Expert Systems With Applications 56 (2016) 177–185

Contents lists available at ScienceDirect

Expert Systems With Applications

journal homepage: www.elsevier.com/locate/eswa

Optimization of digital holographic setup by a fuzzy logic prediction system

Gulhan Ustabas Kaya[a,*], Okan Erkaymaz[b], Zehra Sarac[a]

[a] Department of Electrical and Electronics Engineering, Bulent Ecevit University, 67100 Zonguldak, Turkey
[b] Department of Computer Engineering, Bulent Ecevit University, 67100 Zonguldak, Turkey

ARTICLE INFO

Article history:
Received 15 April 2015
Revised 8 February 2016
Accepted 6 March 2016
Available online 16 March 2016

Keywords:
Digital hologram
Optimization
Fuzzy logic prediction system
Image quality
Required time

ABSTRACT

In this study, the optimization of the digital holography setup is achieved by a using fuzzy logic prediction system. In fact, when this optimization process is experimentally performed, some parameters are changed in the setup. These parameters affect directly the obtained image quality after a reconstruction process, which is determined by normalized root mean square. The aim of this study is to achieve the optimization of digital holographic setup by using both experimental and fuzzy logic prediction systems. Furthermore, the required time during the experimental optimization can be lowered by using a numerical method like the fuzzy logic prediction system. Here, the experimental optimization results and the optimization results obtained by the fuzzy logic prediction system are compared. It is offered that the designed experimental system can be optimized by using an artificial intelligent tool. The applied fuzzy logic prediction model is used the first time for optimization of hologram recording setup. As a result, it is reached a conclusion that the optimization of digital holographic setup can be numerically performed by the fuzzy logic prediction system. Moreover, while digital holographic setup is experimentally designed, the required time for optimization is reduced, as well.

1. Introduction

It is possible that the phase and the amplitude information of the object can be recorded with digital holography (Caulfield, 1979; Hariharan, 1996). While the reconstruction process is performed, the required time for the real time holographic process is considerably shortened via developing CCD and computer technologies (Kronrod, Merzlyakov, & Yaroslavsky, 1972). In the same time, while the image is reconstructed from a recorded hologram (Awatsuji et al., 2008; Ustabas, Onal, & Sarac, (2014), it is aimed to obtain the images with noiseless and extremely high quality. Actually, the most important factors affecting the image quality are the position and size of the object in a digital holographic setup (DHS). To achieve the good interference in the digital holographic setup, the reference and the object waves are required to overlap. Therefore, the object and reference waves must be taken at a certain angle on the horizontal axis while adjusting the object position (Kim, 2010). With parameters of CCD camera known in practice, the angle values can be calculated easily. In addition, the object size and its distance from the CCD camera are used while the angle values are calculated (Ferraro et al., 2004; Kim, 2010). These factors and angles are used to optimize the system (DHS). However, each factor is changed on DHS during an optimization process, so this process takes a lot of time. To prevent this time loss and to optimize the setup in terms of the image quality, the parameters mentioned above can digitally be predicted by the fuzzy logic prediction system. Hitherto, optimization of DHS in terms of the image quality has been achieved by calculating normalized root mean square value (NRMS) (Matoba, Naughton, Frauel, Bertaux, & Javidi, 2002). In the same time, there are a lot of studies in literature to obtain imaging with high resolution by using DHS. For example, the visualization process with high resolution for liquid and solid objects is achieved by Cheng, Lai, Lin, and Tu (2013), and Orzo, Wittner, and Tokes (2013).

In this study, the optimization process for high image quality during digital holographic recording is numerically performed by a Fuzzy logic prediction system. Until now, to realize accurate predictions in well-defined prediction system, the numerical methods have been used such as fuzzy logic method (Bıyıkoglu, Akcayol, Ozdemir, & Sivrioglu, 2005). To transform the actual properties of the systems to a fuzzy value, or vice versa, many membership functions can be created in a fuzzy logic prediction system (Chang, Lin, & Hu, 1995). Also this fuzzy logic method requires the expert knowledge (Akyılmaz, 2005; Yılmaz, & Arslan, 2005; Yumusak, & Ekmekci, 2011). In this method, it is indicated that the output

* Corresponding author. Tel. +90 372 291 18 60.
E-mail addresses: gulhan.ustabas@beun.edu.tr (G.U. Kaya), okan.erkaymaz@beun.edu.tr (O. Erkaymaz), saraczehra@yahoo.com (Z. Sarac).

http://dx.doi.org/10.1016/j.eswa.2016.03.019
0957-4174/© 2016 Elsevier Ltd. All rights reserved.

response changes according to the identified parameters in input. Therefore, the rule table is constituted for the design of system by defining the input and output membership functions. In 1965, the fuzzy logic control method was introduced into the literature by Zadeh for the first time (Zadeh, 1965). Lots of studies about fuzzy logic have been realized so far. For example, it has been applied in medical diagnosis, industrial process and electrical machines control systems, geodetic applications (Chang et al., 1995; Collotta, Bello, & Pau, 2015; Kim, Kim, & Shin, 2014; Yılmaz, & Arslan, 2005).

