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Hardware-Software Implementation of Rigid Image Registration with Particle Swarm Optimization Algorithm

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ABSTRACT
In this paper, SoC based hardware-software implementation is proposed for image registration process using Particle Swarm Optimization (PSO) algorithm. Zynq 7000 SoC platform is used to perform image registration of the standard test images under test.Particle Swarm Optimization (PSO) algorithm is developed in FPGA hardware and is considered as an optimizer that maximizes the Symmetric Index (SI) of the registered images. OpenCV functions are used in SoC hardware for image processing and histogram matching. The similarity of two images is checked using fourdifferent histogram matching functions: (1) Correlation, (2) Chi-square, (3) Intersections and, (4) Bhattacharya distance. Implementation results show that correlation function performs better than other three histogram functions.

Keywords: Particle Swarm Optimization (PSO), image registration, Xilinx's Zynq board FPGA, Mutual Information (MI).

Introduction

The image processing has been extensively uses for solving complex issues. Automatic detection and recognition of the object is the major research task in the field of computer vision and pattern recognition. Image registration is a fundamental task in image processing used to match two or more pictures taken at different times, from different sensors, or from different viewpoints (angle). In recent years, hardware-software hybrid approach to solve the optimized problem is hot research topics in the field of computer vision. Recent devotement in SoC hardware is capable to solve these type of real time applications. Although, developing an image processing algorithm in reconfigurable hardware demands several issues to work out like hardware limitation, Image format conversion, memory, complex mathematical algorithms.
To overcome these issues, we have migrated design tool from ISE-SDK to Vivado-HLS. Zynq 7000 SoC based Hardware-Software co-design proposed. The thought behind utilizing Zynq SoC is to use the software-based OpenCV image processing functions and to perform a few image registrations steps in FPGA.
Different algorithms with a comprehensive survey of the iterative solution of any problem explained by Nadhir et al. (2015). In which, overall performance of various Swarm Intelligence (SI) methods compare with different parameters. Genetic Algorithm (GA), Differential Evaluation (DE), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Artificial Bee Colony (ABC), Cuckoo Search Algorithm (CSA), Glowworm Search Optimization (GSO).
The appropriate method with high accuracy depends on different characteristics of parameters. For presented work, we use a combination of PSO with image registration to get desired results.
The article started with the basics of image registration and PSO and followed by a literature survey. Then hardware-software co-design with using Xilinx's Vivado tool is explained. The implementation of the PSO with hardware architecture demonstrated in the following sections. From there, the different histogram matching techniques with the result presented. In the last conclusion, future scope and limitations explained.

1.1.Image Registration

Image Registration is the process of overlay two or more images of the same scene taken at a different time or at the same time by different sensors as shown in Figure 1. Image registration is a fundamental task in digital image processing used to match two or more pictures taken at different times, from various sensors, or different viewpoints (angle). Virtually all extensive systems that evaluate images (e.g., Image fusion) require the registration of images as an intermediate step. Registration is a significant component that includes matching a target with a real-time picture of a scene for target recognition, monitoring global land usage using satellite images, navigation, and aligning images from different medical modalities (like EMR and CT scan) for diagnosis. Image registration or image alignment algorithms can classify into intensity-based and feature-based. Examples of systems where image registration is a significant component include matching a target with a real-time image.

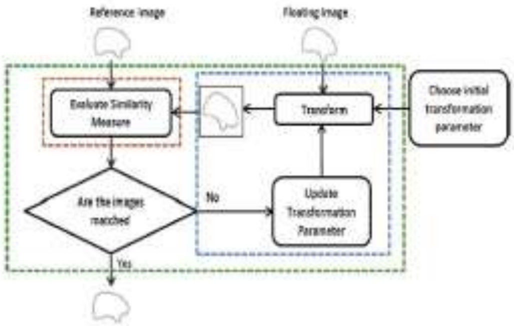

Fig. (1) Image registration [12].

