Automatic Recognition of Weld Regions in Radiographic Images of Welded Joints

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ABSTRACT
The objective of the work consists in the design and implementation of techniques of automatic recognition of weld regions. It is aimed to complete a system of automatic inspection of radiographic images of welded joints. It deals with the problem of the delimitation of the weld regions according to the general scheme of image interpretation systems based on knowledge.

KEY WORDS
Radiographic inspection, image processing, segmentation techniques.

1. Introduction
In the last forty years, the Non Destructive Testing (NDT) methods have gone from being a simple laboratory curiosity to an essential tool in the industry. Nowadays there is no doubt of the outstanding importance of the industrial radiograph over the other NDT, so that the radiographic method has been accepted as an essential factor for the control of welded joints.

Both the difficulty of having experts to reliably detect and classify the defects in welded joints by means of radiographic inspection, and their costly training, justify the efforts for automation in this field. However, the desirable automation of this process encounters the obstacle of the necessary translation of expert’s impressions to computable information. Most of times the approaches are uncertain and the consequence of a biological learning of not well-known mechanisms. The application of techniques typical of Artificial Intelligence allows to modify the expectations of the automation of these tasks.

The present work is framed in the context of an open research line called Analysis of Radiographic Images of Welded Joints. The general objective of the research line can be summed up in the design and implementation of a system of automatic inspection of radiographic images of welded joints. This general objective consists of a series of particular objectives performed in different stages: hardware control for acquisition and storage of images, presentation and manipulation of images on a standard graphic environment, extraction of the relevant features in interest areas and their interactive presentation, pre-processing of the radiographic images to enhance the discriminating features for their following interpretation, multi-level segmentation of the scene to isolate the areas of interest, heterogeneities detection and classification in terms of individual and global features and severity evaluation of defect and degree of acceptance cataloging.

The early four stages of the system, which are directed to highlight the discriminating information that facilitates the expert’s analysis, were approached and resolved in the RXWELD system [1].

The segmentation process of the weld region probably constitutes the most delicate stage in the general system of automatic inspection of welded joints, the benefits of the system will depend of its reliability as a whole[2]. In this stage, the weld region must be isolated from the rest of the elements that compose this joint. Therefore, the scene of interest is framed for a later analysis directed to the detection of possible defects. Different types of processing techniques or specialists can be used for this objective, such as gradient operators, edge detectors, thresholding methods, etc., which are used to search discontinuities (points, lines and edges) on the image. Those specialists were developed and implemented in RXWELD. Nevertheless, this application shows a series of very specific features that make the implemented general purpose techniques fail in their attempt to segment the weld region. They also make depend the reliability of the segmentation process on the application of appropriate sequences of these specialists, starting from the knowledge of the models of objects that we seek to detect.

To sum up, before starting the detection and classification of heterogeneities task for their integration in an interpretation and automatic valuation of defects module, it is necessary the design, implementation and validation of specific segmentation techniques that allow the automatic recognition of welding regions. In brief, it is about solving the problem of the delimitation of the weld regions according to the general outline of images interpretation systems based on knowledge.
2. Weld Region Delimitation

The image segmentation in regions can be obtained from different types of specialists techniques, but the application of none of them provides optimum results for any image type, hence a different technique is used depending on the application type, although this choice is no way simple.

The generic techniques of image segmentation can be classified in two groups: edge-based techniques and region-based techniques. The edge-based methods try to find local discontinuities by means of the application of derivative operators and templates-based edge detection, whereas region-based methods try to find local areas with homogeneous properties, using region-growing techniques, pixels classification, thresholding, clustering algorithms, etc. The region-based techniques result in complete segmentations, but the edge-based techniques are not successful; the results obtained are incomplete and it is necessary a later phase of analysis and edge linking.

There exist many operators able to carry out edge detection as: Sobel, Prewitt, Marr-Hildreth, Shen-Castan, Canny, Kirsch, etc. All the points are often not valid candidates to be edge, and a threshold is usually required. The determination of the threshold is crucial, since in certain areas of the image, small variations of intensity correspond to edges, while in others, the existence of an edge is marked by a great variation of intensity. For this reason, the use of some type of adaptive threshold is frequent [3]. It is clear that, to carry out a good segmentation and obtain good results, it is necessary some specific a priori knowledge about the properties of the image [4]. The way of extracting elementary regions can be carried out from two point of views: classic and fuzzy approach [5]. From the classic point of view, we have segmentation techniques based on threshold (iterative selection, peaks detection, entropy, Chow-Kaneko, GLH, etc.), clustering, region growing (simple connection, hybrid connection, centroid connection, etc.), relaxation, syntactic and semantic approaches, etc. In the same way, fuzzy techniques also include methods based on edge detection, thresholding, clustering and relaxation. Lately, algorithms based on neuronal networks have been developed offering the great advantage of being successful in noisy environments and working in real time. The most used algorithms are those based on Hopfield and Kohonen networks.

