Watermarking Mammograms using Spline based Fractional Wave Packet Transform

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Abstract
Health care systems handle huge amounts of medical data that has to be managed efficiently. These data are prone to increased security risks. These risks need to be addressed. In this paper, we present a watermarking scheme which allows to embed and extract the watermark from mammograms. The proposed method, based on spline based fractional wave packet transform is imperceptible, nonblind and robust.

Keywords: medical image, mammogram, watermarking, imperceptible, spline.

Introduction
Advancements in the field of medicine has introduced multiple challenges that has to be addressed. These include dealing with a wide variety of medical signals. These medical signal modalities range from the traditional electrocardiogram (ECG) to the recent Positron Emission Tomography (PET) and Magnetic Resonance Imaging (MRI). Medical data are stored, accessed and distributed. Medical digital libraries provide access to EPR (Electronic Patient Records), HIS (Hospital Information System)and RIS(Radiology Information system). These EPR circulating in public networks are often at risk and need to be secured. These security measures are governed by strict ethical and legislative rules; the rights owned by the patient and the doctor.

The data presented by researchers at the January 1997 Consensus development Conference discussed facts related to breast diseases detected by mammography. It was shown that mammograms have more prognoses than those detected by other imaging modalities. Mammography detects breast cancer earlier, hence increases the survival rate of the patient. Also, mammograms detects lesions that cannot manifest in the other imaging modalities. Mammograms contain crucial data that need to authenticated and avoid unauthorized manipulation.

Kobayashi et. al. [2] has discussed the considerations that has to be taken into account when dealing with information security. Whilst dealing with security for medical images, one should be aware that providing security is not a strictly technological issue. Further there are no means to ensure total security. Security is an evolving process. These data, too, need to be secured as other medical imaging data.

Medical images need to be secured for reasons other than those for digital data. Watermarking is one such scheme that provides for owner identification, content authentication, tamper detection and copyright protection. Medical image security should provide for reliability. Reliability has two aspects. Firstly, medical data is crucial and tampered medical data may result is misdiagnosis. Secondly, medical images should be authentic to identify the authorship of the information. Confidentiality of the patient’s information and communications secrecy must be maintained, indicating only authorized user accessibility. Medical data should be available for use by entitled users.

Digital Image watermarking characteristics [3] include robustness, imperceptibility, security, verifiability, computational cost, watermark detection, capacity and trade off parameters. There exists a tradeoff between robustness, imperceptibility and capacity, and the watermarking scheme designed should be capable to avoid these tradeoffs. Apart from these, the following are the features of a Medical Image watermarking scheme:

1. Region of Interest (ROI): The watermarking scheme designed must keep the ROI intact.
2. Data Hiding Capability: The watermarking scheme must be capable to hide patient confidential data.
3. Authentication Capability: The watermarking scheme should provide for authenticity.
4. Tamper Localization and Recovery Capability: The watermarking scheme should provide for detection of intentionally modified areas and recovery of the original image.

Watermarking schemes can be broadly classified as spatial domain and frequency domain. In spatial Domain, Yusuk Lim et al.[6] proposed a watermarking scheme for CT Scan Images. The proposed scheme generated binary values from a hash function, and this value was embedded into the LSB of the input image. Another pixel based watermarking scheme was proposed by Rodriguez et al.[9]. The information was embedded into a pixel selected by spiral scan, which started from the centroid of the cover image.
Several frequency domain medical image watermarking schemes exist in literature. Sonika C Rathi and Vandana S Inamdar[7] proposed a watermarking scheme preserving the ROI. They applied 4-level Haar lifting transform to the host image. Multiple watermark was embedded by reading the patients information file in binary format. Giakoumaki et al. [5] proposed multiple watermarking scheme adopting wavelets. The doctors identification is used as the watermark and embedded in the 4th decomposition level, index watermark in the 3rd decomposition level and patient information in the 2nd level. Their scheme was experimented on ultrasound images and is a solution to medical data management and distribution issues. Similarly, another watermarking scheme was proposed by Wakatani[8]. The watermark was embedded into the non-ROI using DWT. This paper discusses the issues related to medical image watermarking and proposes a watermarking scheme that provides for medical data security (mammograms). An overview of the necessity of medical image watermarking is described in Section 1. Section 1 also provides for a brief literature survey on the available medical image watermarking schemes. Section 2 provides an overview of the spline based FRWPT(Fractional Wave Packet Transform) adopted in the proposed watermarking scheme. Section 3 deals with the proposed work. The results of the proposed scheme is tabulated and discussed in Section 4. The work is concluded and future work to further achieve robust watermarking schemes is discussed in Section 5.

