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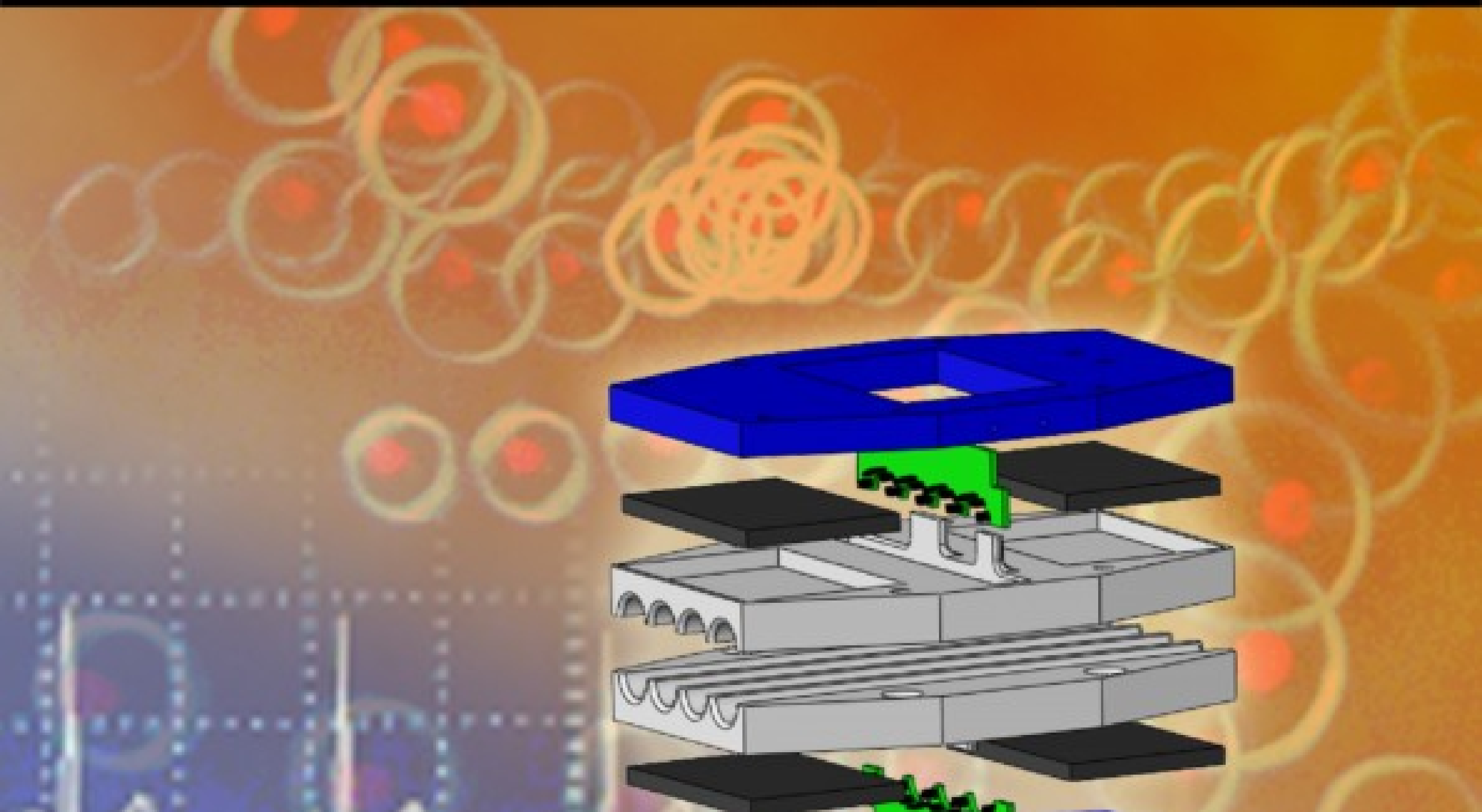

