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A Low Overhead Image Registration Algorithm using DWT and WIPSO for Resource Constrained SBC based Embedded System Application

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***Abstract:** Image registration is a vital but integral component of any image processing application. Fundamentally, image registration involves transforming two or more sets of image data derived from different sources, collected at different instant of times, taken from different perspectives and from different viewpoints, all from different frames of reference into an image in a single coordinate system, a single frame of reference. Over the years, there have been many image registration techniques developed and used in variety of application fields. This paper proposes a computationally low overhead image registration technique that has been tested with variety of images using weight improved particle swarm optimization (WIPSO) algorithm integrated with discrete wavelet transform (DWT). Fundamentally, the proposed scheme comprises of a two-step approach, where the first step involves extraction of the random image from the source image which will serve as an ingredient for the formation of the particle swarm to be used in the WIPSO and the second step involves an explorative search for the target image in the area of interest from the selected population using WIPSO technique. Extensive simulation has established the effectiveness of the proposed soft-computing technique for variety of image registration application; even suitable for deployment in many resource-constrained single board computer based embedded system applications.*

***Keywords:** Particle Swarm Optimization (PSO), Weight Improved PSO, Digital Image Processing, Discrete Wavelet Transform, Weight Improved Particle Swarm Optimization (WIPSO)*

I. INTRODUCTION

The process of digital image registration is a technique which can help us conclude the most appropriate and exact counterpart among two images, which might have been taken at same or different instant of times, by the same or different sensors or cameras and from same or different points of view.

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In most of image processing application ,this is the classical problem faced where analysis is to be performed on two or more images of a subject acquired from different sensors at different times [1]. Some of its examples include mapmaking and photogrammetric involving imaging affecting overlapping coverage and fusion of image data.

This process involves many components; it also finds the optical geometric transformation which maximizes the correspondence across the images. The components are as follows:

A model which defines geometric transformation between the images called Transformation model. It has many classes of non-rigid transformation which includes parametric and non-parametric models .Some are well performed for small deformation while others can be performed well for large deformations.

In order to effectively assess the degree of alignment between the images, a similarity metric can provide a faithful measure. However, in some cases, features such as landmarks, edges or surface and the distance between these features are being used to assess the alignment among the images while in other case the features such as image intensity can be directly used to measure the alignment [1].

To maximize the effective utilization of similarity metric, application of optimization method is a good solution. In several medical imaging applications, non-rigid registration of images can be articulated as an optimization problem, where the key intension is to maximize the computed value of the associated objective function [2].

Broadly, the image registration algorithm can be classified into two categories; the first one being constructed on area based method while the second one is centered on feature based method. In the case of area based method, a predefined window is taken along with the optimization algorithm, which is used to find out the transformation mode between two images, where as in second category the salient features of an image is used for transformation model estimation [3, 4]. Taking the case of remote sensing application, here the area based image registration algorithms are found to be suitable to process images of open terrain regions, whereas, the featured based image registration algorithms can yield accurate result in processing images of urban regions.

For image registration, the Interest point matching (IPM) is a key technique and at the same time, is most difficult aspect too. Now-a-days, this technique has been one of the most researched area [5]. In this paper, we explore the capability of the proposed hybrid algorithm, formed with the help of Discrete Wavelet Transform (DWT), integrated with the Weight Improved Particle Swarm Optimization (WIPSO), employed to achieve effective image registration. Template matching is accomplished by computing the correlation coefficient and the DWT among the target unregistered images of any size and a source image of size $\underline{N} \times N$ pixels. The root mean square (RMS) error metric (e_{rms}) is used as an effective similarity measure. The rest portion of the paper is structured as follows: we have presented discussions on various image registration methods in the immediate following Section 2. The discrete wavelet transform (DWT) has been discussed in Section 3 and in Section 4, we have discussed the PSO technique along with the weight improvement approach to enhance performance of traditional PSO, In Section 5, we have discussed our proposed methodology and the analysis of results of the simulation study of image registration has been presented in Section 6. Finally in Section 7 we have presented the concluding remarks on the outcome of this work.