In addition to these, the fuzzy logic systems and classification methods have been used in different image processing studies in holography recently. Chang et al. (1995) have described fuzzy logic analysis for economically fabrication of holographic optical element in photoresist and have predicted correctly the diffraction efficiency. Zhang and Karim (2000) have constructed a fuzzy inference system which computes fuzzy rules in parallel for Spatial Light Modulator (SLM) based on optic structures. Later on, Hosseini and Yaghmaee, 2014 have designed an adaptive fuzzy inference system for super resolution imaging without optimization. Namely, high-resolution images from low resolution images are obtained by using a fuzzy model. In other study, Zhao, Fan, and Liu (2014) have developed a fuzzy clustering algorithm for image segmentation process.

As mentioned above, in this study, it is aimed to digitally optimize DHS to obtain the high-quality images by using a Fuzzy Logic prediction system. For this optimization process, some parameters of digital holography recording setup are important. In this prediction system, these parameters, which affect the image quality on the DHS, are identified for fuzzy logic prediction method. Moreover, defining the input and output membership functions involves constituting the rule table. The input membership functions are specified according to these parameters. The object size, whose hologram is recorded, is one of the most important parameters, which affects the image quality. Therefore, the object size is taken as first input membership function in this study. In addition, the location of the object and reference waves with respect to each other is another important parameter of affecting the image quality. If the object is closer to the exit point of the reference wave (spatial filter), the image quality can be said to be better. Therefore, the distance between of the object and reference beam is expressed as second input membership function and to put it all in simple terms; it is called the horizontal distance. The object and reference wave paths should be equal when the hologram recording is performed. The distance between the two waves constituted on the basis of this requirement is expressed as optical path difference, which is another important factor of affecting the image quality. Therefore, this parameter is taken as third input membership function in this study. By these defined input functions, the fuzzy logic prediction system is formed with output membership function, which is called as image quality.

In this paper, firstly, the system model of DH is given. While determining the image quality, the NRMS values calculated from image after the hologram reconstruction process is used to achieve the predictions obtained by the fuzzy logic prediction system. Finally, it seems that the results of the experimental study, and the results obtained by the fuzzy logic prediction system keep substantially with each other.

2. Experiment and principles

2.1. The system model

In this section, the recording setup of the Lensless Fourier digital hologram is given in Fig. 1 and the used parameters in the fuzzy logic prediction system are identified. Based on these parameters, the reconstruction results are presented. Then, the fuzzy logic prediction system is explained. This model is adapted to the DHS.

In DHS, the CCD Camera, whose pixel points are located far from $\Delta\xi$ (5 mm) and $\Delta\eta$ (5 mm) on the *x, y* planes respectively and, which has 640 × 480 pixel number, is used when hologram recording is achieved. The planes of *x* and *y* define the coordinates belonging to the object plane. ξ and η give the coordinates of the hologram plane (Kreis, 2005). Here, the reference wave is accepted as a point source. Therefore, this setup is called Lensless Fourier digital holographic (LFDH) setup. It is possible that, the location of the object can mathematically be calculated while the hologram is recorded. The object and the reference waves are interfered on the holographic plane. The angles between the hologram recording medium and the object, reference waves are represented mathematically in Eq. (1) (Kreis, 2005; Wagner, Seebacher, Osten, & Jüptner, 1999).

$$\theta = \theta_1 + \theta_2 \tag{1}$$

Here, θ_1 expresses the angle in Eq. (2), which is occurred between the object wave and the hologram recording medium. The angle, θ_2 (Here, it is accepted as 90°), which is occurred between the reference wave and the hologram recording medium, is defined in Eq. (3). *d*, which is given in Eq. 4, shows the distance between the object and the hologram plane.

$$\theta_1 = \tan\theta_1 = \frac{\frac{d_0}{2} + \frac{N\Delta\xi}{2}}{d} \tag{2}$$

$$\theta_2 = \tan\theta_2 = \frac{\frac{d_0}{2} - \frac{N\Delta\xi}{2}}{d} \tag{3}$$

$$\theta = \theta_1 + \theta_2 = \frac{d_0}{d} \tag{4}$$

where d_0 defines the object size. The difference between A (dotted line) and B (straight line) paths, which are shown in Fig. 1, is the optical path difference and is given as$A - B = d_1$. If the Eq. (4) is written again according to the sampling theorem, Eq. (5) is obtained easily (Kreis, 2005).

$$d > \frac{2d_0(d)\Delta\xi}{\lambda} \tag{5}$$

where, λ gives the used wavelength, and its value is 633 nm in this study. In the hologram recording setup given in Fig. 1, the relative positions of the object and reference waves are shown (Kreis, 2005). The object is positioned as to reference wave in a certain angle. The horizontal distance "c" represents the distance between the object and reference waves. Just as the horizontal distance affects the quality of image reconstructed from the hologram, the distance of the object from the hologram, "*d*", given in Eq. (5) and optic path difference "d_1" also affect the image quality. The following path of the reference wave is represented by the line in Fig. 1 and called as A. The object arm is shown with straight line and called as B. The A and B paths determine the distance from the beam splitter to the CCD camera. To obtain a better interference (good hologram), the A and B paths are desired to be equal in the DHS. As it is understood from the mathematical expression given in Eq. (5), the object size emerges as an important parameter while the object location is described.

Optimization method used in this study is based on these parameters, and this method is the fuzzy logic prediction model. The system model, which affects the image quality, is given in Fig. 2.

The first step in this study, while the object size is accepted constant, optical path difference and the horizontal distance between the object and the reference waves are changed respectively. The reconstructed images of treble clef, which are obtained from the result of changing the horizontal distance and optical path difference, are shown in Fig. 3.