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Research Article

PARALLEL TECHNIQUES FOR DETECTING DEFECTS IN RADIOGRAPHIC EVALUATION OF OIL AND GAS PIPELINES USING IMAGE PROCESSING

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ABSTRACT
Pipelines are the safest and most economical way to transport the gas and condensations over long distances. Radiographic films are used as a tool for identifying welding defects of gas pipelines. The study of welding in oil and gas pipelines has always been one of the most important fields of NDT. Nowadays in many countries, expert interpreters are employed to interpret radiographic films of NDT. The inspectors can identify different levels of welding defects such as pores using radiographic films. Due to the limited number of these interpreters and their unavailability in some cases, there have been a lot of problems. To interpret radiographic films, we should collect and send them to the interpreter's office or his residential place to review them and announce the results. Furthermore, it is impossible to interpret a large number of films correctly in a limited time. The aim of this study is to present a method that can be used to interpret the radiographic films quickly and identify the welding defects in these films using parallel algorithms. Identifying welding defects is possible through image segmentation operation. One of the methods of image segmentation is region growing. The main feature of this method is its good performance on films such as radiographic images, which enjoy less variety. This method determines a pixel in the image as the beginning part and extends the area around the point according to the similarity that exists between the pixels of the image that separates it from the rest. In most proposals for improving the performance of the proposed method, the user specifies the seed coordinates. In this study, the image begins based on a histogram and the last part of the welding area is determined automatically. Then in order to identify defects on the image, a combination of different standard algorithms is used. Simulation results show that the proposed method has covered the shortcomings of previous methods and has made closer the detection of welding defects by computer to that of human, and sometimes is better than human performance. In addition, it has significantly increased the implementation speed.

Keywords: *Welding Defects, Parallel Algorithm, Radiography, Image Processing, Non-Destructive Testing*

INTRODUCTION
History of Image Processing
At early 1920s, one of the initial applications of digital photography was in the newspaper industry. Bertlan photo-transfer service cable transferred images between London and New York through the sea. The images were codified for transfer and at target; they were decoded on a telegraph printer (Figure 1). Mid-to-late 1920s, this system was upgraded, resulting in higher quality images. This new production was similar to processes based on photographic techniques. In 1960s, improvement in computations of technology and the competitive environment led to a wave of works in digital image processing. In 1964, computers were used to improve the quality of images taken from the moon by seven discoverers.
From the early 1980s until today, the use of digital image processing techniques has been increased and currently these techniques are used for any kind of work. In 1990, Hubble telescope could take pictures of objects far away. However, a false reflection made useless a large number of images sent by Hubble. It was this time that image-processing techniques were built to be used to reconstruct the images.

Figure 1: The first digital image that was published in 1921 by a telegraphic printer (Billingsley, 1970)

Statement of the Problem and the Necessity of the Research

Typically for each application in machine vision, an image segmentation phase is first performed. In output of this step, each object in the image is represented by a set of pixels. The purpose of this stage is that the objects and the backgrounds are separated except the sets that are overlapping. Image segmentation is generally based on two characteristics of light intensity and similarity. Methods proposed for segmenting images separate the objects in the image based on one of these two characteristics or a combination of them. For segmenting images, one of the following ways that are proposed in continuation can be used. The first way which is studied is the threshold limit. This method works in this way that by setting a threshold value, the values higher than the threshold limit are considered as an object and the lower values are considered as another object. The key point in this method is to determine the threshold limit. In the method, multilevel threshold limit can also be used. Threshold limit method is a simple method, which is used for optimized images that do not include a lot of objects (Batenburg, 2009). Histogram method is also one of the methods for image segmentation. In this method, a histogram of all pixels in the image is calculated and the ups and downs in the histogram are used for image segmentation (Ohlander, 1978). The color or intensity of light can be used for measurement. The implication of this method is that the image is divided into clusters using the ups and downs of the histogram. The disadvantage of histogram method is that the identification of the ups and downs in the image may be difficult (Ohlander, 1978). Edge detection method is also one of the methods for segmenting images. In this method, the boundary of the objects is detected using rapid changes in brightness intensity or color of the pixels. By detecting these borders, segmentation can be done in the best way (Basturk, 2009). Region growing method is also another method for segmenting images. In general, the way of its working is so that by determining a seed (starting point), the surrounding points are compared with the mean of the seed and other points of the region and in the case of having required similarity are considered as that region. The main problem of this method is that the seed must be determined manually, which prevents its automatic function. Another problem is that the noise severely influences its performance (Fan, 2001). This paper attempts to invent a combination method, which has the best efficacy for welding radiographic images by precisely investigating the algorithms that are subset of one or a combination of the mentioned methods.