II. IMAGE REGISTRATION METHODOLOGY

The basic steps required in the image registration process are shown in Figure 1 below. In this process the input or source image should be matched to the reference or target image by applying some transformation T which maps the coordinates of the source image to the target image.

Logically, the best transformation is that transformation that gives the maximum similarity metric. In order to accomplish the purpose of searching for the best similarity metric, the optimization algorithm (WIPSO in our case) searches for the parameters of the transformation in the given search space to find the best values for the maximum similarity metric.

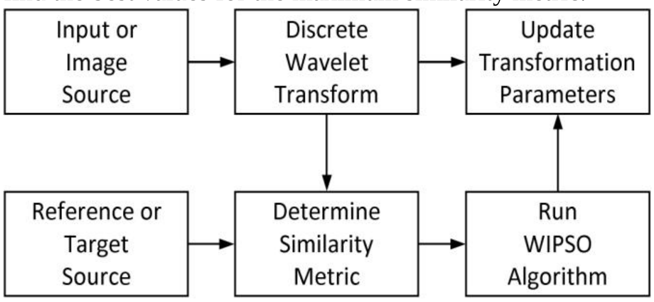

Fig. 1: Block Diagram of the Steps involved in Basic Image Registration Process

III. DISCRETE WAVELENGTH TRANSFORM

The concept of wavelet transform (WT) initially introduced to improve the quality of seismic signal analysis which was traditionally accomplished using Fourier Transform was subsequently found to have application in variety of domains [17]. In fact, the English term 'Wavelet' being originally coined by the geophysicist Jean Marlet and the theoretical physicist Alex Grossmann refers to 'small wave', the sinusoidal wave in Fourier Transform being considered big waves. Thus, the wavelet being a mathematical function useful for application in versatile domains, wavelet transform can be viewed as a complement to the classical Fourier Transform. In principle, wavelet transform is a method of transforming or breaking down into two components; a low-resolution component and a high-resolution component. Wavelet Transform, due to its versatile nature, its scope of application spans variety of fields, such as Localized Corrosion Measurements [18], Light-Weight Reconfigurable Hardware [19], digital watermarking applications [7], digital signal processing applications [16], [20], digital image processing applications [6], [14], [15], [16]. There are many cases proven useful signal processing applications of, like processing of X-ray and magnetic-resonance images (MRI) in medical applications, where the wavelets can be of help to recover weak signals from the noisy signals [16], the end result being a "cleaned up" images without making them blur or confusing, without compromising the finer details. In general, for the basic wavelet being represented as mathematical function $\psi(t)$, there are two broad variants of the basic wavelet transform; (1) the continuous wavelet transform (CWT) and (2) the discrete wavelet transform (DWT). The traditional wavelet transform is a continuous wavelet transform (CWT), which compares a signal with shifted and scaled (i.e., stretched or shrunk) copies of a basic wavelet represented as $\psi(t)$. With t being representing a specific instant of time and s being a scaling factor, if the basis wavelet $\psi(t)$ is centered at t=0 with $t \in [-T/2, T/2]$, then $(1/s)\ \psi((t-u)/s)$ is centered at $t = u$ with $t \in [-sT/2+u, sT/2+u]$ where u is a translational or shifting factor. The discrete wavelet transforms is a variant of the wavelet transform for which the wavelet signal is sampled at discrete intervals that captures both the frequency information as well as the location information, i.e., in DWT, the scale parameter is being discretized under the condition that the scale parameter s is always discretized to an integer powers of 2, i.e., $s=2^i$, i=1,2,3 This paper constructively utilizes the DWT integrated with WIPSO to achieve the key objective of effective image registration. Basically, DWT splits a 1-dimensional signal into two parts; one being the high frequency component and the other one is a low frequency component, in such a way that the edge feature components are captured in the high-frequency part. This process of decomposition continues until the input signal is completely fragmented or the process is aborted by the program based on some termination criteria. In the similar line, the DWT for a 2-dimensional signal can be accomplished by applying the 1-dimentional DWT for each of the two parts separately, so that the final decomposition yields four components, out of which one is low-frequency component and rest three are the high frequency components. This is the first level decomposition. As shown below in the figure-2, the decomposed frequency band fragments are LL1, LH1, HL1, and HH1; the subscript 1 signifies that these are the outcome of 1st level of DWT decomposition. Accordingly, the second level decomposed frequency components as shown are LL2, LH2, HL2, and HH2 [8].

