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REGISTRATION TECHNIQUES FOR MEDICAL IMAGES

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**This Thesis was Submitted in Partial Fulfillment of the Requirements for
the Master's Degree of Computer Science**

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May, 2006

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DEDICATION

To my wonderful parents, my family and my friends for their support.

ACKNOWLEDGEMENT

To my supervisor Dr. Sami Serhan for his continuing support and help, and to my co-supervisor Dr. Moussa Habib for his support and help. I also want to thank the discussion committee.

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LIST OF ABBREVIATIONS

PET: Positron Emission Tomography.

MRI: Magnetic Resonance Imaging.

TPS: Thin-Plate Splines.

E-P: Electrophysiological.

HCM: Hierarchical Chamfer Matching.

ICP: Iterated Closest Point.

RMS Error: Root Mean Square Error.

LA: Long Axis.

REGISTRATION TECHNIQUES FOR MEDICAL IMAGES

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ABSTRACT

This thesis focuses on finding techniques that can be used in cardiac magnetic resonance imaging (MRI) images automatic registration in a simple and a fast way.

In this thesis the following matching techniques are suggested: Gaussian pyramid's third level histogram technique, Root Mean Square Error technique, and Non-base filtered Gaussian pyramid's third level histogram technique.

The suggested techniques depend on using parts of one image to be matched with another image of the same patient in order to find control points or correspondences between these two images.

Gaussian pyramid's third level histogram technique uses the histograms of the third level for both target and template images to find the matched segment. Root Mean Square Error

technique determines the error between the template and the segments. Non-base filtered Gaussian pyramid's third level histogram technique uses the histograms of the third level for both target and template images to find the matched segment, without filtering the original image (level one image) of the Gaussian pyramid but filters both the second and the third levels with Gaussian filter.

Our empirical study using ten sample images, shows that both the first and the third techniques give good results in matching images even with location and size variation of shapes between images but the third technique is better than the first one. The second technique works fine for images of small shape and location variations but does not give good results for images of large variations.

The third matching technique is then used in intra-subject cardiac MRI rigid axial registration.

INTRODUCTION

Image registration is the process of determining correspondences between two images of the same scene, then using these correspondences to transfer these images to become in the same alignment, and now is widely used to medical images.

Medical images registration in general is difficult because of shapes and sizes variations of organs between individuals, and for the same patient during his treatment. Cardiac images registration is harder than other organs registration because of the non-rigid nature of heart and thorax, it is hard to image the same scene twice, beside of that cardiac images differ than other organs images such as brain images in that they have less distinguished features or landmarks, making the process of finding correspondences between images a hard job. For these reasons there are plenty of researches on brain images, mean while heart images registration is a new research field.

The aim of this thesis is to find matching techniques that can be used in finding correspondences between cardiac MR images in order to use them in axial registration.

The suggested matching techniques: Gaussian pyramid's third level histogram technique, Root Mean Square Error technique, and Non-base filtered Gaussian pyramid's third level histogram technique, use Gaussian pyramid in order to sample the images to the third pyramid level, which reduces the image size and so increases performance in terms of matching time. Then segment the target image into smaller images to be compared with the

template image. After determining the correspondent points, axial rigid transformation is used to align the images.

This method is used to register images of the same patient (intra-subject registration), so the apex area and arteries area can be extracted from one of the patient images to be used as templates that will be located using the suggested techniques in his other images. The located segments in the images are considered as the correspondent control points which then can be used in aligning the patient images.

This thesis is organized as follows: chapter 2 lists background information related to this thesis work. Chapter 3 presents some literature review. Chapter 4 talks about the suggested matching techniques, how they work, and their characteristics. Chapter 5 gives an experimental study and analysis for the suggested techniques through using them in cardiac axial registration. Chapter 6 includes the conclusion and suggested future work.

IMAGES REGISTRATION

1. Images Registration

Image registration is the process of determining correspondences between two images of the same scene, and is now widely used to medical images, (Chen, 1997). In other words, image registration is the process of estimating an optimal transformation between two images, (Papademetris, 2006), both spatially and with respect to intensity, (Senthil, 2006).

Image registration can serve as a powerful tool to investigate how regional anatomy is altered in disease, with age, gender, and other clinical or genetic factors. One of the most obvious clinical applications of registration is the area of serial imaging. Comparison of scans from a given patient acquired over various time intervals can be routinely performed to follow disease progression, response to treatment and even dynamic patterns of structure change during organ development, (Makela, 2003).

There are two basic types of medical images, functional body images such as Positron Emission Tomography (PET), which provide physiological information, and structural images such as Magnetic Resonance Imaging (MRI), which provide an anatomic map of the body. The combination of these images can often lead to additional clinical information not apparent in the separate images. Although, the construction of a composite, overlapping medical image, described in the field as medical image registration, has been primarily used in the fusion of functional and anatomical images, it has also been applied to a series of the same modality images such as registering images for the same patient to monitor his

treatment development, this is called intra-registration, while registration of patient images with an Atlas is called inter-registration. (Karin *et al.*, 2000).

1.1 Registration Types

- **Multimodal Registration:** Integrating information from different sources (modality) of images such as registration of PET images with MRI images in order to combine both functional and anatomical information of the case.
- **Single Modality Registration:** Integrating information from the same sources (modality) of images such as registration of MRI images with other MRI images to find similarities or to monitor treatment of a patient.
- **Inter-Subject Registration:** Registering images of different patients, or between an Atlas and patient's images.
- **Intra-Subject Registration:** Registering images of the same patient.

1.2 Transformation Models

- **Rigid Transformation:** An image coordinate is called rigid, when only translations and rotations are allowed, it preserves the distances and angles between points.
- **Affine Transformation:** Maps parallel lines onto parallel lines but does not conserve the angles between lines, it is a rigid transformation plus scale factors and shears.
- **Projective Transformation:** This transformation preserves the straightness of lines but not parallelism (maps lines onto lines).
- **Curved or Elastic Transformation:** Also is called nonrigid transformation, does not preserve the straightness of lines (maps lines onto curves).

Figure 1 shows the different models of transformations.

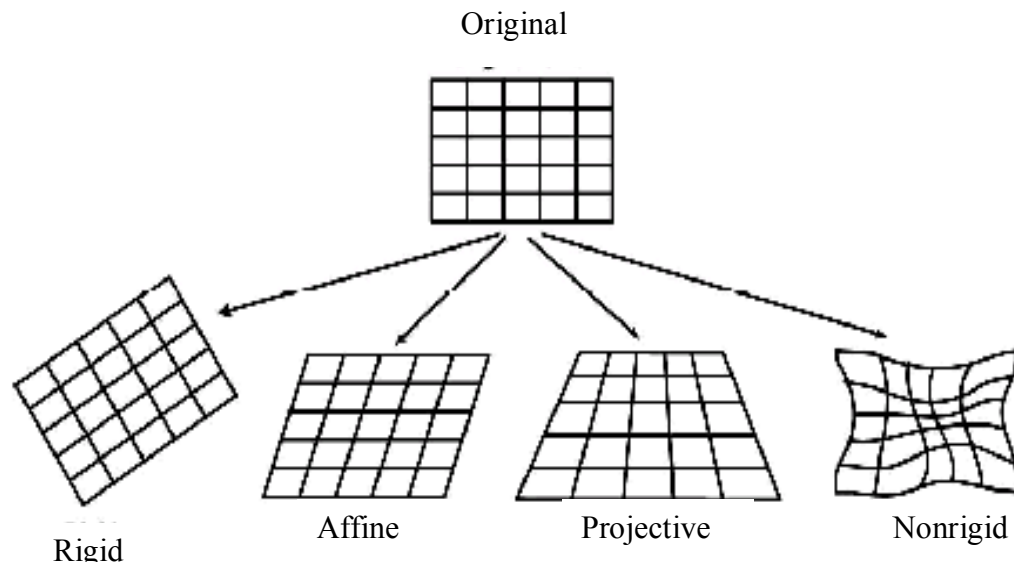


Figure 1: Transformation Models

A transformation is called global if it is applied to the entire image and local if each subsection of the image has its own transformation. Figure 2 shows examples of transformation types.

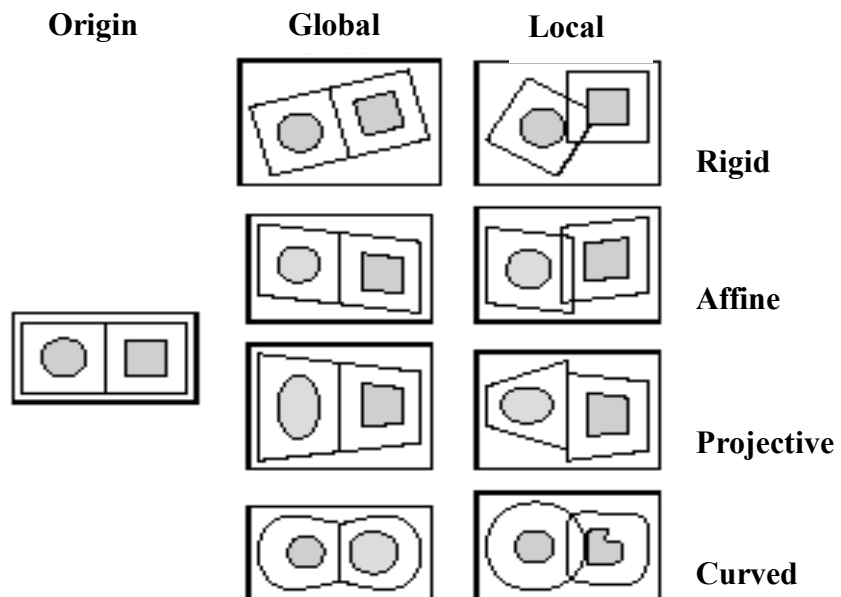


Figure 2: Global and Local Transformations.

1.3 Transformation Functions

After determining correspondences between images, a transformation function is determined to use these correspondences to map one image point by point to the other.

Given the coordinates of N corresponding control points in two images of a scene:

$$\{(x_i, y_i), (X_i, Y_i): i=1 \dots N\},$$

We want to determine a transformation function $\mathbf{f}(x, y)$ with components $f_x(x, y)$ and $f_y(x, y)$ that satisfy $X_i = f_x(x_i, y_i)$, and $Y_i = f_y(x_i, y_i)$, $i=1 \dots N$. Once $\mathbf{f}(x, y)$ is determined, given the coordinates of a point (x, y) in one image, the coordinates of the corresponding point in the other image can be determined.

The following is a list of some transformation functions:

- Rigid Transformation: This transformation is useful when registering images as rigid bodies, see equations 1 and 2.

$$X = x \cos(\alpha) - y \sin(\alpha) + h \dots\dots\dots(1).$$

$$Y = x \sin(\alpha) + y \cos(\alpha) + k \dots\dots\dots(2).$$

Where α and (h, k) are the rotational and translational differences between images.

- Affine transformation: This transformation is useful when registering images taken from a distant platform of a flat scene, see equations 3 and 4.

$$X = ax + by + c \dots\dots\dots(3).$$

$$Y = dx + ey + f \dots\dots\dots(4).$$

Knowing the coordinates of three non-colinear corresponding points in the images the six parameters of the transformation can be determined.

- Projective Transformation: This transformation is useful for registration images obtained from different views of a flat scene, see equations 5 and 6.

$$X = (ax + by + c) / (dx + ey + 1) \dots\dots\dots(5).$$

$$Y = (fx + gy + h) / (dx + ey + 1) \dots\dots\dots(6).$$

Knowing the coordinates of four non-colinear corresponding points in the images, parameters $a - h$ can be determined.

- Thin-Plate Splines (TPS): This transformation is useful when the local geometric difference between images is not large, the point features are rather uniformly spaced, and the number of corresponding points is not very high, see equations 7.

$$\text{For } i \text{ in } [1, N], f(x, y) = A_1 + A_2x + A_3y + \sum F_i r_i^2 \ln r_i^2 \dots\dots\dots(7).$$

$$\text{Where } r_i^2 = (x - x_i)^2 + (y - y_i)^2 + d^2 \dots\dots\dots(8).$$

Equation 8 is the equation of a plate of infinite extent deforming under loads at

$\{(x_i, y_i) : i = 1, \dots, N\}$. The plate deflects under the imposition of loads to take values

$\{f_i : i = 1, \dots, N\}$. d^2 acts like a stiffness parameter.

More relations are obtained from equations 9, 10, and 11.

$$\sum_{i=1}^N F_i = 0 \dots\dots\dots(9)$$

$$\sum_{i=1}^N x_i F_i = 0 \dots\dots\dots(10)$$

$$\sum_{i=1}^N y_i F_i = 0 \dots\dots\dots(11)$$

1.4 Uses of Image Registration

- Image segmentation/deformable atlas.
- Normal vs. abnormal shape/ variation.
- Function brain mapping/removing shape variation.
- Multimodality fusion.
- Surgical planning and evaluation.
- Image guided surgery.
- Template constrained reconstruction.

1.5 Sources of Registration Errors

- Choice of template image/model.
- Feature identification errors: Identification of landmarks, contours, surfaces, segmentations.
- Correspondence ambiguities: Curve/surface/segmentation matching.
- Conflicting feature information: Landmarks, contours, surfaces, segmentation, intensity, modalities.

2. Gaussian Pyramid

The idea of pyramidal image decomposition was first introduced in the early 1980's by P. Burt & T. Adelson as a compact image code, (Burt and Adelson, 1983).

A pyramid is a collection of representations of an image. Each layer of the pyramid is half the width and half the height of the previous layer as shown in figure 3.

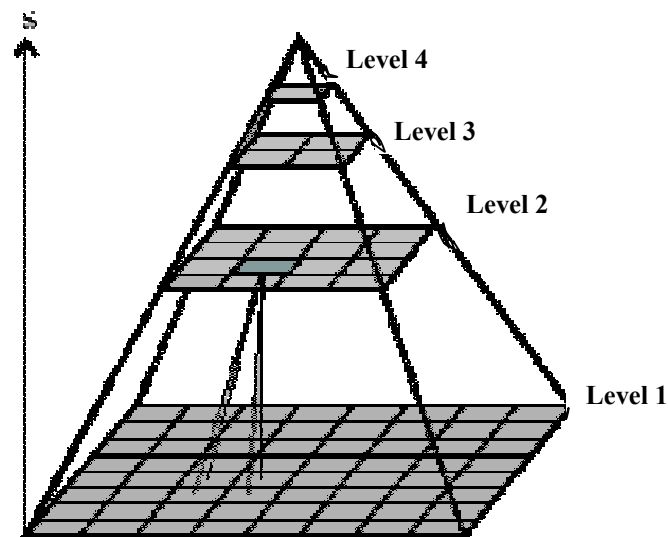


Figure 3: Gaussian Pyramid Levels.

The Gaussian Pyramid is a hierarchy of low-pass filtered versions of the original image, such that successive levels correspond to lower frequencies. (Burt and Adelson, 1983), each image in the pyramid is a representative of the original scene but in a lower resolution, see figure 4.

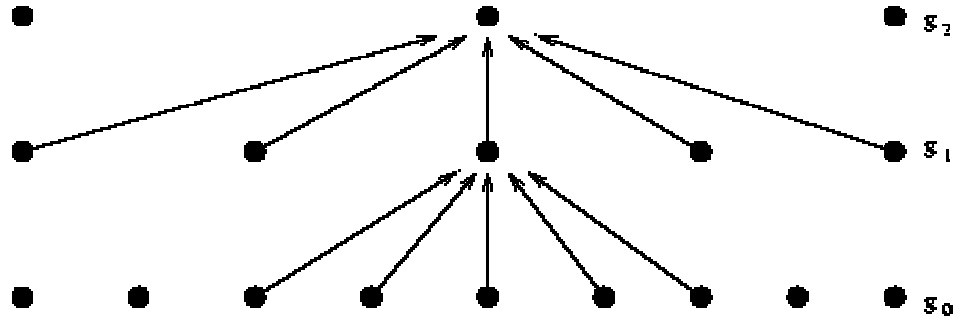


Figure 4: Sampling in the Pyramid.

The low-pass filtering is done using convolution with a Gaussian filter kernel. Where the filter overhangs the image edges, it reflects the image about its edge. Since the lowest frequencies have been removed, the full-size image contains redundant pixels, (Jolion, 2000). The Gaussian Pyramid is defined recursively as in equations 9 and 10, (Konstantinos, 2005).

I is the original image at level 0, $w[m, n]$ is the filter kernel of dimension $[5 \times 5]$.

$$G_0(x, y) = I(x, y), \text{ for level } l=0. \dots \dots \dots (12).$$

$$G_l(x, y) = \sum_{m=-2}^2 \sum_{n=-2}^2 w(m, n) G_{l-1}(2x + m, 2y + n). \dots \dots \dots (13).$$

LITRATURE REVIEW

1. Registration methods

1.1 Registration Methods Based on Geometric Image Features

These methods can be divided into registration of a set of points and registration of edges and surfaces, (Makela *et al.*, 2002).

A. Point-Based Registration:

Often uses a set of pre-defined points to derive a spatial transformation, these points are usually called control points. Control points could be extrinsic, intrinsic or combination of both. Intrinsic control points (Landmarks) are derived from naturally occurring anatomical features, such control points are selected from anatomical features which are derived using segmentation techniques applied to the image contents. While extrinsic control points (markers) are derived from artificially applied markers, such as skin markers.

The advantages of the point based registration methods are that they can be applied to any imaging modalities where markers or landmarks are visible and that the calculation of the registration parameters between two point sets is usually fast. But Registration of skin markers cannot guarantee registration of the heart within the body, since heart position changes with body position, respiration, and cardiac contraction. And there are few spatially accurate anatomical landmarks for heart images, also in some pathological conditions such as ischemia; the functional alterations can hide anatomical landmarks, (Maintz and Viergever, 1996).

B. Edge and Surface based registration:

Also called segmentation based registration methods, they can be rigid model based. These methods involve the determination of corresponding surfaces in different images and the estimation of spatial transformation between these structures, (Makela *et al.*, 2002).

Audette *et al.* (1999), describe most of the used surface segmentation algorithms, they determine what type of information to extract from the 3D surfaces, which typically characterizes their local or global shape, and how to organize this information into a representation of the surface which will lead to improved efficiency and robustness in the registration stage. And then use these information to estimate the transformation which best aligns local primitives in a globally consistent manner or which maximizes a measure of the similarity in global shape of two surfaces

Patient-specific mapping of point based cardiac data to a segmented heart surface requires accurate point-to-surface registration. The hypothesis is that anatomical movement that occurs between electrophysiological (E-P) data and cardiac image acquisition causes the pulmonary veins to have different orientations relative to the heart. (Harris and Robb, 2003), propose a piecewise registration of the atria and veins to produce a more accurate matching of these data sets. They developed phantoms and simulated clinical data accounting for noise and motion to demonstrate the robustness of the point-to-surface registration algorithm.

There are three popular matching approaches:

1. Head-Hat algorithm: Mostly used in brain studies, the surface of one of the images is used as the head and a set of points, extracted from the surface contours in the other image to represent the hat. The hat is then registered to the head by minimizing the distance of hat points from the head surface.

2. Hierarchical Chamfer Matching (HCM): a chamfer distance map is generated from the surface of one of the images. This distance map is then used as a potential function for surface points in the other image and the total potential is minimized.

3. Iterated Closest Point algorithm (ICP): Images are represented using points on a surface. In each iteration of the algorithm, the closest point in one image is determined for all points in the other image. These point correspondences can then be used to register the images using various spatial transformations.

The draw back of segmentation based methods is that the registration accuracy is limited to the accuracy of the registration step.

1.2 Methods Based on Voxel Similarity Measures

These methods can be divided into registration based on moments and principal axes, intensity difference and correlation methods, and methods based on mutual information, (Makela *et al.*, 2002).

A. Methods based on Moments and Principal Axes:

Image registration methods based on moments and principal axes use statistical factors derived from image data. Moments describe the spatial distribution of the mass (intensity) of the image. Registration is performed by overlaying the centroids of the objects, and aligning the principal axes.

If two images are identical except for a translation and a rotation, then they can be registered exactly by bringing their principal axes into coincidence. But these methods are sensitive to shape differences, so they are limited to be used.

The result is usually not very accurate, and the method is not equipped to handle differences in scanned volume well, although some authors attempt to remedy this latter problem. Despite its drawbacks, principal axes methods are widely used in registration problems that require no high accuracy, because of the automatic and very fast nature of its use, and the easy implementation, (Maintz and Viergever, 1996).

B. Intensity Difference and Correlation Methods:

Image intensity difference and correlation methods attempt to determine the best registration by maximizing the similarity between images that differ primarily because of

different image-acquisition conditions, like noise. The assumption of these methods is usually that pixel values in the registered images are strongly correlated. Therefore, these methods are particularly powerful for intra-modality registration methods.

In Penney *et al.* (2004), a method is presented to interpolate between neighboring slices in a grey scale tomographic data set. Spatial correspondence between adjacent slices is established using a nonrigid registration algorithm based on B-splines which optimizes the normalized mutual information similarity measure. Linear interpolation of the image intensities is then carried out along the directions calculated by the registration algorithm.

Gustavo, 2004, implemented a project to produce an independent implementation of a program for nonrigid (nonlinear) registration of 3D multi-channel medical images.

In (Xiu *et al.*, 2002) a two-step elastic medical image registration approach is proposed, which is based on the image intensity. In the first step, the global affine medical image registration is used to establish one-to-one mapping between the two images to be registered. After this first step, the images are registered up to small local elastic deformation. Then the mapped images are used as inputs in the second step, during which, the study image is modeled as elastic sheet by being divided into several subimages.

Perperidis *et al.* (2004), present two registration algorithms for the spatio-temporal alignment of cardiac MR image sequences. Both algorithms have the ability to correct spatial misalignment between the images caused by global and local shape differences. In addition, they have the ability to correct temporal misalignment caused by differences in

the length of the cardiac cycles and by differences in the dynamic properties of the hearts. The algorithms use a 4D deformable transformation model which is separated into spatial and temporal components.

Voxel property based methods using the full image content: are the most interesting methods researched currently. Theoretically, these are the most flexible of registration methods, since they –unlike all other methods mentioned– do not start with reducing the grey valued image to relatively sparse extracted information, but use all of the available information throughout the registration process.

An increasing clinical call for accurate and retrospective registration, along with the development of ever-faster computers with large internal memories, has enabled full-image-content methods to be used in clinical practice. Using the full image content can be applied in almost any medical application area, using any type of transformation, (Makela *et al.*, 2002).

C. Mutual Information:

Mutual information is an information theory measure of the statistical dependence between two random variables or the amount of information that one variable contains about the other. Mutual information can be qualitatively considered as a measure of how well one image explains the other. The mutual information is maximized at the optimal alignment. No assumptions are made regarding the nature of the relation between the image intensities in the registered images. Therefore, the mutual information method is promising in particular for inter-modality registration. Inter-modality registration differs from intra-

modality registration because different medical imaging modalities usually have different intensity characteristics and different resolutions, noise characteristics, and fields of view. Several normalized versions of the mutual information has been proposed because changes in overlap of very low-intensity regions of the image can disproportionately contribute to the mutual information measure, (Senthil, 2006).

Most of commonly used multimodal similarity measures are inherently global and cannot be directly used to estimate local image properties. Rogelj and Kovacic, (2001) have derived a local similarity measure based on joint entropy, which can operate on extremely small image regions.

Chou, (2004) developed a general nonrigid image registration algorithm. It uses spline functions to describe the deformation and uses multi-scale strategy to search for the optimal transformation. Then he presents a new registration operator that is transitive and symmetric. He investigated the theoretical implication of these properties and applies this operator to the registration of sequences of MR cardiac images.