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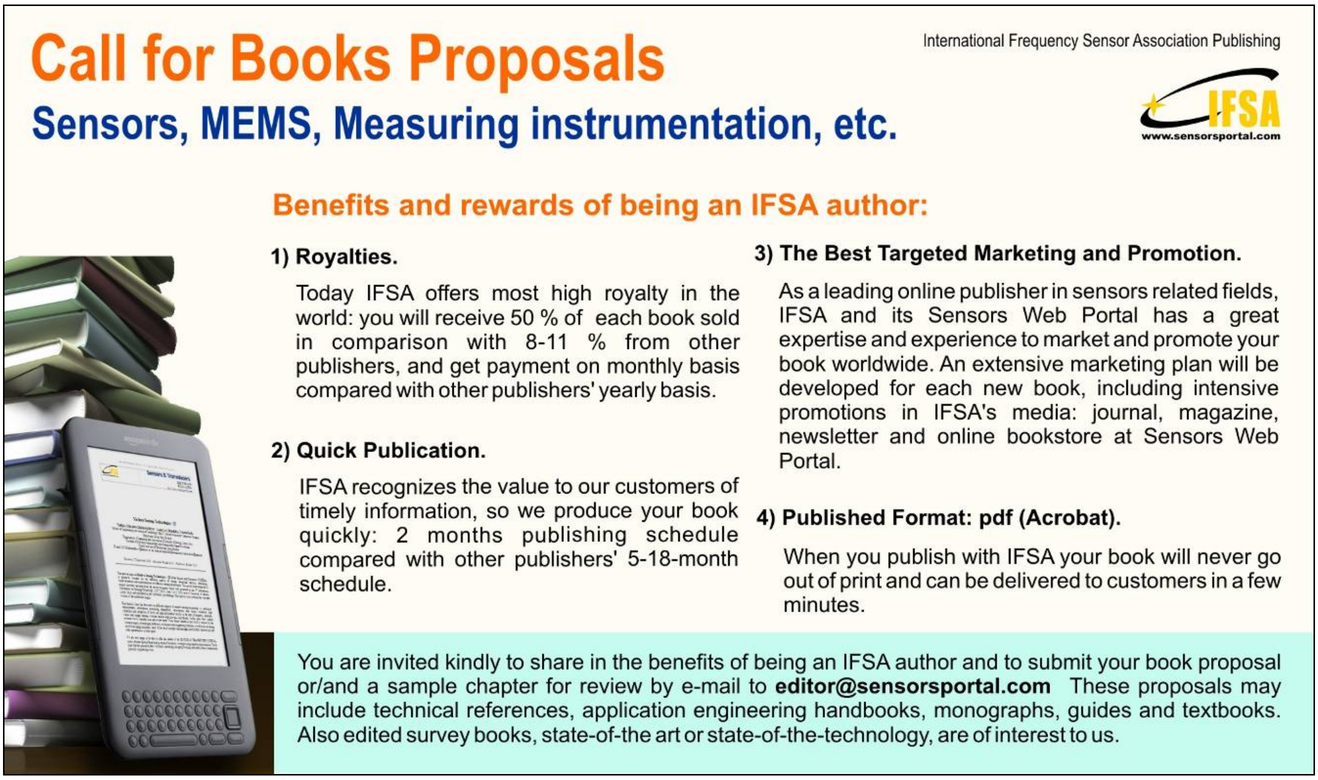

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Composition and Detection Rate of a Symmetry Axis Localization Algorithm for Digital Images

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Abstract: In this paper we describe a novel approach for the extraction of object features from a digital image captured in an industrial environment. The developed algorithm localizes the projected position of the symmetry axis of cylindrical objects. Conventional approaches to this task are often based on e.g. edge detection or image matching to determine object features. These methods tend to be time consuming and are not suited for online applications. The proposed algorithm utilizes sufficient statistics to reduce the amount of data which needs to be evaluated. In addition it determines the symmetry axis not from local but from global image features. This strategy significantly reduces the computation load, while purveying the desired information. Finally, we provide an application example and discuss some properties of the presented algorithm. *Copyright © 2010 IFSA.*

Keywords: Symmetry axis localization, Amplitude projection, Global image features, Online evaluation.

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1. Introduction

In recent years an increasing need for quality assurance in the manufacturing industry has arisen. Improved quality assurance methods offer numerous advantages to manufacturers and, subsequently, to their customers. Manufacturers can use various methods, such as on-line process monitoring, optimization algorithms and improved measurement systems, to improve the efficiency and the quality of their products. These methods facilitate the streamlining of production chains, optimize the utilization of time, energy and raw materials, and reduce the output of deficient goods. For these reasons, it is a necessity for manufacturers to develop novel quality assessment tools.

In this paper we develop a procedure which determines the location of object features. This task can be achieved employing diverse methods. Digital image processing represents one possible method which offers various advantages. The necessary imaging equipment is in general composed of commonly available parts. Imaging methods work without object contact. Hence, these methods do not affect the imaged object. After an image is captured, it can be analyzed using a multitude of algorithms. Difficulties arise when objects of interest are occluded by dust, smoke or objects in the foreground. Varying environmental conditions, such as scene illumination, also pose a challenge for the design of efficient and reliable image processing algorithms. If these difficulties are overcome, digital image processing methods constitute an effective tool for determining the location and orientation of objects.

