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Genetic algorithm based image reconstruction applying the digital holography process with the Discrete Orthonormal Stockwell Transform technique for diagnosis of COVID-19

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A B S T R A C T

World Health Organization has described the real-time reverse transcription-polymerase chain reaction test method for the diagnosis of the novel coronavirus disease (COVID-19). However, the limited number of test kits, the long-term results of the tests, the high probability of the disease spreading during the test and imaging without focused images necessitate the use of alternative diagnostic methods such as chest X-ray (CXR) imaging. The storage of data obtained for the diagnosis of the disease also poses a major problem. This causes misdiagnosis and delays treatment. In this work, we propose a hybrid 3D reconstruction method of CXR images (CXRi) to detect coronavirus pneumonia and prevent misdiagnosis on CXRI. We used the digital holography technique (DHT) for obtaining a priori information of CXRI stored in created digital hologram (CDH). In this way, the elimination of the storage problem that requires high space was revealed. In addition, Discrete Orthonormal S-Transform (DOST) is applied to the reconstructed CDH image obtained by using DHT. This method is called CDH_DHT_DOST. A multiresolution spatial-frequency representation of the lung images that belong to healthy people and diseased people with the COVID-19 virus is obtained by using the CDH_DHT_DOST. Moreover, the genetic algorithm (GA) is adopted for the reconstruction process for optimization of the CDH image and then DOST is applied. This hybrid method is called CDH_GA_DOST. Finally, we compare the results obtained from CDH_DHT_DOST and CDH_GA_DOST. The results show the feasibility of reconstructing CXRI with CDH_GA_DOST. The proposed method holds promises to meet demands for the detection of the COVID-19 virus.

1. Introduction

COVID-19 spread rapidly all over the world after its discovery in China’s Hubei province in December 2019. Since the infectious disease appeared in Wuhan, it has had a huge global impact. Therefore, isolation of patients by establishing an early diagnosis has been an important step in controlling the spread of the disease. For the diagnosis of COVID-19, viral RNA is identified in a reverse transcriptase-polymerase chain reaction (RT-PCR) with laboratory tests. Because, such viruses are composed of RNA rather than DNA, and for these viruses, RNA must be converted to DNA before they are replicated [1]. COVID-19 virus is one such virus. However, research indicates that the symptoms of COVID-19 were not specific and did not always provide an accurate diagnosis. Additionally, RT-PCR testing has proven to be both slow and unreliable in the early stages of the COVID-19 outbreak [1]. In studies conducted in China, the sensitivity of the swab test was proven to be as low as 30%, and this finding was consistent with the RT-PCR test of liquid samples [2,3].

On the other hand, in the early diagnosis and the treatment planning for all patients of the COVID-19 pandemic, computed tomography (CT), ultrasound, chest X-ray imaging, etc. methods play a very important role in imaging modalities considered [2,4].

For instance, CT is explained as highly sensitive to detect cases such as the swab misses [3]. It is claimed that CT has higher sensitivity (over 90%) and real-time results occur at the risk of increased false positives. Therefore, medical imaging techniques have emerged as a useful tool in diagnosis. For instance, with a CT scan, doctors can diagnose a COVID-19 infection that goes deep into the lungs and may have been overlooked with a swab test. However, there can be some disadvantages of CT imaging. According to the American College of Radiology, the specificity of CT scans for COVID-19 appears to be a problem because it can overlap with the findings for influenza, seasonal flu, pneumonia, and lung problems caused by other types of infections [3]. In the study conducted by Thomas and Robert Kwee, it was shown that a negative CT result does not definitely rule out COVID-19. Furthermore, they...
found that a significant number of false-positive chest CT scan results were obtained due to overlapping imaging with many other diseases or other viral pneumonia [5]. In this case, imaging indications are not specific enough to confirm COVID-19 and may only indicate signs of infection. Additionally, since some of the radiation passing through a body is absorbed, in a CT scan the patients, especially the younger patients, are exposed to excessive radiation. Because in particular children or younger persons are more radiosensitive than adults [6]. Therefore, in this method, there have been several scanner disinfection procedures that have to be done [7].