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The convention followed for naming the DWT decomposed image component depends upon the direction of application of the filter to specific images, i.e., vertical direction or horizontal direction.

As an instance, the level-x DWT decomposed image component formed, named as LHx, (*x* being the level of DWT decomposition) which is an outcome concurrent application both low-pass and high-pass filter; low-pass filter being applied in the horizontal direction along with high-pass filter being applied in the vertical direction, and therefore, the four DWT decomposed image component resulted are named accordingly. The coefficient of the level-x DWT decomposed image component named as LLx is called detailed coefficient while the coefficients of the components LHx, HLx and HHx are called approximate coefficients. While the LHx images carry the information about horizontal-edge features of the image, the HLx images carry the information about vertical-edge features of the image. The HHx DWT image components carry the high frequency information and therefore, are extremely noisy and do not contribute anything useful towards the image registration process. However, the level-x DWT decomposed image components LLx contains low-frequency information and therefore are stable and contain useful information and are always used as input to produce the next level DWT decomposed images

As shown in the figure above, at each level of DWT decomposition of the original image of M x M pixels, four new images of M/2 x M/2 pixels are resulted out of the original input image, the size of the new image being formed is ¼ the size of the original image

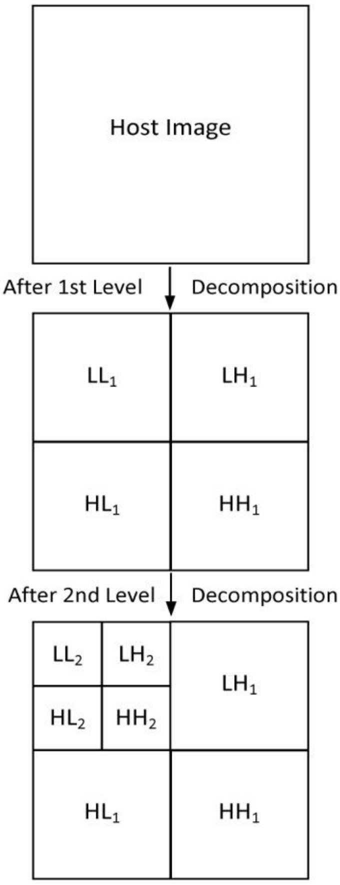

Fig-2: Different Frequency Components of DWT Decomposition Process

IV. PARTICLE SWARM OPTIMIZATION

Kennedy and Eberhart being inspired by the social behavior of creatures in group, in 1995 [11] proposed a population based heuristic optimization technique in the name of particle swarm optimization (PSO) – an evolutionary algorithm in nature mimics bird-flocking and fish schooling where each member of the group or *swarm* is treated as a *particle* share information. As compared to other evolutionary algorithms, PSO has remained an attractive heuristic optimization technique due to its simple structure using fewer control parameters. PSO has been successfully applied either independently or combined or *hybridized* with algorithms to solve problems in numerous fields of application ranging from industrial, medical, social, computational, and many more, such as fault-tolerant scheduling of real-time tasks on multiprocessor based systems [24], image registration [25, 26], optimization of a five-echelon supply chain network [22], acute leukemia segmentation [23] and harmonic reduction in multilevel cascade inverters for renewable energy sources [27]. In a quest for improved performance of optimization for solving problems of specific type or in specific domains of application, many variants of the basic PSO has been proposed by researchers from different fields of study [28, 29]. In this paper, we integrate PSO, specifically the WIPSO with the DWT to achieve the core goal of effective image registration.

