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Connecting Adjacent Images Captured by Machine Vision System of 2D Measurement using Hybrid Genetic Algorithm

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Abstract: *With continually increasing development of the industrial piece manufacturing technology the necessity of using high precision measurement devices is appeared. Machine vision based methods are a group of new approaches for measuring industrial pieces. These methods function by capturing image from the piece, so they don't need to be in contact with the piece during the measurement process and they have acceptable precision. When the total dimensions of the piece can't be fitted in one image frame, it is necessary to capture several images from different regions of the piece in order to cover all area of the piece. In this paper a new precise method for connecting captured images is proposed. In the proposed method two adjacent images are connected based on the recognizing their common part. Searching for the common part in two images is formulated as a genetic optimization problem by proper selection for chromosome structure. The fitness of each chromosome is defined based on the correlation between the first image and translated second image. The used genetic algorithm is hybridized with a classic local search algorithm. This leads to an increment in the speed of algorithm convergence, however the global searching is retained. This method can provide subpixel precision and is robust against the rotation of camera, noise and change of lightness of environment. Unlike the previous methods this method doesn't require to the camera calibration and knowing the amount of camera (piece) movement and therefore doesn't require to a precise camera (piece) displacement system. The practical results for different series of images present the validity of our method.*

Keywords: Machine vision, 2D Measurement, Image connecting, Hybrid genetic algorithm

1 Introduction

With continually increasing development of the industrial piece manufacturing technology the necessity of using high precision measurement systems is appeared. One of new measurement techniques is applying the machine vision methods. They use digital image processing techniques which are very extensive and applicable in different fields. These methods have no contact with the piece, so they are non-destructive. Also they present acceptable precision [1]. These are because in these methods the role of mechanical processes (hardware) is decreased and the presence of the software techniques becomes forceful. A sequence of stages followed in our previous approach for machine vision based measurement was described in reference [2]. The schematic configuration for the hardware of applied system has been shown in figure 1. This approach has consisted of two major phases. In the first phase the machine vision system is calibrated. In other words the transformation factors between 2D object coordinate system and image coordinate system is obtained. The second phase is operation phase where an unknown piece is measured or inspected. This phase is consisted of the following stages. The first stage is image acquisition. The second one is image filtering to reduce the noise effects. Third stage of the phase is high precision subpixel edge detection and the fourth is edge linking

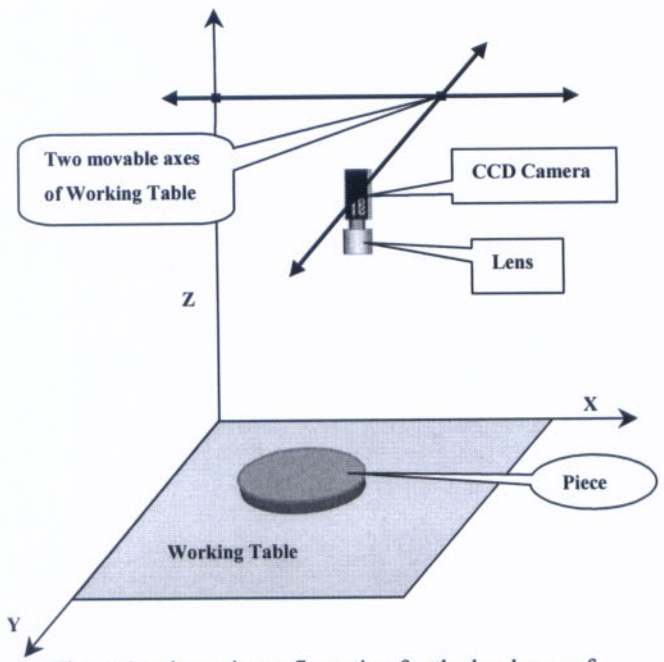

Figure 1: schematic configuration for the hardware of applied system

in which detected edges are connected to their neighbors intelligently and undesired edges are removed. In the fifth stage the continuous binary edges are transmitted to DXF[1] format file using calibration factors. This kind of file can be called by CAD[2] software for measurement and inspection tasks.

In later phase when the total dimensions of the piece can't be fitted in one image frame it is necessary to capture more than one image from the piece in order to cover all area of the piece. The higher desired precision (final resolution) the more amount of zooming is necessary for lens, so the larger number of images will be required to capture. Different images can be obtained by displacing the camera or piece horizontally. In the previous work the adjacent images were connected based on information about the camera (piece) movement and camera calibration. But this approach includes a considerable systematic error.