On the other hand, as for that chest X-ray imaging (CXRI), most hospitals use CXRI as the first-line method that allows the initial assessment of patients. Because in this method, the movement of patients is reduced. The risk of cross-infection is minimized by using portable X-ray units [8,9]. The CXRI method gives faster results compared to the RT-PCR mentioned above. In addition to these features, since the CXRI method is cheaper, easier, and less harmful, it is also preferred more than the CT scans [10]. Thanks to these advantages, CXRI can guide the differential diagnosis to other possible pulmonary parenchymal causes other than COVID-19 infection [11]. However, the disadvantage of the CXRI is adjusting the proper position between the patient and the film. If the distance between the source of the X-ray and the object is not far enough, the distortion of the object can occur. On the other hand, when the object is further from the source, it gets smaller and sharper. This means that in CXRI, magnification and sharpness depending on the distance between the X-ray source and the chest. Thereby, this focusing problem in the CXR images may cause misdiagnosis and delay treatment. However, it is possible to obtain 3D information about the obtained CXR images by applying the digital holography technique. Thus, even if there is a focusing problem in the CXR images, detailed data about the infection or chest can be obtained and an accurate diagnosis can be made. Since all human visual cues such as stereopsis and eye focusing are accounted for by holography, it can be considered to be the ultimate display technology. Since the complete and focused image of the object can be achieved with digital holography, the obtained phase, amplitude, and frequency information allows for characterizing the infection by giving detailed information about the CXR image.

Digital holography has been a widely applied technique to record and reconstructed numerically the objects with 3D information. DH records 3D objects in a two-dimensional (2D) pattern and retrieves numerically using a computer the phase and the intensity of the sample from the recorded holograms. The reconstruction process is performed computer-driven numerically [12]. Since the DH technique was first proposed by Goodman and Lawrence, it has been successfully applied in a wide range of different applications such as surface contouring, particle analysis, microscopy, 3D information processing and etc. [12–15]. The purpose of digital holography is not just to retrieve 3D information. At the same time, the quality and resolution of the reconstructed image are expected to be high. In this context, various methods are performed to increase the image quality and resolution of the images obtained from holograms. For instance, Nomura et al. improved the image quality by superposing the reconstructed images obtained by using different wavelengths [16]. Claus et al. utilized the subpixel sampling method to improve the optical resolution for image quality and phase measurement accuracy [17]. Verrier and Fournier improved the reconstruction process of the recorded holograms, where they predict the characteristic parameters and position of the objects, by utilizing the information redundancy of videos [18]. Furthermore, Funamizu et al. used the spatial correlation features of speckle patterns to increase the spatial resolution required in digital holographic microscopy (DHM) [19]. In addition to all these methods presented in the literature, the Discrete Orthonormal Stockwell Transform (DOST) method can be used to provide the multiresolution in the spatial frequency domain of a signal or image [20]. High-accurate retrieved images can be obtained by using the DOST technique which makes reconstruction more convincing. However, since lower frequencies are subsampled in the DOST technique, it is important that its coefficients are properly distributed. So, in order to provide this distribution, a set of orthogonal unit-length basis vectors, which target a particular region in the time–frequency domain, are constructed by choosing the center of each frequency band, the width of that band, and location in time suitably. We provide solutions to these types of problems in this work which develops a novel method of image reconstruction by using the CDH_GA_DOST technique. In recent years GAs have been widely used for the applications of image reconstruction [21]. Since it requires only to define a genetic representation of the solution domain, it is an easy-to-use algorithm and can be thought as a minimizing problem. The purpose of the genetic algorithm is to find the smaller fitness value that corresponds to the fitter individual. In this paper, we develop an image reconstruction method in digital holography to prevent misdiagnosis on CXR images [22] and confusion of COVID-19 virus with influenza, seasonal flu, etc. infections. A hologram is created by using the CXR images obtained from the database [22]. The CDH_GA_DOST technique is used to increase the quality and the resolution of the images reconstructed from these holograms. In addition, by using digital holography and the genetic algorithm in the reconstruction process, the problem of selecting appropriate parameters encountered in the DOST technique will be overcome. The reconstructed images were obtained by applying the CDH_GA_DOST method and the normalized and centered 2D Fast Fourier Transform (2D-FFT) images are compared. Even though the DOST technique has been used in image compression for a long time, it is can be used for parameterizing the reconstructed image [23]. By applying the CDH_GA_DOST technique, matrices related to amplitude and phase are created. As a result of the application of this technique, the multiresolution images are retrieved. It has been done a performance comparison in the presence of the CXR images for persons with and without the COVID-19 virus. In order to prove the accuracy of the results obtained and to show the advantages of using reconstructed hologram images, the mentioned above algorithms were applied both directly to the CXR images and to the created holograms of these images. The main novelties and contributions are listed as follows.

- We devise digital holography for the first time to promote the diagnosis of COVID-19 from CXR images.
- The storage problem that requires high space for CXR image is eliminated by using CDH.
- We devise to combine the genetic algorithm with DOST method and so that the reconstruction process became a minimizing problem. Therefore, a robust reconstructed image is obtained with the optimization algorithm.
- Different from original CXR images, we devise multiresolution images.
- We devise the ability to obtain 3D information on phase and amplitude.