The Basic Concepts of Image Processing and Review of the Conducted Researches

Today, with various improvements created in the methods of collecting discrete information such as scanners and digital cameras, image processing has many applications. Images resulting from this information have considerably had noise or sensible dullness, and in some cases, suffers from the problem of fading boundaries of the image, which reduces the received image resolution. We call the set of operations and processing performed in order to analyze image in various fields the image-processing science. Image processing science is one of the most applicable and useful sciences in the industry. Pixels are very fine and square-form dots that their accumulation forms the image on the screen or on paper (by printer). As *bit* is the smallest unit of information processed by the computer, *pixel* is the smallest element

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of the displaying or printing hardware and software used to form images. If only two colors (usually black and white) are considered for each pixel, that pixel can be coded by a single bit of information, and if more than two bits are used to represent a pixel, a wider range of colors or gray shades can be provided. The value of each point (full or empty) is saved in one or more bits of information. For simple monochromic images, a bit is sufficient to show each point, but in color images and gray shades, each point requires more than one bit of information. The greater the number of bits used to represent a point, the more the colors and gray shades we can represent. The density determines the dots or resolution of the image. We measure this feature by unit of dot per inch (DPI) or by the number of rows and columns, e.g., 640×480. To display bit map image on a monitor or to print it by a printer, computer converts the image to pixels for displaying on a monitor or to dots for printing. Images based on the bit map are always in the form of the large square-shaped networks. These networks are like chess board or kitchen floor mosaics. These large square-shaped networks composed of smaller squares (Gonzalez, 2002). One of the features we can always express about the networks is that they have dimensions. In fact, network dimensions are the number of squares, which have formed the length and width of the image and not related to the actual size of the picture. An image can be shown by a two-dimensional function of $f(x,y)$, where x and y are called local coordinates and the value of f at each point is called the intensity of image resolution at that point. The term 'gray level' also refers to the resolution intensity of monochromic images. Color images also consist of a number of two-dimensional images. When the values of x and y and the value of $f(x, y)$ are expressed by discrete and finite values, the image is called a digital image. Digitalization of the values of x and y is called sampling and digitalization of the value of $f(x, y)$ is called quantization. To display an M×N image, a two-dimensional matrix with M rows and N columns is used. The value of each element of the matrix represents the intensity of image resolution at that point. Each matrix element is an 8-bit value that can have a value between 0 and 255. Zero represents the dark color (black) and the value 255 represents the light color (white). For example, in figure 2, we have used a matrix with 256 rows and 256 columns to display the image. Each pixel of the image has a value between 0 and 255. Light colors have values close to 255 and dark colors have values close to zero. All functions of image processing use these values and apply necessary actions on the image (Gonzalez, 2002). Separation of two images with the same size means that we subtract the resolution density of corresponding pixels of the images from each other. When subtracting the pixel values, we convert negative values to zero. Adding two images means that we add the intensity of corresponding pixels in two images to each other. One of the most common applications of adding two images is to add a background to the image. Suppose we have several identical images that there are different noises on each of them and we want to improve the quality of the images. In such cases, we can use the averaging of all images, so that we sum the values of the corresponding pixels in all images and then divide it into the total number of images. Obviously, the more the number of images for averaging, the closer to reality the resulted image from their averaging will be (Gonzalez, 2002).

Figure 2: The gray level image

One of the useful features of the object recognition is to use the image information and its edges. Therefore, the use of edges in many machine vision applications and recognition is common. Various algorithms have been developed and proposed for detection. In classical methods of edge detection, we consider local maximums of image gradient as the appropriate representative for the edges. Robert, Sobel and Provit detectors belong to this category. Of other efficient algorithms in this field is Kani edge-detector, which is very applicable due to having the capability of following the edge and removing the image noise by Gaussian filter (Gonzalez, 2009).