Spline Based Fractional Wave Packet Transform

Spline interpolation [10] is widely used in image processing operations. The mathematical expression of a 1D is given by

\[ x(t) = \sum_{k=-\infty}^{\infty} a_k s_k(t) \]  

(1)

where \( a_k \) is the interpolation coefficients determined from the input discrete signal, and \( s_k \) is the interpolation function. At any time, \( (t) \) is defined by a finite number of series members defined by equation (1). This number depends on the B-spline interpolation. If \( S: t_0 < t_1 < \ldots \ldots \ldots < t_n < t_{n+1} \) is a partition on the interval \( (t_0, t_{n+1}) \), then the B Spline function of degree \( n \) on \( S \) is a piecewise polynomial function defined by

\[ B_n(t_0 < t_1 < \ldots < t_n < t_{n+1}) = (n+1)(-1)^{n+1} \sum_{k=0}^{n+1} p_k \]  

(2)

where

\[ p_k = \frac{(t - t_k)^n}{\alpha(t_k)} \]  

\[ \alpha(t_k) = \prod_{j=0}^{n+1} (t_j - t_j) \]  

\[ \alpha(t) = \prod_{j=0}^{n+1} (t_j - t_j) \]  

\[ \sigma(t - t_k) = \begin{cases} (t - t_k)^n & \text{for } t > t_k \\ 0 & \text{for } t \leq t_k \end{cases} \]  

(4)

Similarly, the 2D interpolation is given by

\[ x(u, v) = \sum_{k=-\infty}^{\infty} \sum_{l=-\infty}^{\infty} a_{k,l} s_k(u) s_l(v) \]  

(6)

Splines can be implemented in a simple and efficient way though they are complicated mathematically.

The Wave Packet Transform (WPT) is a variant of the MRA. In the process of the construction of the Dyadic MRA, the subspaces are decomposed as

\[ V_2 C V_1 C V_0 C V_1 C V_2 \ldots \ldots \]  

(7)

In Wavelet Transform (WT), the approximation subspace is peeled off or decomposed as shown in Figure 1.

![Figure 1: Decomposition in Wavelet Domain](image)

It is noted that, the detailed or incremental subspace is not decomposed. In Wave Packet Transform (WPT), the incremental subspace is decomposed in a way similar to the approximation subspace. This is illustrated in Figure2. WPT can also be defined as the Fourier Transform (FT) of a signal windowed by a wavelet, dilated by \( \alpha \) and translated by \( \beta \). WPT is a combination of STFT and Continuous Wavelet Transform (CWT) and is given by

\[ F(x, \alpha, \beta) = \frac{1}{\sqrt{\alpha}} \int_{-\infty}^{\infty} C_{\alpha} \psi \left( \frac{t - \beta}{\alpha} \right) \delta(t) \]  

(8)

The Fractional Wave Packet Transform (FRWPT) is a function of time, frequency and scale. It is a combination of (Fractional Fourier Transform) FRFT[11] and WPT. FRWPT for a signal \( f(t) \) is given by

\[ W_{\alpha}(u, \alpha, b) = \frac{1}{\sqrt{\alpha}} \int_{-\infty}^{\infty} C_{\alpha} \psi \left( \frac{t - b}{\alpha} \right) \delta(t) \]  

(9)

The computation of FRWPT [4] corresponds to the following steps

i. A product by a wavelet
ii. A product by a Chirp
iii. A Fractional transform
iv. Another product by a Chirp
v. A product by complex amplitude factor
Proposed Work
The proposed scheme is divided into two phases. Firstly the embedding phase and secondly, the extraction phase. During the embedding phase, spline based FRWPT is performed on the host image and reference image is generated. The watermark is embedded on the reference image. In the second phase, the watermark is extracted by performing inverse FRWPT. Grey scale image is used as the logo. The embedded watermark is smaller than the host image. Spline interpolation increases the resolution of the image. The block size chosen is 64 X 64. The watermark is embedded 16 times into the host image. The size of the block and the number of times the watermark is embedded may vary from user to user depending on the requirements and the complexity of the approach. The mammogram watermarking scheme proposed provides for two stages of security. Firstly, the value of $\gamma$ defines the embedding strength of the watermark and is crucial. To test this fact, the value of $\gamma$ is varied and the results are tabulated. Secondly, the decomposed bands are swapped in a user defined pattern and watermarking is done. Application of FRWPT provides for robustness and security while dealing with medical images.

The steps involved in the proposed watermark embedding phase is outlined as follows:
1. Apply spline to the input image $P(x,y)$ to obtain $P'(x,y)$.
2. Apply 1-level FRWPT to the spline interpolated image.
3. The position of the subbands is changed by user defined pattern.
4. The reference image $R(x,y)$ is obtained by 1-level inverse FRWPT.
5. The watermark $W(x,y)$ is applied to the reference image. This is the modified reference image image.
6. 1-level fractional wavelet transform is performed on the reference image and the position of the subbands is changed.
7. Finally, perform 1-level inverse FRWPT on step 6 to obtain the watermarked image $P_w(x,y)$.

Similarly, the watermark extraction phase involves the following steps:
1. Perform 1-level fractional wavelet transform on the watermarked image $P_w(x,y)$.
2. Change the positions of all the sub-bands.
3. Perform 1-level inverse FRWPT to obtain the watermarked reference image $R(x,y)$.
4. Extract the watermark $W(x,y)$.
5. Perform 1-level fractional wavelet transform on the watermarked image
6. Change the positions of all the sub-bands.
7. Perform 1-level inverse fractional wavelet transform to obtain the input image.