Determining object features, such as edges or object orientation, from digital images has been a research topic for many years, see for example [1] and [2]. Thus, there already exists a variety of algorithms. These algorithms can be classified according to the basic principles they use. One class uses the Hough Transform (HT) or a variant thereof to localize objects. Examples for this approach are given in [3] and [4]. Due to their structure, HT-based algorithms are computationally expensive if applied to non trivial problems. Other well known classes of algorithms use edge detection techniques, see e.g. [5], or image matching, see e.g. [6]. The availability of abundant processing power has made it possible to employ increasingly complex algorithms. These algorithms are based on modern approaches, which use e.g. statistical methods, see [7]. Due to the long history of digital image processing, numerous algorithms are available which solve standard problems. Nevertheless, there exists no standard solution for arbitrary problems, e.g. for measurement setups with varying illumination or unknown object sizes. Therefore, it is still necessary to develop tailored algorithms for special applications.

This paper describes a novel algorithm which determines the location of the symmetry axis of a cylindrical object within a digital image. First, we define the task and describe the potentials and the restrictions of the measurement setup. Next, we explicate the different stages of the developed algorithm and provide an application example. Finally, we discuss different properties of the presented article and conclude with a list of further possible applications of the developed algorithm.

2. Task Description

The task at hand consists in developing an algorithm which locates the symmetry axis of single steel coils within images. We are interested in the radial symmetry axis. In a post processing step, which is not discussed in this paper, this location is subsequently utilized to determine whether the coils have been properly loaded onto trucks or railway cars. The images are captured after the loading process is completed. The coils appear as large cylindrical objects in the images. The algorithm is intended to be implemented as a part of a software tool for online quality assessment. Because processing time is scarce, one of the top priorities is to devise a fast and efficient procedure. The images are captured in a factory hall. This causes various limitations to the assumptions we can work on. We have only limited influence on the scene illumination. Shadows cast by moving machines, trucks and freight cars as well as variations due to weather conditions need to be considered. The cylindrical objects occur in different sizes and are clad in various kinds of packaging. The image background may contain arbitrary objects and/or patterns. Based on these considerations we decided to utilize image properties, which reappear in every image, to develop a solution.

There exist several image properties which can be utilized to solve the task. The images are captured after the coils have been placed into loading trays. These trays are always aligned in parallel to the image boarders. Thus, the alignment of the coils is known. Although the reflectivity of the coils varies according to their respective packaging, the coils predominantly appear as the brightest objects in the images. The camera has been positioned above the approximate center of the coils. This configuration is illustrated in Fig. 1. In combination with the chosen zoom lens this has the following consequences. Firstly, the coils appear near the center of the images. Secondly, the coils make up a large proportion of the image, in general at least 30 % of the image area. The listed properties characterize global image properties. In contrast to local properties, which are caused by singular objects, the global properties consist of a combination of various features. Therefore, global properties are more resistant to variations in environmental parameters, such as illumination. Hence, instead of using the local features of the cylindrical objects, or of elements within the background, we utilize the global image features, which are dominated by the cylindrical objects, to develop a solution.

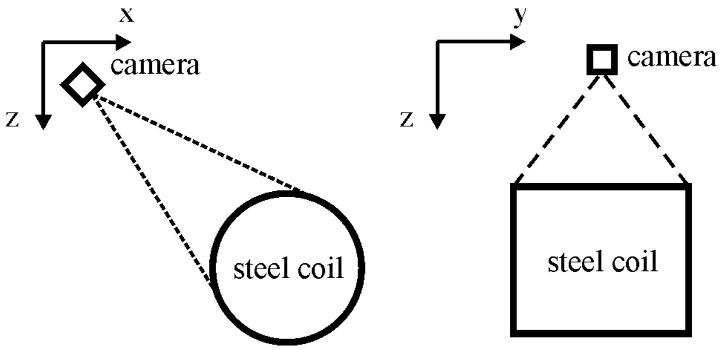

Fig. 1. Illustration of the measurement setup depicting view angle and camera position.

3. Proposed Algorithm

The proposed algorithm consists of four main parts. First, the algorithm starts with a vertical projection of the pixel values. Second, edges are extracted by applying a threshold algorithm to the projection result. Next, the edges are classified and erased, if they do not belong to a certain category. Finally, the remaining edges are evaluated, utilizing a modified correlation algorithm to extract the location of the symmetry axis directly from the edges. In an additional processing step, tangents to the borders of the cylindrical objects are found. The different parts of the algorithm are consecutively discussed in detail in this section.

