to insert watermark in compressed PNG images where average PSNR value is 61.29, MSE value is 0.56 and a correlation value is 0.98. In [32] a combination of SVD and DWT has been proposed and author claim that the scheme is robust against the noise and geometric attack where average PSNR value is 48.645. Author [33] splits the wavelet coefficients into separate parts and inserts watermark for different energy levels in such a way that the watermark is unable to exceed the JND of each wavelet coefficient.

Most watermarking techniques have an optimization problem between robustness and imperceptibility. That is, either the method is good at detecting the alteration or it is good at preventing someone from tampering by distorting the image too much on tampering. Many techniques focus on encryption and decryption algorithms like RSA and MD5 checksum which are time-consuming. It becomes hard to manage images with these techniques while keeping security as well as compression in mind. Some methodologies implement hybrid techniques, but those techniques are too complex and increase the time complexity too image which makes them bad for the medical background. Many techniques are somewhat dependent on ROI and ROI regions-based methods, but they still cause noticeable distortions in RNOI regions. Authentication can heavily distort the original picture if the watermark is removed. Chaotic Fragile Watermarking can be employed to recover the original image as well as to authenticate it.

4. Performance measures

The imperceptibility of the scheme is established on six different DICOM images. The results are examined in terms of image quality metrics viz. PSNR, MSE, NC and Q. PSNR and NC are used as a measure for perceptual imperceptibility. For the watermark visibility estimation, PSNR is used which is defined as follows [6]**:**

$$MSE = \frac{1}{m * n}\sum_{i=0}^{m}\sum_{j=0}^{n}\left(A_{ij} - B_{ij}\right)^2$$

$$PSNR = 10 * \log_{10}\frac{(Max)^2}{\frac{1}{m * n}\sum_{i=0}^{m}\sum_{j=0}^{n}\left(A_{ij} - B_{ij}\right)^2}$$

$$SNR = 10 * log_{10}\frac{\sum_{i=1}^{n}\sum_{j=1}^{m}\left(A_{ij}\right)^2}{\sum_{i=1}^{n}\sum_{j=1}^{m}\left(A_{ij} - B_{ij}\right)^2}$$

To measure the quality of the watermarking scheme NC are used between the original image I *and* the watermarked image I^+, which is defined as follows.

$$NC = \frac{\sum_{c=1}^{3}\sum_{x=1}^{p}\sum_{y=1}^{q}\left(I(x,y,c) \times I^+(x,y,c)\right)}{\sqrt{\sum_{c=1}^{3}\sum_{x=1}^{p}\sum_{y=1}^{q}(I(x,y,c)^2)}\ \sqrt{\sum_{c=1}^{3}\sum_{x=1}^{p}\sum_{y=1}^{q}(I^+(x,y,c)^2)}}$$

Universal image quality index Q [1] is mathematically defined as follows.

$$Q = \frac{4\sigma_{xy}\bar{x}\bar{y}}{\left(\sigma_x^2 + \sigma_y^2\right)[(\bar{x})^2 + (\bar{y})^2]}$$

where,

$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$ and $\bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i$

$\sigma_x^2 = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2$ and

$$\sigma_y^2 = \frac{1}{N-1}\sum_{i=1}^{N}(y_i - \bar{y})^2$$

$$\sigma_{xy} = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})\,(y_i - \bar{y})$$

$x = \{x_i |\ i = 1,2,3 \ldots\ldots, N\}$ and $y = \{y_i |\ i = 1,2,3 \ldots\ldots, N\}$

X and Y are the original and the test image signals respectively.

Universal image quality index Q can also be defined as the product of three components:

$$Q = \frac{\sigma_{xy}}{\sigma_x\sigma_y} \times \frac{2\bar{x}\bar{y}}{(\bar{x})^2 + (\bar{y})^2} \times \frac{2\sigma_x\sigma_y}{\sigma_x^2 + \sigma_y^2}$$

Structural Similarity Matric Index (SSIM)

It is utilized to evaluate the likeness between the actual image and watermark image. SSIM value lies between -1 to +1, if SSIM=1, then, both actual image and watermark image are exactly similar.

$$\text{SSIM}(x, y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy}+c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2+c_2)}$$

Where μ_x : the average of actual image and μ_y: the average of watermarked image.
σ^2_x : the variance of original cover and σ^2_y : the variance of watermarked image with covariance σ_{xy}.
Where, $c_1$and c_2 are free parameters.

Table1 shows the performances comparison of different watermarking scheme based on performance majors' like PSNR, NC and SSIM. Figure3 and figure2 depict the that the highest PSNR achieved in scheme [34] and better SSIM achieved in [16] and [9] and the scheme [22] [12] [9] achieved the good NC.