Any image registration technique's fundamental characteristic is the type of spatial transformation or mapping used to overlay two images properly. The most common changes are rigid-body, affine, projective, perspective, and global polynomial. Rigid-body transformation is composed of a combination of rotation, a translation, and a scale change. An example shows in Figure 2.

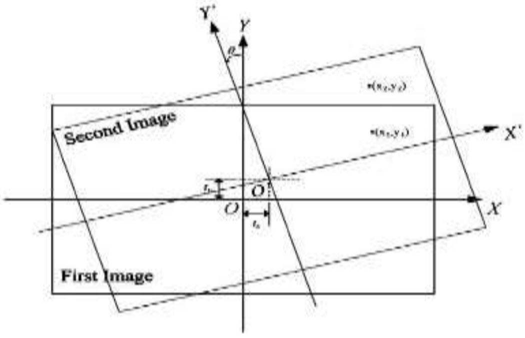

Fig. (2) Rigid-body transformation composed of a combination of a rotation a translation and a scale change [2].

It typically has four parameters, which map a point (XL, YI) of the first image to an end (X2, Y2) of the second image as follows

There is a different method of image registration: (1) Intensity-based and feature-based image registration (2) Single modality and multimodality image registration (3) Rigid and non-rigid image registration. Intensity-based image registration methods compare intensity patterns in images via correlation metrics, while feature-based image registration methods find correspondence between image features such as points, lines, and contours. The image registration method is an image acquired by the same sensor in a single modality, whereas in multimodality, the image registration method, the image acquired by the different sensors. In rigid image registration, only two transformations related to translation and rotation used. In contrast, in non-rigid image registration, one copy is to be deformed to match another to account for the non-linear local anatomic variations between the images.Floating image (Test image) transformed using collective transformation - rigid-body, affine, projective, perspective, or global polynomial. The converted image matched with the reference image using similarity measures, Mutual Information (MI) process. The transformation parameter updated according to the similarity coefficient, and the process repeats until the best matches found.

Four basic transformation parameters are composed of a combination of Rotation angle (θ), Scale (S) and translation (t) as shown in equation (1),

$$\begin{bmatrix} x2 \\ y2 \end{bmatrix} = \begin{bmatrix} t_x \\ t_y \end{bmatrix} + S \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x1 \\ y1 \end{bmatrix} \text{Or } \overline{p}_2 = \bar{t} + s\Re\overline{p}_1 \quad (1)$$

Where P1 and P2 are the coordinate vectors of the two images, t is the translation vector, s is a scalar scale factor, and R is the rotation matrix.

1.2. Particle Swarm Optimization

Particle Swarm Optimization (PSO) is a nature-inspired evolutionary and stochastic optimization technique to solve computationally hard optimization problems. PSO based on the movement and intelligence of swarms developed by James Kennedy and Russ Eberhart in 1995. The swarms inspired PSO in nature, such as a swarm of fish, birds. In PSO, a swarm of n individuals (particles) communicates directly or indirectly with one another using search directions (gradients). The algorithm uses to find a global optimum using the self-iteration process. During feedback, optimum value finds using search for the global best and searching for the local best. PSO composed of 3 vectors: (1) X-vector – record the current location of the particle in search space (2) P (Position) -vector – records the location of the best solution found by other particles (3) V (Velocity)- vector – records direction for which particle travel in if undisturbed. All these vectors are continuously updated. The Genetic Algorithm (GA) method has a selective operator, whereas, in the case of PSO, there is no particular operator. Yau et al. (2012) explained the PSO algorithm and its application in image processing fields. Fig. (3) Shows a basic block diagram of the PSO