Section 2 reviews related works and highlights the difference of the proposed method in this paper from other methods in the literature. In Section 3, the detailed information about image acquisition by using digital holography via simulation, the proposed CDH_GA_DOST technique and the dataset is reviewed. Section 4 is devoted to the framework of the reconstruction and simulation results. CXR images of COVID-19 and viral pneumonia cases are analyzed. In Section 5, the reconstruction with digital holography examples of CXR images of persons with and without the COVID-19 virus are presented. Throughout Section 5, we compare the performance of applying digital holography to CXR images by calculating the mean squared error, mean absolute error, peak signal-to-noise ratio, and structural similarity and evaluate the results. Finally, the concluding remark is included.
2. Related works and motivation

There have been various researches based on designing artificial intelligence (AI) models to diagnose COVID-19 via CXR images [29]. In addition to these studies, Wang et al. developed a deep rank-based average pooling network (DRAPNet) model to recognize COVID-19 and they proved that their model is effective in distinguishing COVID-19 from other infectious diseases [25]. Ismael and Şengür used pre-trained deep convolutional neural network (CNN) models to classify COVID-19 and healthy CXR images. They achieved 92.6% success in classifying by using the ResNet50 model [26]. Toraman et al. [27] proposed a convolutional CapsNet to perform the detection of COVID-19 based on CXR images and their method yielded a 97.24% accuracy rate for binary classification. Sobahi et al. [28] developed an attention-based 3D CNN model with residual connections and they used binary and multiclass classifications for ECG-based COVID-19 detection. The authors attained 99.0% and 92.0% accuracy for binary and multiclass classifications, respectively.

However, in the studies mentioned above, although AI models have been designed for the detection of COVID-19 using images obtained from CXR, alternative imaging, image acquisition or reconstruction methods are not presented to eliminate the problems in the imaging phase of CXR. Therefore, in this paper, digital holography which provides to obtain 3D information on phase and amplitude is proposed for the first time to promote the diagnosis of COVID-19 from CXR images. In addition, unlike existing studies in the literature, a robust reconstructed image is obtained by combining genetic algorithm and DOST method. Thanks to the method proposed in this study, both multiresolution and robust reconstructed CXR images can be obtained with the use of hologram or genetic algorithm and DOST methods. Thus, this paper does not study classification like previous papers, it proves the feasibility of reconstructing images of CXR with DOST_GA method to meet demands for detection of COVID-19 virus.

3. Materials and methods

Image compression techniques are applied to remove excess information from the images without losing image quality and information. Thus, basic information can be extracted by transformation techniques that can be reconstructed to retrieve the images to an acceptable level to human eyes [29]. Images have been processed by using various techniques, such as predictive image coding, scalar/vector quantization, and transform algorithms [30]. Among these techniques transform algorithms, which are Discrete Cosine Transform (DCT), Discrete Orthogonal Stockwell Transform and etc., are the most efficient way to restore an image with partial coefficients. To validate the superiority of DCT and DOST transform, several studies have been conducted. For instance, Rhee and Kang proposed discrete cosine transform (DCT) based on the generalized deconvolution technique. They proved the superiority of this method, which they assumed to be a computationally efficient reconstruction algorithm, with theoretical and experimental results [31]. Gu et al. introduced a new reconstruction method based on DCT employing to parameterize the reconstructed image. They showed that the performance of their work is too high when compared with conventional model-based iterative image reconstruction algorithms and image coding algorithms such as traditional nonparametric MOBIIR codes [32]. The ability of perfect frequency localization, multiresolution decomposition, and some other advantages in terms of time-frequency analysis caused DOST to rise to prominence. However, there have been various successful applications of DOST in a variety of research to verify that the DOST significantly reduces the storage and calculation cost [33]. Wang and Orchard used a new automated image reconstruction algorithm based on discrete orthonormal Stockwell transform (DOST) to provide a multiresolution spatial-frequency imagery of a signal and image. They show that the proposed algorithm achieves higher performance over the related compression techniques [34].

Despite DOST is a relatively new method compared to other transform algorithms, it has been used in many areas such as image texture analysis, image compression, signal analysis, and image restoration [35]. Huang et al. performed a study using DOST to denoise and compress medical images [36]. Thresholding denoising using DOST is introduced for medical image compression as described in [37]. Yusof et al. compared the DOST performance for the reconstruction of medical images [38]. In addition, transforms such as Discrete Wavelet Transform (DWT) and q-Recursive Zernike Moment (q-RZM) have been used to reconstruct the images.