A. Classical Particle Swarm Optimization:

The basic PSO or the classical PSO shares many similarities in variety of aspects with the traditional evolutionary algorithms like GA and DE. PSO, in general starts with a randomly generated initial population (swarm) of members birds (particles) forming the search space of size Np, where each particle in the search space represents a candidate solution to the problem at hand. Every candidate solution in the problem space is represented by two vectors: a position vector x and a velocity vector v. An optimal solution is then searched in the population, evolving them generation by generation in the process. Conceptually, each particle in the population moves from its current position to a new position with a velocity around the multidimensional search space to locate the desired optimal solution, the quality of the solution so obtained is being evaluated on the basis of its fitness value, represented by a function of its current position, denoted as $f(x)$. While the particles fly in the search space, they follow simple principles to evolve their behaviour

i. Every particle exhibits a propensity to moves towards its experience of personal best previous position denoted by a vector **p** based on its own knowledge as well as the knowledge of its nearby particles, and
ii. During the movement in the search space, each particle also attempts to resemble their personal best performance **p** with the achievement of the global best particle in the whole swarm, denoted as **g**.

Considering each particle of dimension n, mathematically, the position and velocity of any random i^{th} particle in the swarm, $i \in [1,Np]$, in the t^{th} generation can be denoted by a respective position and velocity vector as: and respectively.

Mathematically, the principle to evolve each particle's behavior due to their position and velocity vector can be expressed as

$$\mathbf{v}_i^{t+1} = \omega\mathbf{v}_i^t + c_1 r_1(\mathbf{p}_i^t - \mathbf{x}_i^t) + c_2 r_2(\mathbf{g}^t - \mathbf{x}_i^t), \quad (1)$$

$$\mathbf{x}_i^{t+1} = \mathbf{x}_i^t + \mathbf{v}_i^{t+1} \quad (2)$$

where:

r1, r2 : are uniform random number in the interval [0,1],

ω : is the inertia weight associated with the velocity of the particle that controls the flexibility of the medium in which the bird flies,

c1, c2 : are the positive acceleration coefficients that controls the propensity of the particle towards the local and global best results, respectively,

v^t : velocity of the particle at the i^{th} iteration,

x^t : position of the particle at the t^{th} iteration, and

The rule for updating personal best value of i^{th} particle in t^{th} iteration can be expressed as:

$$\mathbf{p}_i^t = \begin{cases} \mathbf{p}_i^{t-1} & if\, f(\mathbf{x}_i^t) > f(\mathbf{p}_i^t) \\ \mathbf{x}_i^t, & otherwise \end{cases} \quad (3)$$

Similarly, the global best value of the swarm in t^{th} iteration can be expressed as:

$$\mathbf{g}^t = \begin{cases} \min\ f(\mathbf{p}_i^t)\Big|_{i=1}^{NP} & \text{if}\ \min\ f(\mathbf{p}_i^t) \le f(\mathbf{g}^{t-1}) \\ \mathbf{g}^{t-1}, & \text{otherwise} \end{cases} \quad (4)$$

The pseudo code for the implementation of the PSO Algorithm is given in the figure-3 and the flowchart is presented in the figure-4 below:

```
BEGIN
  INITIALIZE parameters;
  FOR each particle
    INITIALIZE particle position and particle velocity;
  END
  DO
    FOR each particle
      CALCULATE fitness value;
      IF (the fitness value is better than
        the best fitness value (pBest) in history)
        set current value as the new pBest;
    END
    SELECT the particle with the best fitness value
                  of all the particles as the gBest;
    FOR each particle
      CALCULATE particle velocity;
      UPDATE particle position;
    END
  WHILE (TERMINATION CONDITION not satisfied)
END
```