Wachowiak *et al.* (2004) proposed a new hybrid particle swarm technique that incorporates initial user guidance. Multimodal registrations with initial orientations far from the ground truth were performed on three volumes from different modalities. Results of optimizing the normalized mutual information similarity metric were compared with various evolutionary strategies. The hybrid particle swarm technique produced more accurate registrations than the evolutionary strategies in many cases, with comparable convergence. These results demonstrate that particle swarm approaches, along with evolutionary techniques and local

methods, are useful in image registration, and emphasize the need for hybrid approaches for difficult registration problems.

Table 1 shows a comparison between some of different types of registration methods, (Makela *et al.*, 2002).

Table 1: Comparisons of Registration Techniques

Author	Modalities	Object	Trans.	Method
Based on geometric image features				
Point-Based Registration				
Wirth	CT-MR	Thorax	Elastic	Interpolation & Elastic function
Thorax Surface-Based Registration				
Makela	MR-PET	Heart	Rigid	Chamfer
Heart Surface-Based Registration				
Nekolla	PET-SPECT	Heart	Rigid	-
Registration methods based on voxel similarity measures				
Intensity Difference and correlation methods				
Bacharach	PET-PET	Heart	Rigid	Correlation coefficient
Mutual Information				
Carrillo	MR-MR	Abdom	Rigid	Mutual information

THE SUGGESTED MATCHING TECHNIQUES

This chapter explains the suggested matching technique, how they work and their characteristics.

Three techniques are suggested to match template with target image, Gaussian pyramid 3rd level histogram, Gaussian pyramid 3rd level rmse, and non-base filtered Gaussian pyramid 3rd level histogram.

The first suggested technique compares between the histograms of both the template and each target's segments using L_1_norm *see equation (14)*. The segment with the lowest L_1_norm value is considered to match the template and is labeled. This approach solves the problem of location variation between images. The problem in using this approach is the time spent to compare the histogram of the template with the histogram with each segment due to the large number of segments in the target image, to solve this problem and to enhance the time of matching, Gaussian pyramid is used to sample both the target and the template images into multi-resolution images, *see equations (12) and (13)*.

The second technique uses root-mean-square (rms) error; *see equation (15)*; to compare between the template and each of the target's segments. The segment with the lowest rmse value is considered to match the template and is labeled. For enhancing matching time, Gaussian pyramid is used to sample the images into lower resolutions.

The third technique compares between the histograms of both the template and each target's segments using L1_norm, The segment with the lowest L1_norm value is considered to match the template and is labeled. This approach solved the problem of location variation between images. The problem of using this approach is the time spent to compare the histogram of template with the histogram of each segment due to the large number of segments in the target image, to solve this problem and to enhance the time of matching, Gaussian pyramid is used to sample both target and template images into multi-resolution images, then the histograms of the third level images are compared. The difference between this approach and the first one is that the original image (first level of the pyramid) is not filtered with Gaussian filter as the rest of the pyramid levels, while in the first technique each image of the pyramid is filtered using Gaussian filter.

L1_Norm: An estimation of the difference amount between two vectors v and m .

$$l_1\text{-Norm} = \sum_i |v_i - m_i| \dots \dots \dots (14)$$

Root-Mean-Square (rms) Error: An estimation of the error between two images, (Gonzalez and Woods, 2002). It estimates the differences amount between two images I' and I both of size $(M \times N)$.

$$e_{rms} = \sqrt{\frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} [I'(x, y) - I(x, y)]^2} \dots \dots \dots (15).$$

1. Matching Using the Histogram of Gaussian Pyramid's Third Level Image

In this Approach both Images (the Target, and the Template) are resampled using Gaussian Pyramid technique using equation (12) and (13), Then the template 3rd level histogram is calculated to be compared with the target segments 3rd level histograms using L_1_Norm value see equation (14). See figure 5 which shows the steps of this technique

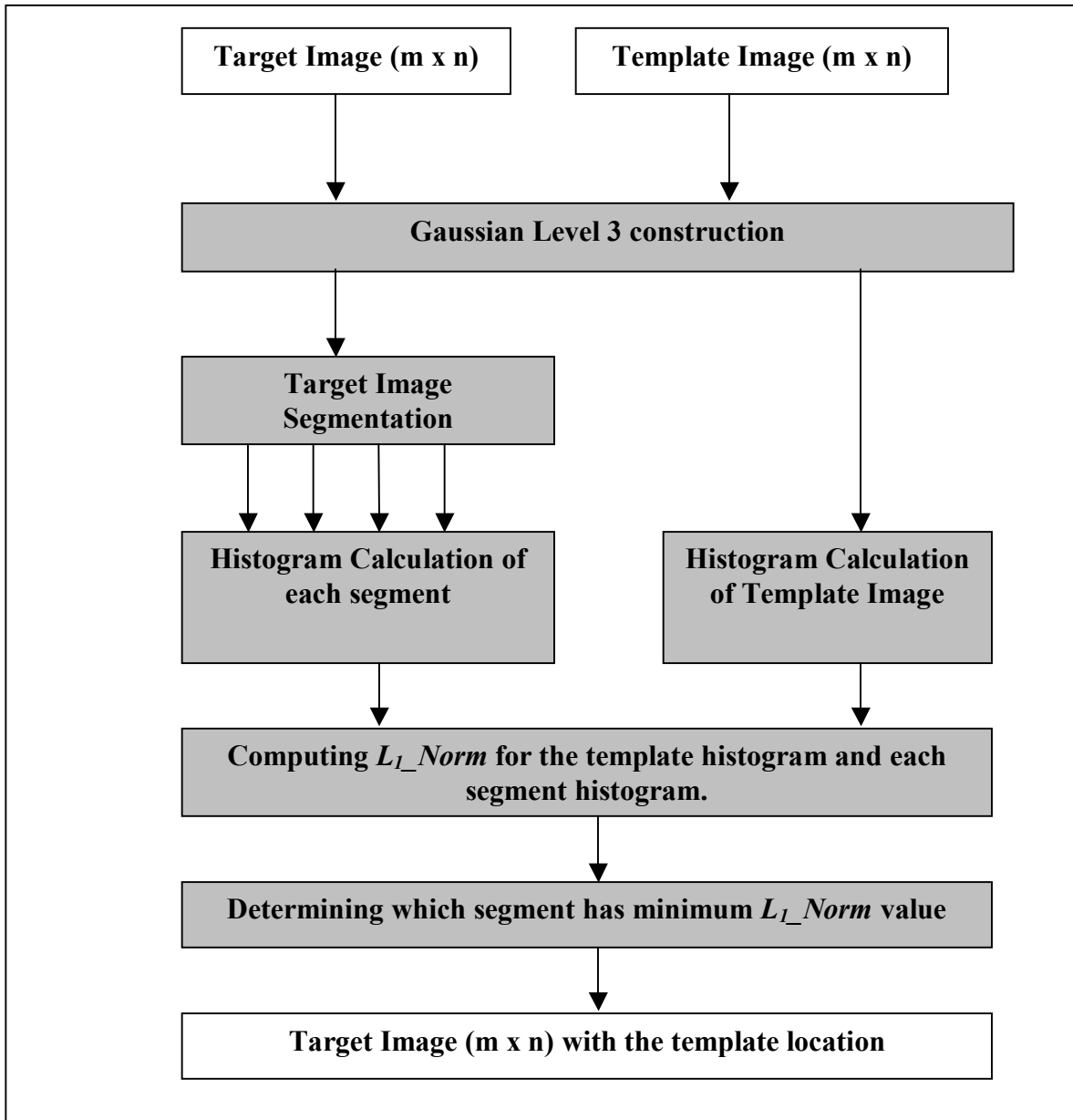
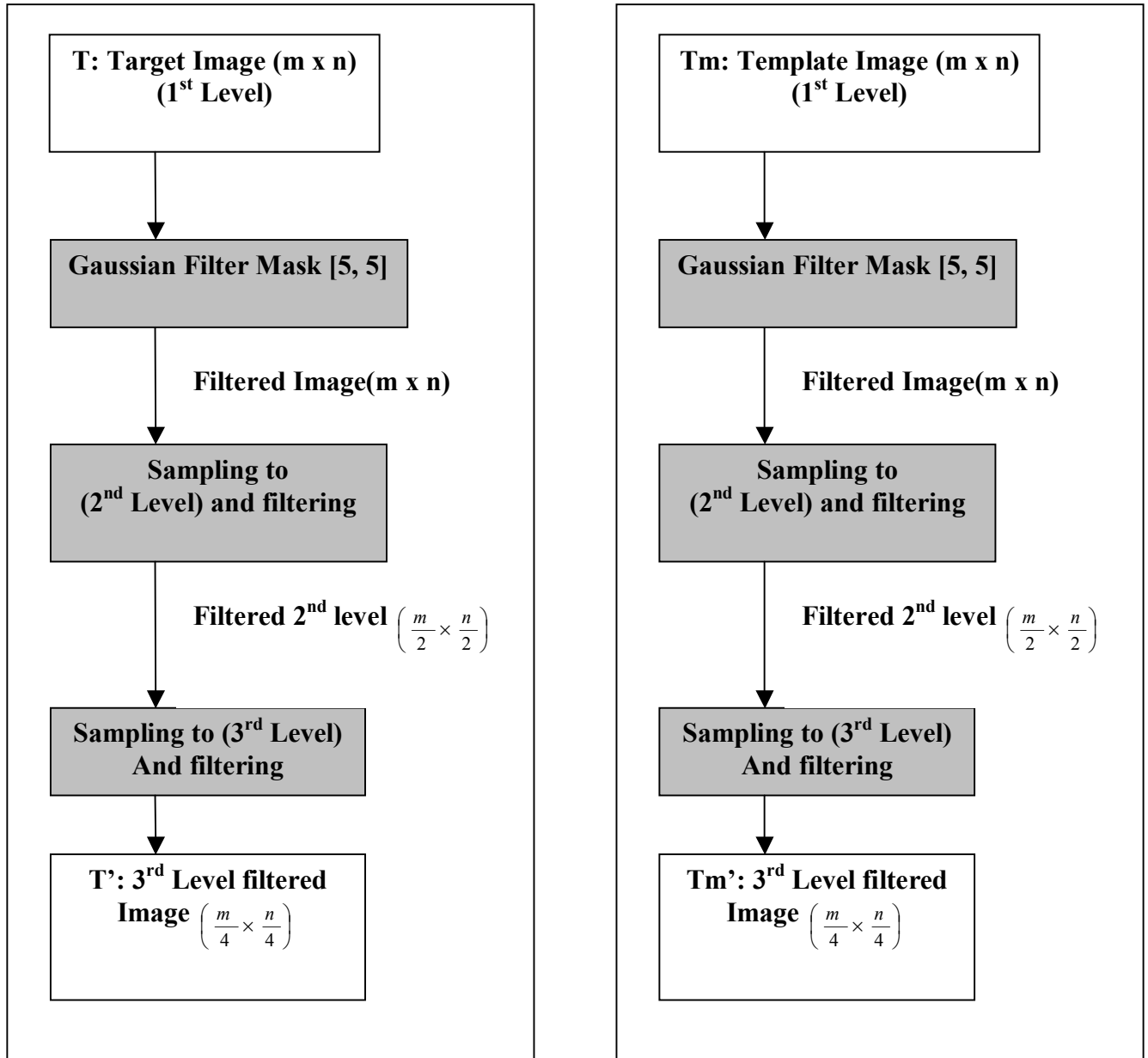


Figure 5: Steps of using 3rd level histograms technique in matching.

1.1 Steps of Matching

1.1.1 Constructing the Third Level of Gaussian Pyramid:

Figures 6 and 7 show the steps of constructing the 3rd level image; as discussed previously; for both target and template images.



Figures 6, 7: The steps of constructing 3rd level image for both target and template images.

1.1.2 Target Segmentation:

The System segments the target image into smaller segments with height and width equal to the template height and width starting from the first pixel (1, 1). For each segment, the histogram is computed and compared to the template histogram by calculating the L_1_norm value. And then the procedure is repeated for the next pixel (1, 2), and so on for each pixel in the target image. The following example illustrates the process of segmentation. Figure 8 shows an example of 10 x 10 target image and a 3 x 3 template image.

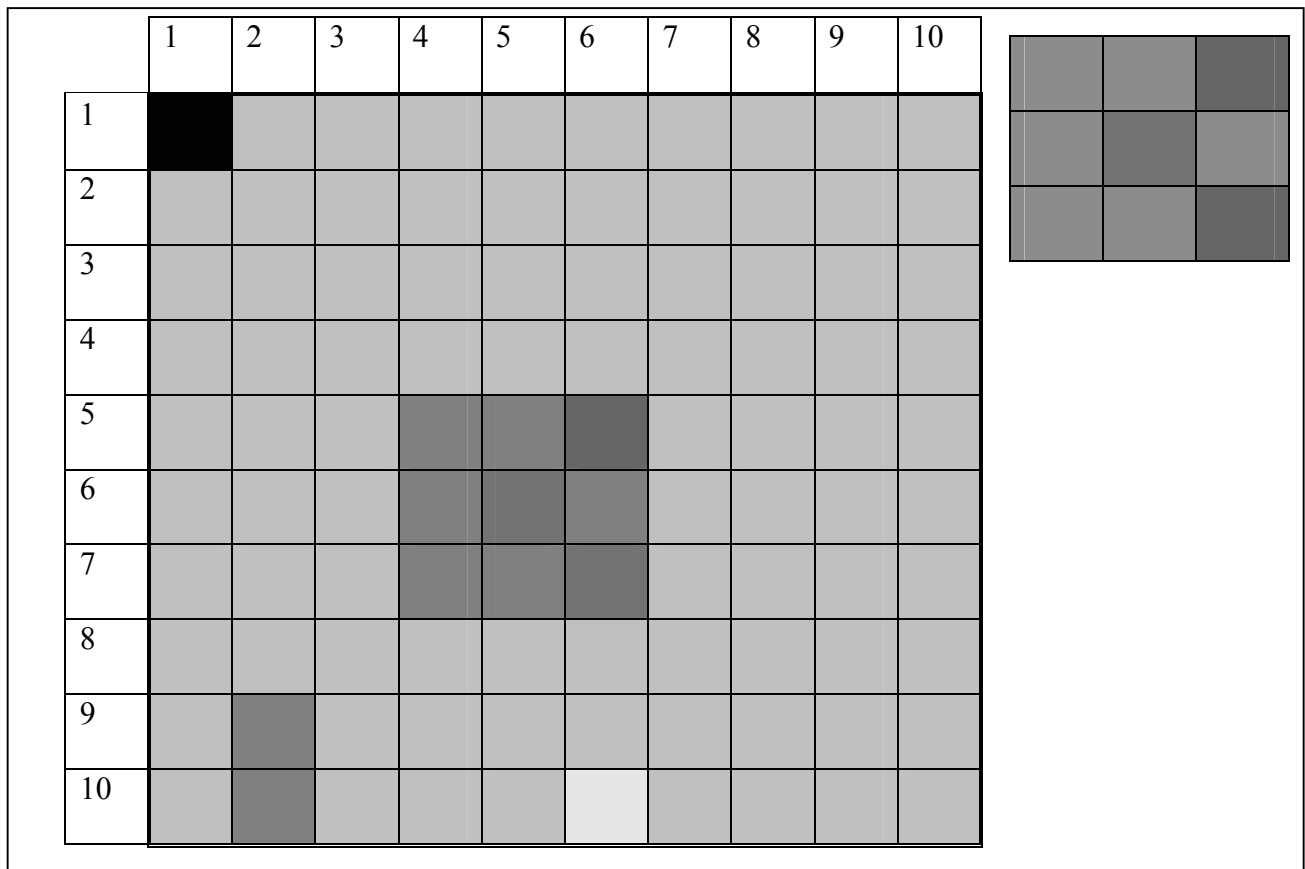


Figure 8: An illustrative example of target and template images.

Starting from pixel (1, 1) to pixel (8, 8) for each pixel a segment of size 3 x 3 is taken to be compared with the template which is of the same size 3 x 3. It is obvious that the best matching segment is that one starting at x=5, y=4, See figure 10. Figure 9 shows the number of pixels that will cover the segmentation process.

$$\text{Number of segments} = (Tr - Tmr + 1) * (Tc - Tmc + 1) \dots\dots\dots(16).$$

Where

Tr : numbers of rows in the Target. Tmr : numbers of rows in the Template.

Tc : numbers of columns in the Target. Tmc : numbers of columns in the Template

	1	2	3	4	5	6	7	8	9	10
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										

Figure 9: The number of pixels that will cover the segments.

From here we can understand the main key of using the sampling technique which will reduce the number of pixels in both images, and the number of comparisons, because the less number of pixels we have the less number of segments to be compared. The segment with the least L_1_norm value will be marked as the template match.

1.1.3 Calculating L_1_Norm and labeling the matched segment:

After segmenting the target image 3rd level and calculating the histograms of each segment they will be compared with the template 3rd level image histogram using L_1_norm , the matched segment is the one with the lowest L_1_norm value, *see equation (17)*. Figure 10 shows the labeled segment in our previous example.

Matched Segment =

$$\left\{ (x, y) \left| \text{Min} \left(\sum_{i=1}^{256} \text{abs} (Tm'[i] - T'seg_k[i]) \right) \text{for } 1 < k < n \right. \right\} \dots\dots\dots(17).$$

Where n is the number of segments as in equation (16), Tm' is template histogram, $T'seg_k$ is the Target k th segment histogram.

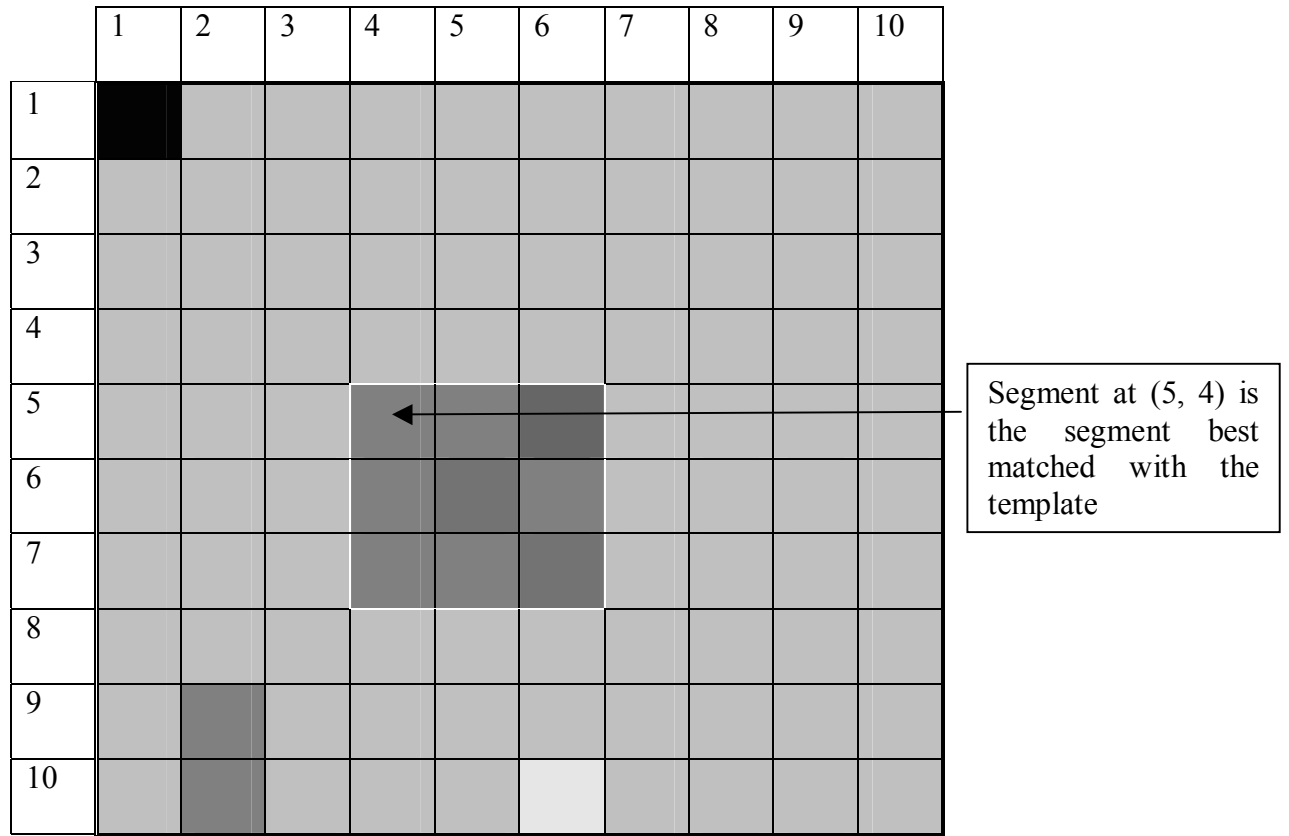


Figure 10: The matched Segment.

2. Using the Root-Mean-Square Error of Gaussian Pyramid's Third Level

In this Approach both Images the Target and the Template are resampled using Gaussian Pyramid technique. Then the target 3rd level image is segmented into smaller segments each one has the same width and height as the template 3rd level image described in the previous section. Each segment is compared with the template 3rd level image using rms error value, *see equation (15)*. The matched segment is the one with lowest rms error value. Figure 11 shows this approach steps.

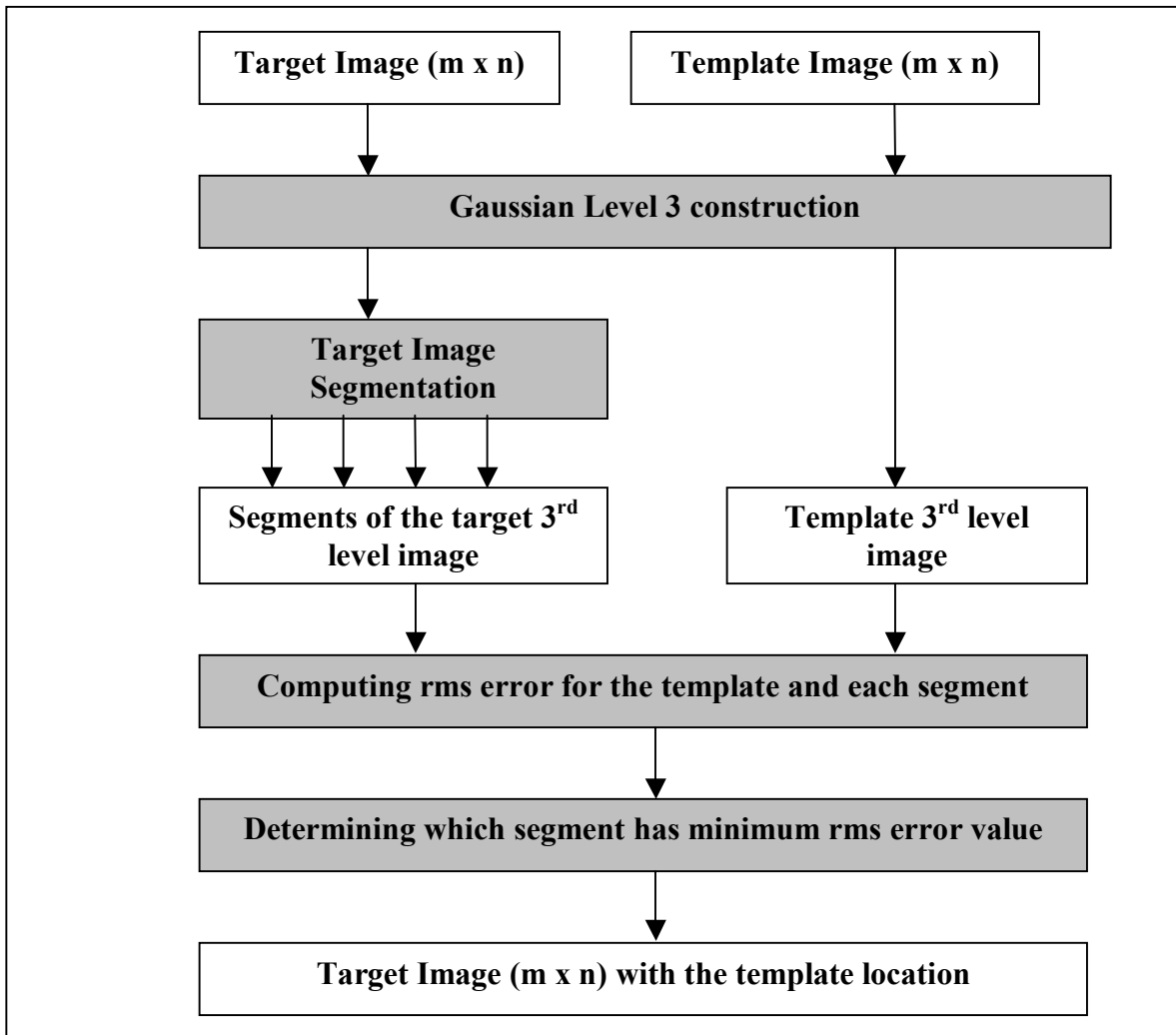


Figure 11: Steps of the second technique.