In this paper a new method for connecting captured images from industrial pieces is proposed. This approach connects two adjacent images based on recognizing their common part. Searching for the common part in two images is formulated as a genetic optimization problem.

In the next section general description of problem will be expressed. After definition of image registration, which the main idea of proposed method has risen out of it, the proposed method will be introduced in the third section. Section 4 is allocated to description of genetic based solution of problem, which includes genetic algorithm and applied hybrid genetic algorithm structure. The results of executing the implemented method for some real images are represented in section 5. Finally in section 6 we will conclude.

2 General Description of Problem

In measurement process when the surface of a piece is large enough or lens has been set to a high zooming, one can't cover all area of the piece completely by taking only one image. Therefor it is necessary to take several images from different regions of the piece by moving the camera or piece horizontally. These images are called partial images. To have the possibility of measuring or inspecting the distance between each pair of points or each existing feature (like line segment, circle, angle, arc, ellipse and so on) on the total area of piece assembly, it is necessary to connect partial images with an acceptable precision. The method has been used for connecting the partial images in our previous work was based on following information:

1- knowing the amount of camera movement

2- knowing the camera calibration factors

3- parallelism condition of the image coordinate axes with working table coordinate axes

In order to have enough precision in image connecting process all subsystems which produce this information should have an error less than the final desired maximum error for image connecting process.

• **Movement Error**

The subsystem has been used for moving the camera is consisted of two stepper motors that displace the movable axes of working table. The precision of these stepper motors is 0.05 mm. The camera is vertically fastened to these axes overlooking the surface of working table.

• **Calibration Error**

The calibration is performed using a known circular pattern. The error of this subsystem is related to the focal length which has been tuned for lens. For a topical state this error is approximately 0.05 mm.

[1]Drawing eXchange File

[2]Computer Aided Design

• **Parallelism Error**

If image axes aren't parallel with working table axes, moving along any axis of working table results in a displacement which will have component along the other axis of the image too and this leads to another error.

Therefore a machine vision based measurement system that uses this method for connecting its partial images will get involved in large error.

The new method proposed in this paper is a high precision method for connecting these images. This method is robust and independent of all the previous limitations and is able to provide subpixel precision.

3 Proposed Method

3.1 Image Registration

Digital image registration is an important subject for many applications, such as medical imagery, robotics, visual inspection, remote sensing and surveying [3][4]. Image registration is a process that determines the most accurate relative orientation between two or more images. Given two images, image registration attempt to coincide the second image to first one using translation and rotation transforms so that the common part of images overlaps as well as possible.

3.2 New Approach Based on Image Registration

According to aforementioned statements, based on the common part of two adjacent images we can slide one of images on the other one so that the common part of second image coincide with common part of the first image exactly (figure 2).

The produced situation after matching the common part of two images is the desired connection (figure 2(D)). To have a higher precision, (subpixel precision) images should be zoomed initially (each pixel should be fragmented into several smaller pixels). A criterion is required to indicate how much the common part of two images is coincided. The criterion used here is the correlation function of two images when the second image is translated by vector **r** respect to first image (figure 2(C,D)). This function is defined as follows:

$$C(\mathbf{A},\mathbf{B}^{\mathbf{r}}) = \frac{\sum_{i=1}^{H_r}\sum_{j=1}^{W_r}(\mathbf{A}_{i,j}-\overline{\mathbf{A}}_r)(\mathbf{B}_{i,j}-\overline{\mathbf{B}}_r)}{\sqrt{\sum_{i=1}^{H_r}\sum_{j=1}^{W_r}(\mathbf{A}_{i,j}-\overline{\mathbf{A}}_r)^2\sum_{i=1}^{H_r}\sum_{j=1}^{W_r}(\mathbf{B}_{i,j}-\overline{\mathbf{B}}_r)^2}} \qquad (1)$$

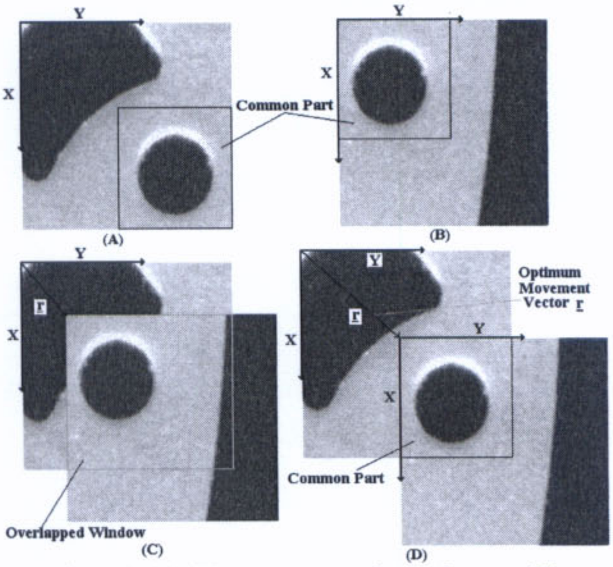

Figure 2: (A),(B) common part in two images, (C) incomplete coincidence, (D) complete coincidence