Fig. 3: Pseudo Code Algorithm for PSO

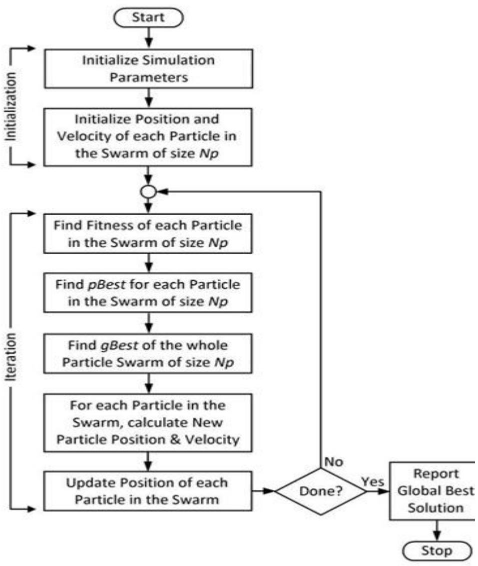

Fig. 4: Flow Chart for PSO

B. Weight Improved PSO

Weight Improved PSO (WIPSO) algorithm is a variant of PSO Algorithm [21, 30], where it is proposed to enhance the global search quality, the inertia weight factor and the cognitive and social components (c_1, c_2) of standard PSO algorithm have been configured [15,16]. Using the modified inertia weight factor the velocity-update equation presented above in Eqn.(1), i.e. using the WIPSO method can be rewritten as [14]:

$$\mathbf{v}_{id}^{t+1} = \omega\mathbf{v}_{id}^t + c_1 * rand() * (\mathbf{p}_{best}^t - \mathbf{p}_{id}^t) + c_2 * rand() * (\mathbf{g}_{best}^t - \mathbf{p}_{id}^t), \quad (5)$$

where

$$W_{new} = W_{\min} + w * rand1()$$

w is calculated using below equation

$$w = W_{\max} - [(W_{\max} - W_{\min}) * It]/(It_{\max})$$

$$C_1 = C_{1\max} - (C_{1\max} - C_{1\min}) * (It/It_{\max})$$

$$C_2 = C_{2\max} - (C_{2\max} - C_{2\min}) * (It/It_{\max})$$

$C_{1\max}$, $C_{1\min}$ – represents the initial and final values of the cognitive components,

$C_{2\max}$, $C_{2\min}$ – represents the initial and final values of the social component, and

$rand1()$ – denotes the randomly generated number between [0,1]

The WIPSO with DWT based Algorithm for Image Registration is as follows:

Step 1: Select the size of the population, (Np), the number of generations (N), $\omega_{\min}$, $\omega_{\max}$, $c_{1\min}$, $c_{1\max}$, $c_{2\min}$, $c_{2\max}$.

Step 2: Initialize the velocity component and the position component for all the particles to a value set randomly well within their pre-specified or approved legal ranges.

Step 3: Initialize the generation counter, $t = 1$.

Step 4: Evaluate the value of the fitness merit for each of the particle according to the preset objective function.

Step 5: Compare the evaluated value of particle's fitness merit with its $Pbest_i$. If the current fitness merit value is better than the previous $Pbest_i$ value, then set the $Pbest_i$ merit value equal to the current fitness value. This process step helps identify the particles in the neighborhood with the best success achieved so far, and therefore assigns its index to the *Gbest* value.

Step 6: Update the velocity of the particle with the help of the global best (*Gbest*) value and individual best ($Pbest_i$) value of each particle computed according to eqn. (5).

Step 7: Update the particle position with the help of the updated velocities, as a result of which, each particle changes it position computed according to eqn. (2).

Step 8: If the preset stopping criterion is not met, then increment the generation counter, $t = t + 1$ and return to the Step 4 above to continue with the next round simulation else terminate.