3. Non-Base Filtered Gaussian Pyramid's 3rd Level Image Histogram

This technique works the same as the first technique but filtering image levels with the Gaussian filter starts from the 2nd level of the pyramid. The original image (1st level) is kept unfiltered. See figure 12 which shows the pyramid construction process.

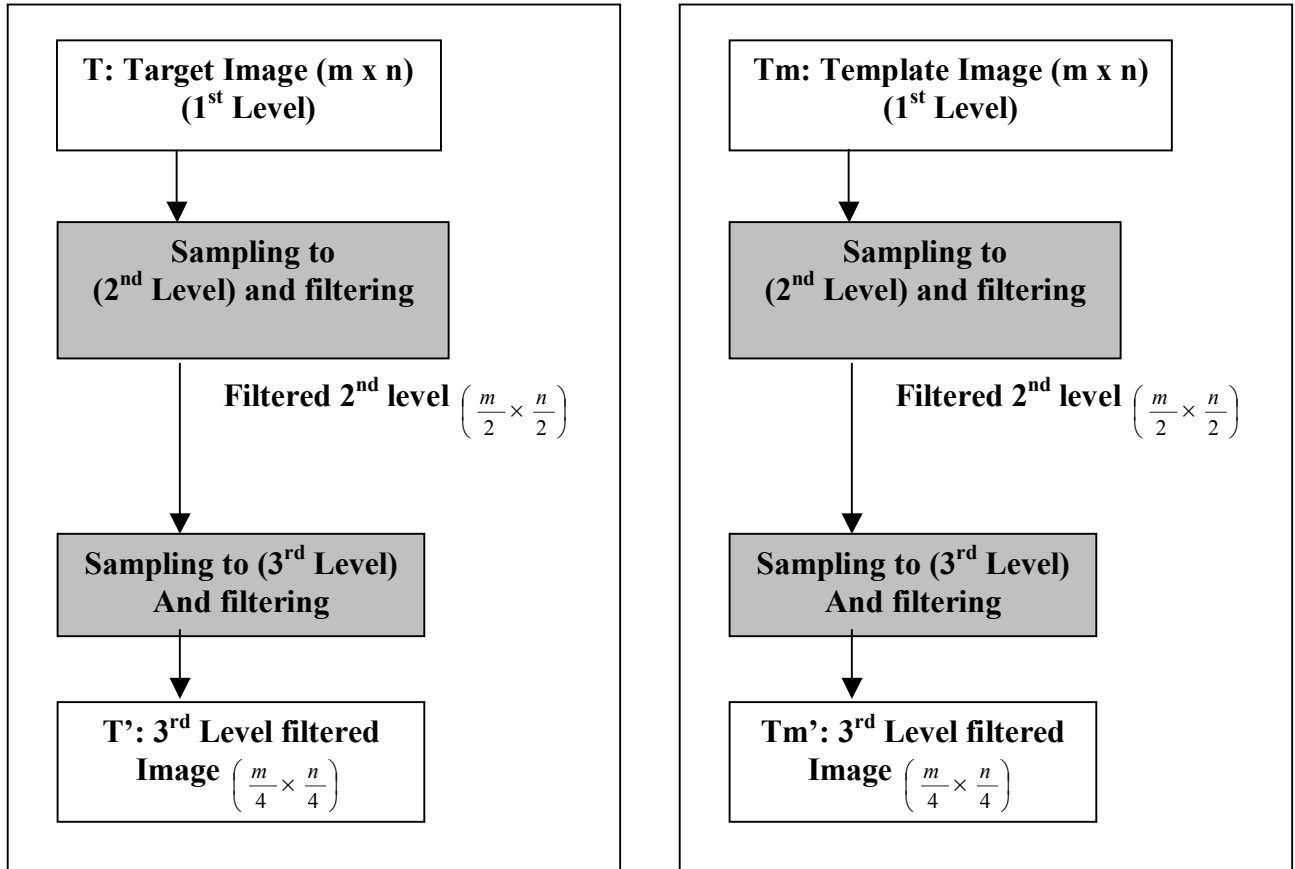


Figure 12: Steps of constructing Gaussian pyramid in the third technique.

4. Using Threads for Reducing the Matching Performance Time

The previous techniques are implemented using matlab, Due to the independency in segments comparisons with template image, the previous techniques are implemented using threads in java language. Each thread takes a pixel location to extract the segment and calculate its histogram to be compared with the template histogram as in the first and third techniques, or compares the segment intensity values with the template using rms error. This way the comparison processes will be done in parallel, reducing the total system time. Steps are illustrated in figure13.

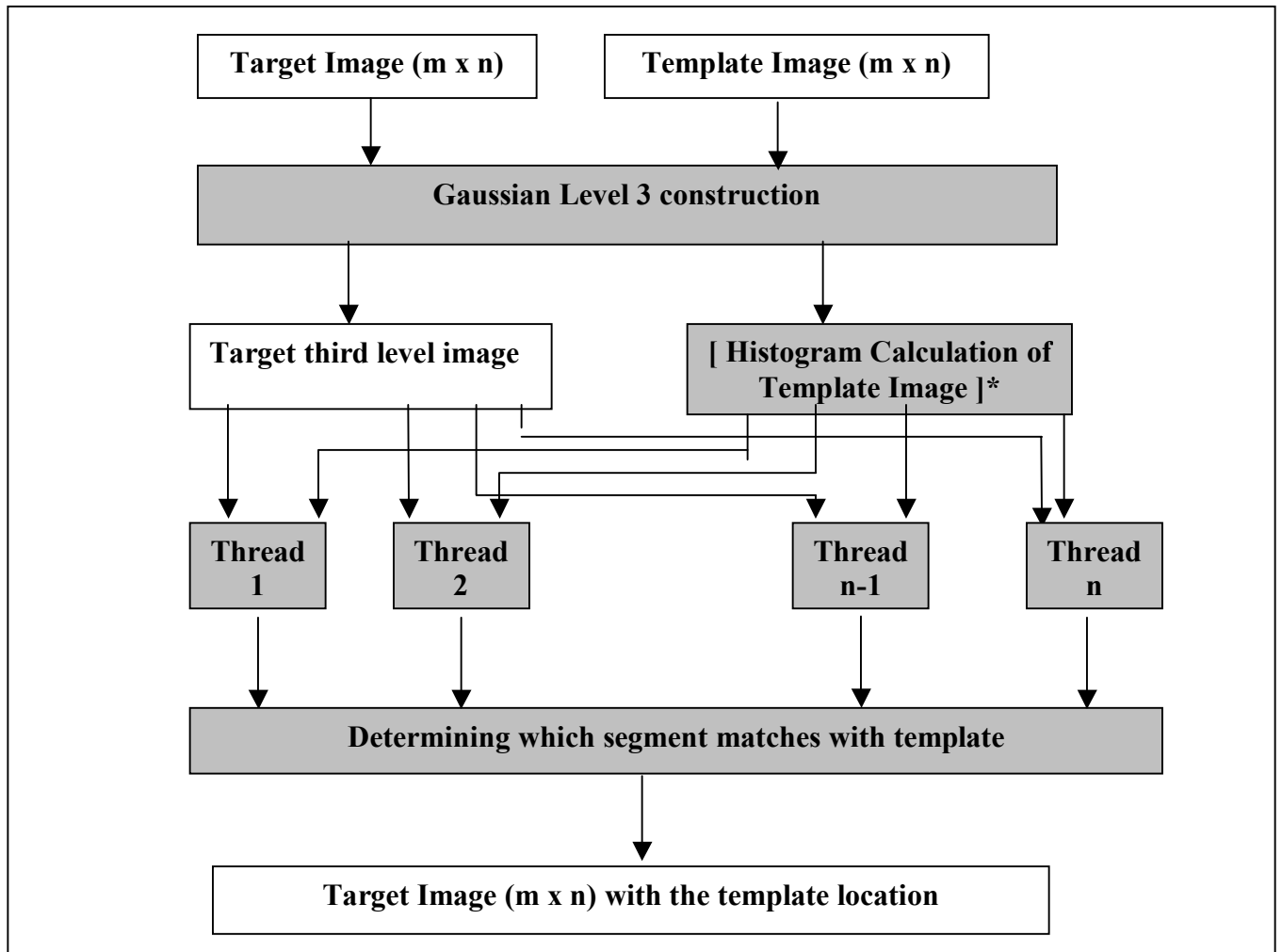


Figure 13: Steps of matching using threads.

EXPERIMENTAL STUDY AND ANALYSIS

The sample data used to test the techniques are six LA cardiac images obtained from Philips medical site, two spine MRI images obtained from Red River Valley Radiology Associates site, and two brain images obtained from Harvard Brain MRI Atlas.

1. Gaussian Pyramid 3rd Level Image Histograms

In this section the experiments results for the first suggested technique (using histograms of the Gaussian pyramid 3rd level images) will be listed. The system was tested on long axis (LA) heart MRI images in both systole and diastole states, and on Spine MRI image.

1.1 Long Axis Heart MRI Images

In this section the results of applying the suggested technique on heart MRI images in both systole and diastole states will be listed. Both of the images were rotated in order to test the suggested system on rotated images.

▪ Long Axis Heart Systole MRI in Normal Orientation

The image shown in figure 14 is a heart MRI image in a systole state obtained from Philips medical site.



Figure 14: LA Heart Systole MRI

This image is considered as the target image which will be matched with template images of Arteries and Apex shown in figures 15 and 16 taken from the same image shown in figure 14.

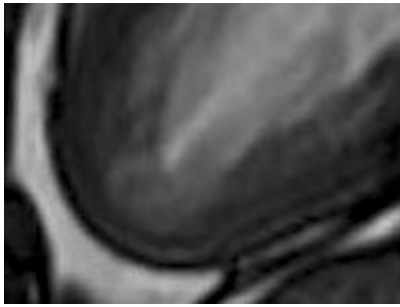


Figure 16: Apex MRI (150 x 199).



Figure 15: Arteries MRI (135 x 161).

❖ Gaussian Pyramid 3rd level construction

In this stage both of the target and template images will be sampled into the third level after filtering each level with Gaussian filter of size (5 x 5). As shown in figure 18 the target image (1st level) size is (600 x 600), after filtering the target and sampling it into the 2nd level the size will be reduced to (300 x 300). Figure 17 shows the 3rd level of the target image which is constructed after filtering the 2nd level with Gaussian filter of size (5 x 5), the 3rd level size is (150 x 150).

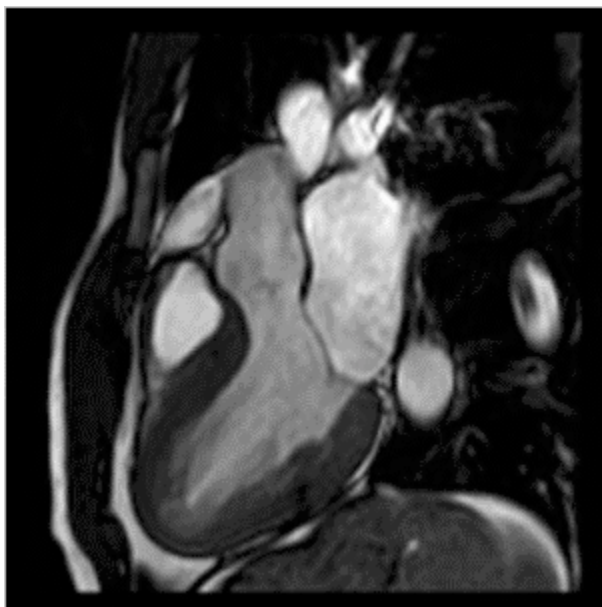


**Figure 18: LA Heart Systole MRI 2nd level
(300 x 300).**



**Figure 17: LA Heart Systole MRI 3rd
level (150 x 150).**

As we can see the 3rd level image decreases the size of the image and so decreases the number of pixels in the image and keeps the details of the image which gives the best results matching wise and time wise.

The same procedure is applied on the template images, figures 20 and 19 show the Apex template in the 2nd level with size (75 x 99) and 3rd level with size (38 x 49) consequently.

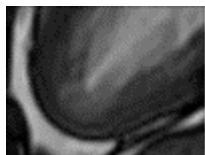


**Figure 20: Apex MRI 2nd level
(75 x 99).**



**Figure 19: Apex MRI 3rd level
(38 x 49).**

Figures 21 and 22 show the Arteries templates in the 2nd level with size (68 x 80) and 3rd level with size (34 x 40) consequently.



**Figure 21: Arteries MRI
2nd level (68 x 80)**



**Figure 22: Arteries MRI
3rd level (34 x 40)**

Each of the target 3rd level and template 3rd level images is filtered using Gaussian filter then the target 3rd level image is segmented. The histogram of each segment is compared with the histogram of the template image by calculating the L1_norm value. The segment which has the minimum L1_norm is labeled.

The result of matching the Apex template with the target image is shown in figure 23, the matched segment is labeled in a white box.



Figure 23: LA Heart Systole MRI with Apex segment labeled

The technique located the Apex template at the area labeled in white, this segment has the minimum L1_norm value among the other segments, Figures 24 and 25 show the histograms of the template image and the located segment.

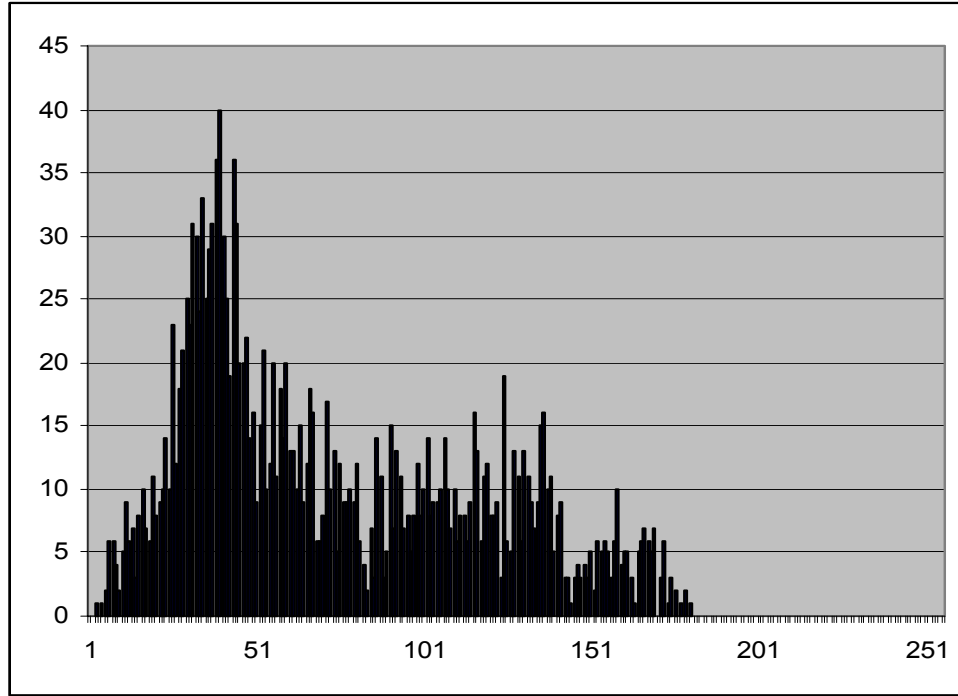


Figure 24: The histogram of the Apex 3rd level template image.

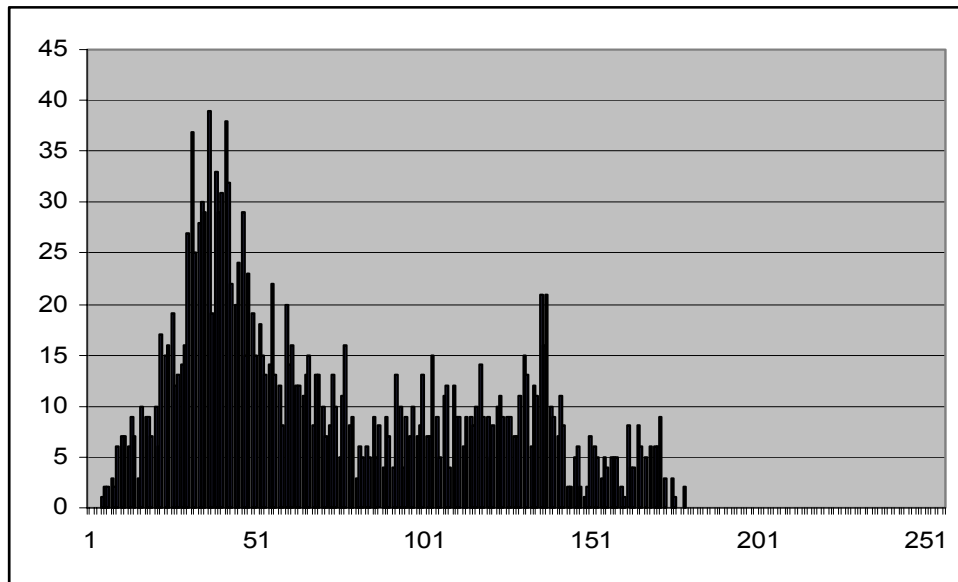


Figure 25: The histogram of the Apex located segment 3rd level.

The difference between these two histograms calculated by $L1_norm$ is 630. The located segment starts at pixel (416, 104), while the original Apex template is located at (411,99) so as we can see the shift in the x direction is 5, and in the y direction is 5 pixels.

The same procedure is done for matching the Arteries template with the target image, the result is shown in figure 26.



Figure 26: Heart Systole MRI with Arteries segment.

The $L1_norm$ value of comparing both histograms at this segment is 552, the upper left pixel of this segment is located at (36,256) while the original template location is at (34,242) which makes the error shift value is equal to 2 in the x direction and 14 in the y direction.

Figures 27 and 28 show the histogram of the 3rd level template and the located 3rd level segment image histogram.

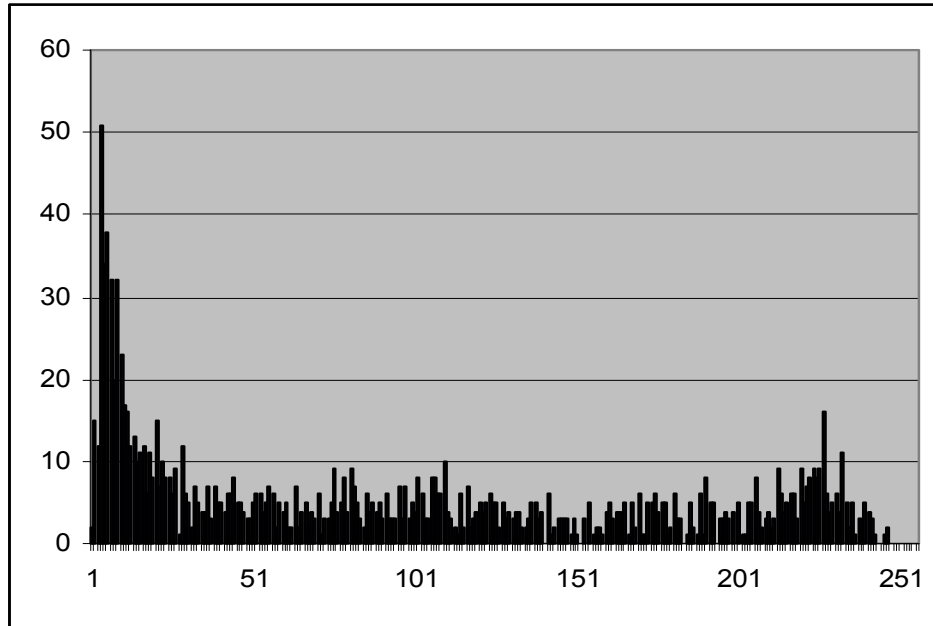


Figure 27: Arteries template 3rd level image histogram.

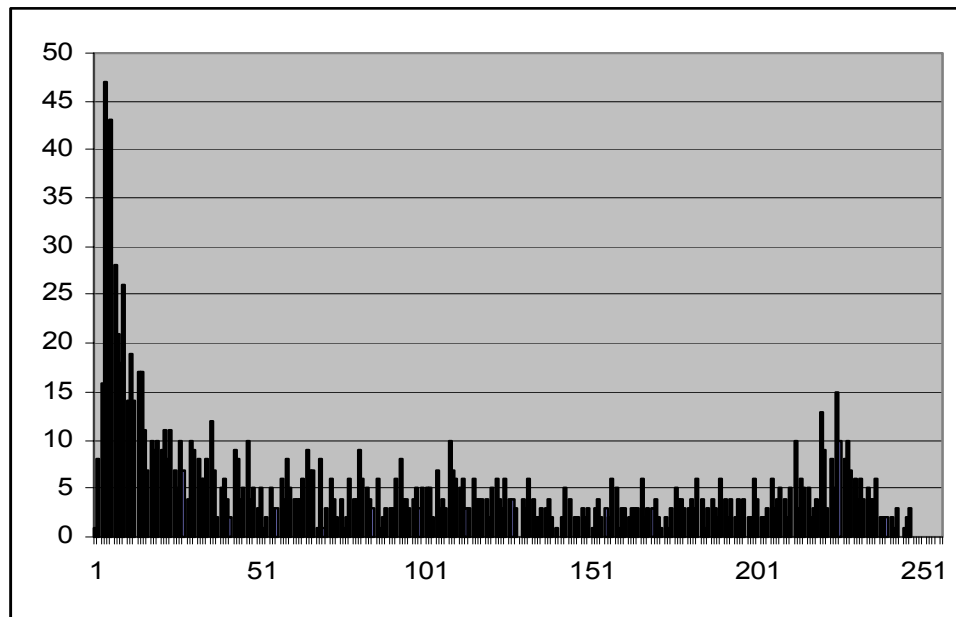


Figure 28: Arteries Segment 3rd level image histogram.

▪ Long Axis Heart Systole MRI in 90° Rotation

The image shown in figure 29 is a rotated heart MRI image in a systole state obtained from Philips medical site.

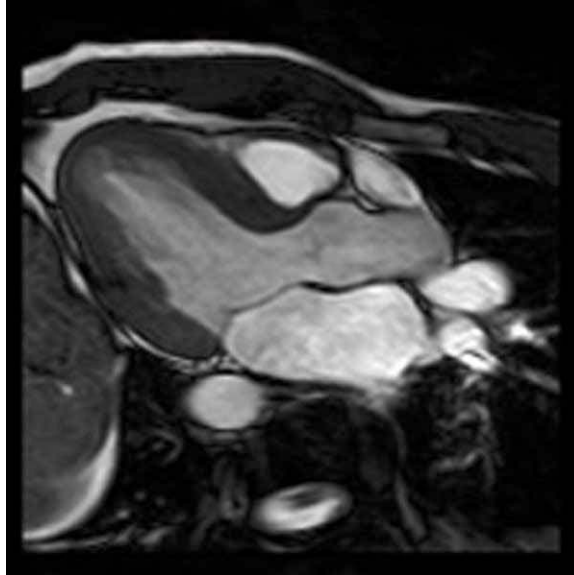


Figure 29: Rotated LA Heart Systole MRI.