In the current work, as well as the genetic algorithm and DOST method is used in the reconstruction of CXR images, images are obtained from the holograms created numerically by simulation using the MATLAB program. Unlike the previous studies, after genetic algorithm and 2D-DOST applying to the images obtained by both methods, these images were analyzed in the frequency region. We have seen there is a need for reconstructing multiresolution images with accurate parameters; reduced noise level and likelihood functions that do not necessitate any prior processing on images. We provide solutions by use of a genetic algorithm to all of these requirements in this work which develops a novel method for reconstruction of CXR images and detection of COVID-19 virus. In addition, the differences between the proposed CDH_GA_DOST method and the CDH_DHT_DOST techniques are compared with the help of the image quality measurement metric methods. Fig. 1 summarizes the workflow of the proposed reconstruction method based on the genetic algorithm. First, the images which belong to CXR images of healthy and diagnosed patients with COVID-19 to be analyzed are selected. Thereafter, a binary genetic algorithm is applied to find the optimal reconstructed image and then reduced sub-images are used to apply the DOST method and each transformed sub-images are analyzed in the frequency domain. Each of these steps is discussed in more detail in the following subsections.

3.1. Image acquisition by using digital holography via simulation

Holography is a technique that commonly used to record and reconstruct the 3D information of an object. Recent advances in computer technology have permitted creating the holographic patterns and
performing the reconstruction with the computer-driven numerical reconstruction of the created image. In addition, 3D objects are recorded in 2D holographic interference patterns with digital holography. It retrieves both the phase and amplitude information of the objects from the created-recorded holograms and allows the analysis of these images in the frequency domain.

In this work, the holographic patterns are created with simulation by using CXR images. This process is depicted as a flowchart in Fig. 2.

To make a brief statement, the hologram is first created with simulation based on mathematical expression [39]. These mathematical expressions are given in Fig. 2. Here, the coordinate axis is identified as (x,y). \( O_{\text{object}}(x,y) \) and \( R_{\text{incident}}(x,y) \) are called object and reference waves, respectively. \( t(x,y) \) is a transmission function that is used for defining wave propagation. The propagated wave spreads from the object plane (x,y) toward the recording-detector plane (X,Y). The wavelength of the light (\( \lambda \)) is correlated with the number of waves (\( k = 2\pi/\lambda \)). The distance between the object plane and the detector plane is given as \( |\vec{r} - \vec{R}| \), where the phase is neglected.

A sample image and its created hologram obtained from simulation are depicted in Fig. 3a and b, respectively.

After the hologram is created, the image is reconstructed from the created hologram by using inverse Fast Fourier algorithm [39]. The Fourier transform algorithm is one of the most widely preferred methods for reconstructing images in optical interference analysis and was first used by Takeda in optical profilometry [40]. Hence, the reconstruction process can be defined mathematically.

In this context, firstly, the \( U_{\text{detector}}(x,y) \), which is the mathematical definition of interference pattern refers given in Fig. 2, including amplitude and phase information parameters are briefly expressed as follows.

\[
U_{\text{detector}}(x,y) = g(x,y) + p(x,y)
\]  

Here, \( g(x,y) \) and \( p(x,y) \) give the amplitude and phase information of the hologram, respectively. To define the phase information \( p(x,y) \) given in (1), the Fourier transform of the equation should be taken.

\[
G(k_x,k_y) = A(k_x) + C(k_x - k_{0x}, k_y) + C^*(k_x - k_{0x}, k_y)
\]

where \( A(k_x) \) is the background density of the hologram and represents the amplitude. \( C(k_x - k_{0x}, k_y) \) and \( C^*(k_x - k_{0x}, k_y) \) expressions are the pattern spectrum with distortion and contain phase information. They represent the real and imaginary parts of the phase, respectively.

In order to find the real phase information of the hologram created by simulation, first of all, the inverse Fast Fourier transform of the expression given by (2) is taken.

\[
p(x,y) = \tilde{\mathcal{F}}^{-1}(G(k_x,k_y))
\]

\[
\phi(x,y) = \tan^{-1}\left(\frac{\mathcal{F}(p(x,y))}{\mathcal{R}(p(x,y))}\right)
\]

Then, a phase hologram of one amplitude is created using the phase information obtained with the Inverse Fast Fourier transform. Finally, the real image of the object is obtained from this expression.

\[
r(x,y) = \exp(i\phi(x,y))
\]

\[
\Gamma_r(\zeta,\eta) = \tilde{\mathcal{F}}^{-1}(r(x,y))
\]

The reconstructed image obtained from Fig. 3 by using inverse Fast Fourier algorithm is given in Fig. 4.