Flowchart of the WIPSO with DWT based Algorithm for Image Registration is as given below:

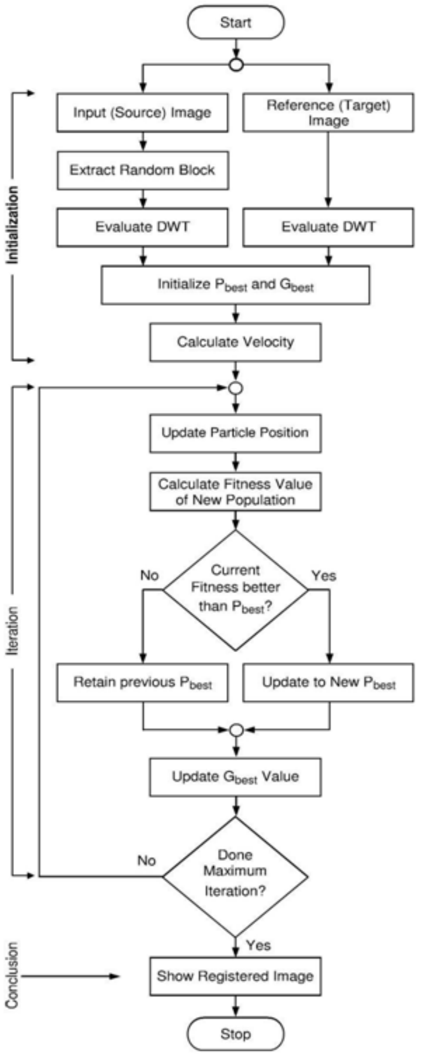

Fig. 5: Flowchart for the WIPSO based IR Algorithm incorporating DWT

V. PROPOSED METHODOLOGY

The objective of this proposed algorithm is to implement a computationally efficient image registration algorithm for versatile and variety applications that employs weight improved particle swarm optimization (WIPSO) integrated with discrete wavelet transform (DWT). Fundamentally, the proposed algorithm implements the process of finding the portion of target image in the source image as a search space optimization problem achieved with the help of WIPSO. The role WIPSO played here is that it selects some random member from the randomized population that presents the locational coordinate of a random pixel from inside the source image. The randomized population includes the size of a window to be extracted. During the construction of the randomized population, every member of the population corresponds to a specific window inside the image. Each window that presents itself as a part of the source image has some fitness merit value associated with it. The fitness merit value is computed using the DWT with corresponding root-mean-square (RMS) error value. The corresponding RMS value presenting degree of disagreement among the selected (randomly picked) sub-window and the target image block presents a measure of fitness. New population is then generated by updating the corresponding velocity and positional parameter value. This entire process forms a complete cycle. This complete cycle is repeated iteratively for a pre-defined numbers of iterations. Upon stabilization of the convergence of the measure of fitness presented by the g_{best} value, helps us arrive at the desired optimized window of image registration.

VI. RESULT ANALYSIS

In this section we present the result of simulation of the proposed algorithm executed in 400 iterations over 5 epochs each. The simulation was carried out involving Figure-6 to Figure-9 as the input images with Figure-10 to Figure-15 being set as the target image for the simulation, with Figure-10 and Figure-11 being two variant targets for the same source image Fugure-6. Figure-15, Figure-17, Figure-19 and Figure-21 were being the output of the proposed image registration algorithm corresponding to input images Figure-6 to Figure-9 respectively, with the corresponding performance plots presented by Figure-16, Figure-18, Figure-20 and Figure-22, respectively. The performance plots being presented here are self-explanatory that exhibits a good convergence pattern as shown by the proposed algorithm.