Figure 3: The edge detection using Kani edge detector

Image histogram is a graph by which the number of pixels of each level of brightness is specified in the input image. Suppose the input image is a gray level image with 256 brightness levels, so each pixel of image can have a value in the range of 0 to 255. To get the image histogram, it is enough to calculate the number of pixels in each brightness level by measuring all p pixels of the image. We can also achieve normal histogram by dividing the values of the histogram into the total number of image pixels. Normalization of the histogram causes the histogram values are set in the range. Figure 4 shows an image with the normalized histogram. One of the applications of histogram is in the autofocus of digital cameras, such that the camera lens moves from beginning to end and at each step of its motion takes a picture of the scene. Then, it calculates the contrast of the taken image using its histogram. Once the lens reaches the end of its motion, a place of lens motion where the image has had the highest contrast is determined as the locus of lens. This method is one of the simplest ways of autofocus of camera and as we can guess this algorithm will have some drawbacks in the scenes, that there are dark and bright colors together, and we have to apply some changes in it (Gonzalez, 2009).

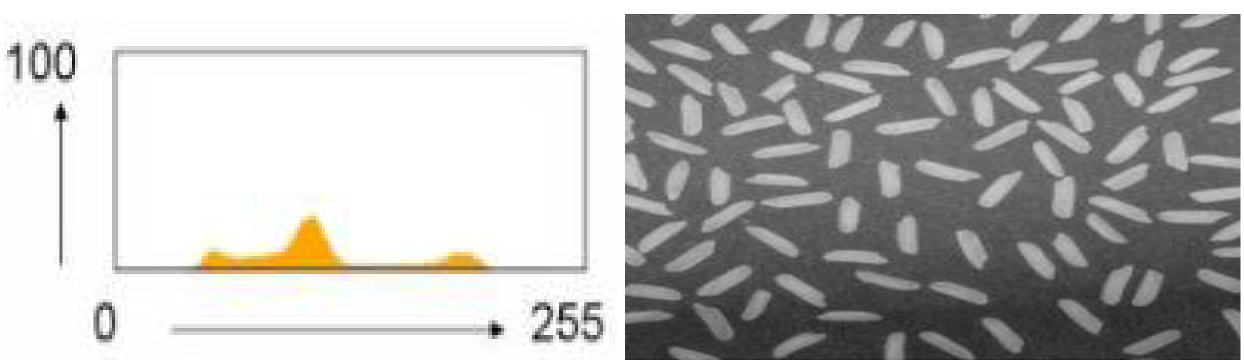

Figure 4: An image with the normalized histogram

Another usage of histogram is to increase the contrast in images with low contrast. When we say the image contrast is low, it means that the difference between the minimum and maximum image brightness is low (Gonzalez, 2009). Histogram equalization causes the contrast of the input image increase as much as possible. For example, Figure 5 shows an image before and after histogram equalization.