3.2. CDHG_GA_DOST algorithm

The proposed CDHG_GA_DOST algorithm is accomplished with the MATLAB program. Algorithm 1 presents the full procedure of GA steps applied to the reconstruction of the CXR images.

For this work, mean absolute error (MAE) fitness function has been used to reconstruct the image which is defined as follows:

\[
F = (1 + E_M)^{-1}
\]

where \( E_M \) is the MAE value between the reference or measured image and computed reconstructions [23]. Once GA is applied and the optimum solution is found, the image parameterizations are aligned.

![Fig. 2. Calculation steps of creating holographic image.](image1)

![Fig. 3. Digital holographic images (a) a sample image (b) created hologram (interference pattern).](image2)

![Fig. 4. The reconstructed image.](image3)
Algorithm 1 The genetic algorithm applied to the reconstruction of the CXR images

1: Generate the initial population
2: Evaluate the fitness of each individual
3: Determine the fittest individual
4: Apply the reproductive operators to create offspring
5: Determine the individuals by evaluating the offspring
6: Stop if the stopping criteria are met otherwise repeat the step

Since all pixel values of the image are now in correspondence, DOST can be applied to obtain frequency domain analysis and to detect the COVID-19 virus. Image quality is an important issue in the analysis of medical images. Recently, various techniques such as Principal Component Analysis (PCA), Wavelet-based methods, etc. are applied to medical images to be helpful for diagnosis [41]. However, among these methods, the DOST method is younger than the others. It can be useful in image processing and applied successfully to medical images [42]. First, 2D Fourier Transform (2D-FT) will be defined to describe the process of calculating the DOST of a 2D image in the frequency domain.

The 2D-FT of a function and inverse 2D-FT transform can be calculated as given in (8) and (9), respectively.

\[
H[m, n] = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} h[x, y] e^{-2\pi i (mx/M + ny/N)} \quad (8)
\]

\[
h[x, y] = \frac{1}{MN} \sum_{m=-M/2}^{M/2-1} \sum_{n=-N/2}^{N/2} H[m, n] e^{2\pi i (mx/M + ny/N)} \quad (9)
\]

Considering the (8) and (9), the 2D-DOST of a \(N \times N\) image \(h[x, y]\) is calculated as,

\[
S[x', y', v_x, v_y] = \frac{1}{\sqrt{2^{\nu_x+\nu_y}}} \sum_{n=0}^{2^{\nu_x}-1} \sum_{m=0}^{2^{\nu_y}-1} H[m + v_x, n + v_y] e^{2\pi i (nx'/2^{\nu_x-1} + ny'/2^{\nu_y-1})} \quad (10)
\]

where \(v_x = 2^{\nu_x-1} + 2^{\nu_x-2}\) and \(v_y = 2^{\nu_y-1} + 2^{\nu_y-2}\) are defined as the horizontal and vertical frequencies, respectively [43]. The inverse
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Table 2

**DOST coefficients for normal cases.**

| k | l | m | n | x |
|---|---|---|---|---|

**The results obtained by using the CXR images**

2D-DOST transform is similar to the case 1D given in ref [43].

\[ H[m, n] = \sqrt{2^{p_x - 1} x 2^{p_y - 1}} \sum_{m=-2^{p_x - 2}}^{2^{p_x - 2} - 1} \sum_{n=-2^{p_y - 2}}^{2^{p_y - 2} - 1} s[m - v_x, n - v_y] e^{-2\pi i (m x / N + n y / N)} (11) \]

Then, by performing inverse FT, the image can be reconstructed as given in (12),

\[ h[x, y] = \frac{1}{N^2} \sum_{m=-N/2}^{N/2-1} \sum_{n=-N/2}^{N/2-1} H[m, n] e^{2\pi i (m x / N + n y / N)} (12) \]

DOST transform ensures information for the \((v_x, v_y)\) frequencies which include a bandwidth of \(2^{p_x - 1} x 2^{p_y - 1}\) frequencies and defines the amplitude of each Fourier frequency component in the horizontal and vertical directions by the minimum number of points. Hence the DOST technique can be quickly calculated and enables every pixel of a large image to be analyzed in seconds. However, DOST coefficients are important to store and recover the image efficiently. Therefore, the parameters in DOST such as the center of each band, and widths of that bands have to be chosen appropriately to obtain proper coefficients. Thus, most features of an image can be captured [23].