Fig 6: Source Image-1

Fig 7: Source Image-2

Fig 8: Source Image-3

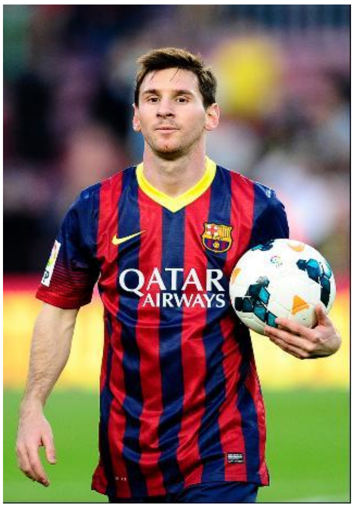

Fig 9: Source Image-4

(Fig. 10: Target Image- 1)

(Fig. 11: Target Image- 2)

(Fig. 12: Target Image- 3)

(Fig. 13: Target Image- 4)

(Fig. 14: Target Image- 5)

All the source images are of different shapes and sizes. The simulation is being performed with a population size of 50 for 400 iterations over 5 epochs. The image registration is done for the above test images by first finding the wavelet transform for the features being extracted.

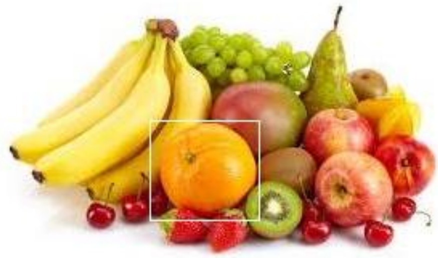

Fig. 15: Registered Image Output-1

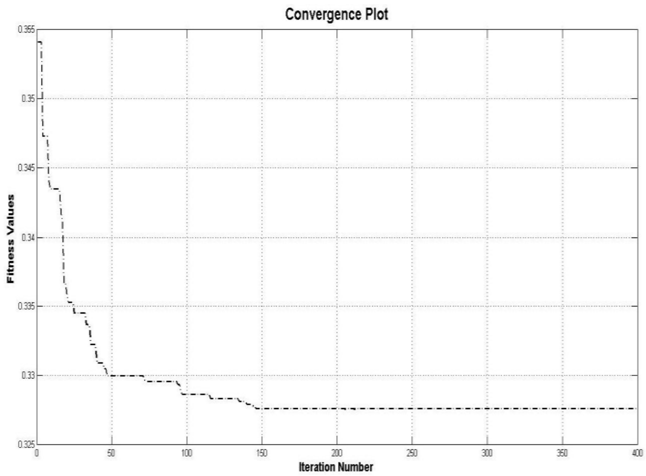

Fig. 16: Image Registration Performance Plot-1

Fig. 17: Registered Image Output-2

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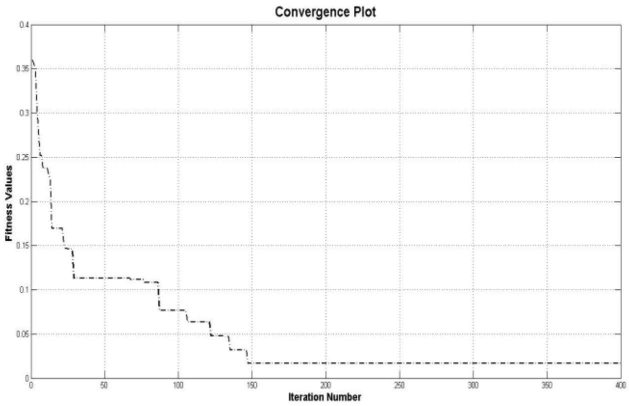