In simple cases of welded joints, for example a plane piece with walls of medium thickness (5 mm.), more or less laborious thresholding operations together with the use of appropriate local properties can detect and mark the boundaries of the weld region with enough efficiency. However, thresholding operation is not enough for a weld region in pieces of high thickness or with serious irregularities as undercuts, contribution material lacks, reinforcements, form irregularities and so on, it is necessary to resort to other techniques.

It is interesting to note the relative lack of published works about the localisation of welds in automated radiographic inspection applications. Koshimizu and Yoshida [6] describe an approach based on simple edge detection in the 'expected' area of the weld region. For many applications this is unsuitable since the component is likely to change orientation and position during the inspection procedure. Furthermore, if the component being welded is of complex geometry then the simple edge detection of the weld boundaries may prove insufficient. Additional problems arise if the weld image contains significant amounts of noise or if the transition between weld and base material is somewhat diffuse. For these reasons a novel technique of adaptively recognising the weld region has been developed by Lawson and Parker [7] which is based on a multi-layer artificial neural network (ANN). The training of the network is achieved with a single image showing a typical weld in the run which is to be inspected, coupled with a very simple schematic weld 'template'.

In order to solve the problems appearing in the segmentation techniques previously mentioned, it is necessary to resort to the previous knowledge of radiographs of welded joints. In this sense, we have carried out and implemented a proposal in this work. This proposal resorts to the information provided by the radiograph to carry out its analysis. This proposal is an adaptation of the procedure used by Carreira [1996] for the delimitation of lungs contour on thorax images [8]. Basically, this technique makes successive segmentations on the image to isolate the weld region, after a previous phase of contour elimination. This proposal has been called progressive segmentation technique.

3. Progressive Segmentation Technique

This proposal to get the delimitation of the weld region assumes the formal framework of interpretation of images based on knowledge. The analysis process is carried out in three levels. In the low level, operations independent of the domain knowledge are performed on the image. This knowledge is implicitly used in the middle level and explicitly in the last phase or high level.

The control structure can be understood, on one hand, as a bottom-up control: we begin with a x-ray image on which several operations are developed, obtaining intermediate images until getting a final image on which the weld region appears alone. But this is not the only type of control, in the last part of the system hybrid control is used, where the flow is determined by the region type in search. The control is governed by the image characteristics regarding the identification of the weld region contour.

The previous three levels are connected through a database. This database store the original image, the different intermediate results and the final image with the isolated welded region. Intermediate results are images which have been obtained from the original image by different operations, as labelling, contouring, elimination of unnecessary information etc.
**Low level block:** The objective of the low level block is to segment the image in a group of homogeneous elementary regions. Even when these regions do not necessarily coincide with significant regions, they will constitute the elements for the interpretation of the scene. Two successive segmentations of the image are realized in this block. We attempt to divide the original image in diverse elementary regions in the first segmentation.

![Diagram of Low Level Block](image)

**Middle level block:** The objective of the second phase or middle level block is the refinement of the segmentation obtained in the previous block, confirming or not the presence of contours. It uses space information obtained from the image plane and takes the form in the use of parameters that control the process [11]. The image of contours obtained in the low level block is subjected to a process of vertexes codification that facilitates ulterior operations. This codification is carried out on the base of an ordinal number between 1 and 4, taking into account the four main directions. Therefore, beginning or ending contour vertexes will be considered as vertexes of order 1, contour continuation vertexes as vertexes of order 2, and as vertexes of order 3 and 4, those that constitute crossing points of three or four contours. The information generated from vertexes codification is managed in a data structure (array of properties), where all the contours and their longitudes are stored.

After the process of vertexes codification, the contour filing proceeds with the objective of purifying the detected contours, so that they can be traced tracked, starting from a initial vertex, directly, until their end, except for the crossing points among contours.
Once finished the filing, the obtained image is prepared for the contour tracking that will give rise to the elaboration of the array of properties of coded contours. This array of dimensions n contours x maximum length, where every labelled contour and their length are stored, will let know what pixel belongs to the contour and its location within the contour.

Once obtained the properties array, the polished process of the initial segmentation is developed, determining if the obtained contours are to be eliminated, modified or maintained. Domain knowledge is now introduced by means of three parameters that refer to the contrast threshold between two regions, likelihood percentage between two merit functions. It embraces grey level criteria, longitude and adjacent information and a last parameter indicating the minimum relationship among longitudes of two contours [12]. In the figure 2 the process is illustrated.

With the data available from the properties calculation and rectangle calculation stages, it will be possible to identify the weld region among all the regions. For that purpose, some criteria that most characterise all the weld regions will be established regarding the size of the region, average grey level and spatial position. The criterion determination is based on the analysis of the results obtained after the application of the progressive segmentation algorithm to a collection about 50 radiographs. If the regions typical of a weld region are defined, those that do not fit these features are eliminated. The basic scheme followed in this last block is shown in figure 3. An example of application of this technique is illustrated in figure 4.