3.3. **Dataset and implementation**

A thorough assessment of the proposed reconstruction method has been conducted on the healthy and COVID-19 patient datasets, obtained from Ref. [22]. This dataset consists of ten CXR images that belong to five healthy and five COVID-19 patients. All codes were executed on a Window 7 machine equipped with an Intel Core i7 CPU (3.5 GHz and 16 GB RAM).

In this work, the names of used CXR images, which are obtained from Ref. [22] for COVID-19 and viral pneumonia cases are person808_virus_1442, person701_virus_1297, bacteria_2136, person500_bacteria_2105, person5_bacteria_15 respectively. These names are defined as a,b,c,d, and e, respectively throughout the paper. Additionally, normal cases are normal2_IM_0925_0001, normal2_IM_0860-0001, IM_0226-0001, IM_0764_0001, IM-0480-0001, respectively. These names are defined as k,l,m,n, and x, respectively throughout the paper, too. To make the images more apparent, 2D-DOST coefficients of the original CXR images and the reconstructed CXR images using the proposed method obtained from created hologram are plotted in Tables 1 and 2, respectively. These tables are obtained for COVID-19 and viral pneumonia cases and normal cases.
4. Results

The work conducted here builds on that reconstruction of CXR images and detection of COVID-19 with the help of the proposed image and compared the results to the original CXR images. In this

| Samples | CXR Image | RIOF-CDH | DHT | DOST | RIOF-CDH GA | DOST |
|---------|-----------|----------|-----|------|-------------|------|
| a       | nc-fft2   | dost2    | nc-fft2 | dost2 | nc-fft2 | dost2 |
| b       | nc-fft2   | dost2    | nc-fft2 | dost2 | nc-fft2 | dost2 |
| c       | nc-fft2   | dost2    | nc-fft2 | dost2 | nc-fft2 | dost2 |
| d       | nc-fft2   | dost2    | nc-fft2 | dost2 | nc-fft2 | dost2 |
| e       | nc-fft2   | dost2    | nc-fft2 | dost2 | nc-fft2 | dost2 |

While the main DOST coefficients are centered at the high spatial frequency corner, it is clearly seen that the lower frequency coefficients are close to zero. Additionally, it can be seen from Tables 1 and 2 that the obtained coefficients of DOST appear to be lower in amplitude for the cases of COVID-19 and viral pneumonia than normal cases.
Table 4
The results of normal cases with related images by giving the nc-fft2, dost2 for (a) k (b) l (c) m (d) n (e) x.

| Samples | CXR Image  | RIOF-CDH_DHT_DOST | RIOF-CDH_GA_DOST |
|---------|------------|-------------------|------------------|
| k       | nc-fft2    | dost2             | dost2            |
| l       | nc-fft2    | dost2             | dost2            |
| m       | nc-fft2    | dost2             | dost2            |
| n       | nc-fft2    | dost2             | dost2            |
| x       | nc-fft2    | dost2             | dost2            |

In Table 3, CXR images of COVID-19 and viral pneumonia cases are analyzed. While original images given in Table 3(a–e) are investigated, it can be seen that the lungs seem darker in the case of COVID-19 than bacteria. However, it can be seen in Table 3(a–e) that the darkening
in the lungs decreases according to the bacterial density. Therefore, in order to prevent confusion with COVID-19 and to provide correct diagnosis and treatment by obtaining detailed data about the chest, frequency analysis so that image reconstruction can be necessary and beneficial in such cases. If the DOST transforms and normalized and centered FFT transforms of the original images given in Table 3(a–e) are investigated, it can be seen that, as the darkness in the lungs increases, the darkness in the frequency analysis increases, too. Also, it can be seen that the frequency oscillations and center frequency amplitude are higher for the bacterial cases than the COVID-19 cases even if there is a very dense bacterial condition. Additionally, to make the results more persuasive, a representative qualitative analysis is also carried out. The reconstructed images obtained from CDH_DHT_DOST and the proposed method CDH_GA_DOST that correspond to RIOF-CDH_DHT_DOST and RIOF-CDH_GA_DOST respectively, are analyzed. Table 3 shows that the center frequency amplitudes and frequency oscillations for the DOST transform of the reconstructed images using proposed method are much closer to the ones for original images in the COVID-19 cases.

Table 4 presents the results obtained for the normal cases (without COVID-19 or viral pneumonia). It can be seen that proposed reconstruction process is more successful than COVID-19 or viral pneumonia cases for all of the normal cases. In addition, the center frequencies and frequency oscillations obtained by the proposed CDH_GA_DOST method are almost similar to the original CXR images and reconstructed images obtained with RIOF-CDH_DHT_DOST. In addition, by comparing Tables 3 and 4, it can be easily seen that the center frequency amplitudes in the case of COVID-19 and viral pneumonia are much lower than in the normal case.