In the first step, the algorithm projects the pixel values of the image. The pixel values represent brightness levels within the image. Image projection is a basic concept of digital image processing, and is mentioned in many introductory books, e.g. in [8] and [9]. Images may be projected along arbitrary directions. Based on the knowledge about the alignment of the cylindrical objects we utilize vertical projection. Fig. 2 illustrates the procedure. The figure shows the bright image of the projection of a cylindrical object embedded in a grey background, which is denoted by $I(x,y)$. Below the image the graph of the projection result is plotted. The effect of the bright object on the result is obvious. The vertical projection is defined by Equation (1):

$$V[x] = \frac{1}{Y}\sum_{y=1}^{Y} I(x,y), \tag{1}$$

where $I(x,y)$ represents the matrix of image pixel values and Y denotes the number of rows. The advantage of this procedure consists in the significant data reduction. Because we are only interested in variations of the global image features along the x-axis, the requirements for sufficient statistics are met, and therefore no significant information is lost via the projection along the y-axis. The intermediate result consists of a vector $V[x]$ containing averaged pixel values.

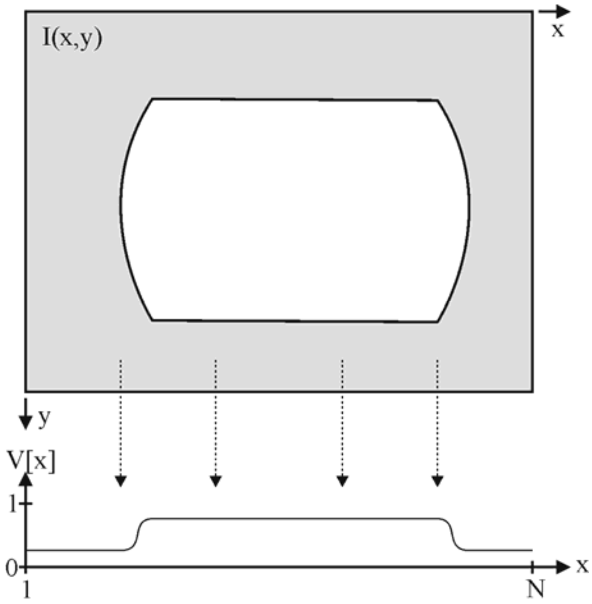

Fig. 2. Illustration of the vertical projection procedure.

The previous step yielded the averaged brightness values along the y-axis. In the next stage, these values are utilized to locate the position of edges in the image. We proceed by calculating a morphological gradient, following the ideas in [10]. Equation (2) defines a morphological gradient, which is obtained by calculating the maximum difference of elements of $V[x]$ within an interval of length $2p+1$:

$$F[x] = \max(V[x-p:x+p]) - \min(V[x-p:x+p]), \tag{2}$$

The gradient defined in Equation (2) can only assume positive quantities. If the gradient within the interval is significant, we interpret this as the occurrence of an edge. In a second step we apply a threshold which removes insignificant results. This procedure provides a vector, which contains the respective gradient values at indices where edges occur, and zeros where no edges were localized. In contrast to an elementary analysis, where only the immediately adjacent elements are evaluated, this approach provides smooth and more accentuated edges which benefits subsequent analysis.

The next step of the algorithm evaluates the result of the edge detection procedure. There are several possible sources of edges, which are detected by the previously described procedure. In general, edges are detected:

- at the boundary between bright and dark image areas, e.g. bright cylindrical object and dark background,
- if small bright objects are embedded in dark image areas, e.g. reflective scrap material,
- if strips of dark material are embedded in bright image areas, e.g. metal clamps.

We are mainly interested in edges which are produced by large cylindrical objects. Therefore, we attempt to remove all other edges. Edges at the boundary between bright and dark areas can be distinguished from other edges by comparing the surrounding brightness levels. The brightness levels at both sides of the boundary of cylindrical objects differ strongly. In comparison, the brightness around the edge of a metal clamp is roughly at the same level. The same holds for bright objects in dark image areas. Hence, we compare the brightness levels in a defined distance on both sides of the located edges. An edge is removed, if the difference lies below a certain threshold. This procedure provides a vector $G[x]$ containing mostly valid edges.