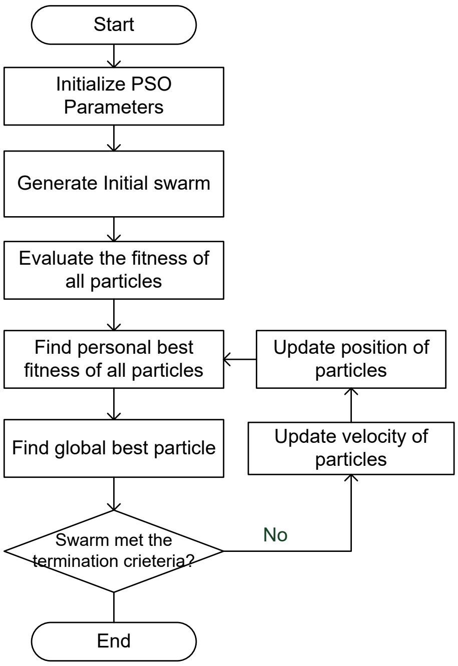

Fig. (3) Block diagram of the PSO algorithm.

algorithm. Initialize swarm with a random position, where w is inertia weight and c1, c2 is continually learning. Pbest is the optimum position. Gbest is the optimum position. Xi is the present position of each particle.

2.Literature Survey

The optimization algorithm using a combination of software and hardware to the real-time solved problem is to gain attention for many academic people as well as industries. The combination of image segmentation with PSO explained by Chander et al. (2011). In this paper, the self-iterative scheme of multilevel thresholding has used, giving better results than the bi-level thresholding method for the complex computational problem. The proposed method has been compared with the gaussian smoothing method, symmetry duality and GA-based methods, and produced better results than all of these methods.

The combination of the PSO and image registration process is explained by Fatemeh et al. (2012). They proposed Modified Normalized Mutual Information (MNMI) for image registration. Mutual Information (MI) is a reliable criterion for verifying similarity index in the field of the medical image registration process. The limitation of the method is that this method is not accurate in the presence of substantial shear distortions between the images.

The object detection with the help of PSO and DE is described by Roberto et al. (2013). The PSO method works better for the object detection of human body pose estimation and DE hippocampus localization in histogram images. The PSO gives more relevant results with quick solutions compare to DE. Future work in the direction of proper image segmentation helps for the accurate detection of the different objects. Future works are also in the direction of the implementation of a more sophisticated DE/PSO method. Kwok et al. (2013) have proposed the PSO method for eliminating illumination effect in a colored image. The limitation of this method based on the selection/adjustment of the linear multiplicative color channel. Future work improvingthe PSO method to satisfy both information gain &color correction for the multi-objective optimization problem.

The PSO algorithm has several advantages compared to other algorithms, including robustness to control parameters, computational efficiency, and easy implementation. So, many kinds of research work with PSO or with modified PSO to get the desired output. Like, Sandip et al. (2014) have proposed a quantum-inspired genetic algorithm (QIGA) and quantum-inspired particle swarm optimization (QIPSO) for bi-level thresholding. The proposed methods have been compared with their classical counterparts and later with the quantum evolutionary algorithm (QEA) to evaluate the performance among all participating algorithms for three tests of images. Future research for the use of quantum mechanics reduced the time complexity compared to other algorithms. Zheng et al. (2018) have proposed Guided Dynamic Particle Swarm Optimization (GDPSO). The proposed method has compared with different variants of PSOs. The GDPSO method also performs better for digital image watermarking. The proposed method has removed the limitation of PSO in terms of premature convergence and local stuck problem.

Smita Pradhan and Dipti Patra (2015) have proposed a hybrid algorithm for real brain MR images and cardiac images to optimize similarity measures using image registration. The proposed method algorithm compared with the Bacterial Foraging Algorithm (BFA), Quantum behaved Particle Swarm Optimization (QPSO), and hybrid BF-PSO algorithm. The proposed BF-QPSO method has good results compared to another method in terms of structure similarity (SSIM) index, misregistration error (MRE). The limitation of the proposed method is that computation time is higher than the other method. Zhuang et al. (2016) have proposed a combination of PSO and Powell search methods to obtain better performance than traditional methods. The PSO method has searching speed fast initially, but poor performance in a later stage. In contrast, the Powell search method has a strong search capacity, but with time requirements and search, performance is highly sensitive to the initial values. The proposed method can correct rotation, translation, and scaling operations without additional optimization algorithms.