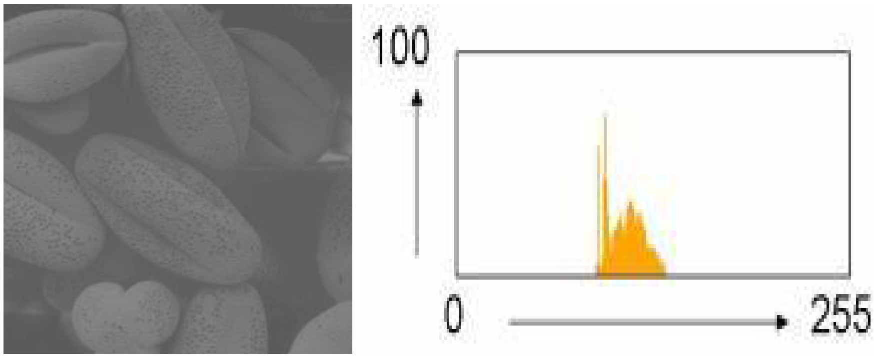

Figure 5a: Image before histogram equalization

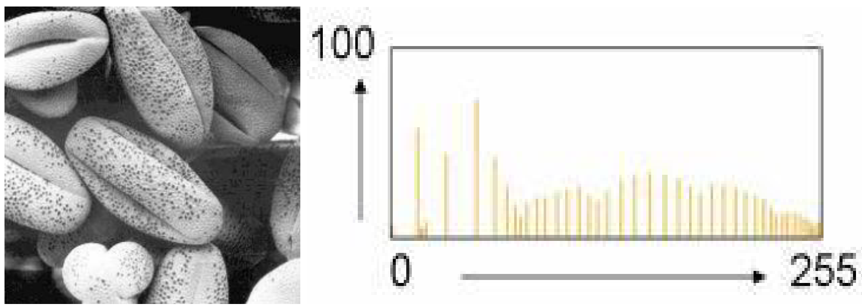

Figure 5b: Image after histogram equalization

Review of Literature

There are a variety of image interpretation systems which have created to detect welding defects in existing products to overcome the certain limitations such as the problem of inaccuracy in images, anisotropic brightness, conflicts, or disturbance of surface or sub-surface defects. However, the new system to interpret the images is necessary to overcome all the above-mentioned problems.

Over the past four decades, extensive production markets in the world have faced with severe competition for producing higher quality and lower cost productions. This has resulted in the broad improvements in technology required for automating the production processes, but the problems of interpretation and quality control has not been fully resolved yet. Because of these problems in the industry, the need for serious research on interpretation and quality control is essential. Interpretation of weld quality is performed using a variety of nondestructive tests. Although, the experts of image interpretation and quality control have better efficacy than machines of image interpretation in many cases, but they get quickly tired and the process of interpretation becomes slow and is ultimately delayed. Interpretation of weld defects when large numbers should be counted and interpreted is too difficult. Many stages of interpretations are time consuming and boring for interpreters. According to research done, the rate of human performance in visual interpretation is as much as 10% of energy consumption and cost of the mechanized systems (Carrasco, 2011). Moreover, expansion and development of interpreters' skills through training them is difficult and time consuming. Therefore, in such circumstances, the use of mechanized interpretations is a good alternative for interpreters. Non-destructive testing (NDT) includes methods for detecting defects in objects without changing them. Valid detection of the weld defects is one of the most important measures in NDT. Since the human factor is significantly effective in evaluations, therefore it is necessary to improve these methods. Welding is one of the main processes to connect and create a lot of artifacts and designed structures such as automobiles, ships, airplanes, spacecrafts and gas pipelines (Waren, 2009). Shafeek *et al.,* (2004) introduced a new automated system for detection and evaluation of welding defects in gas pipelines using radiographic films. This video system which is used to capture radiographic films can use various image processing and computer algorithms to detect welding defects and calculate the necessary information.

Shafeek *et al.*, (2004) introduced another visual system in which various image processing and computer image algorithms are use to take image by radiographic film to detect weld defects and take decision to adopt them using international standards. This system is capable to detect and test the main types of defects in welded gas pipelines that have been covered and protected. They are only applied to take separated images by radiographic films that are used to detect subsurface defects.

On the other hand, developments in the field of image processing, computer images, artificial intelligence and other fields have dramatically improved the efficiency of visual interpretation techniques. According to reports, about 60 to 90 percent of image applications in the existing devices relate to visual mechanized interpretations. The advantage of it is that it describes the objects numerically; therefore, it provides selection of good properties for success of algorithms. Generally, two-dimensional features are computationally simpler than three-dimensional features (Kim, 1999). Jagannathan (1997) proposed a new system to interpret the images of mechanized devices in the corrugated soldering area. Considering this technique, a smart histogram is obtained from the gray level histogram of the images and classifies the connections through various ways, and finally, it used the neural networks to identify and classify defective soldered joints.

Description of Problem

The large number of radiographic images of pipelines with long distance makes difficult and time consuming the detection of defects. The most difficult problem in the interpretation process is to detect the defects precisely in radiologic films. Interpretation of radiographic films by humans is too difficult when a large number of defects is counted and evaluated. It is clear that various experts do not have similar ideas about a particular film and even an expert may have different idea about one film at the beginning and end of the workday. In this section, we will introduce a new automated visual system for the detection and evaluation of weld defects of gas pipelines by studying radiographic film. Radiographic films of the welded pipelines are produced with radiographic testing (RT). This method is based on recording different doses of radiation absorbed by conventional radiographic film. The different levels of absorption produce an image of the studied object on a film. Film is chemically changed in order to specify the internal and external image of the object. We call this film the radiographic film. If the tested object by radiographic testing (RT) has some defects, the amount of radiation which is passed through the defected region to the rest of the film is more. The produced radiographs are interpreted and its integration can be evaluated by the interpreter or automatic interpretation systems.