where $\mathbf{H}_r$ and $\mathbf{W}_r$ are height and width of the overlapped windows. $\overline{\mathbf{A}}_r$ and $\overline{\mathbf{B}}_r$ are the mean intensities of these windows in two images. $\mathbf{A}_{i,j}$ and $\mathbf{B}_{i,j}$ are intensities of pixels located in the overlapped windows of two images. The mentioned correlation functions is an objective function depending on contains of images can have several local optima. Additionally noise which may be caused by different sources [5,6] affects the objective function and adds some false optima to it. Considering these problems and due to competence and robustness of genetic algorithms in noisy environments, it is preferable using these algorithms rather than classic optimization approaches for solving this problem.

Variation of lightness conditions in the environment may lead to difference between the overall intensities of different images, however this has no effect on the objective function because the mean value of intensity is subtracted from intensity of each pixel. In this problem the aim is to find the vector **r** so it maximizes the correlation function of two overlapped windows of images.

In order to speed up the convergence and have a continuously improving in local search phase of applied genetic algorithm, this algorithm has been combined with a local classic search algorithm. More details about the applied genetic algorithm have been stated in the next section.

4 Genetic Based Solution of problem

4.1 Genetic Algorithm

The genetic algorithm is a stochastic parallel search technique that mimics natural evolution to solve problem in a wide variety of domains such as optimization, automatic programming, machine learning and modeling of complex systems. Particularly, the GA is used as an optimization algorithm for the solution of complex engineering problems. This optimization algorithm starts the search in the decision space with a random initial population of individual called a generation. Each individual is a potential solution for the optimization problem and typically is represented by a binary string known as chromosome. The GA is basically a method for moving from one generation to a new generation, using a set of biologically inspired operators, i.e. selection, crossover and mutation. According to evolutionary theory based on Charles Darwin's model, individuals with better performance or fitness (having a cost function value) have more chance to be included in the new generation. Therefor during each generation the GA performs probabilistic and fitness proportionate selection to choose chromosomes for further processing by other operators. After selecting two chromosomes (parents), the crossover or recombination operator is applied with a constant probability rate to produce new chromosomes (offspring) in the new generation. This operator exchanges subparts of two selected chromosomes like sexual recombination in the biology. Because all genetic structures in the search space can not be produced by crossover operator, the mutation operator is used to create different structures in the population. It changes randomly the values of some bits (genes) in each selected chromosome. The forgoing three steps are repeated until the next generation is completed. The GA proceeds for a fixed number of generation or until a stopping criterion is satisfied. It should be noted that the above description introduces the GA in general whereas the implementation can be carried out in different forms. Researchers have experimented with different types of selection mechanism (roulette-wheel selection, tournament selection,), crossover (uniform crossover, single or two point crossover,), representations and special-purpose operators. Additionally elitism is an useful and popular mechanism that is used in the GA to improve convergence of the search process. Elitism selection methods ensure that some of the good solutions will not be lost. The most important advantages of the GA are its ability to search globally optimal solution and its flexibility in the modeling of complex optimization problems.

The two main steps for the translation of an optimization problem to an evolutionary optimization problem are chromosome representation and chromosome evaluation. In the first step, which is problem specific, the solution of the optimization problem is represented in the form of a chromosome. In the second step, an evaluation function serving as fitness function is introduced in order to compare the chromosome in the evolution process. The encoding of the problem and the selection of a proper fitness function have important effects on the success of the GA method.