The PSO uses in many applications like transportations engineering, flood management, manufacturing industry. Hybrid PSO with software and mobile applications in the ice manufacturing industry is demonstrated by Rapeepanet al. (2020). A 3D visualization method for flood risk management with the help of PSO has analyzed by Zhi et al. (2020). The vehicle Adhoc network (VANET) is a combination of network and computer technology. VANET shares the information in the form of vehicle to vehicle (V2V), vehicle to infrastructure (V2I) to improve traffic management. Bao et al. have proposed (2020) clustering V2V routing with the help of PSO.

3.HARDWARE SOFTWARE CO-DESIGN USING XILINX'S VIVADO TOOL

3.1. Pso In Image Registration

To develop an image processing algorithm in reconfigurable hardware demands several issues to work out like Hardware Limitation, Image format conversion, Memory and complex mathematical algorithms. To overcome these issues, we have migrated our design tool from ISE-SDK to Vivado-HLS.The thought behind utilizing Zynq SoC is to use the software-based OpenCVimage processing functions and to perform a few image registrations steps in FPGA. As XSG does not support a closed-loop interface with the FPGA board, optimization could not perform in an iteratively.

3.2. Hardware Architecture

To utilize PSO in the image registration process efficiently,

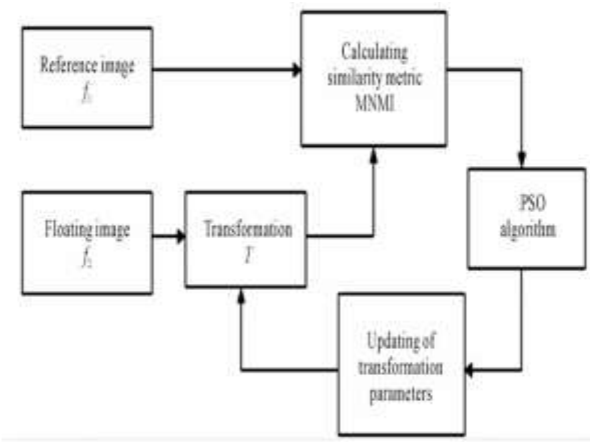

Fig. (4) Block diagram of image registration method using particle swarm optimization.

we have proposed the hardware architecture shown in fig.5. PSO uses 20 different sets of swarms (here 20 image's MI value). PSO maximizes the Mutual Information (MI) value between the test images and reference images by optimizing the transformation parameter,i.e., Rotation angle(Ø), Scale (S), shear (H], translation (T). Transformation function translates the test image using an "affine" transformation. Similarity measure block maps both reference image and transformed image (Resulting Image) and calculates the similarity coefficient. These values sent to PSO. PSO assigns new (and improved) parameter values to the transformation block, and the sequence repeats.

In the process of Image registration, as seen from Fig.5, otimization algorithm - PSO is implemented in Artrix FPGA and other processes uch as histogram maching, image file i/o and image transformation is carried out in Zynq programmable system which has ARM cortax A9 prosessor. This HW- SW architecture offers great software flexiblity in term of use of OPENCV library and benifit of hardware parallelism in the optimization process.