The simulations described above attempt to provide a robust diagnosis of digital holography based on the frequency analysis with the proposed method CDH_GA_DOST and increase the diagnosis and treatment abilities of the clinicians by examining the frequency changes in the images. However, visual quality may deteriorate because images are exposed to deterioration due to various reasons in processes such as image acquisition, storing, and recovering any image. For this reason, it is necessary to measure the image quality, which is important for image processing applications. Image quality assessment means inferring the image similarity (or differences) between original images and degraded images. To measure the image quality without time-consuming and expensive way, objective evaluations, have been used in recent years. Mean squared error (MSE), mean absolute error (MAE), peak signal-to-noise ratio (PSNR) and structural similarity (SSIM) are the well-known objective methods.

The most common predictor of the image quality measurement metric is MSE. It measures the average of the square errors and close to zero values are better for MSE [42]. MAE is the mean absolute error between the original and recovered images. The large value of MAE means that image is poor quality [44,45]. The ratio between the maximum possible signal power and the power of the distorting noise is calculated by PSNR. The small value of PSNR corresponds to poor image quality [46]. The similarity between the original and recovered images is measured by SSIM [45]. MSE, MAE, PSNR and SSIM metrics are used to evaluate the quality of the reconstructed images in this work. The mathematical expressions for MSE, MAE, PSNR and SSIM are defined in (13), respectively:

\[ MSE = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} (x(i,j) - y(i,j))^2 \]

\[ MAE = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} |x(i,j) - y(i,j)| \]

\[ PSNR = 10 \log_{10}(2^2 - 1)^2 / \sqrt{MSE} \]

\[ SSIM = \frac{(2\mu_x \mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \]

\[ ((x)^2 + (y)^2 + C_1) \]

The expressions given in (13) are defined in Table 5.

Using (13), the similarity between the original CXR and the CXR images reconstructed from the created hologram by using both methods is deduced. Tables 6 and 7 present the results extracted for COVID-19 and viral pneumonia cases and normal cases, respectively. In the figures in Table 6, for all columns in the first and third lines, the left ones correspond to the original CXR images. The figures on the right of these columns belong to the reconstructed ones with the help of CDH_DHT_DOST and the proposed method CDH_GA_DOST that corresponds to RIOF-CDH_DHT_DOST and RIOF-CDH_GA_DOST, respectively. In addition, in the second and fourth lines, the similarity between these images is given by calculating SSIM values. As it can be seen from Table 6, for both COVID-19 and viral pneumonia cases, the reconstructed figures RIOF-CDH_GA_DOST which are obtained by the proposed method pretty well match the original ones.

Similar to Table 6, the first and third rows in Table 7, the left ones correspond to the original CXR images. The figures on the right of these columns belong to the reconstructed ones RIOF-CDH_DHT_DOST and RIOF-CDH_GA_DOST that are obtained with the help of CDH_DHT_DOST and the proposed method CDH_GA_DOST methods, in the first and third lines respectively. In addition, in the second and fourth lines, the similarity between these images is given by calculating SSIM values. As it can be seen from Table 7, for normal cases, the reconstructed figures RIOF-CDH_GA_DOST obtained by the proposed CDH_GA_DOST method, pretty well match the original ones as the results presented in Table 6. Besides all these results, when the images presented in Tables 6 and 7 are compared, it can be seen that in the case of the COVID-19 and viral pneumonia cases, luminosity in the lungs slightly affects the reconstruction performance.

In order to examine the images given visually in Tables 6 and 7 with numerical values, MAE, MSE, PSNR, SSIM values between the original and reconstructed images for normal and COVID-19 conditions are calculated in Tables 8 and 9 for RIOF-CDH_DHT_DOST and the RIOF-CDH_GA_DOST, respectively. As mentioned above, the obtained values for normal cases for all of the evaluation metric criteres are better than COVID-19 and viral pneumonia cases due to the luminosity in the CXR images. In addition, it can be seen easily from Table 9 that the proposed method provides better results for both normal and COVID-19 and viral pneumonia cases in all metrics.