When radiographic films are produced, image quality indicators (IQI) are adapted to on the radiographic films to give quantitative information about the sensitivity of the films produced. Image quality indicators are experimental cables that accurately control the dimensions and are produced by the same type of material which is used for radiography. The sensitivity of image quality indicators is measured based on the minimum visible size proportion to the thickness of the weld metal. Radiographic films used in this work are obtained from the projects of provincial gas companies and technical consulting companies in Iran. Radiographic films which are created of iridium 192 (Ir-192) are based on API 1104 standard that have been produced to meet the desired quality level.

The system presented by Jagannathan (1997) also is solely used to identify defects of the soldered areas. For this purpose, a camera and a movable table with several controllers and a microprocessor are used. The piece is placed on the table and when the table moves in front of the camera, several images are taken from it. The image data are then transferred to computer via RS232 port. To detect the defects, the neural network is used. To do so, a number of images are used for network training and based on these images the system detects the defects.

The system proposed by Saint (2012) also apparent weld defects (exterior surface) have been studied. For this purpose, images are taken from four LED lighting zone with different angles of the welded zone. Welds are classified in 4 different groups: acceptable, incomplete weld, extra-welded and non-welded groups. To detect defects, 80 different images (20 images for each group) were used to train the neural network. Then, performance of the system was examined using another 80 images, which the performance of the system was confirmed in 95% of cases.

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MATERIALS AND METHODS

The Research Method

The aim of this study is to provide a system for detecting defects in metal pipelines using radiographic films. This system, compared to the system provided by Shafeek *et al.*, applicable on any operating system and uses standard algorithms for image processing. In addition, to detect defects and dimensions of radiographic films, it does not require creating windows and getting additional information from the user.