4.2 Applied Hybrid Genetic Algorithm

As mentioned before, the aim of solving this problem is finding the optimum vector **r** . This vector has two components **x** and **y** which can also be negative. The selected chromosome contains the binary codes equivalent to these numbers, but for eliminating the deceptive effect of sign bits and simplicity in software implementation the numbers have been added to offsets to be always positive. The range of valid values for **x** and **y** are as follows:

$$|\mathbf{x}| < 2^{\left\lfloor \mathrm{LOG}_2^{M} \right\rfloor} \quad , \quad |\mathbf{y}| < 2^{\left\lfloor \mathrm{LOG}_2^{N} \right\rfloor} \qquad (2)$$

where M and N are height and width of image respectively. The applied genetic algorithm uses the selection, elitism, crossover and mutation operators. Elitism operator causes the population always keeps it's best individual for the next generation. Population size is 100 and the number of generations is 30. Selection mechanism in the 8 first generations is random selection and fitness is not important. Further in the reproducing the new generation two similar individuals can't be selected together. The probability of crossover is set 0.7 and cutting positions are middle of code strings associated with **x** and **y** and the boundary between two strings. The probability of mutation changes dynamically from 0.32 for first generation and 0.2 for last generation. During this operation one bit from **x** and one bit from **y** change. These abnormal properties of the applied genetic algorithm are for keeping diversity. In the end of each generation best individual (solution) has been improved by one pixel. It means if the best solution in the current generation is (**x**,**y**) it will change to one of its eight neighbors ($(x\pm1,y\pm1)$, $(x, y\pm1)$ and $(x\pm1,y)$) if this new solution has a better fitness. This is the classic phase of the algorithm. The reason why improving the solution is as much as only one pixel is that for each improvement step eight fitness evaluations should be performed however the current best individual is not necessarily in the domain of global best individual. For reducing the calculation time consumed for evaluating the fitness function, it is possible to calculate only the correlation of a limited number of samples rather than all pixels. Also it is better to use smaller sample size for the first generations and larger sample size for the last generations [7].

5 Results

The foregoing algorithm has been implemented using Visual C++ programming software. In this implementing crossover and mutation operators were modeled by means of logical operators. A four-bytes integer variable was used as chromosome however only a part of its bits were used. Figures 3(A,B) and 5(A,B) show two pairs of images which are to be connected. Figures 4 and 6 show the results of connecting the images in figures 3 and 5 respectively using proposed algorithm. The final error through proposed method in the presented results is less than one pixel. In these examinations no initial zooming is used. However if initial zooming is used the results will be better. Some noise has been added to images in figures 3(A,B), the result (figure 4) shows the robustness of algorithm against the noise. However the image in figure 3(B) is resultant of camera movement only in one direction relative to its original position (figure 3(A)), the result of connecting these images (figure 4) shows both components of translation vector are non-zero. This is because of a bit amount of rotation of camera which is not visible and correctable in practice. Although figures 5(A,B) are images of two regions of a piece which have been captured in different illuminations of environment, fortunately this illumination variation has no effect on the performance of algorithm (figure 6). Figure 7 is the result of connecting images in figures 5(A,B) only based on knowing the camera movement and calibration (previous method).