In addition to all these, it should be emphasized that on the basis of the high-performance results obtained with the genetic algorithm, the need to set the parameters required for the algorithm correctly. In this context, to ensure the algorithm work accurately and found the optimum solution, some parameters should be set. These parameters are population, number of genes and chromosomes, mutation, selection, and crossover. Among these parameters, the gene and chromosome numbers depend on the model parameters. On the other hand, the big search area is obtained with the large size of the population. The new chromosomes are determined with crossover probability. In general, due to the replacing the all parents with new chromosomes in the next generation, the crossover probability is chosen between the range of 0.8.
Table 6
Images of obtained SSIM values.

| SSIM between COVID-19 and viral pneumonia cases for original and RIOF-CDH_DHT_DOST images |
|---------------------------------|
| ![Image 1](image1.png) | ![Image 2](image2.png) | ![Image 3](image3.png) | ![Image 4](image4.png) | ![Image 5](image5.png) |

| SSIM between COVID-19 and viral pneumonia cases for original and RIOF-CDH_GA_DOST images |
|---------------------------------|
| ![Image 6](image6.png) | ![Image 7](image7.png) | ![Image 8](image8.png) | ![Image 9](image9.png) | ![Image 10](image10.png) |

Table 7
Images of obtained SSIM values.

| SSIM between normal cases for original and RIOF-CDH_DHT_DOST images |
|---------------------------------|
| ![Image 11](image11.png) | ![Image 12](image12.png) | ![Image 13](image13.png) | ![Image 14](image14.png) | ![Image 15](image15.png) |

| SSIM between normal cases for original and RIOF-CDH_GA_DOST images |
|---------------------------------|
| ![Image 16](image16.png) | ![Image 17](image17.png) | ![Image 18](image18.png) | ![Image 19](image19.png) | ![Image 20](image20.png) |
and 0.95. In addition, mutation probability is preferred as only 0.05% to 1% [47].

In this study, 100 individuals are chosen for the population. 100 chromosomes and 25 000 genes are taken for the optimal solution after 50 testing process. Moreover, the probability of crossover is set at 0.95 and probability of mutation is taken as 0.001.

5. Discussion and conclusion

Although machine learning (ML) techniques have been proved to be efficient alternatives in detecting or classifying challenging COVID-19 diagnosing problems and have started to attract great recent attention from the researches interested in determining COVID-19 pneumonia. In this context, various studies for COVID-19 detection via CXR and CT scans have been published in the literature. However, the main purpose of these researches is to diagnose COVID-19 virus CXR or CT scans. Nevertheless, there may occur defects during the imaging process via CXR or CT. The focusing problem in the CXR images may cause misdiagnosis and delay the treatment. To overcome this problem and prevent misdiagnosis on CXR images and confusion of COVID-19 virus with influenza, seasonal flu, etc. infections, image reconstruction processes are performed. In this work, the results indicate that digital holography provides an advantage in examining X-ray images, as 3-dimensional information of X-ray images can be obtained with a hologram. In addition, when imaging is performed optically instead of X-ray, patients are prevented from being exposed to radiation. DOST is a technique that is often used for the reconstruction of images. However, it can be challenging in some cases to reconstruct the multiresolution images with accurate parameters; reduced noise level, and likelihood functions that do not necessitate any prior processing of images. Because, while reconstructing the image by using the DOST method, the parameters have to be determined appropriately. If the proper values for the parameters are not chosen, the margin of error between the original image and the reconstructed one increases. Moreover, using various algorithms to determine the appropriate values increases the computational load and the complexity of the method. Therefore, we provide solutions by the use of a genetic algorithm to all of these requirements in this work. In addition, there has been any research based on analysis with the DOST method for images reconstructed from holograms which are created by using digital holography. The novelty of this work is that the DOST technique is combined with the genetic algorithm and used for CXR images reconstructed from the hologram. It has been observed that the application of the proposed method to the images which are reconstructed with DHT_DOST, provides more convenience in diagnosis and treatment. The obtained reconstructed image qualities have been judged by applying the metrics explained in the previous section and the methods of CDH_DHT_DOST and the proposed CDH_GA_DOST from CXR images have been assessed numerically. Consistent results are obtained for all the metrics in the case of the proposed method is used. In this paper, we have shown that the combination of DOST, genetic algorithm, and digital holography techniques can be considered as an alternative reconstruction method in the reconstruction process.

In addition to all these results, in this study, the storage problem of images of CXR that requires large space has been overcome by using CDH. The size of each image used for this study is approximately 74 kilobytes. However, the area occupied by the holograms of these images created by simulation is approximately 1.9 kilobytes. In other words, it takes up 37 times less space. If we calculate for the 10 images presented as an example in this study, 370 times less space will be needed to store the images than the actual storage area. Moreover, real images can be reconstructed from holograms at any time without any loss of data.

This study is the first to devise digital holography to promote the diagnosis of COVID-19 from CXR images with the help of the combination of the genetic algorithm and DOST method; thus, it can be further extended to other diseases or imaging systems, i.e. MRI or CT by applying the proposed method for the dataset of that imaging method which is seen as future work.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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