The final step of the algorithm consists in the search for symmetries within the result of the previous step. The idea is to utilize the global properties of the image. In Section 2 we proposed that the properties of the cylindrical objects govern the global image properties. Hence, in connection with the algorithm up to now, the remaining edges are related to the cylindrical object. From this it follows, that the point, which lies at the center of the detected edges, corresponds to the position of the symmetry axis of the cylindrical object. The position can be determined by checking for each vector element if the edges are aligned symmetrically around it. This is achieved by employing the modified correlation algorithm which is presented as pseudo code:

```
for(i1 = 1:length(G[x]))
    n1 = i1;
    n2 = i1+1;
    while(n1>=1 && n2 <= length(G[x]))
        if(G[n1] != 0 && G[n2] != 0)
            S[i1] = S[i1]+G[n1]+G[n2];                    (3)
        end
    n1 = n1-1;
    n2 = n2+1;
    end
end
```

where $S[x]$ contains the result of the analysis. The main difference in comparison to the autocorrelation algorithm is based on the varying length of the correlated vectors.

The procedure consists of several steps. First, a position between two vector elements is chosen. Second, beginning with the adjacent elements, the algorithm checks whether both elements contain an edge value. If this is the case, the values are added to and stored in the corresponding element of the result vector $S[x]$. Then the next pair of elements is checked by the algorithm until there exist no more element pairs. Finally, the next position is chosen. In addition, it is necessary to notice that edges are symmetric to themselves on a local level. This influences the result of the algorithm. In order to eliminate this influence we need to exclude edges which lie in the proximity of the currently evaluated point. The procedure is illustrated in Fig. 3 and Fig. 4. Each element of the result vector $S[x]$ contains the sum of all edge values which are symmetrically aligned around its position. The element with the maximum value represents the position of the symmetry axis.

In a post-processing step, the tangents to the edges of the cylindrical object can be determined easily. Starting at the symmetry axis it is necessary to search for the outermost pair of edges in whose center the symmetry axis is situated. The position of these edges represents the position of the tangents.

Fig. 3. Result of the edge extraction procedure applied to the result vector $V[x]$ in Fig. 2.

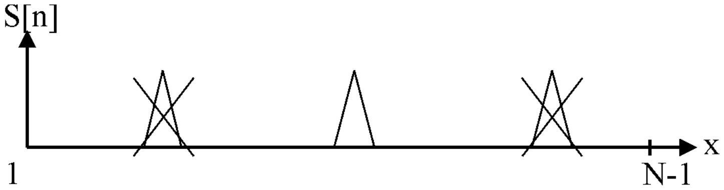

Fig. 4. Result of the symmetry analysis of $G[x]$ illustrated in Fig. 3 with crossed out local symmetries.

4. Application Example

The algorithm has been developed for locating the symmetry axis of steel coils. The task has been described in detail in Section 2. The digital images are captured in a factory hall using an industrial camera featuring a resolution of 1392×1040 pixels. The camera has been mounted onto the lifting crane which couples camera and crane movement. In general, the steel coils measure between 1 to 1.5 m in width and 1.5 to 2 m in diameter. From the distance between the camera and the coils results a pixel size of approximately 2×2 mm. It is required to locate the position of the symmetry axis with an accuracy of ± 30 mm. This equates to an allowable maximum deviation of ± 15 pixels.

In this section we present an application example. Fig. 5 (a) shows a typical photo of a coil which has been loaded to a freight car. The bulk of the loading tray is occluded by the coil. The coil is clad in cardboard and clamped with metal strips. Both features produce noticeable vertical edges. The background consists primarily of dark background containing numerous features, while the coil appears as a bright object in the image.

At first, the vertical projection of Fig. 5 (a) is calculated. The calculation result is illustrated in Fig. 5. (b). The resulting vector displays some interesting features. Embedded in the dark and complex background exist sparse and small bright objects. Due to the inherent averaging of the projection algorithm, neither these objects nor other patterns have a visible effect on the result. The edges of the coil, as well as the packaging and the clamps, are evident in the result. Horizontal features, such as the metal clamps, also do not noticeably affect the projection result.

Fig. 5 (c) illustrates the result of the edge detection algorithm. The remaining edges represent the position of the coil itself, the clamps and the cardboard packaging on the surface of the coil. All other features, including some spare edges, have been removed. It is worth noting, that through the composition of the edge detection algorithm the magnitude of the edges is preserved. This data is useful for the localization of the point of maximum symmetry.

Finally, the modified correlation algorithm is applied to the intermediate result in Fig. 5. (c). The result is illustrated in Fig. 5. (d). It consists of three different domains. The two small outer peaks at around index position 500 and 1200 represent the degree of symmetry between the coil edge, the packaging and the clamps at the left and right edge of the coil. The large central peak indicates the location of the symmetry axis. The adjoining smaller peaks indicate regions where some edges on the left side are symmetric to edges on the right side and vice versa.