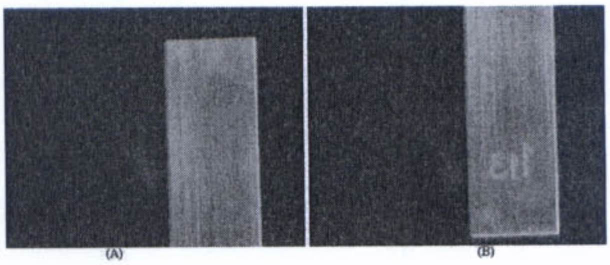

Figure 3: Two images of two regions of a gauge block

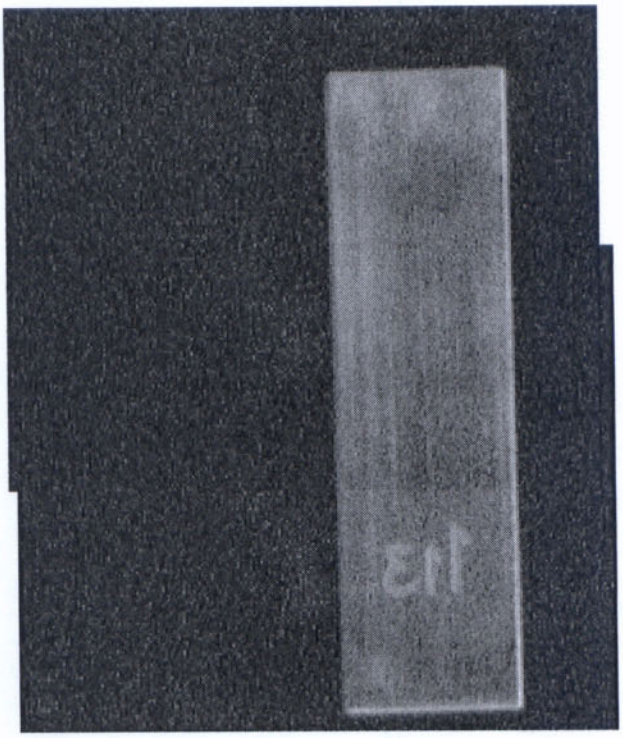

Figure 4: Connecting the two previous images using proposed algorithm

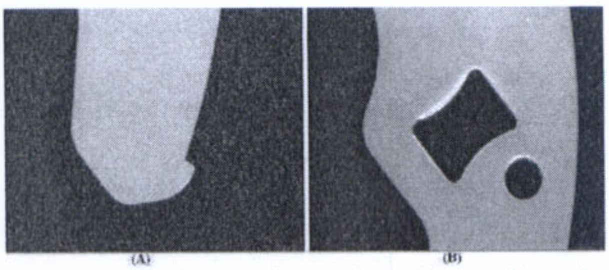

Figure 5: Two images of two regions of a manufactured piece

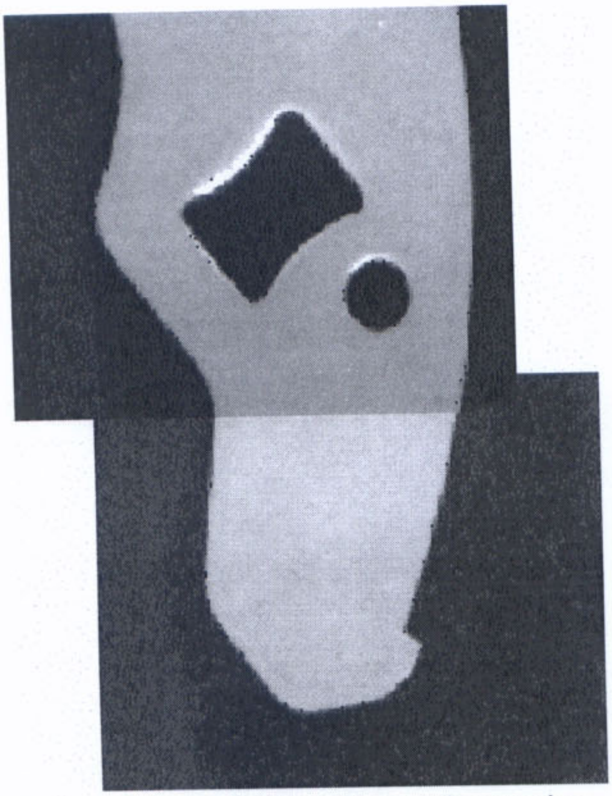

Figure 6: Connecting the two previous images using proposed algorithm

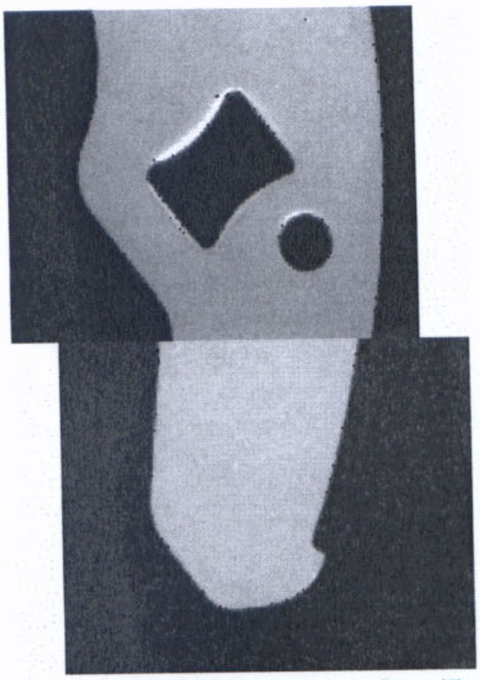

Figure 7: Connecting the two images in figure(5) using previous method (knowing the camera movement and calibration)

6 Conclusion

One of the most important stages followed in a machine vision system of 2D measurement is connecting partial images captured from different regions of a piece. Without applying a precise technique to accomplish this task final results of measurement system won't have an acceptable precision. The proposed method is a useful and completely new technique in machine vision based measurement systems. When this technique is used in the measurement system, it is not necessary to be worried about the precision of applied stepper motors and camera calibration because this technique is hardware independent. Additionally it is robust against the noise and illumination variations of environment. The error of this method is less than one pixel. In order to have a further precision (subpixel) for connecting images one can use an initial zooming for images.

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