Fig. 18: Image Registration Performance Plot-2

Fig. 19: Registered Image Output-3

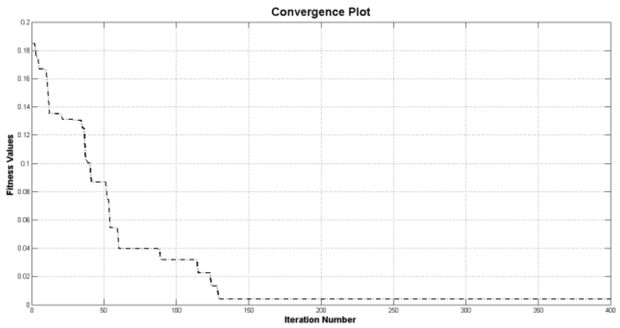

Fig. 20: Image Registration Performance Plot-3

Fig. 21: Registered Image Output-4

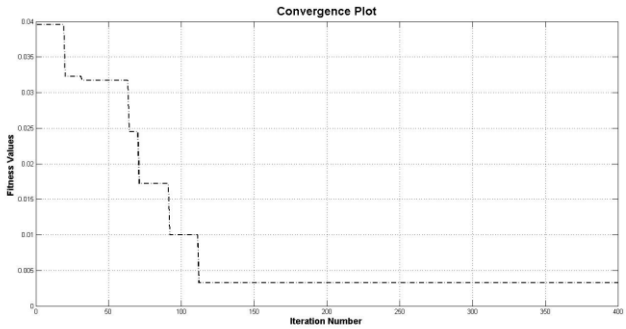

Fig. 22: Image Registration Performance Plot-4

Fig. 23: Registered Image Output-5

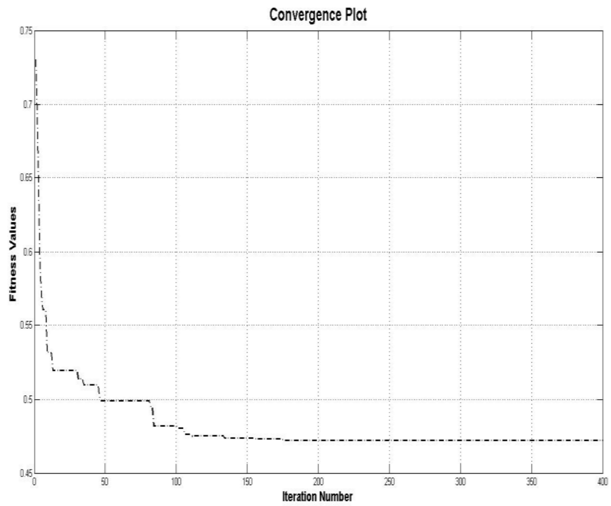

Fig. 24: Image Registration Performance Plot-5

Table-1 given below is self-explanatory which presents a concise abstract of whole simulation process carried out. The table presents the population size being taken for each source image with the designated target image and the point during the iteration source were the convergence gets stabilized

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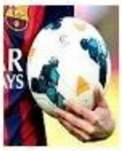
Source Image	Target Image	Population Size	Point of Convergence
		50	147
		50	146
		50	129
		50	112
		50	165

The results presented above shows the registered image along with their corresponding performance plot. The performance plots indicate the number of iteration along the *x*-axis and the fitness values along the *y*-axis. Since we have considered the nature of solution to solve a minimization problem, therefore the performance plots shows the decrement in the value of the fitness function. Observations from the visual accuracy of target image registration on corresponding source image as well as the convergence pattern achieved as apparent from the plot establishes the truthfulness of the proposed approach.

VII. CONCLUSION

In this paper, we have presented a computationally efficient algorithm for image registration applications that employs weight improved particle swarm optimization (WIPSO) integrated with discrete wavelet transform (DWT). Due to its low computational overhead, the algorithm is found to be suitable for deployment in resource constrained (like memory and processing speed) single board computing systems, such as Raspberry Pi. The proposed algorithms worked efficiently by adopting the approach of extracting the sub-images from the source images and then by finding the parameters for the enhanced PSO, i.e., the coefficients for the WIPSO that compared with DWT coefficients of the target images; and in turn, this leads to the formulation of the optimization problem. Here, WIPSO plays the key role of effectively optimizing the convergence to quickly get the targeted image being registered.

The image registration method presented in this paper has been applied to various types of images of different features and tested on variety of platforms. Experimental results with various images have exhibited a simple, yet effective and efficient approach to fast image registration in which the source image was shown to be transparently overlapping with the extracted interest point region computed using the DWT algorithm integrated with. The proposed algorithm was implemented using clean Matlab code (i.e., without using proprietary native Matlab library routines) and is under further modifications for further improvements planned to achieve.

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