This image is considered as the target image which will be matched with template images of Apex and Arteries shown in figures 15 and 16. These templates were taken from the image shown in figure 14 in the normal orientation in order to test the technique on large amount of variation between images.

As discussed previously the 3rd level image is constructed for both the template and the target images, then the target 3rd level image is segmented and each segment histogram is calculated to be compared with the template 3rd level image histogram. Figure 30 shows the result of matching the Apex template with the target image.

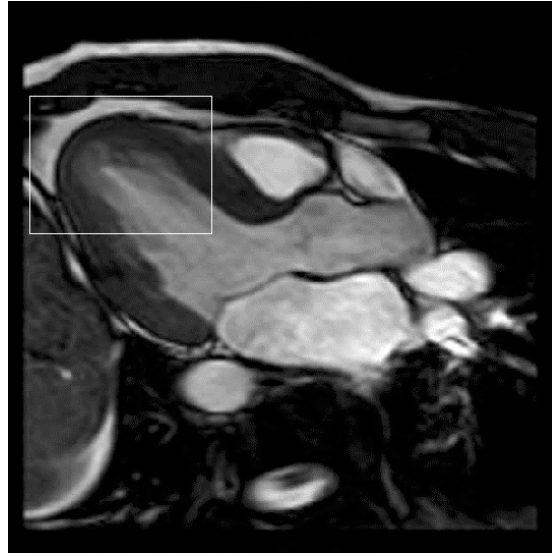


Figure 30: Rotated LA Heart Systole MRI with Apex segment.

The technique located the Apex template at the area labeled in white, this segment has the minimum L1_norm value among the other segments, Figures 31 and 32 show the histograms of the template image and the located segment.

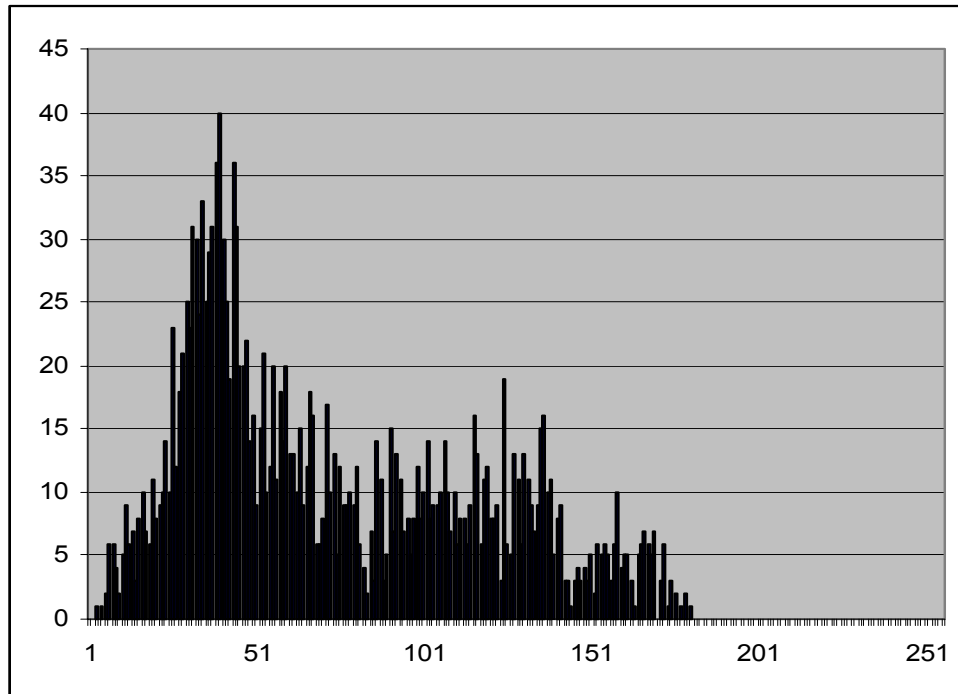


Figure 31: The histogram of the Apex 3rd level template image.

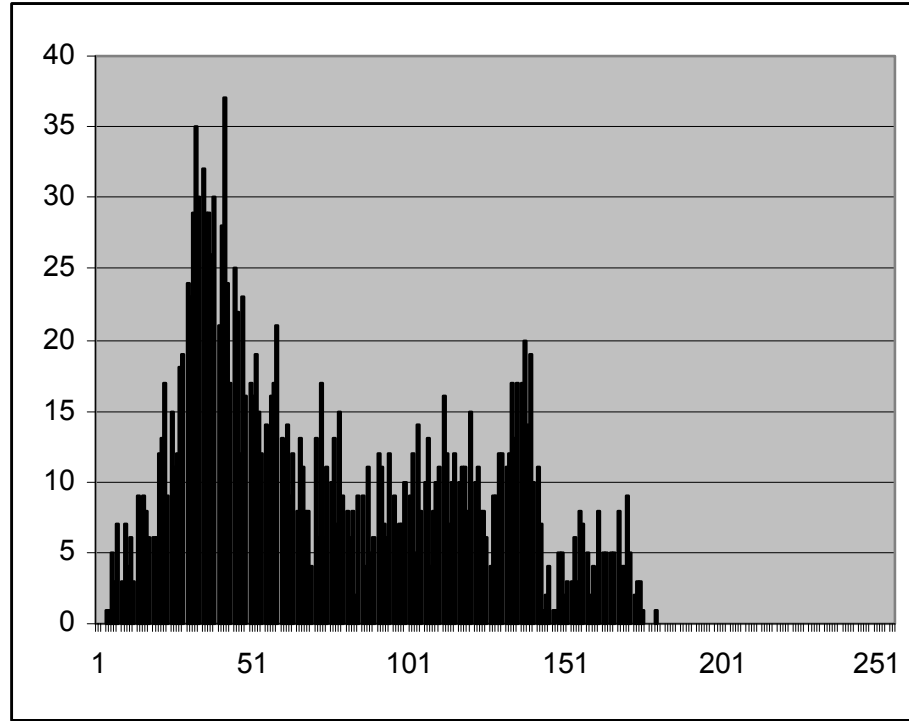


Figure 32: The histogram of the Apex 3rd level located segment.

The difference between histograms of figures 31 and 32, calculated by $L1_norm$, is 606. The located segment starts at pixel (104, 24), while the approximate Apex template location in the rotated image is at (97,33) so as we can see the shift in the x direction is 7, and in the y direction is -9 pixels.

The same procedure is done for matching the Arteries template with the target image, the result is shown in figure 33.



Figure 33: Rotated Heart Systole MRI with Arteries segment.

The $L1_norm$ value of comparing both histograms at this segment is 564, the upper left pixel of this segment is located at (256,424) while the approximate template location in the rotated image is at (242,423) which makes the error shift value equals to 14 in the x direction and 1 in the y direction.

Figures 34 and 35 show the histograms of the 3rd level template image and the located 3rd level segment image, the figures show how close both template and segment images even with large variation of rotation between them and this is the key of using histograms no matter what difference in locations or shapes histograms will not vary that much.

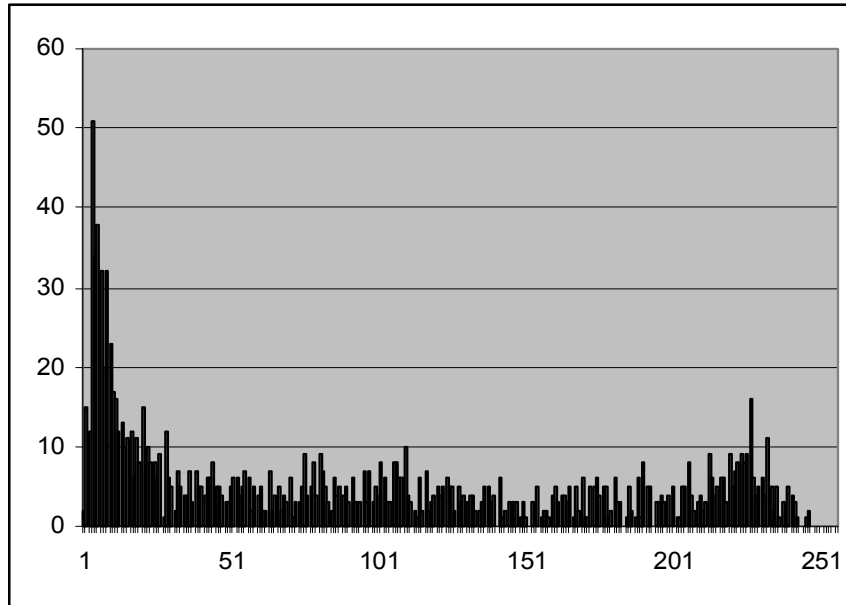


Figure 34: Arteries template 3rd level image histogram.

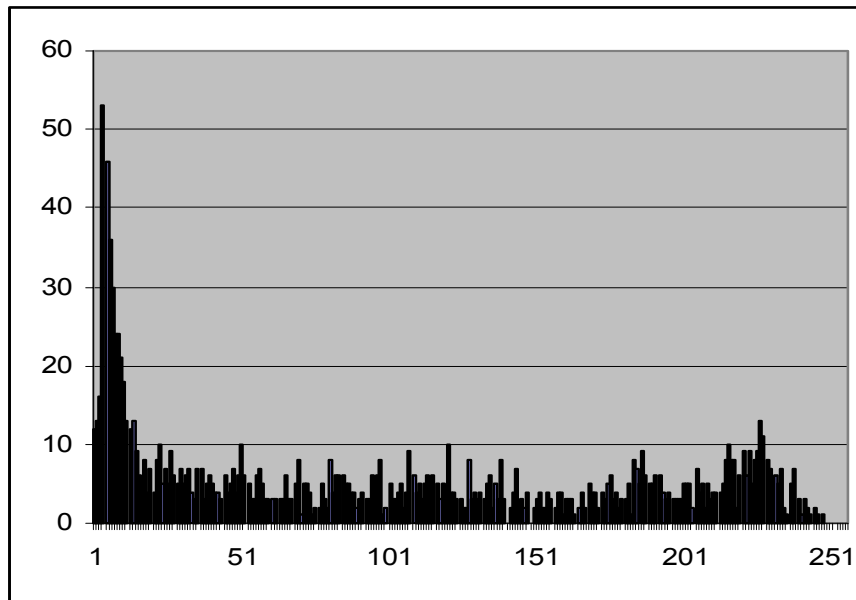


Figure 35: Arteries segment 3rd level image histogram.

- **Long Axis Heart Diastole MRI in Normal Orientation**

The image shown in figure 36 is a heart MRI image in diastole state obtained from Philips medical site.

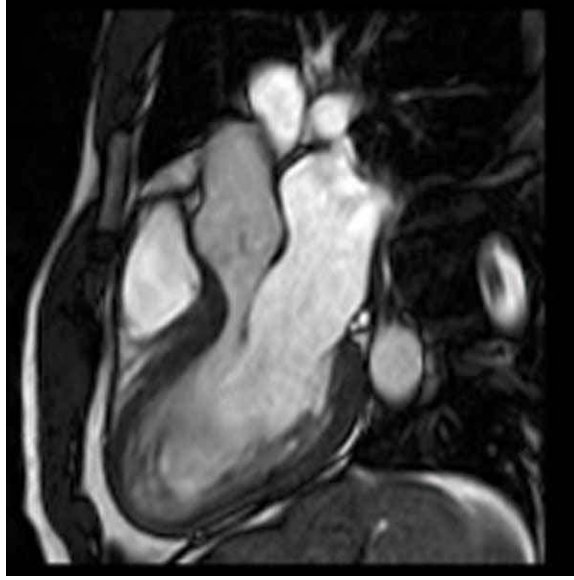


Figure 36: LA Heart Diastole MRI.

This image is considered as the target image which will be matched with template images of Apex and Arteries shown in figures 15 and 16 taken from the same image shown in figure 14 in order to test the technique whether it can match heart parts in different heart states.

For both template and target images the 3rd level image is constructed as described previously, and then the histogram of the template image is compared with each of the 3rd level images of segments to find out the segment with minimum L1_norm. Figure 37 shows the result of matching Apex template with the target image.



Figure 37: LA Heart Diastole MRI with Apex segment labeled

The value of the $L1_norm$ at this segment is 836.

Figures 38 and 39 show the histograms of the template image and the located segment.

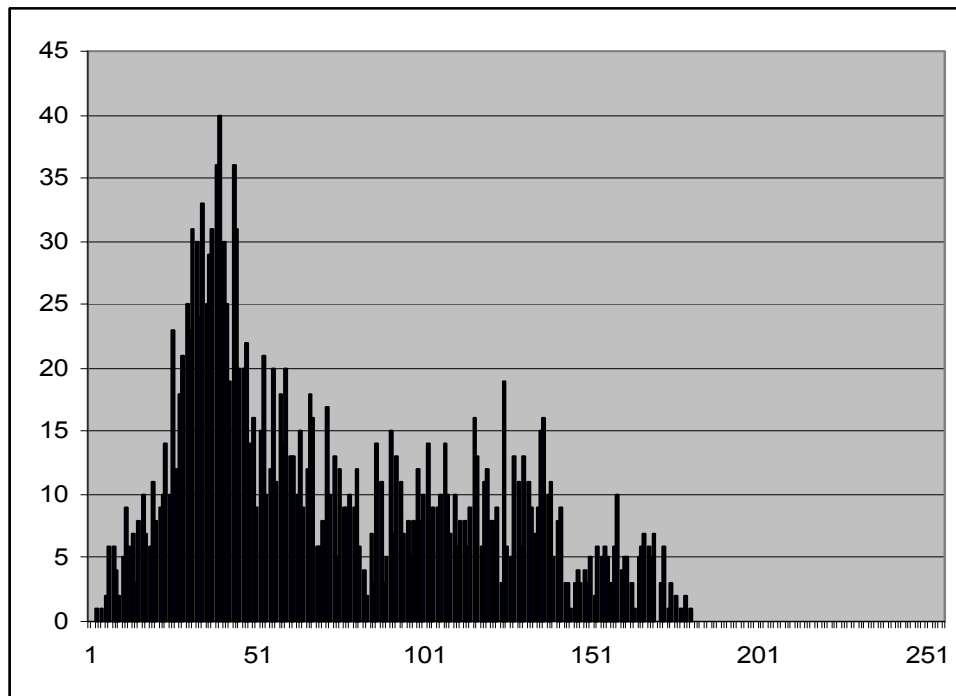


Figure 38: The histogram of the 3rd level Apex template image.

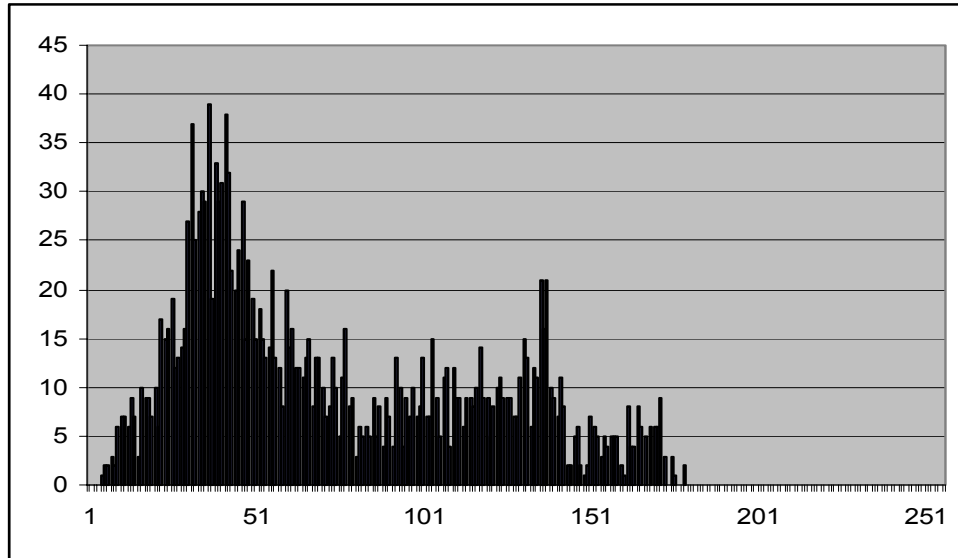


Figure 39: The histogram of the 3rd level Apex located segment.

The located segment starts at pixel (440, 156), while the original Apex template is approximately located at (425,74) so as we can see the shift in the x direction is 15, and in the y direction is 82 pixels. This huge shift values were due to the variation of intensity values between systole and diastole states.

The same procedure is done for matching the Arteries template with the target image, the result is shown in figure 40.

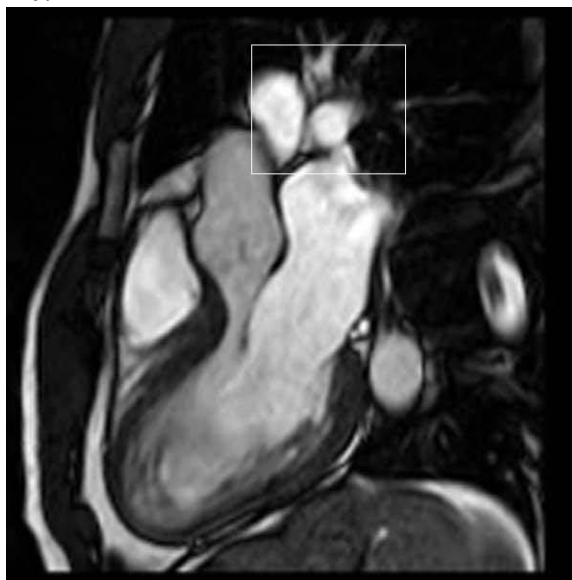


Figure 40: Heart Diastole MRI with Arteries segment.

The L1_norm value of comparing both histograms at this segment is 612, the upper left pixel of this segment is located at (40,256) while the original template approximate location is at (29,226) which makes the error shift value is equal to 11 in the x direction and 30 in the y direction.

Figures 41 and 42 show the histograms of template 3rd level image and the located segment 3rd level image.

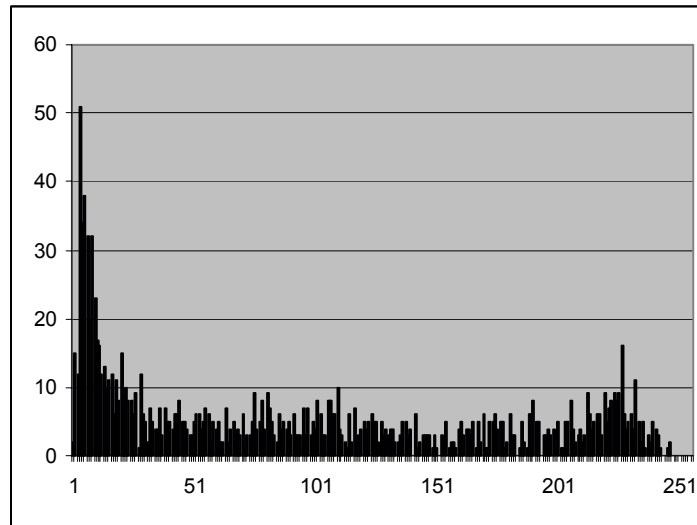


Figure 41: Arteries template 3rd level image histogram.

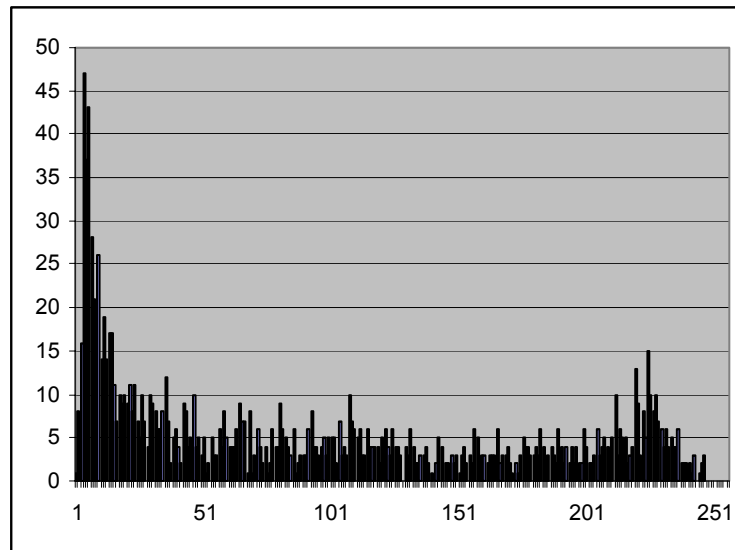


Figure 42: Arteries Segment 3rd level image histogram.

▪ Long Axis Heart Diastole MRI in 90° Rotation

The image shown in figure 43 is a rotated heart MRI image in a diastole state obtained from Philips medical site.

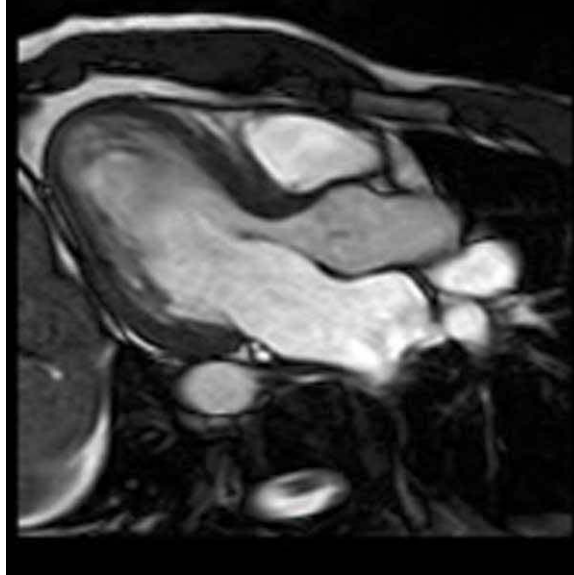


Figure 43: Rotated LA Heart Diastole MRI

This image is considered as the target image which will be matched with template images of Apex and Arteries shown in figures 15 and 16. These templates were taken from the image shown in figure 14 in the normal orientation in order to test the technique on large amount of intensity, location, and shape variations between images.

As discussed previously the 3rd level image is constructed for both the template and the target images, then the target 3rd level image is segmented and each segment histogram is calculated to be compared with the template 3rd level image histogram. Figure 44 shows the result of matching the Apex template with the target image.

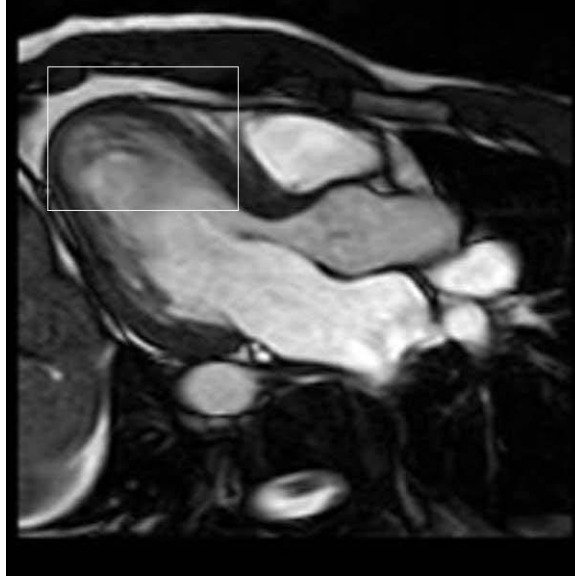


Figure 44: Rotated LA Heart Diastole MRI with Apex segment.