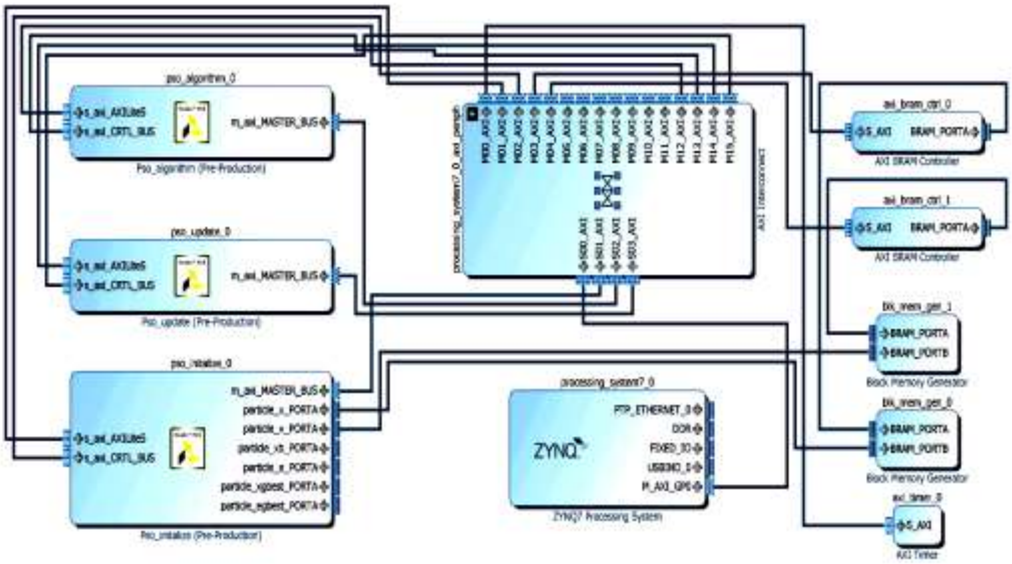

Fig. (5) Hardware architecture implemented on Xilinx's Zedboard board-Artrix FPGA.

4. HISTOGRAM-MATCHING TECHNIQUES

The correlation approach uses for the correlation coefficient as a measure of similarity between the reference for each location (x,y) in the target image. The result is maximum for locations where the references have correspondence (pixel by pixel) to the sub-image located at (x,y).The chi-squared test used to determine whether there is a significant difference between the expected images and the observed images in one or more categories. The intersection test is for the given lines or curves that have the same coordinate values at some points. Bhattacharyya distance measures the similarity of two discrete or continuous probability distributions. Below Four types of histogram matching functions are tested:

Correlation	$d(H_1,H_2)=\frac{\sum_I (H_1(I)-\bar{H}_1)(H_2(I)-\bar{H}_2)}{\sqrt{\sum_I (H_1-\bar{H}_1)^2 \sum_I (H_2-\bar{H}_2)^2}}$ Where, $d(H_1, H_2)$ = histogram matching value $\bar{H}_k=\frac{1}{N}\sum_j H_k(j)$ $H_1(I)$ = histogram array of image1 $H_2(I)$ = histogram array of image2 N = no. of histogram bins	[M0]
Chi-Square	$d(H_1,H_2)=\sqrt{1-\frac{1}{\sqrt{\bar{H}_1\bar{H}_2N^2}}\sum_I H_1(I),H_2(I)}$	[M1]
Intersection	$d(H_1,H_2)=\min(H_1(I),H2(I))$	[M2]
Bhattacharya distance	$d(H_1,H_2)=\sqrt{1-\frac{1}{\sqrt{\bar{H}_1\bar{H}_2N^2}}\sum_I H_1(I),H_2(I)}$	[M3]

5.Experimental Results

Fig. 5 shows the outcome of registration process by considering four different histogram matching profile. It is clearly visible that Correlation function performs better than other three histogram matching functions.
Fig. 6 Graph of Similarity Index versus PSO run for various histogram matching functions: 1) M0 = Correlation function, 2) M1= Chi-Square function, 3) M2 = Intersection function and, 4) M3 = Bhattacharyya distance function. From this graph it is clear that Correlation function performs better than other three functions. Bhattacharyya distance function provides the lowest similarity index over 25 PSO run.