Table1: PSNR, NC and SSIM comparison of different watermarking schemes

	PSNR	**NC**	SSIM	SNR
Ref. [22]	31.14	1		
Ref. [16]	50.26		0.9325	46.34
Ref. [12]	44.36	.9982		41.36
Ref. [34]	85.15	.9876		
Ref. [35]	51.35	0.9845		
Ref. [9]	37.84	0.9925	0.9476	
Ref. [36]	57.64	0.9872		54.25

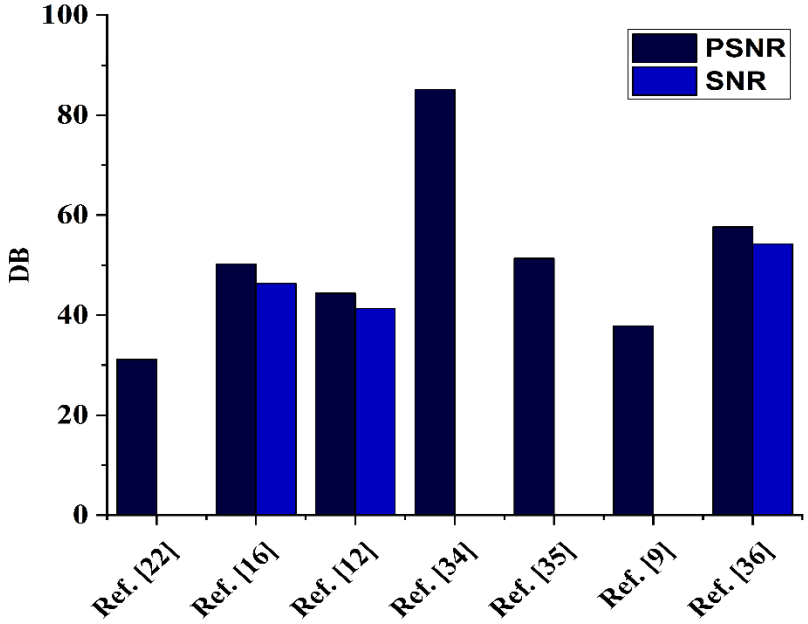

Figure2: PSNR and SNR comparison of different watermarking schemes

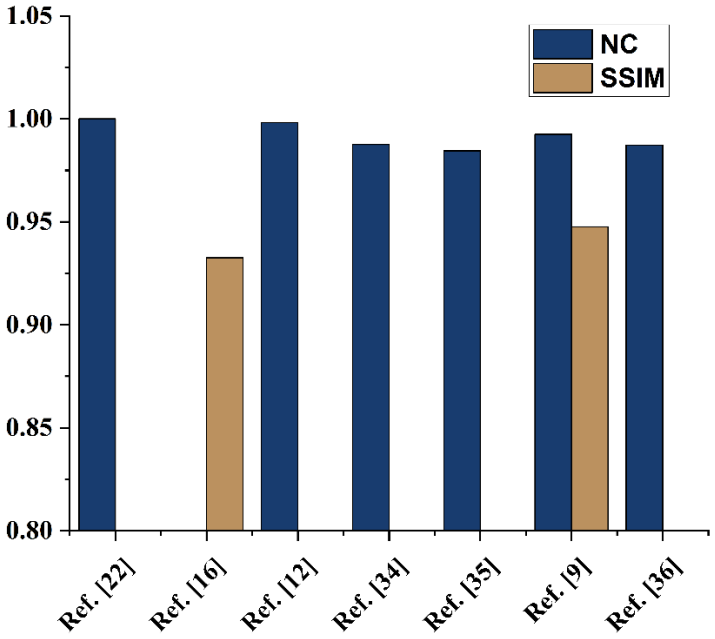

Figure3: NC and SSIM comparison of different watermarking schemes

5. Conclusion

In medical imaging, a lot of sensitive data is at stake. It has now become easier and easier to do piracy and steal medical images or confidential patient data now that everyone has access to digital computing devices and affordable internet. In this paper, various techniques that can be incorporated to apply watermarking on the medical images are discussed. Various research gaps that still need to be fulfilled to make watermarking in the medical field more efficient and robust. This survey can prove helpful for the researchers to decide the right combinations of techniques that they want to incorporate to meet their research goals.

6. References

[1] Riaz, Sidra, and Sang-Woong Lee. "Image authentication and restoration by multiple watermarking techniques with advance encryption standard in digital photography." 2013 15th International Conference on Advanced Communications Technology (ICACT). IEEE, 2013.

[2] Anand, Ashima, and Amit Kumar Singh. "Watermarking techniques for medical data authentication: a survey." Multimedia Tools and Applications (2020): 1-33.