The technique located the Apex template at the area labeled in white, this segment has the minimum $L1_norm$ value among the other segments. Figures 45 and 46 show the histograms of the template image and the located segment.

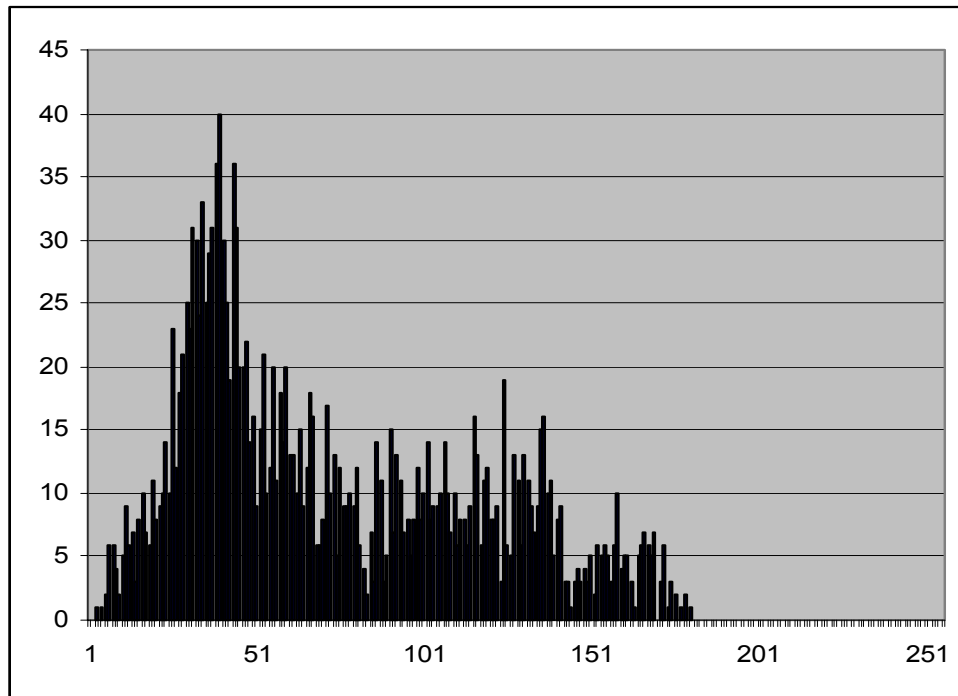


Figure 45: The histogram of the 3rd level Apex template image.

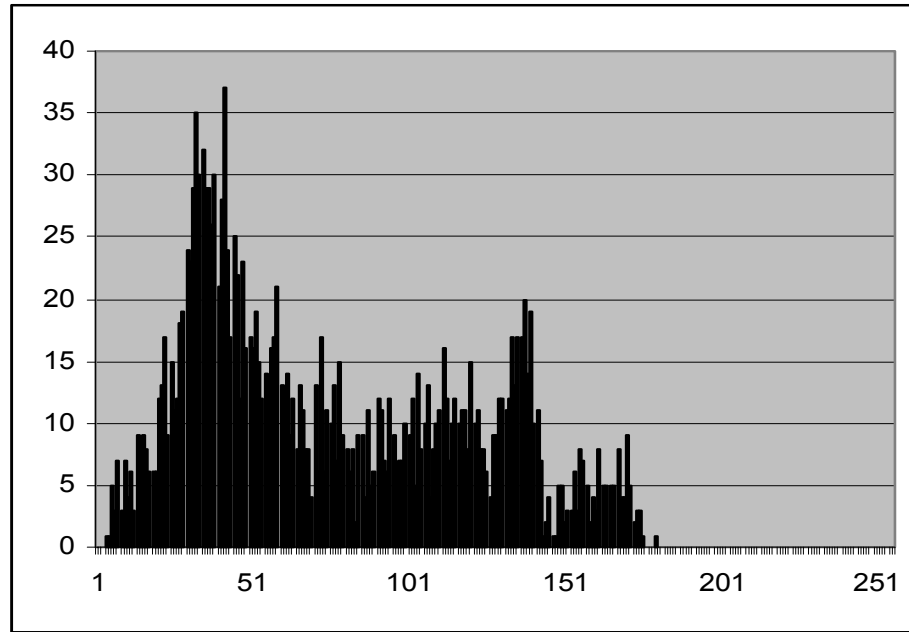


Figure 46: The histogram of the 3rd level Apex located segment.

The difference between these two histograms calculated by $L1_norm$ is 952. The located segment starts at pixel (72, 44), while the approximate Apex template location in the rotated image is at (83,21) so as we can see the shift in the x direction is -11, and in the y direction is 23 pixels.

The same procedure is done for matching the Arteries template with the target image, see figure 47.

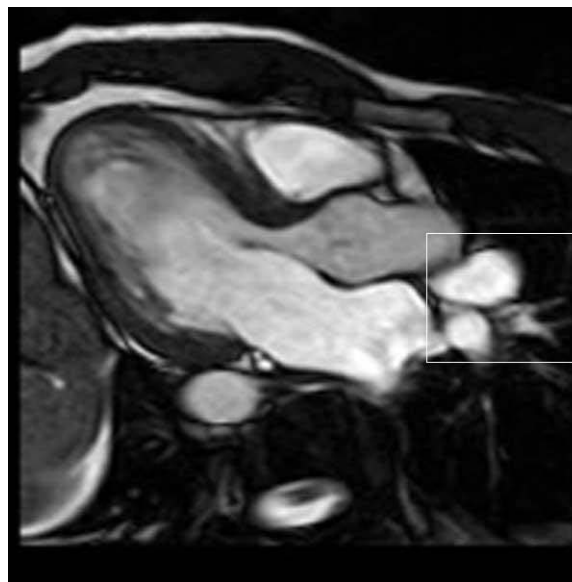


Figure 47: Rotated Heart Diastole MRI with Arteries segment.

The L1_norm value of comparing both histograms at this segment is 630, the upper left pixel of this segment is located at (236,436) while the approximate template location in the rotated image is at (228,434) which makes the error shift value equals to 8 in the x direction and 2 in the y direction.

Figures 48 and 49 show the histograms of the 3rd level template image and the located 3rd level segment image, these figures show how close both template and segment images even with large variation of rotation between them.

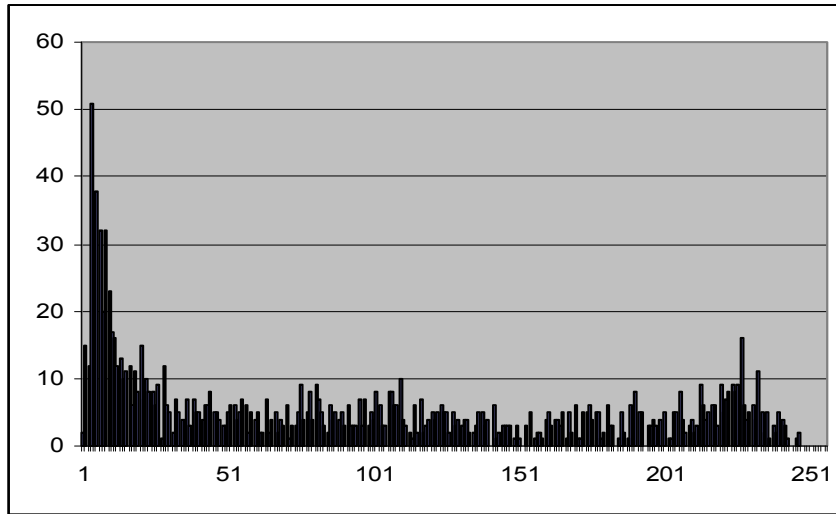


Figure 48: Arteries template 3rd level image histogram.

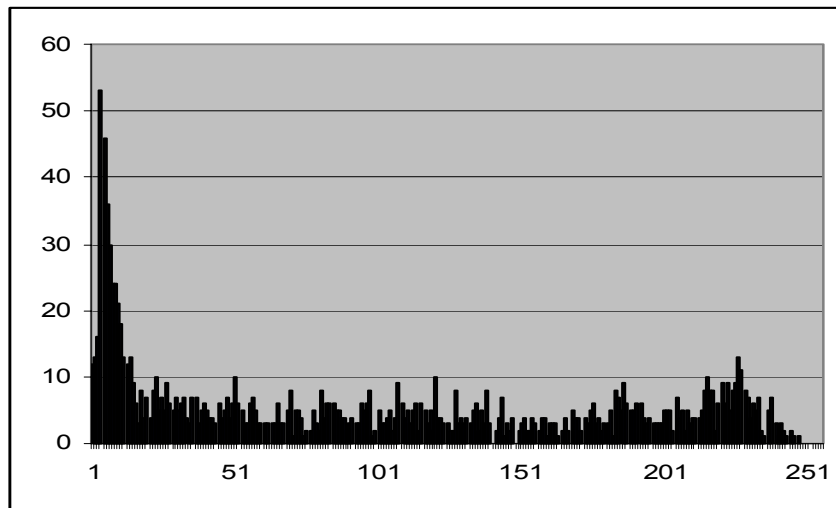


Figure 49: Arteries segment 3rd level image histogram.

Comparisons:

Table 2 shows the L1_norm values for Apex located segments in both non-rotated and rotated heart systole and diastole images to compare between them, see figure 50 which shows how close the values in both cases, from here we can see that histograms are invariant to rotation of images.

Table 2: L1_norm values for Apex located segments

Images	L1_norm
Normal Orientation Systole	630
Rotated Systole	606
Normal Orientation Diastole	836
Rotated Diastole	952

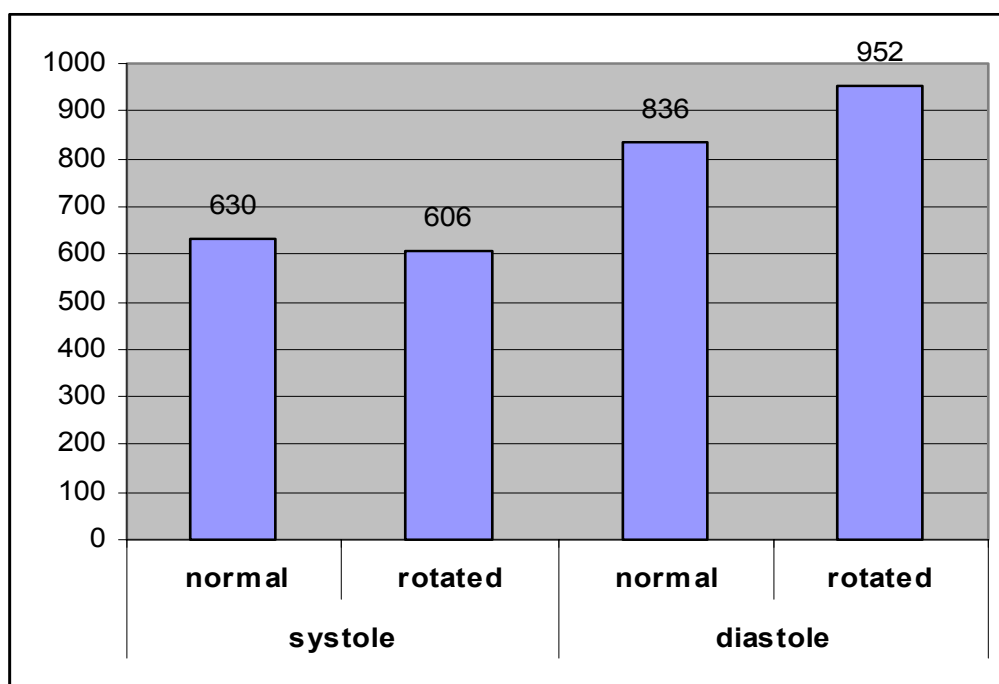


Figure 50: Comparison chart for L1_norm values of Apex located segments

Table 3 shows the L1_norm values for Arteries located segments in both non-rotated and rotated heart systole and diastole images to compare between them, see figure 51 which shows how close the values in both cases, from here we can see that histograms are invariant to rotation of images.

Table 3: L1_norm values for Arteries located segments

Images	L1_norm
Normal Orientation Systole	552
Rotated Systole	564
Normal Orientation Diastole	612
Rotated Diastole	630

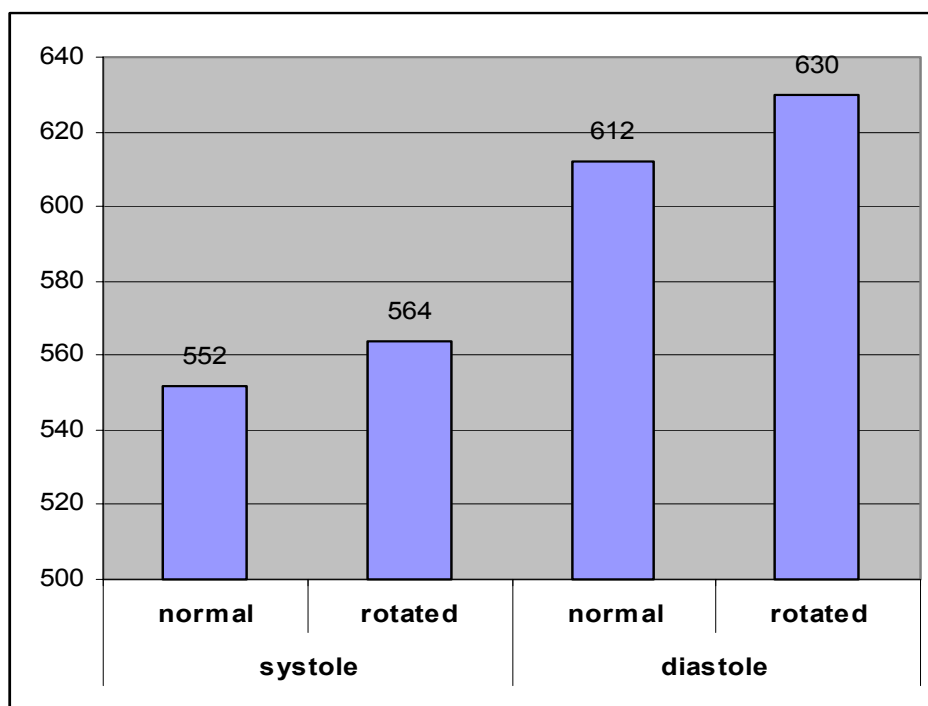


Figure 51: Comparison chart for L1_norm values of Arteries located segments

1.2 Spine MRI Image

This section discusses the results of applying the suggested technique on a spine image in order to test the technique on different organs in human body.

▪ Spine MRI in Normal Orientation

The image shown in figure 52 is a spine MRI image obtained from Red River Valley Radiology Associates site.



Figure 52: Spine MRI Image (494 x 405)

The shown image is considered as the target image which will be matched with Vertebra template image shown in figure 53, taken from the same image shown in figure 52.

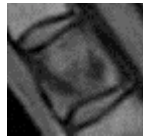


Figure 53: Vertebra template Image (66 x 70)

❖ Gaussian Pyramid 3rd level construction

In this stage both of the target and template images will be sampled into the third level after filtering each level with Gaussian filter of size (5 x 5). The target image (1st level) size is (494 x 405), after filtering the target and sampling it into the 2nd level the size will be reduced to (247 x 202) as shown in figure 55. Figure 54 shows the 3rd level of the target image which is constructed after filtering the 2nd level with Gaussian filter of size (5 x 5). The 3rd level size is (124 x 101).



Figure 55: Spine 2nd level image.



Figure 54: Spine 3rd level image.

As we can see the 3rd level image decreases the size of the image and so decreases the number of pixels in the image and keeps the details of the image which gives the best results matching wise and time wise.

The same procedure is applied on the template image, figures 57 and 56 show the Vertebra template in the 2nd level with size (33 x 35) and 3rd level with size (17 x 17) consequently.



Figure 56: Vertebra 2nd level
(33 x 35)



Figure 57: Vertebra 3rd level
(17 x 17)

Each of the target 3rd level and template 3rd level images is filtered using Gaussian filter then the target 3rd level image is segmented. The histogram of each segment is compared with the histogram of the template image by calculating the L1_norm value. The segment which has the minimum L1_norm is labeled.

The result of matching the Vertebra template with the Spine target image is shown in figure 58, the matched segment is labeled in a white box.



Figure 58: Spine MRI with Vertebra segment.

The technique located the vertebra template at the area labeled in white, this segment has the minimum L1_norm value among the other segments, Figures 59 and 60 show the histograms of the template image and the located segment.

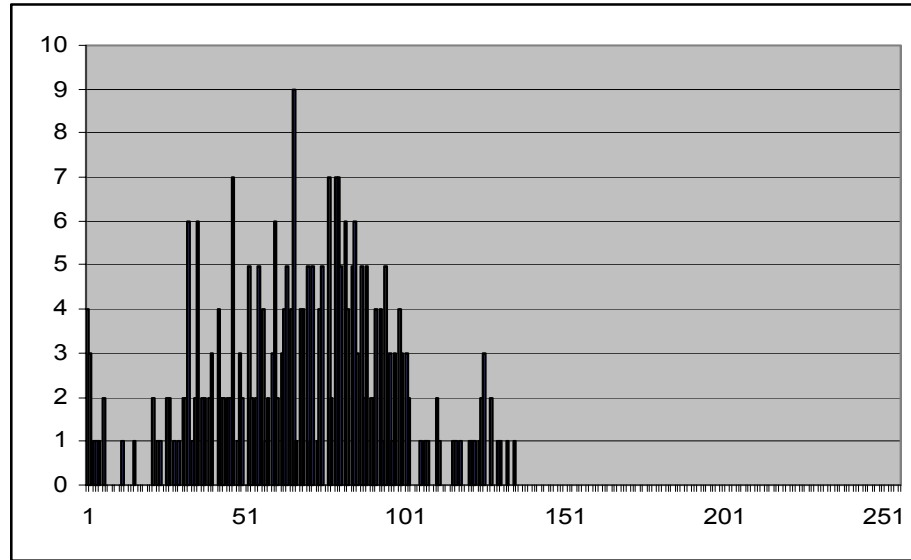


Figure 59: The histogram of the 3rd level Vertebra template image.

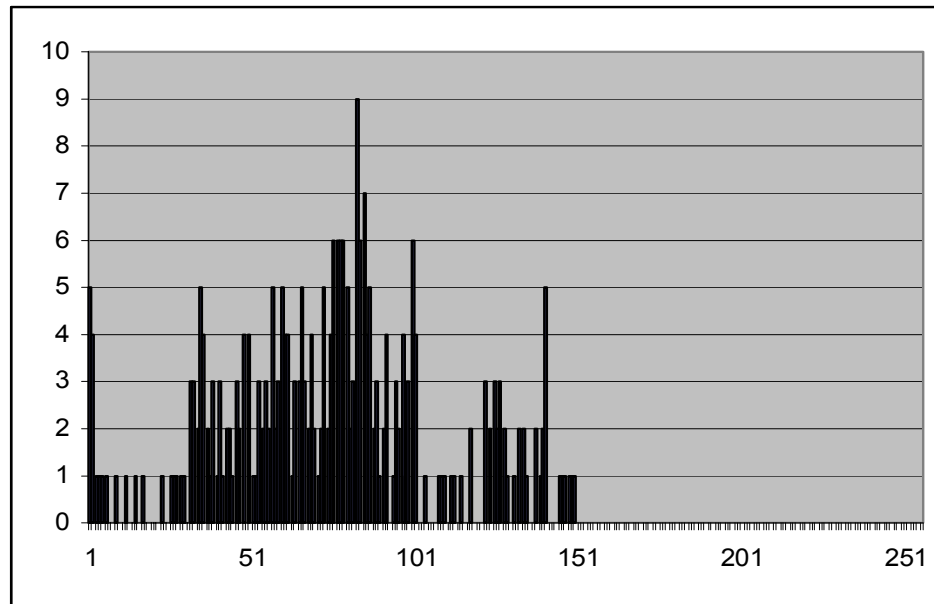


Figure 60: The histogram of the 3rd level Vertebra located segment.

The difference between these two histograms calculated by $L1_norm$ is 188. The located segment starts at pixel (272, 132), while the original Vertebra template is located at (285,136) so as we can see the shift in the x direction is -13, and in the y direction is -4 pixels.

▪ Spine MRI Image in 90° Rotation

The image shown in figure 61 is a spine MRI image obtained from Red River Valley Radiology Associates site.



Figure 61: Rotated Spine MRI Image (405 x 494).

This image is considered as the target image which will be matched with Vertebra template image shown in figure 53. This template is taken from the image shown in figure 52 in the normal orientation in order to test the technique on large amount of variation between images.

As discussed previously the 3rd level image is constructed for both the template and the target image, then the target 3rd level image is segmented and each segment histogram is calculated to be compared with the template 3rd level image histogram. Figure 62 shows the result of matching the Vertebra template with the target image.

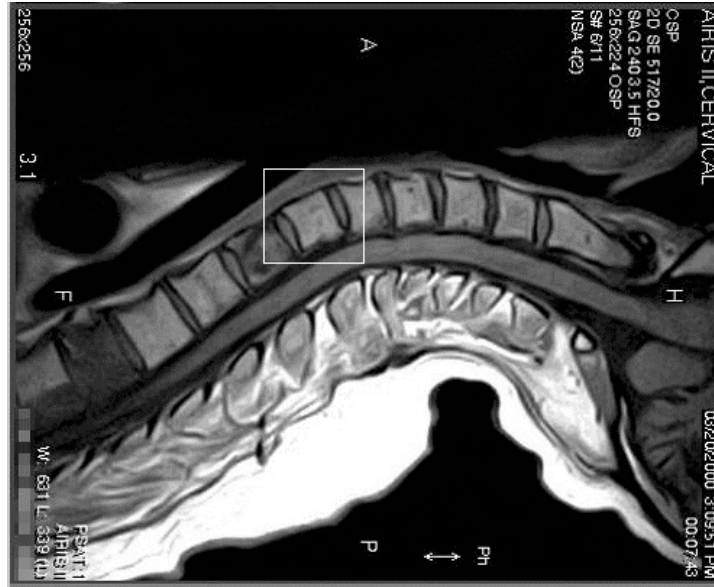


Figure 62: Rotated Spine MRI with Vertebra segment.

The technique located the Vertebra template at the area labeled in white, this segment has the minimum $L1_norm$ value among the other segments, Figures 63 and 64 show the histograms of the template image and the located segment.