In a post processing step, the tangents to the coil edges are determined. Starting from the position of the symmetry axis, the algorithm searches for the outermost pair of edges in the vector. This procedure is illustrated in Fig. 5. (d). The outermost pair of edges indicates the location of the coil tangents. Both, the position of the symmetry axis and the position of the coil tangents, are illustrated in Fig. 5. (e). In this example the symmetry axis has been localized with sufficient accuracy.

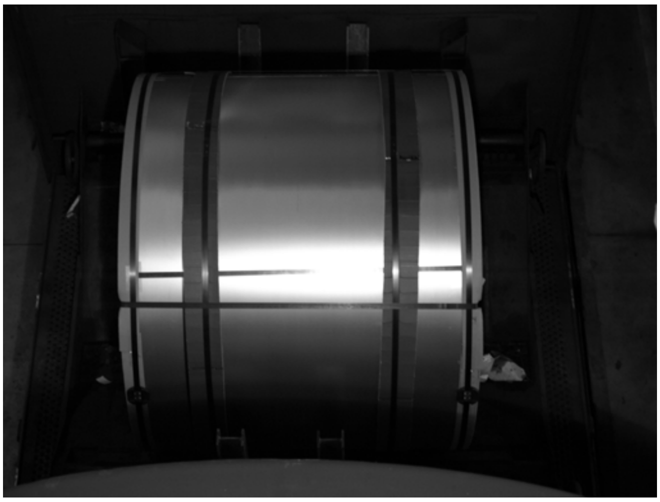

Fig. 5. (a) Example image showing a steel coil which rests in a loading tray on a freight car.

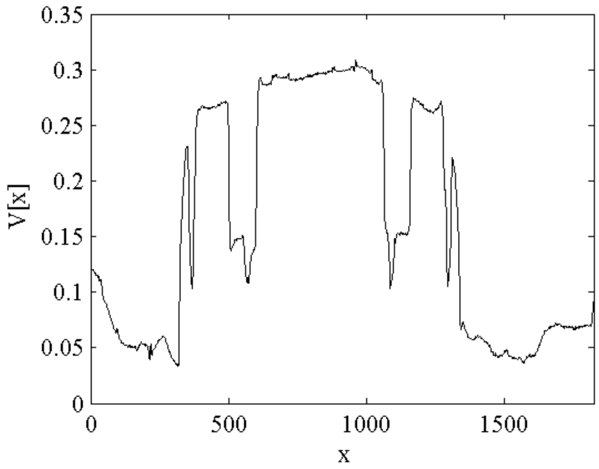

Fig. 5. (b) Result of the vertical projection procedure applied to Fig. 5. (a).

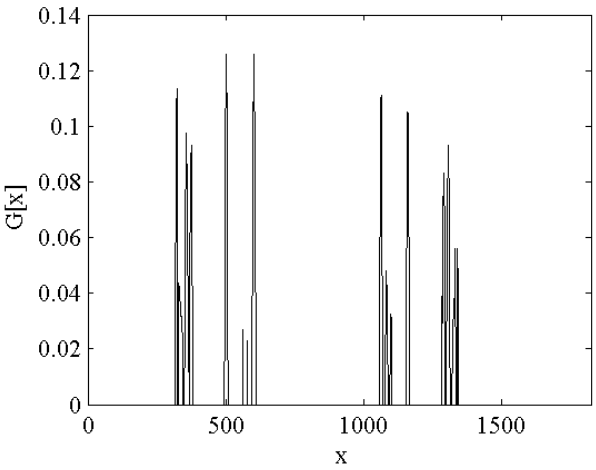

Fig. 5. (c) Edges detected in Fig. 5. (b).

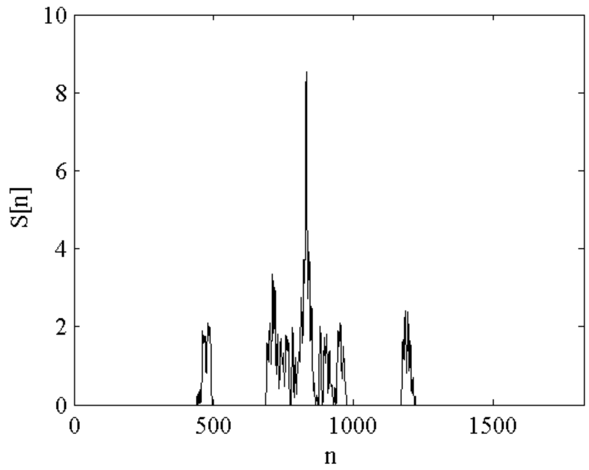

Fig. 5. (d) Result of symmetry analysis of Fig. 5. (c).