[3] Singh, K. U., Singh, V. K., & Singhal, A. Color Image Watermarking Scheme Based on QR Factorization and DWT with Compatibility Analysis on Different Wavelet Filters. Journal of Advanced Research in Dynamical and Control Systems, 10(06) (2018), 1796-1811.

[4] Mohanty, S. P. (1999), "Digital Watermarking: A Tutorial Review", URL: www.csee.usf.edu/~smohanty/research/Reports/WMSurvey1999Mohanty.pdf

[5] Wu, Chuan-Fu, and Wen-Shyong Hsieh. "Digital watermarking using zerotree of DCT." IEEE Transactions on Consumer Electronics 46.1 (2000): 87-94.

[6] Hernandez, Juan R., Martin Amado, and Fernando Perez-Gonzalez. "DCT-domain watermarking techniques for still images: Detector performance analysis and a new structure." IEEE transactions on image processing 9.1 (2000): 55-68.

[7] Singh, Amit Kumar, et al., eds. Medical image watermarking: techniques and applications. Springer, 2017.

[8] Mehta, Bharti, and Simpe Rani. "Segmentation of Broken Characters of handwritten Gurmukhi Script." *International Journal of Engineering Sciences* 3 (2014): 95-105.

[9] Miyazaki, A. "An improved correlation-based watermarking method for images using a nonlinear programming algorithm." NSIP 2005. Abstracts. IEEE-Eurasip Nonlinear Signal and Image Processing, 2005.. IEEE, 2005.
[10] Singh, K. U., & Singhal, A. (2018). Channelized Noise Augmentation to Endorse DICOM Medical Image for Diagnosing. Journal of Advanced Research in Dynamical and Control Systems, 10(06), 2228-2247.
[11] Abd El-kader, Sherine M., and Basma M. Mohammad El-Basioni. "Precision farming solution in Egypt using the wireless sensor network technology." Egyptian Informatics Journal 14.3 (2013): 221-233.
[12] Ko, Lu-Ting, et al. "Nested quantization index modulation for reversible watermarking and its application to healthcare information management systems." Computational and mathematical methods in medicine 2012 (2012).
[13] Sharma, Abhilasha, Amit Kumar Singh, and S. P. Ghrera. "Secure hybrid robust watermarking technique for medical images." Procedia Computer Science 70 (2015): 778-784.
[14] Roček, Aleš, et al. "A new approach to fully-reversible watermarking in medical imaging with breakthrough visibility parameters." Biomedical Signal Processing and Control 29 (2016): 44-52.
[15] Tseng, Kuo-Kun, et al. "Wavelet-based watermarking and compression for ECG signals with verification evaluation." Sensors 14.2 (2014): 3721-3736.
[16] Eswaraiah, Rayachoti, and E. Sreenivasa Reddy. "Medical image watermarking technique for accurate tamper detection in ROI and exact recovery of ROI." International journal of telemedicine and applications 2014 (2014).
[17] Ko, Lu-Ting, et al. "A novel fractional-discrete-cosine-transform-based reversible watermarking for healthcare information management systems." Mathematical Problems in Engineering 2012 (2012).
[18] Ho, Anthony TS, Xunzhan Zhu, and Yong Liang Guan. "Image content authentication using pinned sine transform." EURASIP Journal on Advances in Signal Processing 2004.14 (2004): 185761.
[19] Aherrahrou, N., and H. Tairi. "PDE based scheme for multi-modal medical image watermarking." Biomedical engineering online 14.1 (2015): 108.
[20] Khandare, Shrinivas, and Urmila Shrawankar. "Image bit depth plane digital watermarking for secured classified image data transmission." Procedia Computer Science 78 (2016): 698-705.
[21] Kuppusamy, K., and K. Thamodaran. "Optimized image watermarking scheme based on PSO." Procedia engineering 38 (2012): 493-503.
[22] Liu, Guoyan, Hongjun Liu, and Abdurahman Kadir. "Wavelet-based color pathological image watermark through dynamically adjusting the embedding intensity." Computational and Mathematical Methods in Medicine 2012 (2012).
[23] Laouamer, Lamri, et al. "Robust watermarking scheme and tamper detection based on threshold versus intensity." Journal of Innovation in digital Ecosystems 2.1-2 (2015): 1-12.
[24] Bhattacharya, Sharbani. "Watermarking digital image using fuzzy matrix compositions and rough set." matrix 5.6 (2014).
[25] Saadi, K. Ait, Ahmed Bouridane, and Abdelrazek Guessoum. "Combined fragile watermark and digital signature for H. 264/AVC video authentication." 2009 17th European Signal Processing Conference. IEEE, 2009.
[26] Shelke, Nitin A., and Dr PN Chatur. "Blind Robust Digital Video Watermarking Scheme using Hybrid Based Approach." International Journal of Computer Science and Information Technologies 5.3 (2014): 3619-3625.
[27] N. Nikolaidis, I. Pitas,Robust image watermarking in the spatial domain,Signal Processing,Volume 66, Issue 3,1998,Pages 385-403,ISSN 0165-1684.
[28] Fallahpour, Mehdi, et al. "Tampering detection in compressed digital video using watermarking." IEEE Transactions on Instrumentation and Measurement 63.5 (2014): 1057-1072.