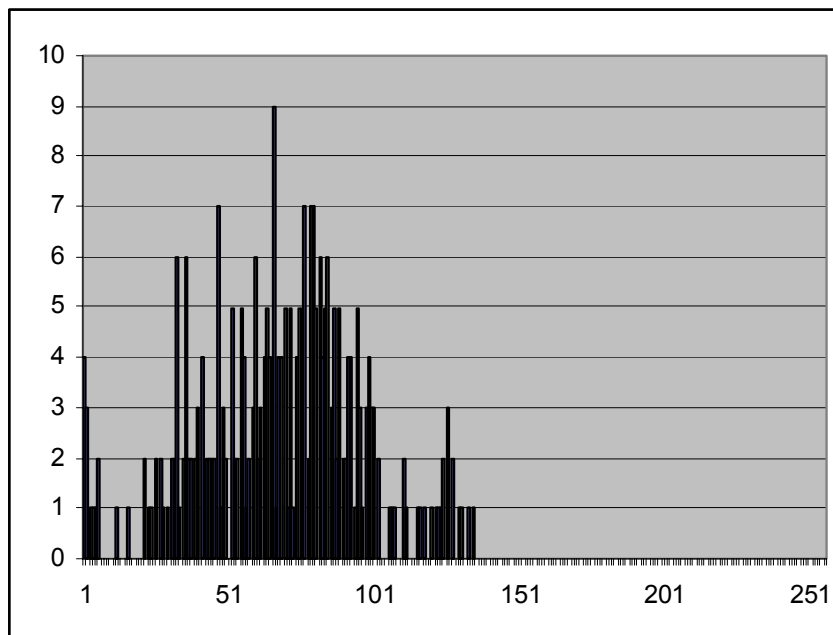


Figure 63: Vertebra template 3rd level image histogram

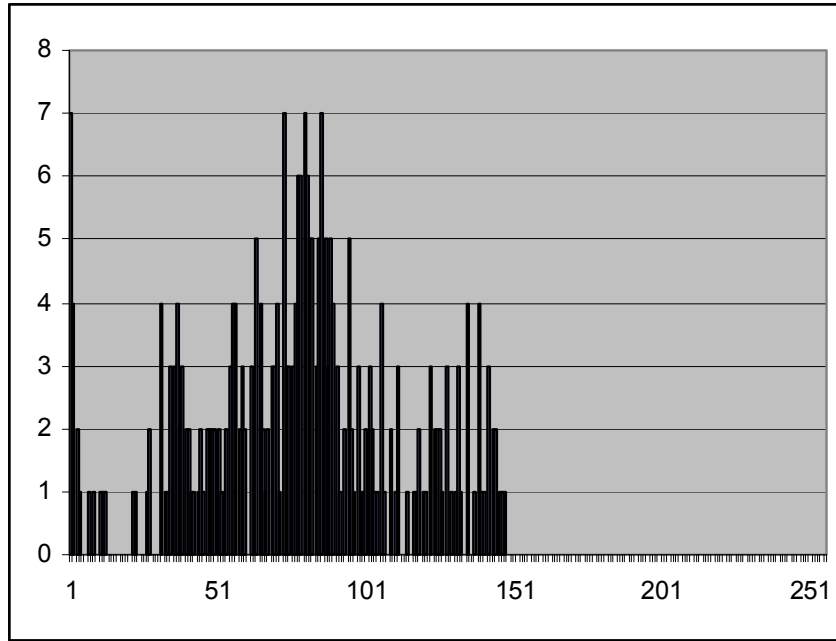


Figure 64: Vertebra segment 3rd level image histogram

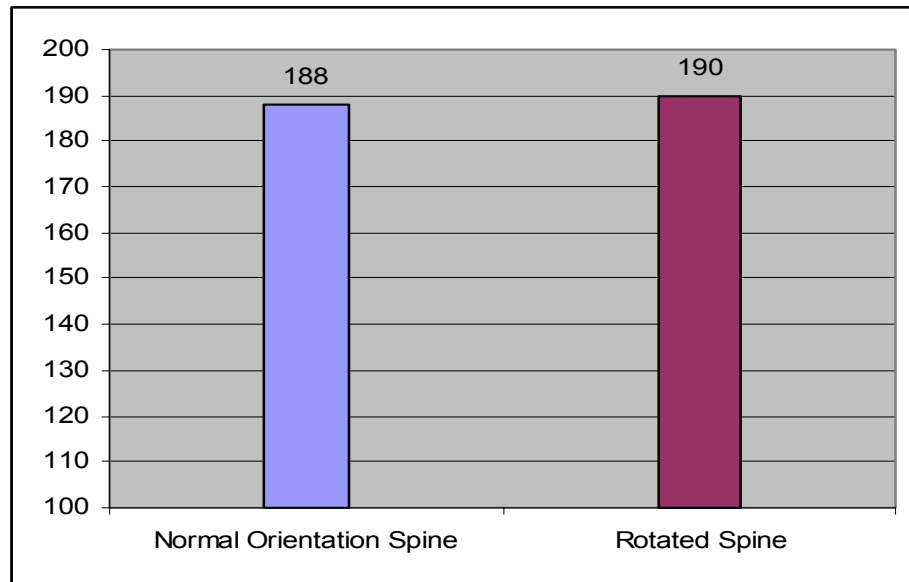
The difference between these two histograms calculated by L1_norm is 190. The located segment starts at pixel (116,176), while the approximate Vertebra template location in the rotated image is at (137,138) so as we can see the shift in the x direction is -21, and in the y direction is 38 pixels.

Comparisons:

Table 4 shows the L1_norm values for Vertebra located segments in both non-rotated and rotated spine images to compare between them, see figure 65 which shows how close the values in both cases.

Table 4: L1_norm values for Vertebra located segments

Images	L1_norm
Normal Orientation Spine	188
Rotated Spine	190

**Figure 65: Comparison chart for L1_norm values of Vertebra located segments.**

The next table (5) shows a summary of the shift values calculated for located segments using this technique.

Table 5 : Shifts summary in both x and y directions.

Target	Template	Shift in X	Shift in Y
Normal Orientation Heart Systole	Apex	5	5
	Arteries	2	14
Rotated Heart Systole	Apex	7	-9
	Arteries	14	1
Normal Orientation Heart Diastole	Apex	15	82
	Arteries	11	30
Rotated Heart Diastole	Apex	-11	23
	Arteries	8	2
Normal Orientation Spine	Vertebra	-13	-4
Rotated Spine	Vertebra	-21	38
Average		10.7	20.8

The average of the shifts in all of the previous experiments is calculated using equations 18 and 19. n is the number of experiments.

$$X_{average} = \frac{\sum |x_i|}{n} \dots\dots (18)$$

$$Y_{average} = \frac{\sum |y_i|}{n} \dots\dots (19)$$

2. Root Mean Square Error of Gaussian Pyramid 3rd level Images

In this section the experiments results for the second suggested technique (using rms error value of the Gaussian pyramid 3rd level images) will be listed. The system was tested on heart MRI images in both systole and diastole states, and on Spine MRI image.

2.1 Long Axis Heart MRI Images

This section shows the results of applying the suggested technique on heart MRI images in both systole and diastole states.

▪ Long Axis Heart Systole MRI in Normal Orientation

The target image in this experiment is the same one shown in figure 14. It will be matched with Apex and Arteries templates shown in figures 15 and 16. Here each of the target and template images is sampled into the 3rd level Gaussian Pyramid image as explained in the previous section.

After sampling, the target 3rd level image is segmented into smaller segments as the previous technique, then the system will compare between the template 3rd level image and the segment 3rd level image by rms error which estimates the difference between images by comparing each corresponding pixels from both images, so it is a good estimator for images having the same alignment.

The result of matching heart systole MRI with Apex template is shown in figure 66.



Figure 66: Heart systole MRI with Apex segment.

The difference between the template and the labeled segment is calculated by rms error and it was 7.79. The located segment starts at pixel (416, 104), while the original Apex template is located at (411,99) so as we can see the shift in the x direction is 5, and in the y direction is 5 pixels. The same procedure is done for matching with Arteries template. Figure 67 shows the result of the matching process.

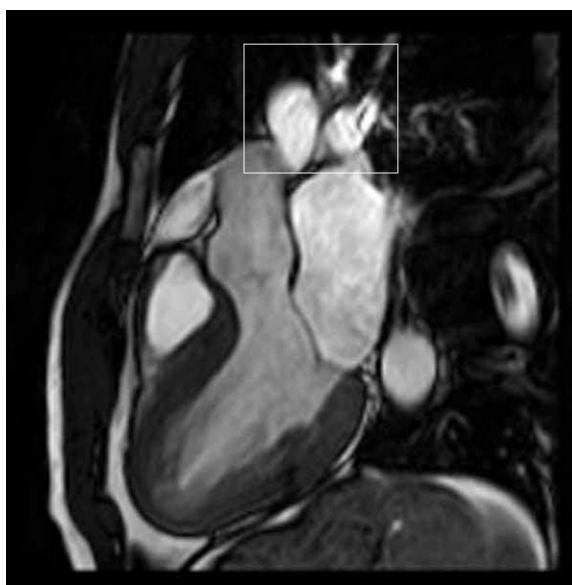


Figure 67: Heart systole MRI with Arteries segment.

The difference between the template and the labeled segment calculated by rms error is 10.73. The located segment starts at pixel (36, 248), while the original Arteries template is located at (34,242) so as we can see the shift in the x direction is 2, and in the y direction is 6 pixels.

▪ Long Axis Heart Systole MRI in 90° Rotation

The target image in this experiment is the same one shown in figure 29. It will be matched with Apex and Arteries template images shown in figures 15 and 16. Here each of the target and template images is sampled into the 3rd level Gaussian Pyramid image as explained in the previous section. After sampling, the target 3rd level image is segmented into smaller segments as the previous technique, then the system will compare between the template 3rd level image and the segment 3rd level image by rms error which estimates the difference between images by comparing each corresponding pixels from both images. The result of matching rotated heart systole MRI with Apex template is shown in figure 68.

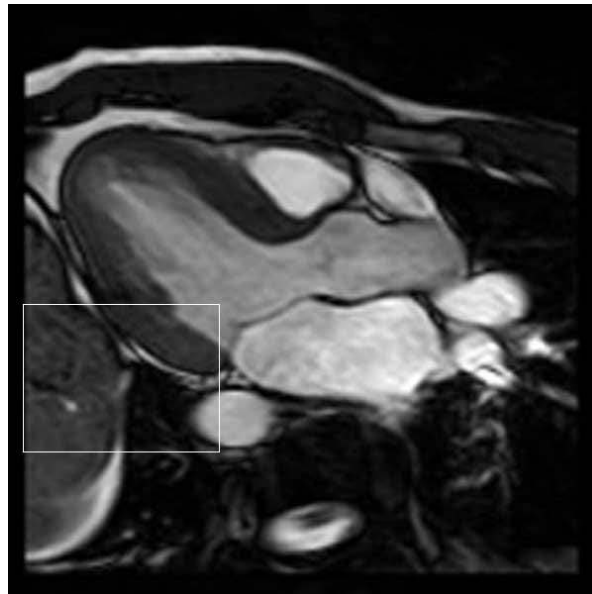


Figure 68: Rotated Heart systole MRI with Apex segment

The difference between the template and the labeled segment calculated by rms error is 52.80. The located segment starts at pixel (304, 16), while the original Apex template is approximately located at (97,33) so as we can see the shift in the x direction is 207, and in the y direction is -17 pixels. The same procedure is done for matching with Arteries template. Figure 69 shows the result of the matching process.



Figure 69: Rotated Heart systole MRI with Arteries segment.

The rms error value for this matching is 69.51, the segment is located at (96,228), while the approximate location is at (242,423), and the shift value in the x direction is -146 and -195 in the y direction.

The large values in shifts are obvious in both cases, that is because rms error calculates the difference between corresponding pixels, it depends on the order of intensity values of pixels, so it is affected by rotation or any shape, size, or location variations.

▪ Long Axis Heart Diastole MRI in Normal Orientation

The target image in this experiment is the same as the one shown in figure 36. It will be matched with Apex and Arteries templates shown in figures 15 and 16. Here each of the target and template images is sampled into the 3rd level Gaussian Pyramid image as explained in the previous section.

After sampling, the target 3rd level image is segmented into smaller segments, then the system will compare between the template 3rd level image and the segment 3rd level image using rms. The result of matching heart diastole MRI with Apex template is shown in figure 70.



Figure 70: Heart Diastole MRI with Apex segment.

The difference between the template and the labeled segment calculated by rms error is 29.87, The located segment starts at pixel (428, 84), while the original Apex template is

located at (425,74) so as we can see the shift in the x direction is 3, and in the y direction is 10 pixels.

The same procedure is done for matching with Arteries template. Figure 71 shows the result of the matching process.

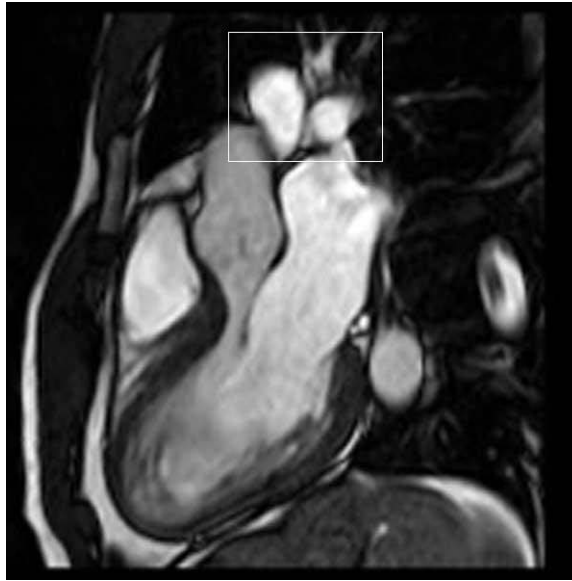


Figure 71: Heart Diastole MRI with Arteries segment.

The difference between the template and the labeled segment calculated by rms error is 31.60. The located segment starts at pixel (32, 232), while the original Arteries template is located at (29,226) so as we can see the shift in the x direction is 3, and in the y direction is 6 pixels.

▪ Long Axis Heart Diastole MRI in 90° Rotation

The target image in this experiment is the same one shown in figure 43. It will be matched with Apex and Arteries template images shown in figures 15 and 16. Here each of the target and template images is sampled into the 3rd level Gaussian Pyramid image. After sampling, the target 3rd level image is segmented into smaller segments, then the system will compare between the template 3rd level image and the segment 3rd level image by rms error.

The result of matching rotated heart diastole MRI with Apex template is shown in figure 72.

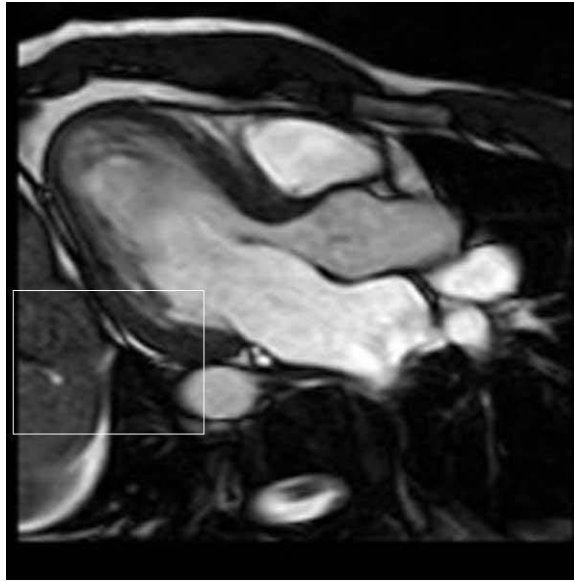


Figure 72: Rotated Heart Diastole MRI with Apex segment

The difference between the template and the labeled segment calculated by rms error is 51.65. The located segment starts at pixel (300,8), while the original Apex template is approximately located at (83,21) so as we can see the shift in the x direction is 217, and in the y direction is -13 pixels. The same procedure is done for matching with Arteries template. Figure 73 shows the result of the matching process.

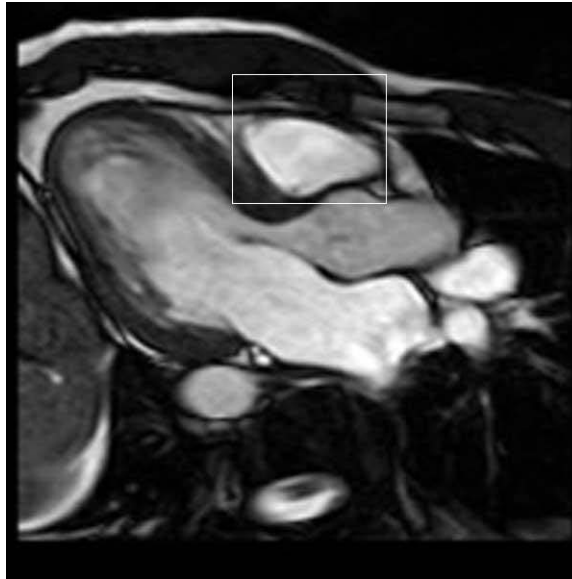


Figure 73: Rotated Heart Diastole MRI with Arteries segment.

The rms error value for this matching is 66.37, the segment is located at (76,236), while the approximate location is at (228,434), and the shift value in the x direction is -152 and -198 in the y direction.

The large values in shifts are obvious in both cases, that is because rms error calculates the difference between corresponding pixels, it depends on the order of intensity values of pixels, so it is affected by rotation or any shape, size, or location variations.

Comparisons:

Table 6 shows the rms error values for Apex located segments in both non-rotated and rotated heart systole and diastole images to compare between them, see figure 74 which shows that the numbers are irrelative, rms error is not invariant to rotation, location, and shape variations.

Table 6: RMSE values for Apex located segments.

Images	RMSE X 10⁻²
Normal Orientation Systole	779
Rotated Systole	5280
Normal Orientation Diastole	2987
Rotated Diastole	5165

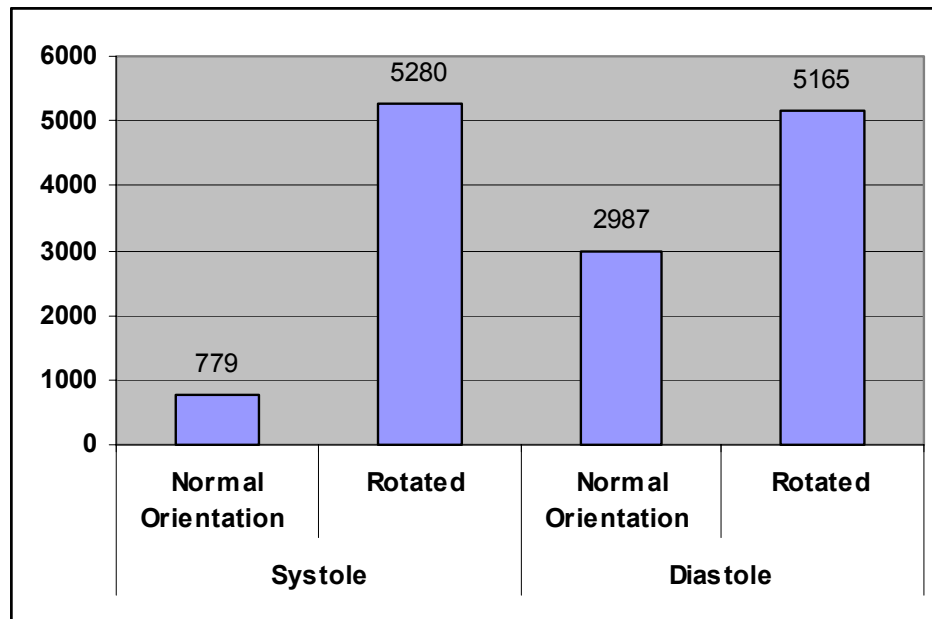


Figure 74: RMSE values for Apex segments

Table 7 shows the rms error values for Arteries located segments in both non-rotated and rotated heart systole and diastole images to compare between them, see figure 75 which shows that the numbers are irrelative, rms error is not invariant to rotation, location, and shape variations.

Table 7: RMSE values for Arteries segments

Images	RMSE X 10⁻²
Normal Orientation Systole	1073
Rotated Systole	6951
Normal Orientation Diastole	3160
Rotated Diastole	6637

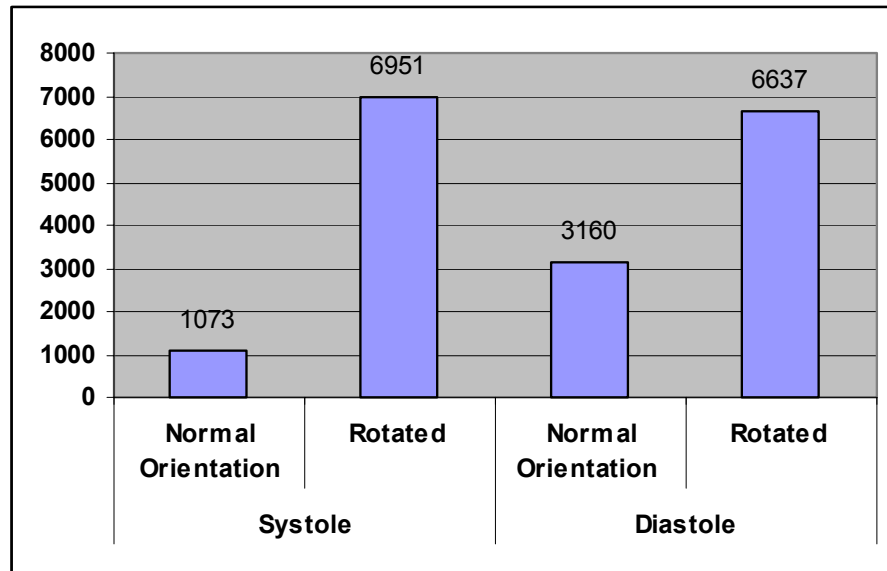


Figure 75: RMSE values for Arteries segments

2.2 Spine MRI Image

▪ Spine MRI in Normal Orientation

The spine MRI image shown in figure 52 is used in this experiment as the target image to be matched with the vertebra template image shown in figure 53. Figure 76 shows the result of using the rms error technique in matching.



Figure 76: Spine image with Vertebra segment.

The rms error value at this matched segment is 10.46 and it is located at (288,144), while the original location is at (285,136), the shift in the x direction is 3 and in the y direction is 8.

▪ Spine MRI in 90° Rotation

The spine MRI image shown in figure 61 is used in this experiment as the target image to be matched with the vertebra template image shown in figure 53. Figure 77 shows the result of using the rms error technique in matching.

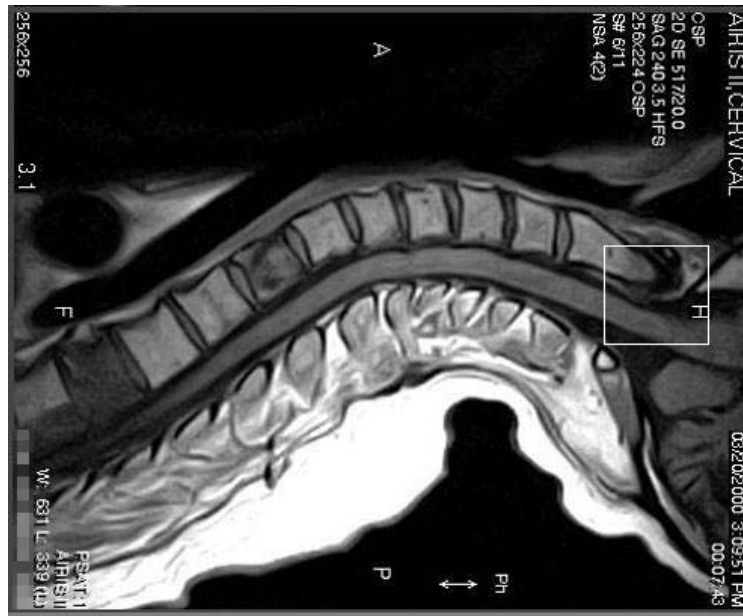


Figure 77: Spine image with Vertebra segment.

The rms error value at this matched segment is 33.31 and it is located at (160,396), while the approximate location is at (137,138), the shift in the x direction is 23 and in the y direction is 258.

Comparisons:

Table 8 shows the RMSE values for Vertebra located segments in both non-rotated and rotated spine images to compare between them, see figure 78 which shows that the values are irrelative.