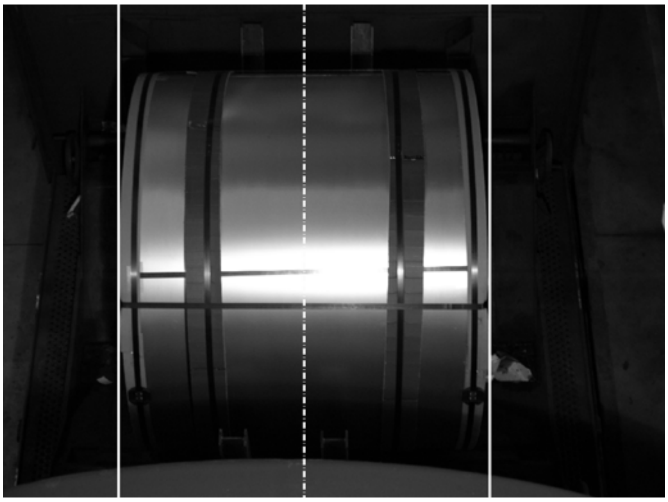

Fig. 5. (e) Illustration of example picture with drawn in detected symmetry axis and coil edges.

5. Algorithm Properties

In this section we analyze the proposed algorithm with regard to two different aspects. First, we discuss the benchmark which was utilized to rate the performance. Afterwards, we explore the effectiveness in terms of asymptotic computational complexity.

5.1. Detection Rate

The performance of the algorithm is determined by utilizing a benchmark. The benchmark consists of the precision, up to which the symmetry axis can be localized. If the position of the symmetry axis deviates 15 pixels or less from its manually determined position, the algorithm is considered to have located the axis successfully. Utilizing this definition, a detection rate can be defined. The detection rate indicated in Table 1. and Table 2. is defined as the ratio of successful determinations to the total number of images.

The detection rate was utilized for the optimization of the algorithm parameters. In Section 3 several parameters were defined during the development of the algorithm, namely two different thresholds and three different interval lengths. These parameters configure the sensitivity and selectivity of the various sub-procedures. They were determined utilizing training images while considering the detection rate. The training images cover numerous possible illumination levels, coil sizes, etc. Through an iteration process the detection rate was optimized. Employing the optimized set of parameters, the training images have been evaluated. Table 1 indicates the deviation of the calculated from the manually determined location of the symmetry axis. In addition, the detection rate of 82.76 % is specified. Table 2. indicates the same information concerning a set of test images and specifies the corresponding detection rate of 82.19 %. It worth noting, that especially for the training images the symmetry axis can be determined with either high or very low precision. This indicates the existence of conflicting parameter sets, which will be discussed in the next paragraph.

Table 1. Precision of localization and detection rate for the training images.

Deviation in pixels	**± 5**	**± 5 - 10**	**± 10 - 15**	**± 15 - 20**	**± 20 - 30**	**> 30**
Number of images	21	3	0	0	0	5
					Detection rate:	82.76 %

Table 2. Precision of localization and detection rate for the test images.

Deviation in pixels	**± 5**	**± 5 - 10**	**± 10 - 15**	**± 15 - 20**	**± 20 - 30**	**> 30**
Number of images	48	10	2	3	3	7
					Detection rate:	82.19 %

The detection rates appear to be low, but it is necessary to keep in mind the severe restrictions which are part of the task definition. The task allows for a wide range of variations in scene illumination, coil sizes, packaging types, etc. The optimization process has indicated, that while it is possible to locate the symmetry axis within every training image for certain sets of parameters, it is not possible to achieve this by employing a single set of parameters. Thus, the detection rate is acceptable. Nevertheless, the detection rate can be improved, if additional information about the measurement setup is obtainable, or if the environmental conditions, such as scene illumination, can be controlled.

5.2. Asymptotic Computational Complexity

The second important aspect of the algorithm consists in the amount of processing power it requires. A suitable benchmark for this aspect is provided by the asymptotic computational complexity. This well known benchmark is defined in numerous works, e.g. in [11], in terms of the Landau notation. The Landau notation indicates how the processing power required by an algorithm is related to the number of elements which are processed by the same algorithm. For the special case of a square image the complexity is $O(k)$, where k represents the total number of elements in the image. This means that for a square image the required processing power increases linearly with the number of elements. The reason for this very low complexity roots in the utilization of sufficient statistics described in Section 3.

6. Conclusions

In this paper we have described the development of an algorithm which localizes the symmetry axis of cylindrical objects in digital images. The task entailed the industrial environment where the images are captured as well as requirements concerning online evaluation. The presented algorithm uses global features to solve the task. This approach enables reliable localization and adequate detection rates, while saving computational resources.