[29] Sinsinwar, Komal, and S. P. S. Chauhan. "A Survey of Digital Image Watermarking Optimization Algorithms Inspired by Nature.
[30] Upadhyay, Smriti, and Kiran Jain. "Genetic Algorithm based High Quality Image Watermarking using Multi Resolution Wavelet Transform."
[31] Gupta, Kirtika, and C. S. Rai. "Designing and Performance Evaluation of a 3-Level Watermarking Based On Encryption and Compression." (2017).
[32] Malik, Vinita, Neeti Sangwan, and Sukhdip Sangwan. "Digital Watermarking using DWT-SVD Algorithm." Advances in Computational Sciences and Technology 10.7 (2017): 2161-2171.
[33] Z. H. Wei, P. Qin and Y. Q. Fu, "Perceptual digital watermark of images using wavelet transform," in IEEE Transactions on Consumer Electronics, vol. 44, no. 4, pp. 1267-1272, Nov. 1998. doi: 10.1109/30.735826
[34] Wicaksana, Arya, and Maria Irmina Prasetiyowati. "Digital Watermarking for Color Image Using DHWT and LSB." 2019 5th International Conference on New Media Studies (CONMEDIA). IEEE, 2019.
[35] Tuncer, Türker, Fatih Özyurt, and Engin Avcı. "A novel bit based reversible image watermarking method." 2017 International Conference on Computer Science and Engineering (UBMK). IEEE, 2017.
[36] Abd-Eldayem, Mohamed M. "A proposed security technique based on watermarking and encryption for digital imaging and communications in medicine." Egyptian Informatics Journal 14.1 (2013): 1-13.
[37] Abhishek Kumar, et al. "The state of the art of deep learning models in medical science and their challenges". Multimedia Systems. (2020).
[38] Abhishek Kumar, et al. "Efficient data transfer in edge envisioned environment using artificial intelligence based edge node algorithm". Transactions on Emerging Telecommunications Technologies. (2020).
[39] Ambeth Kumar, V.D. et al. "Active volume control in smart phones based on user activity and ambient noise". Sensors (Switzerland) 20. 15(2020): 1-17.
[40] Vengatesan, K. et al. "Analysis of Mirai Botnet Malware Issues and Its Prediction Methods in Internet of Things". Lecture Notes on Data Engineering and Communications Technologies 31. (2020): 120-126.
[41] Vimal, V. et al. "Artificial intelligence-based novel scheme for location area planning in cellular networks". Computational Intelligence. (2020).
[42] Kumar, A. et al. "Comparative Analysis of Data Mining Techniques to Predict Heart Disease for Diabetic Patients". Communications in Computer and Information Science 1244 CCIS. (2020): 507-518.
[43] Sayyad, S. et al. "Digital Marketing Framework Strategies Through Big Data". Lecture Notes on Data Engineering and Communications Technologies 31. (2020): 1065-1073.
[44] Kumar, V.D.A. et al. "Exploration of an innovative geometric parameter based on performance enhancement for foot print recognition". Journal of Intelligent and Fuzzy Systems 38. 2(2020): 2181-2196.
[45] Vengatesan, K. et al. "Secure Data Transmission Through Steganography with Blowfish Algorithm". Lecture Notes on Data Engineering and Communications Technologies 35. (2020): 568-575.
[46] Lone, T.A. et al. "Securing communication by attribute-based authentication in HetNet used for medical applications". Eurasip Journal on Wireless Communications and Networking 2020. 1(2020).
[47] Vengatesan, K. et al. "Simple Task Implementation of Swarm Robotics in Underwater". Lecture Notes on Data Engineering and Communications Technologies 35. (2020): 1138-1145.
[48] Kesavan, S. et al. "An investigation on adaptive HTTP media streaming Quality-of-Experience (QoE) and agility using cloud media services". International Journal of Computers and Applications. (2019).

[49] Ankit Kumar, Vijayakumar Varadarajan, Abhishek Kumar, Pankaj Dadheech, Surendra Singh Choudhary, V.D. Ambeth Kumar, B.K. Panigrahi, Kalyana C. Veluvolu, Black Hole Attack Detection in Vehicular Ad-Hoc Network Using Secure AODV Routing Algorithm, Microprocessors and Microsystems, 2020, 103352, https://doi.org/10.1016/j.micpro.2020.103352