Table 8: RMSE values for Vertebra located segments

Images	RMSE X 10⁻²
Normal Orientation Spine	1046
Rotated Spine	3331

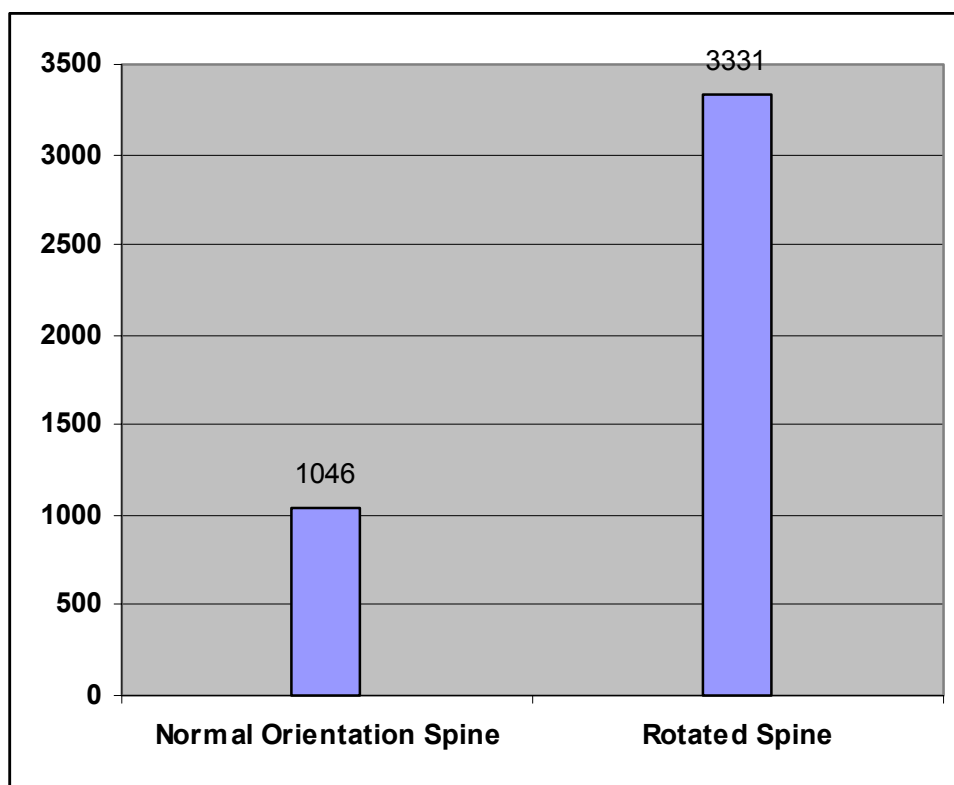


Figure 78: RMSE values for Spine Images

Table 9 shows a summary of the shift values calculated for located segments using this technique.

Table 9: Shifts summary in both x and y directions

Target	Template	Shift in X	Shift in Y
Normal Orientation Heart Systole	Apex	5	5
	Arteries	2	6
Rotated Heart Systole	Apex	207	-17
	Arteries	-146	-195
Normal Orientation Heart Diastole	Apex	3	10
	Arteries	3	6
Rotated Heart Diastole	Apex	217	-13
	Arteries	-152	-198
Normal Orientation Spine	Vertebra	3	8
Rotated Spine	Vertebra	23	258
Average		76.1	71.6

The average of the shifts in all of the previous experiments is calculated as shown above using equations 18 and 19.

3. Non-Base Filtered Gaussian Pyramid 3rd level Image Histograms

This technique has the same steps as the first technique but here the original image (1st level image in the pyramid) is not filtered with Gaussian filter, but the other levels are all filtered.

In this section the experiments results for this suggested technique will be listed. The system is tested on heart MRI images in both systole and diastole states, and on Spine MRI image.

3.1 Long Axis Heart MRI Images

In this section the suggested technique will be tested on heart MRI images in both systole and diastole states, and on rotated images.

▪ Long Axis Heart Systole MRI in Normal Orientation

The target image in this experiment is the same one shown in figure 14. It will be matched with Apex and Arteries template images shown in figures 15 and 16. Here each of the target and template images is sampled into the 3rd level Gaussian Pyramid image but without filtering the 1st level image.

After sampling, the target 3rd level image is segmented into smaller segments, then the system will compare between the template 3rd level image histogram and each segment 3rd level image histogram by calculating L1_norm of the histograms differences.

The result of matching heart systole MRI with Apex template is shown in figure 79.



Figure 79: Heart systole MRI with Apex segment.

The difference between the template and the labeled segment calculated by $L1_norm$ is 566. The located segment starts at pixel (420, 120), while the original Apex template is located at (411,99) so as we can see the shift in the x direction is 9, and in the y direction is 21 pixels.

The same procedure is done for matching with Arteries template. Figure 80 shows the result of the matching process.



Figure 80: Heart systole MRI with Arteries segment.

The difference between the template and the labeled segment calculated by $L1_norm$ is 572, the located segment starts at pixel (36, 248), while the original Arteries template is located at (34,242), so as we can see the shift in the x direction is 2, and in the y direction is 6 pixels.

▪ Long Axis Heart Systole MRI in 90° Rotation

The target image in this experiment is the same one shown in figure 29. It will be matched with Apex and Arteries templates shown in figures 15 and 16. Here each of the target and template images is sampled into the 3rd level Gaussian Pyramid image as explained in the previous section. After sampling, the target 3rd level image is segmented into smaller segments, then the system will compare between the template 3rd level image histogram and the segment 3rd level image histogram by calculating the L1_norm value.

The result of matching rotated heart systole MRI with Apex template is shown in figure 81.

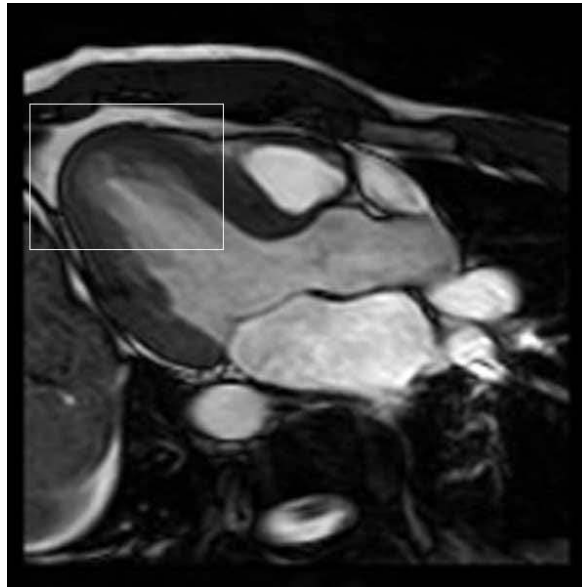


Figure 81: Rotated Heart systole MRI with Apex segment

The difference between the template and the labeled segment calculated by $L1_norm$ is 608, The located segment starts at pixel (104,24), while the original Apex template is approximately located at (97,33) so as we can see the shift in the x direction is 7, and in the y direction is -9 pixels.

The same procedure is done for matching with Arteries template. Figure 82 shows the result of the matching process.



Figure 82: Rotated Heart systole MRI with Arteries segment.

The $L1_norm$ value for this matching is 572, the segment is located at (236,424), while the approximate location is at (242,423), and the shift value in the x direction is -6 and 1 in the y direction.

▪ Long Axis Heart Diastole MRI in Normal Orientation

The target image in this experiment is the same as the one shown in figure 36. It will be matched with Apex and Arteries templates shown in figures 15 and 16. Here each of the target and template images is sampled into the 3rd level Gaussian Pyramid image but without filtering the 1st level image.

After sampling, the target 3rd level image is segmented into smaller segments, then the system will compare between the template 3rd level image histogram and the segment 3rd level image histogram by calculating the L1_norm.

The result of matching heart diastole MRI with Apex template is shown in figure 83.



Figure 83: Heart Diastole MRI with Apex segment.

The difference between the template and the labeled segment calculated by $L1_norm$ is 836. The located segment starts at pixel (440,144), while the original Apex template is approximately located at (425, 74) so as we can see the shift in the x direction is 15, and in the y direction is 70 pixels.

The same procedure is done for matching with Arteries template. Figure 84 shows the result of the matching process.



Figure 84: Heart Diastole MRI with Arteries segment.

The difference between the template and the labeled segment calculated by $L1_norm$ is 610. The located segment starts at pixel (48,256), while the original Arteries template is approximately located at (29,226) so as we can see the shift in the x direction is 19 and in the y direction is 30 pixels.

▪ Long Axis Heart Diastole MRI in 90° Rotation

The target image in this experiment is the same one shown in figure 43. It will be matched with Apex and Arteries template images shown in figures 15 and 16. Here each of the target and template images is sampled into the 3rd level Gaussian Pyramid image. After sampling, the target 3rd level image is segmented into smaller segments, then the system will compare between the template 3rd level image and the segment 3rd level image by L1_norm.

The result of matching rotated heart diastole MRI with Apex template is shown in figure 85.

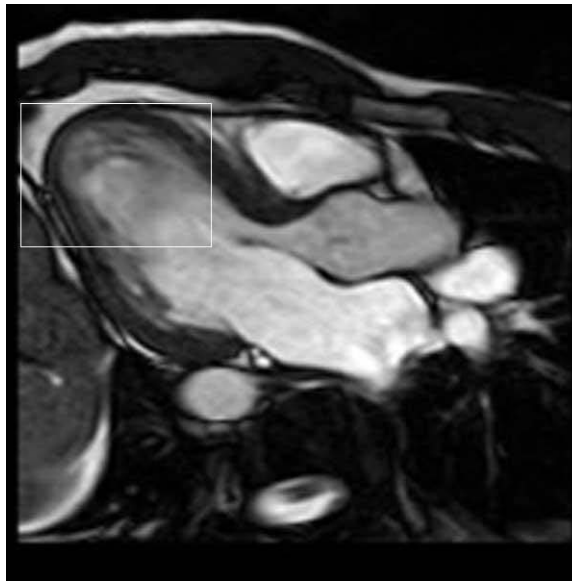


Figure 85: Rotated Heart Diastole MRI with Apex segment

The difference between the template and the labeled segment calculated by $L1_norm$ is 948, The located segment starts at pixel (104,16), while the original Apex template is approximately located at (83,21) so as we can see the shift in the x direction is 21, and in the y direction is -5 pixels.

The same procedure is done for matching with Arteries template. Figure 86 shows the result of the matching process.

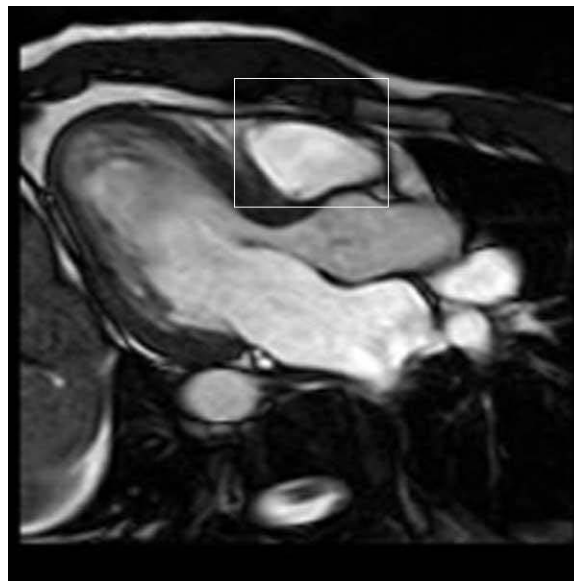


Figure 86: Rotated Heart Diastole MRI with Arteries segment.

The $L1_norm$ value for this matching is 632, the segment is located at (252,436), while the approximate location is at (228,434), and the shift value in the x direction is 24 and 2 in the y direction.

Comparisons:

Table 10 shows the L1_norm values for Apex located segments in both non-rotated and rotated heart systole and diastole images to compare between them, see figure 87 which shows that the numbers are close and that shows that histograms are invariant to rotation.

Table 10: L1_norm values for Apex located segments.

Images	L1_norm
Normal Orientation Systole	566
Rotated Systole	608
Normal Orientation Diastole	836
Rotated Diastole	948

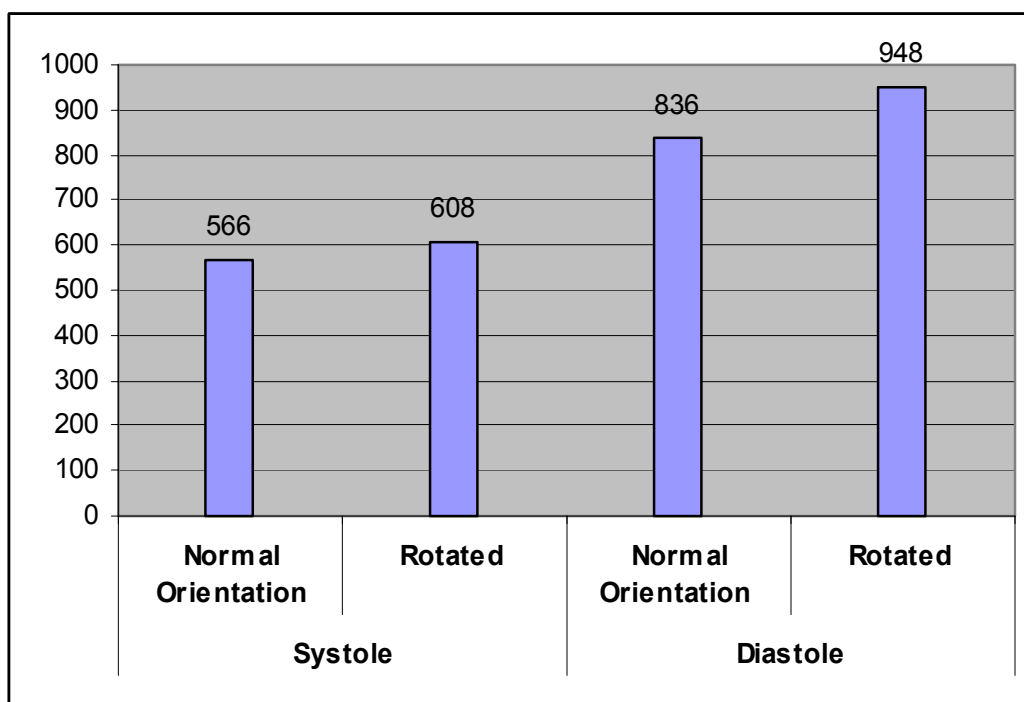


Figure 87: L1_norm values for Apex segments

Table 11 shows the L1_norm values for Arteries located segments in both non-rotated and rotated heart systole and diastole images to compare between them, see figure 88 which shows that the numbers are close together.

Table 11: L1_norm values for Arteries segments

Images	L1_norm
Normal Orientation Systole	572
Rotated Systole	572
Normal Orientation Diastole	610
Rotated Diastole	632

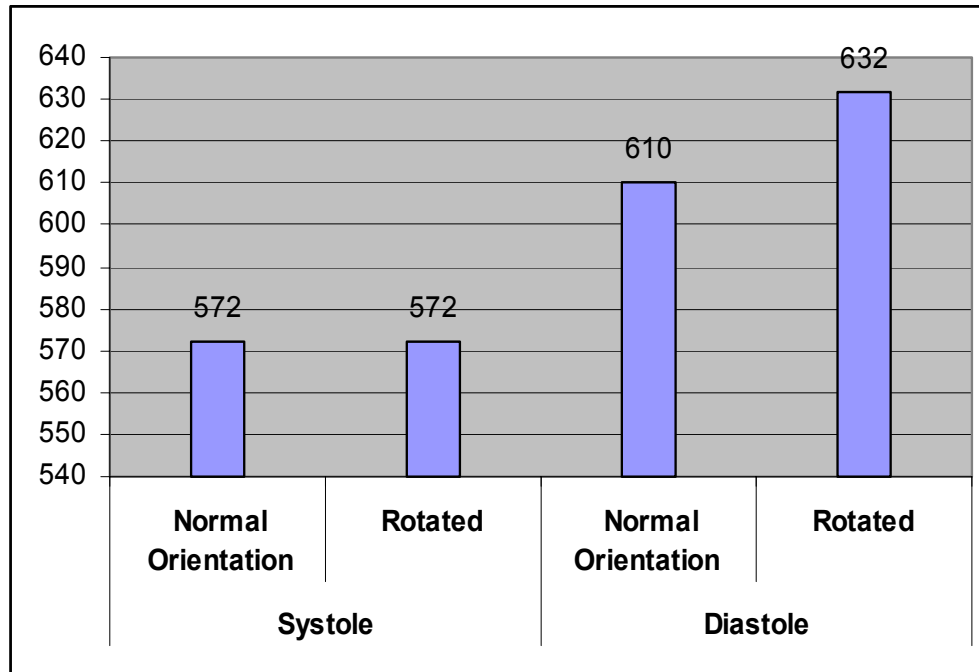


Figure 88: L1_norm values for Arteries segments

3.2 Spine MRI Image

▪ Spine MRI in Normal Orientation

The spine MRI image shown in figure 52 is used in this experiment as the target image to be matched with the vertebra template image shown in figure 53. Figure 89 shows the result of using the 3rd level image histogram of the non-base filtered Gaussian pyramid technique in matching.



Figure 89: Spine image with Vertebra segment.

The L1_norm value at this matched segment is 160 and it is located at (276,136), while the original location is at (285,136), the shift in the x direction is -9 and in the y direction is 0.

▪ Spine MRI in 90° Rotation

The spine MRI image shown in figure 61 is used in this experiment as the target image to be matched with the vertebra template image shown in figure 53. Figure 90 shows the result of matching.

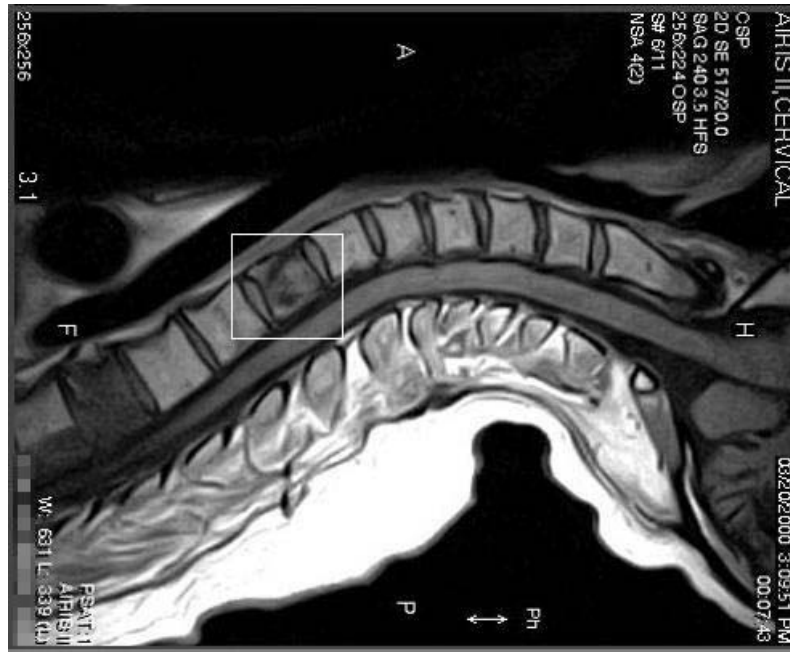


Figure 90: Rotated Spine image with Vertebra segment.

The L1_norm value at this matched segment is 184 and it is located at (144,140), while the approximate location is at (137,138), the shift in the x direction is 7 and in the y direction is 2.

Comparisons:

Table 12 shows the L1_norm values for Vertebra located segments in both non-rotated and rotated spine images to compare between them, see figure 91 which shows how close the values in both cases.

Table 12: L1_norm values for Vertebra located segments

Images	L1_norm
Normal Orientation Spine	160
Rotated Spine	184

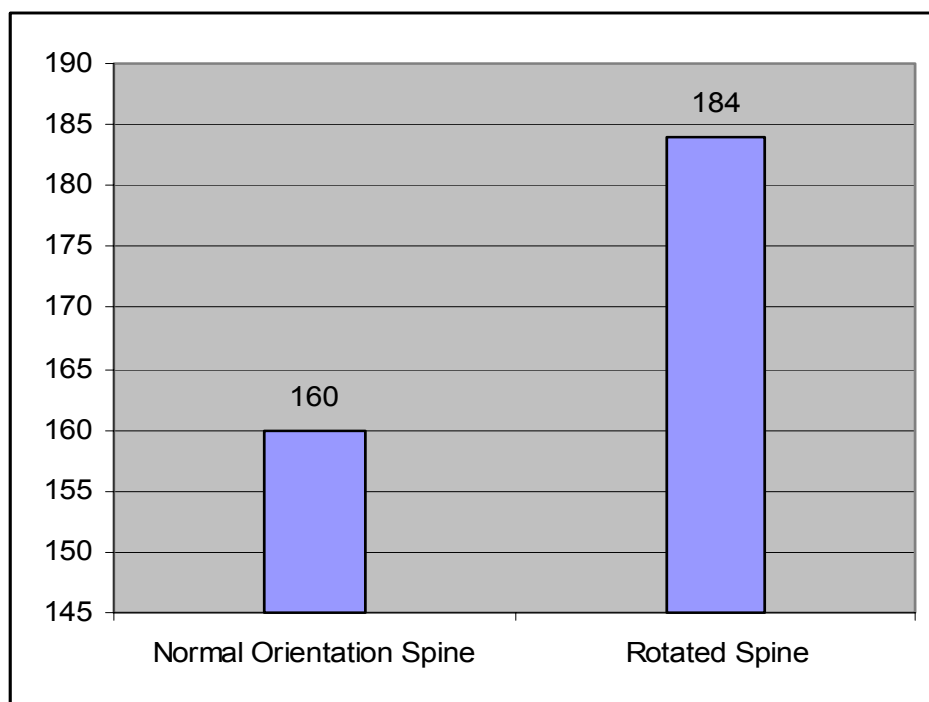


Figure 91: L1_norm values for Spine Images

Table 13 shows a summary of the shift values calculated for located segments using this technique.

Table 13: Shifts summary in both x and y directions

Target	Template	Shift in X	Shift in Y
Normal Orientation Heart Systole	Apex	9	21
	Arteries	2	6
Rotated Heart Systole	Apex	7	-9
	Arteries	-6	1
Normal Orientation Heart Diastole	Apex	15	70
	Arteries	19	30
Rotated Heart Diastole	Apex	21	-5
	Arteries	24	2
Normal Orientation Spine	Vertebra	-9	0
Rotated Spine	Vertebra	7	2
Average		11.9	14.6

The average of the shifts in all of the previous experiments is calculated using equations 18 and 19.

4. Results and Comparisons

In this section a comparison between the three suggested techniques is shown in tables 14 and 15.

For a summary of more experiments see appendix A.

Table 14: Comparison between shifts averages for each techniques in each direction.

First Technique		Second Technique		Third Technique	
X	Y	X	Y	X	Y
10.7	20.8	76.1	71.6	11.9	14.6

Table 15: The overall average of shifts for each technique.

First Technique	Second Technique	Third Technique
15.75	73.85	13.25

The averages of the first and the third techniques are close because they both use histograms in matching, which are invariant for rotation, shape, and size variations. The third technique which leaves the 1st level unfiltered gave the best results then the first technique which filters all pyramid levels, the second technique has a large shifts average, which makes it unreliable at all, see figures 92 and 93.