The algorithm has been developed utilizing a rapid prototyping system (MATLAB® R2009a, 64 bit on the following system: IntelCore2Quad, 2.83 GHz, 4 GB RAM). It takes approximately 0.04 s to evaluate the algorithm, which is already fast enough for online evaluation. By implementing the algorithm in the C programming language, an improvement in computation speed by a factor 5 should be achievable.

There exist several possibilities for improvements. The precision and the detection rate of the algorithm can be improved if certain requirements are met. The manipulation of the scene illumination would benefit the detection rate. Additional knowledge about the type of packaging would enable the application of distinct optimized parameter sets.

The concept of global image features can be useful for fast edge detection algorithms. The approach disregards insignificant image details, which is an advantage, if they are negligible compared to the objects of interest. Variants of the approach can be used to extract other object features, e.g. the orientation of objects may be determined by creating and analyzing sub-images.

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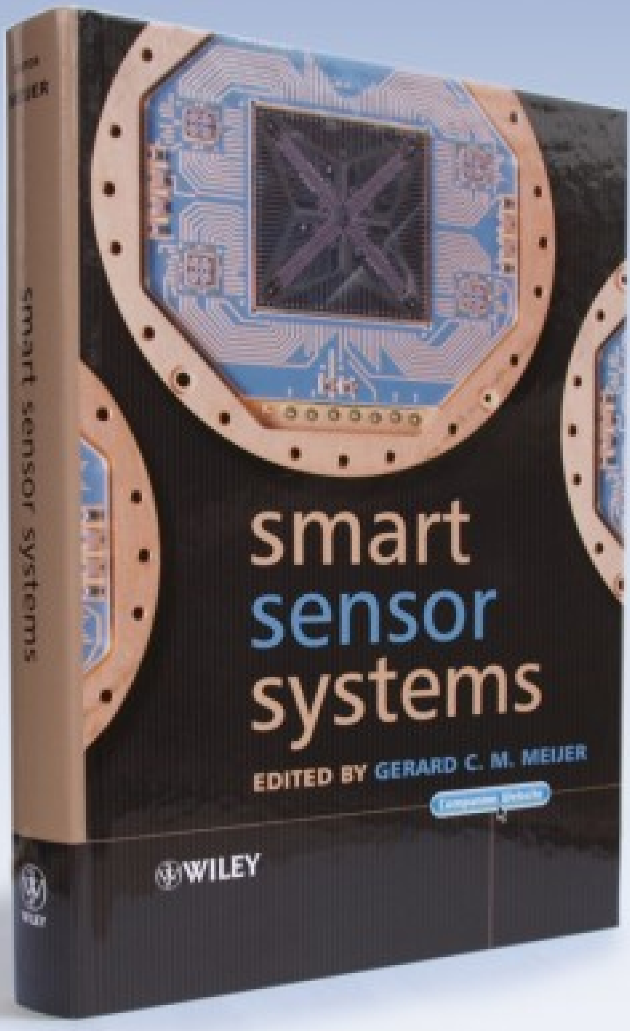
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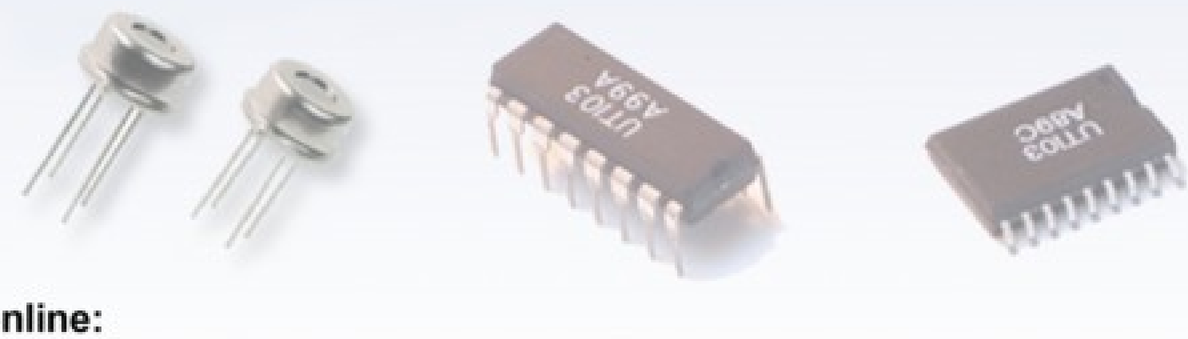
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