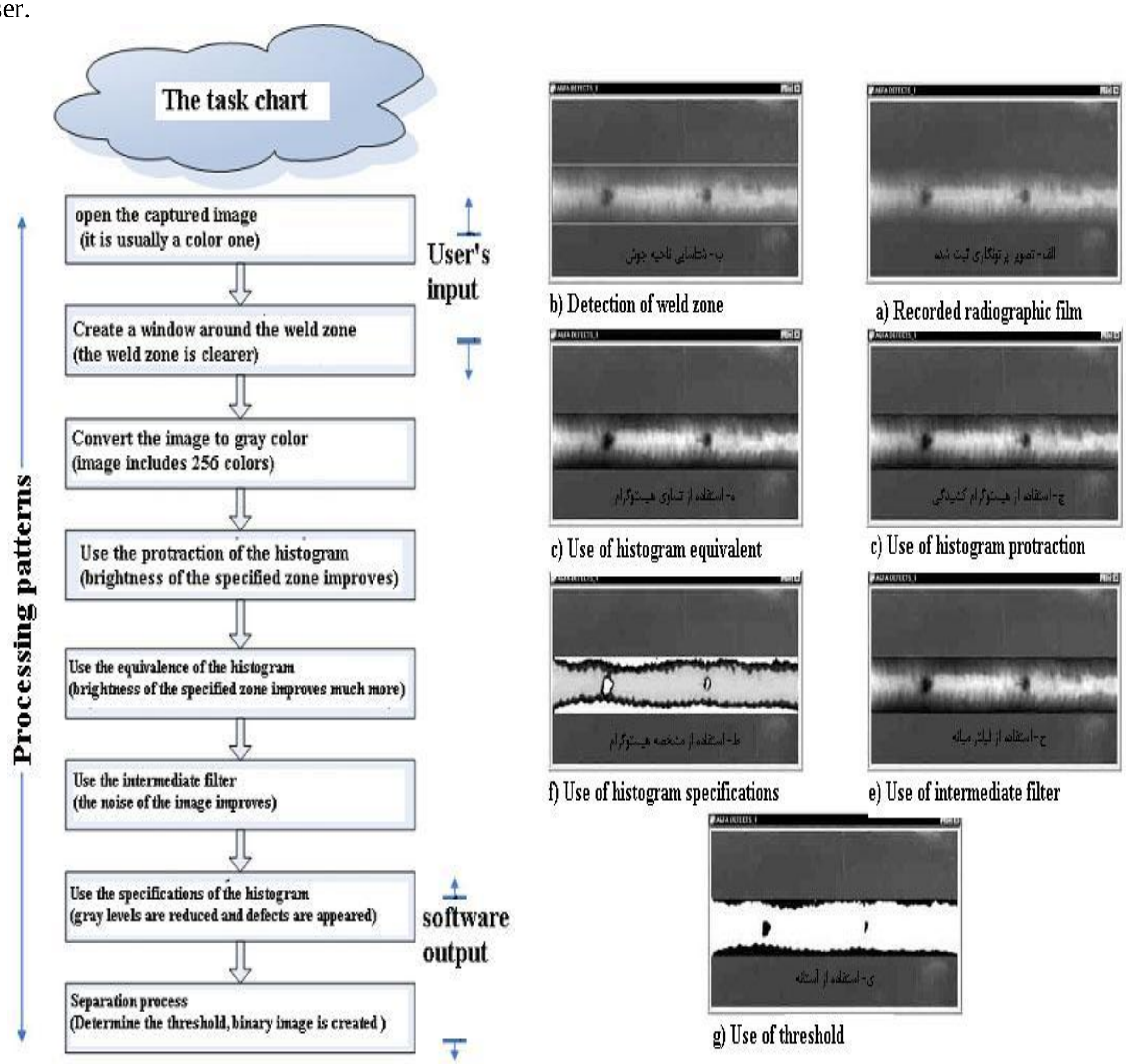

Figure 6: The main algorithms used to detect weld defects; Fig. (7) The results of system performance on images

In this system, the dimensions of the film are not important and the system automatically recognizes the weld area, that is, this system is used for each type of film. To identify the boundaries of the welding, image histogram is used and the weld zone is easily identifiable. To detect defects and enhance image quality, the standard algorithms are used. To test the system also like the system provided by Shafeek *et al.,* we have used the ideas of the expert of film interpretation (interpreter) and the system performance has been tested based on his idea on 80 different films with different light intensities. In addition, the provided system fixes the lack of details that have been caused due to darkness of the film, which its

cause is the lack of storage of films on magnetic tools. Also there is the possibility of saving images resulting from processing, and there is no need to reprocess the images in reviewing the images.
The provided visual system includes two parts: hardware and software. The hardware consists of a conventional computer with Windows XP or Win 7 operating system and also a digital camera and a light table. The software used also is 2013 version of MATLAB software to detect and evaluate defects in radiographic film of gas pipelines. This software is such that behaves with images such as mathematical matrices and makes easy doing mathematical operations on them, therefore any other software does not require. In addition, this software supports a great variety of image formats, such as: BMP, TIFF, GIF, JPG, PCX, and TGA. Work stages are as follows:
(A) Radiographic film is placed on the light table,
(B) The image is captured and saved by a digital camera,
(C) The image is transmitted to the computer using the interface software and saved as a BMP format file.
(D) The file is opened by MATLAB software and converted to a gray image,
(E) The weld zone is identified, and then the various algorithms are respectively used to detect defects.
Many parameters such as lens focal distance, lighting conditions, and the focus on the quality of the recorded images are influential. To obtain high-quality images, the radiographic films should be recorded under optimal conditions. IQI produced on the radiographic films are considered as an optimum target for evaluating the obtained image quality. Therefore, the conditions of record should be adjusted so that each IQI characteristic can be clearly seen on radiographic films.
There are many image processing algorithms in MATLAB software to be used in radiographic recorded images to detect weld defects and to extract useful information from them. Figure 6 shows a diagram of the basic algorithms used in MATLAB software. As it is clear in figure, these algorithms are used in the order they have shown.

RESULTS AND DISCUSSION

Simulation and Analysis Results

As shown in figure 7, a special radiographic film AGFA (the reference of weld radiographic interpretation) is used for testing. Approaches to identify defects of this image have been shown in the figure. Figure 7-c shows a special window after using histogram stretching algorithm surrounding the whole weld zone. In this image, the form of weld surface is improved and the two defects seem darker. As it is seen in figure 7-d, further improvement is obtained by using the algorithm of the equivalent histogram. In Figure 7-e, the image intermediate filter is used, so the image seems smoother than figure 7-d. In figure 7-f, the histogram certain algorithm has been used and defects are more obvious. Figure 7-g shows the binary image of weld zone after using the threshold calculation.