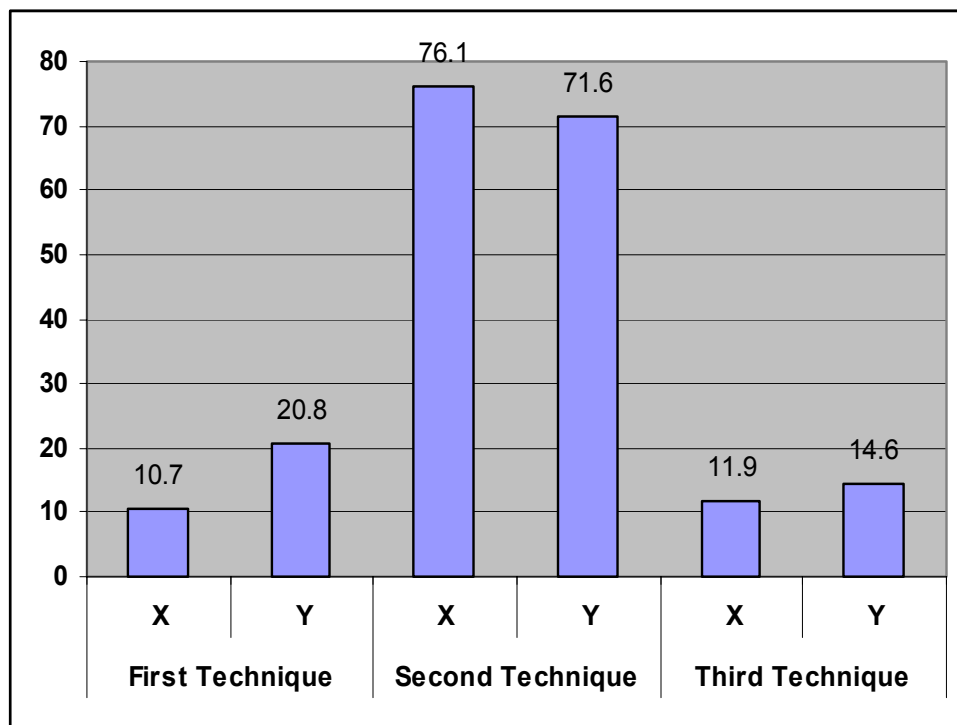


Figure 92: Shift averages comparisons for the three techniques

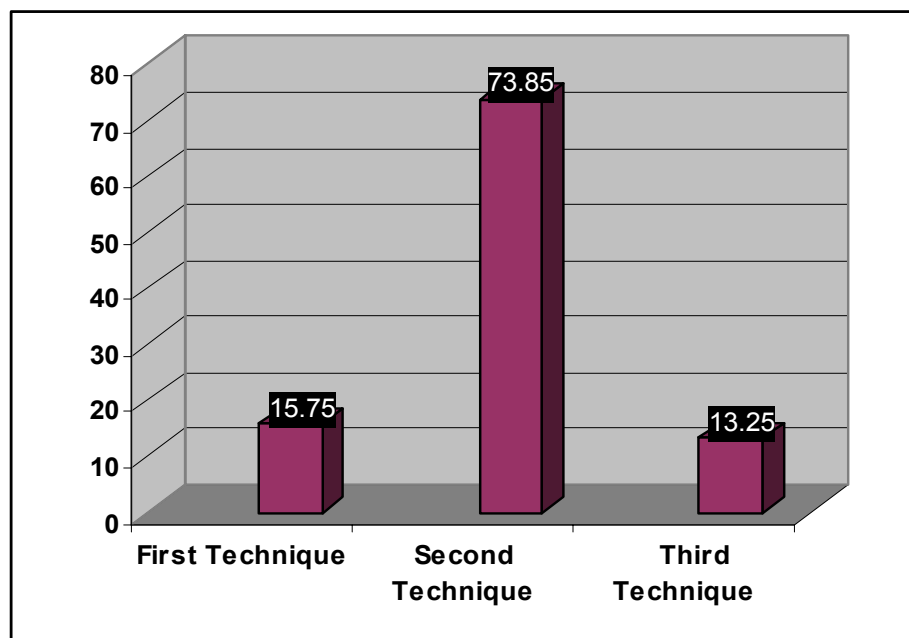


Figure 93: Overall shift averages for each technique.

5. Time comparisons using Threads

In this section the time performance in seconds of applying the matching process for image's 1st, 2nd, 3rd Levels with and without using threads are listed to be compared in table 16, the test is applied on a target image of size (600 x 600) with a template of a size (150 x 199) using Pentium (R) 4 CPU 2.80 GHz, 512 MB of RAM. Figure 94 shows a chart of the time performance of each level used in matching. As we can see the largest the size of the image the largest the time spent in matching operation, so that using the 3rd level is helpful in matching process even without using threads.

Table 16: Comparisons of Performance time in seconds

	Without Using Threads	Using Threads
1 st level	10800	94
2 nd level	7200	13
3 rd level	214	2

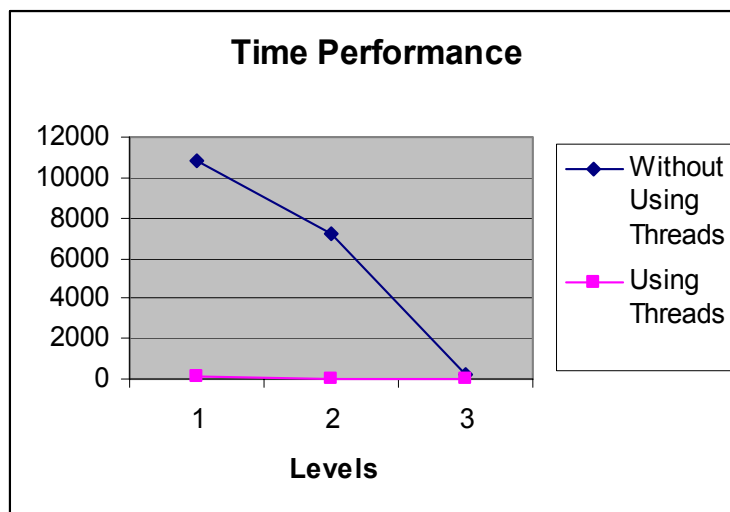


Figure 94: Time performance chart

The matching process average time without using threads can be expressed by as $O(N^4)$ where N is the number of pixels of the target image because of the segmentation process and calculating the histograms in each segment. But with using threads the average time will be $O(N^2)$ where N is the number of pixels of the target image.

6. Cardiac Images Axial Registration

To register two images you need to locate correspondences between these two images, such as points, surfaces, and edges. These correspondences are called control points.

In the previous sections three techniques were suggested and tested to locate similarities between images by using templates or sub images. Once the correspondences are located the images will be aligned together using a suitable transformation function. One of the major techniques used to align cardiac images is the axial registration using rigid transformation, in which the axis line is determined for each image and then both images are rotated to get their axes into the same orientation.

This approach is tested using the non-rotated heart systole MRI with the rotated heart systole MRI, see figures 95 and 96.



Figure 95: Non-Rotated Heart Systole MRI



Figure 96: Rotated Heart Systole MRI.

The system will use the third matching technique, due to its high results among the other techniques, to locate the Apex and the Arteries parts for each image. Figure 97 shows the heart MRI image with the two segments located and labeled in white box, a line is used to illustrate the procedure of aligning, figure 98 shows the rotated heart MRI image with both Apex and Arteries located in white box and a line shows the orientation of the image.

By taking the starting points of the two located segments in each image, the slopes of the two lines will be calculated and then both images will be rotated to be aligned in the same orientation. See figure 99 which shows both images in the same alignment.



Figure 97: Heart MRI image with Apex and Arteries labeled.

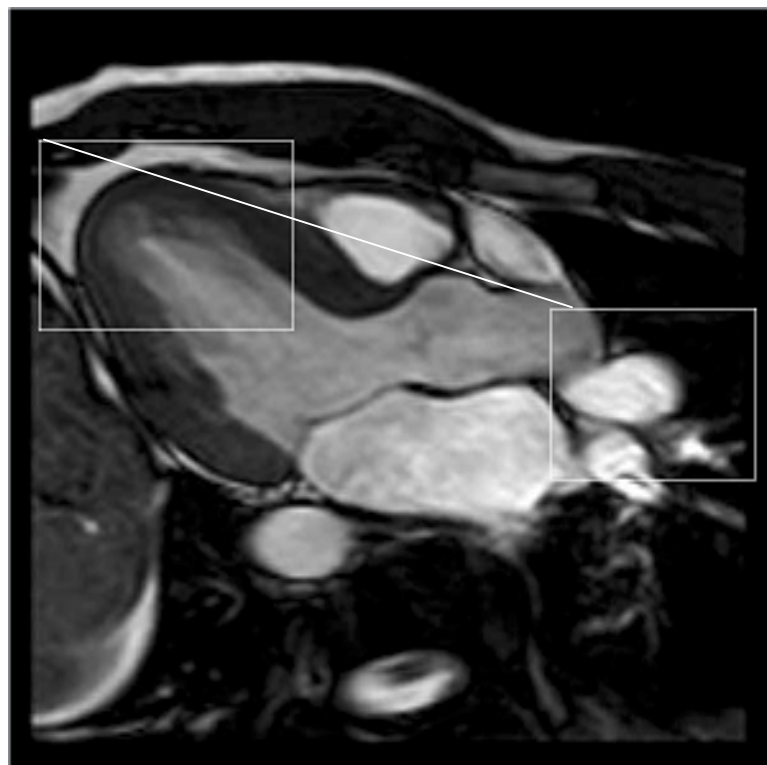


Figure 98: Rotated MRI image with Apex and Arteries labeled.

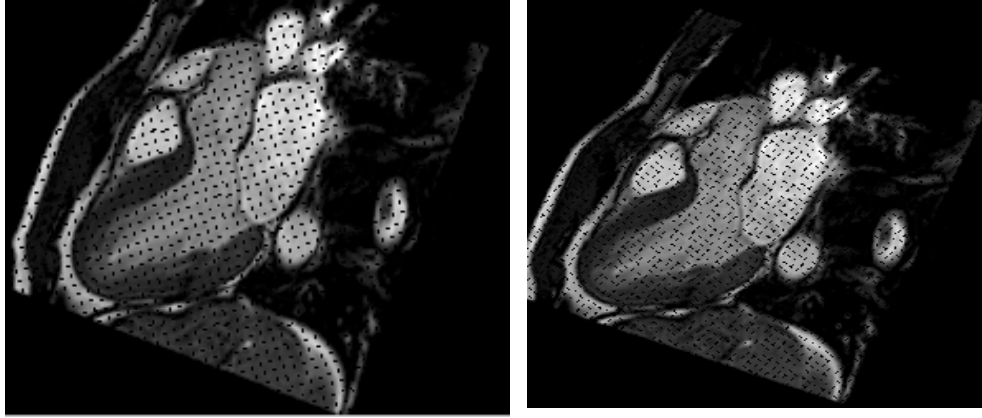


Figure 99: Aligned Images

In the non-rotated heart MRI, the Apex segment start point is (420, 120), and the Arteries segment start point is (36, 248), the slope equals: -0.33. The slopes are calculated using equation 20.

$$Slope = \frac{y_2 - y_1}{x_2 - x_1} \dots\dots\dots(20). \text{ Where } (x_1, y_1), (x_2, y_2) \text{ are points on the line.}$$

In the rotated heart MRI, the Apex segment start point is (104, 24), and the Arteries segment start point is (236, 424), the slope according to equation 20 equals to 3.03.

From the slopes values the angles of both lines are calculated using inverse tangent. The first image is rotated by 69° and the second image is rotated by -21° using the rigid transformation function equations (1) and (2).

CONCLUSION AND FUTURE WORK

1. Conclusion

Cardiac medical images in general are hard to be studied and registered due to the non-rigid nature of heart and thorax, the continuous movement of heart makes it hard to image the same scene in different imaging stages, so that the researches on this field are few.

Three techniques are suggested to match images in order to find automatic control points, then using rigid axial registration to align cardiac MRI intra-subject images. Gaussian pyramid's third level histogram technique, Root Mean Square Error technique, and Non-base filtered Gaussian pyramid's third level histogram technique.

Our empirical study using ten sample images, shows that filtering the second and third levels of the Gaussian pyramid and leaving the first level unfiltered as in the third technique enhances the matching results of the first technique which filters all pyramid's levels, they both give good results in matching images with large shapes, and location variations. The second technique which uses root mean square error to find amount of error between images gives good results for images with small shape and size variations but it does not work for other images.

These techniques depend on intensity similarities, so they can be used to other organs such as spine and brain MR images.

2. Future Work

- Intra-subject heart images in the systole and diastole states are tested; the test can be expanded using other parts of the human body.
- A database of cardiac MRI features and pathology effects on organs shapes could be prepared to be used in cardiac content-based retrieval system.

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APPENDIX A

▪ Summary of Results for Gaussian Pyramid 3rd level histogram technique

Table 17 shows the minimum L1_norm values for each comparison and the location of the upper left corner pixel of the segment which is labeled as template match.

Table 17: Summary results of the first technique

Target Name	Template Name	L₁_Norm	Located X	Located Y
Heart MRI Systole	Apex	630	416	104
Heart MRI Systole	Arteries	552	36	256
Heart MRI Systole	Vein	308	228	488
Heart MRI Systole	Left Atrium	420	164	212
Heart MRI Systole	Valve	412	260	288
Heart MRI Systole Rotated	Apex	606	104	24
Heart MRI Systole Rotated	Arteries	564	256	424
Heart MRI Systole Rotated	Vein	336	456	276
Heart MRI Systole Rotated	Left Atrium	548	148	324
Heart MRI Systole Rotated	Valve	446	268	228
Heart MRI Diastole	Apex	836	440	156

Heart MRI Diastole	Arteries	612	40	256
Heart MRI Diastole	Vein	388	420	472
Heart MRI Diastole	Left Atrium	542	352	148
Heart MRI Diastole	Valve	580	348	184
Heart MRI Diastole Rotated	Apex	952	72	44
Heart MRI Diastole Rotated	Arteries	630	236	436
Heart MRI Diastole Rotated	Vein	368	440	80
Heart MRI Diastole Rotated	Left Atrium	594	160	84
Heart MRI Diastole Rotated	Valve	608	160	120
Brain	CC	266	168	120
Brain Rotated	CC	364	268	240
Spine	Vertebra	188	272	132
Spine Rotated	Vertebra	190	116	176

▪ Summary of Results for the Gaussian Pyramid 3rd level RMSE Technique

Table 18 shows the minimum rms error values for each comparison and the location of the upper left corner pixel of the segment which is labeled as template match.

Table 18: Summary results of the second technique

Target Name	Template Name	RMSE	Located X	Located Y
Heart MRI Systole	Apex	7.79	416	104
Heart MRI Systole	Arteries	10.73	36	248
Heart MRI Systole	Vein	3.18	232	480
Heart MRI Systole	Left Atrium	11.62	156	212
Heart MRI Systole	Valve	12.98	260	280
Heart MRI Systole Rotated	Apex	52.80	304	16
Heart MRI Systole Rotated	Arteries	69.51	96	228
Heart MRI Systole Rotated	Vein	52.39	356	4
Heart MRI Systole Rotated	Left Atrium	39.60	184	144
Heart MRI Systole Rotated	Valve	43.88	280	212
Heart MRI Diastole	Apex	29.87	428	84
Heart MRI Diastole	Arteries	31.60	32	232

Heart MRI Diastole	Vein	10.38	236	468
Heart MRI Diastole	Left Atrium	27.75	144	196
Heart MRI Diastole	Valve	29.77	332	228
Heart MRI Diastole Rotated	Apex	51.65	300	8
Heart MRI Diastole Rotated	Arteries	66.37	76	236
Heart MRI Diastole Rotated	Vein	51.33	224	4
Heart MRI Diastole Rotated	Left Atrium	40.89	144	100
Heart MRI Diastole Rotated	Valve	45.93	212	128
Brain	CC	16.05	164	140
Brain Rotated	CC	53.83	216	248
Spine	Vertebra	10.46	288	144
Spine Rotated	Vertebra	33.31	160	396

▪ Summary of Results for the Non-base Filtered Gaussian Pyramid 3rd level

Table 19 shows the minimum L1_norm error values for each comparison and the location of the upper left corner pixel of the segment which is labeled as template match.

Table 19: Summary results of the third technique

Target Name	Template Name	L1_norm	Located X	Located Y
Heart MRI Systole	Apex	566	420	120
Heart MRI Systole	Arteries	572	36	248
Heart MRI Systole	Vein	332	240	472
Heart MRI Systole	Left Atrium	416	164	212
Heart MRI Systole	Valve	458	252	284
Heart MRI Systole Rotated	Apex	608	104	24
Heart MRI Systole Rotated	Arteries	572	236	424
Heart MRI Systole Rotated	Vein	302	456	264
Heart MRI Systole Rotated	Left Atrium	546	140	324
Heart MRI Systole Rotated	Valve	462	268	232
Heart MRI Diastole	Apex	836	440	144
Heart MRI Diastole	Arteries	610	48	256

Heart MRI Diastole	Vein	398	236	472
Heart MRI Diastole	Left Atrium	538	356	140
Heart MRI Diastole	Valve	552	348	184
Heart MRI Diastole Rotated	Apex	948	104	16
Heart MRI Diastole Rotated	Arteries	632	252	436
Heart MRI Diastole Rotated	Vein	366	444	268
Heart MRI Diastole Rotated	Left Atrium	590	156	84
Heart MRI Diastole Rotated	Valve	612	156	120
Brain	CC	272	10	136
Brain Rotated	CC	352	212	244
Spine	Vertebra	160	276	136
Spine Rotated	Vertebra	184	144	140

▪ Validations

The original templates locations that must be located by the techniques are listed in table 20.

Table 20: The original upper left pixel location that must be detected by the techniques.

Target Name	Template Name	Located X	Located Y
Heart MRI Systole	Apex	411	99
Heart MRI Systole	Arteries	34	242
Heart MRI Systole	Vein	230	475
Heart MRI Systole	Left Atrium	154	206
Heart MRI Systole	Valve	255	275
Heart MRI Systole Rotated	Apex	97	33
Heart MRI Systole Rotated	Arteries	242	423
Heart MRI Systole Rotated	Vein	473	242
Heart MRI Systole Rotated	Left Atrium	203	281
Heart MRI Systole Rotated	Valve	273	199
Heart MRI Diastole	Apex	425	74

Heart MRI Diastole	Arteries	29	226
Heart MRI Diastole	Vein	237	461
Heart MRI Diastole	Left Atrium	142	194
Heart MRI Diastole	Valve	278	245
Heart MRI Diastole Rotated	Apex	83	21
Heart MRI Diastole Rotated	Arteries	228	434
Heart MRI Diastole Rotated	Vein	195	293
Heart MRI Diastole Rotated	Left Atrium	247	180
Heart MRI Diastole Rotated	Valve	460	234
Brain	CC	161	132
Brain Rotated	CC	132	266
Spine	Vertebra	285	136
Spine Rotated	Vertebra	137	138

Table 21 compares between the different techniques according to shift values.

Table 21: Comparisons of accuracy results between the different techniques

Target	Template	First Technique Shifts	Second Technique Shifts	Third Technique Shifts
Heart MRI Systole	Apex	5,5	5,5	9,21
Heart MRI Systole	Arteries	2,14	2,6	2,6
Heart MRI Systole	Vein	-2,13	2,5	10,-3
Heart MRI Systole	Left Atrium	10,6	2,6	10,6
Heart MRI Systole	Valve	5,13	5,5	-3,9
Heart MRI Systole Rotated	Apex	7,-9	207,-17	7,-9
Heart MRI Systole Rotated	Arteries	14,1	-146,-195	-6,1
Heart MRI Systole Rotated	Vein	-17,34	-117,-238	-17,22
Heart MRI Systole Rotated	Left Atrium	-55,43	-19,-137	-63,43
Heart MRI Systole Rotated	Valve	-5,29	7,13	-5,33
Heart MRI Diastole	Apex	15,82	3,10	15,70
Heart MRI Diastole	Arteries	11,30	3,6	19,30
Heart MRI Diastole	Vein	183,11	-1,7	-1,11

Heart MRI Diastole	Left Atrium	210,-46	2,2	214,-54
Heart MRI Diastole	Valve	70,-61	54,-17	70,-61
Heart MRI Diastole Rotated	Apex	-11,23	217,-13	21,-5
Heart MRI Diastole Rotated	Arteries	8,2	-152,-198	24,2
Heart MRI	Vein	245,-213	29,-289	249,-25
Heart MRI Diastole Rotated	Left Atrium	-87,-96	-103,-80	-39,-209
Heart MRI Diastole Rotated	Valve	-300,-114	-248,-106	-304,114
Brain	CC	7,-12	3,8	-1,4
Brain Rotated	CC	136,-26	84,-18	80,108
Spine	Vertebra	-13,-4	3,8	-9,0
Spine Rotated	Vertebra	-21,38	23,258	7,2

For each technique the average of shifts in each direction is calculated. Table 22 shows the averages of shifts in each direction for each technique, and figure 100 shows a chart for these results, as we can see the least average value is the best one.

Table 22: Average of shift values.

Average of Shifts	First Technique		Second Technique		Third Technique	
	X	Y	X	Y	X	Y
	59.9	38.54	64.12	68.70	49.37	35.3

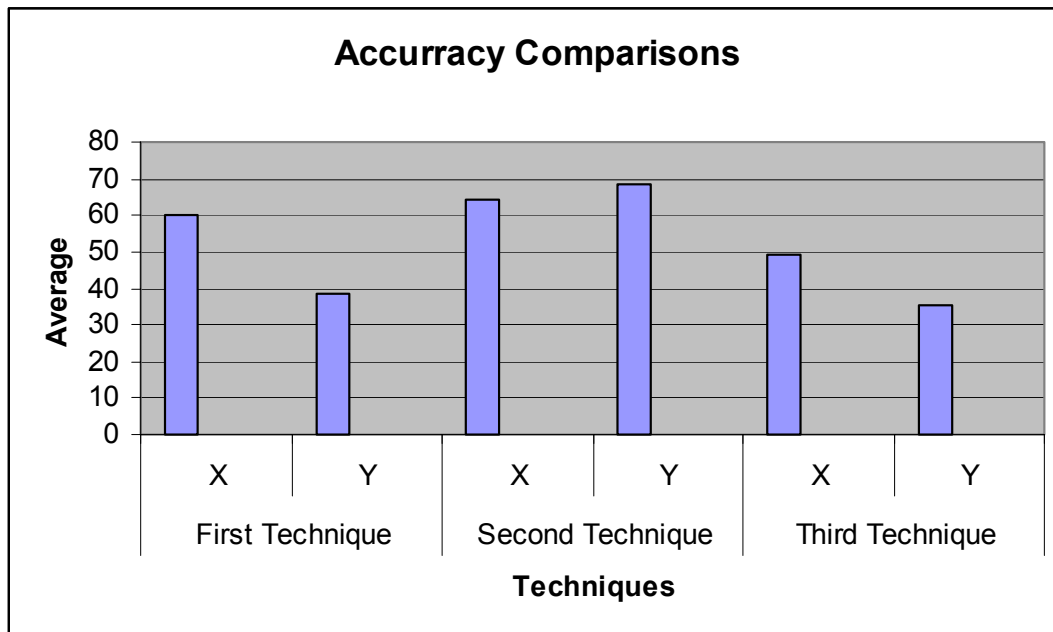


Figure 100: Comparisons between techniques average values.

طرق لتسجيل الصور الطبية

اعداد

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ملخص

تركز الرسالة في دراستها على ايجاد طرق بسيطة وسريعة لاستخدامها في تسجيل صور الرنين المغناطيسي للقلب اوتوماتيكيا .

الطرق المقترحة تعتمد على استخدام اجزاء من احدى الصورتين المراد تسجيلهما لمطابقتها مع اجزاء الصورة الاخرى.

هذه الرسالة درست ثلاثة طرق مختلفة وجميعها تستخدم هرم جاوس لتقليل حجم الصور والذي من شأنه ان يسرع عملية المقارنة .

الطريقة الاولى تعتمد على مدرج صورة الطبقة الثالثة من هرم الصورة الاولى لمقارنته مع مدرج صورة الطبقة الثالثة للصورة الثانية وهذه الطريقة اعطت نتائج جيدة حتى بوجود فروقات في الصور . اما الطريقة الثانية تعتمد على مقارنة صور الطبقة الثالثة للصور الاصلية مباشرة بحساب جذر المعدل التربيعي للاختلافات بين الصور وقد اعطت هذه الطريقة نتائج جيدة في الصور التي ليست فيها اختلافات من حيث الازاحات . الطريقة الثالثة تشبه الطريقة الاولى لكن هنا لا يتم فلترة الصور الاصلية وجميع صور طبقات الهرم الاخرى . هذه الطريقة - الثالثة - اظهرت نتائج افضل من الطرق الاخرى عند مقارنة الصور حتى بوجود ازاحات كبيرة في الصور .