**High level block:** The last phase or high level block will have the original image and the elementary regions image from the middle phase as inputs, and the resulting image with the weld region completely isolated as output. From the input images morphological, positional and relational properties characteristic of each region are calculated, (average value of grey level, area, center of masses coordinates and maximum and minimum value in two directions. Once these parameters are calculated the regions union is realized. In a parallel way to the calculation of properties, and for the purpose of locating each region spatially, the rectangle containing each region is calculated. Once the rectangles are calculated, the maxim coordinated that each region reaches will be determined in the ordinates and abscissas axes, what will let establish if two or more regions are intersections.
4. Validation and discussions

The validity of these techniques has been measured comparing them with the results obtained applying different generic algorithms of segmentation. Different techniques can be more successful depending on how "truth" is defined; majority vote, consent opinion, expert opinion, retrospective revision.

As comparative element, the area of the weld region was used, called "real weld region". It was manually identified by an experienced inspector of welded joints, quantifying in percentage the difference area between the real weld region and the weld region detected by each technique.

It is questionable to compare different segmentation techniques to get the weld region isolation because there is not a generic radiographic image database in which all the algorithms can compete. The degree of difficulty will depend on the image database used. As solution, we opted to qualify the images used in function of their own difficulty. Two different schemes of qualification were used. In the first one, the expert inspector qualified each radiograph in three categories depending on their radiographic appearance: radiographs of low, medium and high complexity. In the second scheme, three quantitative measures were used to characterize the image database. The first measure was thickness of the pieces of joint which was also classified in two categories: < 15 mm and > 15 mm joints thick. Using contrast as second measure, the database was ordered in three groups: low, medium and high contrast radiographs. Finally, considering the aspect of the grey level histograms, the images were grouped in another two categories: images with overlapped or non-overlapped histograms.

The results obtained from the group of techniques application that successfully detect the weld region in some of the test images are shown in table 1. We can notice that all the methods, apart from progressive segmentation, are unable to segment the weld region at least for one of the images. The profile-based segmentation technique, is the second method that offers a better mean, being located at 44.55%. However, it is unable to detect the weld region on some images of high level complexity. Finally, the progressive segmentation technique provides the best results, with a mean of difference area at 17.86%. Moreover, it is the only technique that works for all the tested images, for any complexity level. On the other hand, the adjustment for images of medium and low level is extremely good, providing a difference area below 10% for numerous cases.

Table 1. Adjustment values for different methods

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Mean v.</td>
<td>27.51</td>
<td>91.94</td>
<td>31.488</td>
<td>100</td>
</tr>
<tr>
<td>Iter. Sel.</td>
<td>26.13</td>
<td>47.72</td>
<td>12.732</td>
<td>100</td>
</tr>
<tr>
<td>GLH</td>
<td>27.63</td>
<td>48</td>
<td>12.452</td>
<td>100</td>
</tr>
<tr>
<td>Kapur</td>
<td>30.38</td>
<td>63.2</td>
<td>2.748</td>
<td>100</td>
</tr>
<tr>
<td>Entropy</td>
<td>23.67</td>
<td>69.92</td>
<td>9.468</td>
<td>100</td>
</tr>
<tr>
<td>Yager</td>
<td>46.1</td>
<td>75.36</td>
<td>14.908</td>
<td>100</td>
</tr>
<tr>
<td>Two peaks</td>
<td>53.28</td>
<td>85.52</td>
<td>25.068</td>
<td>100</td>
</tr>
<tr>
<td>Profile</td>
<td>14</td>
<td>44.55</td>
<td>15.902</td>
<td>100</td>
</tr>
<tr>
<td>Progres. S.</td>
<td>1.07</td>
<td>17.86</td>
<td>42.592</td>
<td>41.87</td>
</tr>
</tbody>
</table>

Global Mean: 60.452

5. Conclusions

The conclusions and main contributions that in our opinion this work presents are the following: We have presented and analysed the aspects related to the design and implementation of one new specific techniques of segmentation to get the automatic recognition of weld regions. This technique, progressive segmentation, assumes the formal framework of images interpretation based on knowledge.

After a test phase and updating to the specific technique proposed, we have assessed the relative benefits in comparison with other generic techniques. To sum up the validation process developed on fifty radiographs from the collection of the IFW (International Institute of Welding), we conclude that the technique proposed offer good results, which was able to isolate the weld region in all cases.

Finally, with the qualification indexes obtained from the image database, we have developed a process of comparison of the results obtained in the application of the proposed technique against the seven generic techniques that showed a better behaviour. We conclude that the progressive segmentation technique overcomes the other techniques in all cases and it is close to the detection realized by an expert in 82.14% mean.
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References