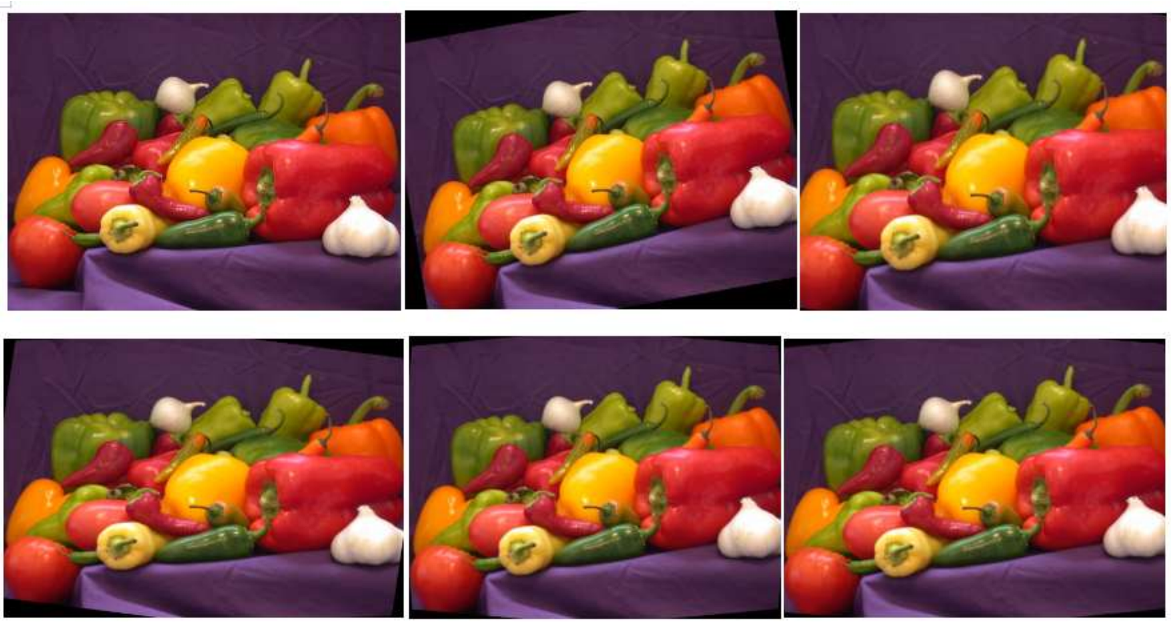

Fig. 5 [a] reference image peeper.png (512 x 384), [b] test image (Rotated by +10 degree, [c] resulting image from Correlation function (25 runs), [d] resulting image from Chi-Square function (25 runs), [e] Resulting image from Intersection function (25 runs), [f] resulting image from Bhattacharyya distance function (25 runs).

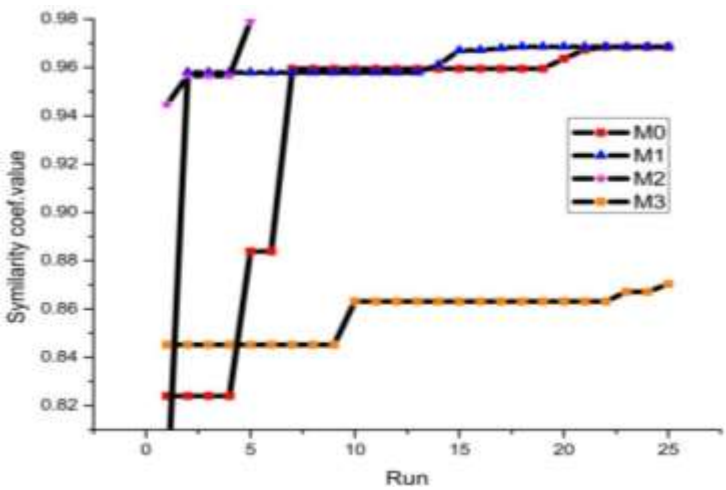

Fig.6 Graph of Similarity Index versus PSO runs for various histogram matching functions.

6.Conclusion

PSO tested as an optimizer for the image registration process. The reference image is rotated by 10 degrees and set as a test image. Using affine transformation here, we have used the OpenCV library for the same. The first image translated to match the reference image. Then various histogram matching functions are tested to measure' the symmetric measure's value with the help of PSO. The correlation function gives better results compared to the other three functions Chi-Square, Intersection, Bhattacharyya distance.

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