Conclusion

Conclusion and Suggestions

Separation of the boundaries of image for processing is related to types of the imager. As it can be seen in figure (7k), the gray scale of the defects is closer to the gray value of the surrounded area. Although two defects were detected, but it seems that the right hand defect is less than the main defect, because its boundary pixels of the defect have the light gray colors. Therefore, it is suggested that the surrounding area of each defect is specified separately and processing is performed on that area. Although a histogram system with appropriate density has been created and tested using many radiographic images, but some images needs a little change to have a proper input in density histogram. Pre-processing and algorithms of image improvement significantly influence on the results of the detected defects. Most of defects can be detected successively using mentioned algorithms. However, the change in the threshold level may trivially change the form of the detected defects but the general form of defects does not change.
Radiography is the most common method of non-destructive testing (NDT) and is broadly used to test the weld area of steel pipelines. Based on the subject maters stated the traditional method of film interpretation has some strengths and weaknesses that are as following:

Advantages of Traditional System

- The interpretation cost of each film through current system is less than that of mechanized system,
- It is possible to employ the interpreter person at any place (no electric power and special equipment is needed),
- The interpreter is able to explain about the image and its defects,
- In low quality images, the experience of the interpreter can help him in detecting defects.

Disadvantages of the Current Method

- The cost of training interpreters of the images is too high,
- Development of the interpreters' skills through their training is difficult and time-consuming,
- The interpreter person gets tired during the interpretation process,
- The interpretation process of images by interpreters is slow and time-consuming,
- Interpretation of radiography films with low quality is impossible,
- The efficacy of interpreter and correct interpretation is higher in initial hours of work that the last hours,
- The interpretation is a difficult task when a lot of welds must be counted and interpreted,
- Sometimes the interpretations of an interpreter are different at the beginning and end of office hours (human error),
- Sometimes different interpreters have different ideas about interpretation of a single film.

In the present study, we introduced an advanced system which is based on image processing to evaluate the defects of welding automatically in radiography. To test the system, 80 radiographic films at 4 different groups and 20 films per each group were used. It should be noted that to classify the films in theses groups, we have used the opinions of the interpreter. The groups used include: films without defect, films with one defect, films with two defects, and films with more than two defects. The performance of the system in processing images without defect is 100% identical with the interpreter's idea. In processing images with one defect is 95% identical with the interpreter's idea. In processing images with two defects, it is 100% identical with the interpreter's idea. In images with more than two defects, the performance of the system is better than interpreter, and in an image that the interpreter had detected three defects the system had detected four defects. The results of this test have been presented in table (1) and diagram (1). In addition, the proposed system fixes the lack of details which have been created due to darkness of the film and its reason is the lack of saving films on magnetic tools.

Table 1: Specifications of the studied films

Image group	Number of images for testing	Number of images detected by expert	Number of images detected by system	Percentage of agreement of the interpreter's ideas with system
Films without defect	20	20	20	100
Films with one defect	20	20	19	95
Films with two defects	20	20	20	100
Films with more than two defects	20	19	20	105

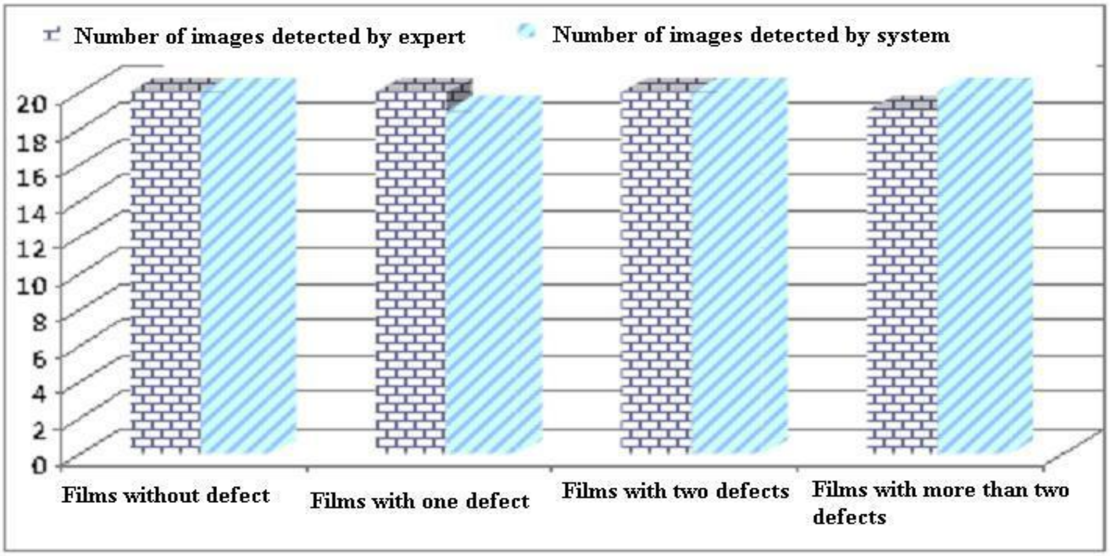

Diagram 2: Comparative diagram of the studied films by interpreter and system

As we mentioned previously, the use of parallel techniques especially pipelining method in the used algorithms has reduced the process time significantly. In this study, a system with two processors has been used. The real proportion of processing times to time of their series implementation using paralleled algorithms was about 40%. Table (2) represents the real time for detecting defects in the images of the four groups based on common and parallel methods. As we can see in the diagram (2), in the case of using parallel algorithms the time required to do calculation has been reduced than the common method and if we need to process a large number of images this value will be more significant.

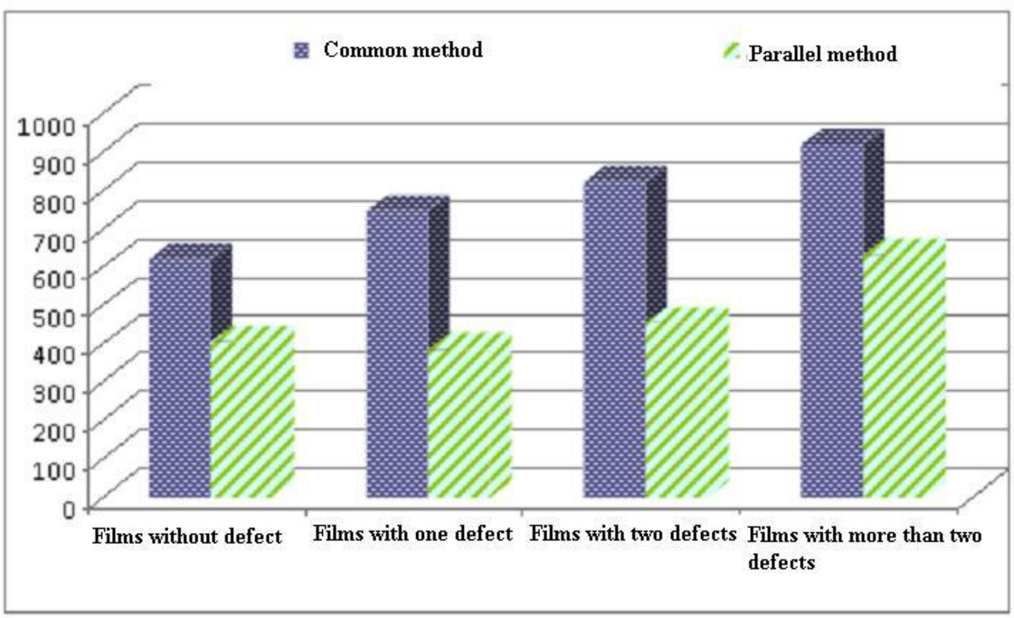

Diagram 2: Comparative diagram of real time for detecting defects

Suggestions and Future Works

In the case of using complementary information such as welding hour, welder’s code, climatic region, temperature of environment, the rate of humidity, and wind speed, etc., and creating a database using original images and processed images, we can select the best welder in necessary times such that the minimum errors exist in welding process.

Table 2: Real time for detecting defects

Image group	Number of images for testing	The required time for detecting defects (seconds)		Percentage of time reduction
		Common method	Parallel method	
Films without defect	20	616	402	34.74026
Films with one defect	20	742	382	48.51752
Films with two defects	20	816	452	44.60784
Films with more than two defects	20	916	628	31.44105

In addition, we can extract the circumference and area of the defects by standardizing the images.

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