Results and Discussions
Performance analysis of the proposed scheme is explored in Matlab. Various Mammogram images from the MIAS Database is considered as the test image. Figure 3 shows the test images used from the MIAS Database and Figure 4 shows the watermarked images. The strength of the watermark defined by $\gamma$ is chosen by trial and error method. It is clear that the watermark is invisible to the Human Visual System (HVS). A binary image (logo-BMW) is used as the watermark. PSNR (Peak Signal to Noise Ratio) and correlation coefficient of the embedded and the extracted watermark are the performance evaluation metrics used. Since spline interpolation increases the resolution of the image, resizing is done to obtain an input image of $256 \times 256$. Another option is to perform decomposition on the host image to obtain an input image of $256 \times 256$. The reference image is obtained by decomposition (2 level) of the input image using the FRWPT. The watermarked image is subjected to common attacks as shown in Table 1 and Table 2.

![Figure 3: MIAS Database Test Images](Image)

![Figure 4: Watermarked Images](Image)

![Figure 5: Relationship between $\gamma$ and Correlation Coefficient](Image)
The watermarked image is subjected to $13 \times 13$ Median filtering and it is found that the image quality and the extracted watermark quality is degraded. The correlation coefficient of the extracted watermark and the original watermark is ideally similar under Gaussian attacks. The correlation coefficient is near ideal during Weiner Filtering. The proposed scheme is robust to compression attack. Most of the information was lost in cropping (200 $\times$ 200 pixels), yet some part of the watermark could be extracted. Ideally medical images are not cropped, though cropping can be applied to the Non – ROI preserving the ROI. In this case most of the medical image is not lost. Due to spline interpolation, the proposed scheme is most suited for resizing applications. Increasing the resolution of the medical image for a clear view is sometimes necessary. It is observed the proposed scheme possesses a linear relationship for the test images used. Graphical results are shown in Figure 5.

Table 1: Correlation Coefficients of Extracted Watermarks ($\gamma=1$)

<table>
<thead>
<tr>
<th>Attack</th>
<th>mdb001 PSNR</th>
<th>Correlation Coefficient</th>
<th>mdb179 PSNR</th>
<th>Correlation Coefficient</th>
<th>mdb156 PSNR</th>
<th>Correlation Coefficient</th>
<th>mdb322 PSNR</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>No attack</td>
<td>51.840</td>
<td>1.000</td>
<td>52.404</td>
<td>1.000</td>
<td>51.323</td>
<td>1.000</td>
<td>49.9886</td>
<td>1.000</td>
</tr>
<tr>
<td>Salt and pepper noise</td>
<td>26.904</td>
<td>0.192</td>
<td>26.457</td>
<td>0.164</td>
<td>26.936</td>
<td>0.262</td>
<td>26.735</td>
<td>0.214</td>
</tr>
<tr>
<td>Cropping</td>
<td>8.165</td>
<td>0.043</td>
<td>8.176</td>
<td>0.041</td>
<td>10.834</td>
<td>0.102</td>
<td>9.995</td>
<td>0.077</td>
</tr>
<tr>
<td>Compression</td>
<td>46.423</td>
<td>0.476</td>
<td>48.570</td>
<td>0.383</td>
<td>45.224</td>
<td>0.553</td>
<td>45.728</td>
<td>0.479</td>
</tr>
<tr>
<td>Rotation</td>
<td>12.531</td>
<td>0.038</td>
<td>9.228</td>
<td>0.001</td>
<td>9.883</td>
<td>0.025</td>
<td>10.286</td>
<td>0.042</td>
</tr>
<tr>
<td>Resizing</td>
<td>61.039</td>
<td>1.000</td>
<td>61.025</td>
<td>1.000</td>
<td>59.810</td>
<td>1.000</td>
<td>58.632</td>
<td>1.000</td>
</tr>
<tr>
<td>Sharpening</td>
<td>38.768</td>
<td>0.975</td>
<td>38.188</td>
<td>0.929</td>
<td>37.908</td>
<td>0.952</td>
<td>37.820</td>
<td>0.941</td>
</tr>
<tr>
<td>Guassian Filter</td>
<td>56.102</td>
<td>1.000</td>
<td>52.812</td>
<td>0.999</td>
<td>51.764</td>
<td>1.000</td>
<td>50.812</td>
<td>0.996</td>
</tr>
<tr>
<td>Weiner Filtering</td>
<td>52.454</td>
<td>0.869</td>
<td>53.479</td>
<td>0.868</td>
<td>50.898</td>
<td>0.849</td>
<td>51.757</td>
<td>0.822</td>
</tr>
<tr>
<td>Median filtering</td>
<td>39.865</td>
<td>0.036</td>
<td>39.791</td>
<td>0.017</td>
<td>38.872</td>
<td>0.026</td>
<td>36.4377</td>
<td>0.058</td>
</tr>
</tbody>
</table>

Table 2: Correlation Coefficients of Extracted Watermarks (mdb001)

<table>
<thead>
<tr>
<th>$\gamma$</th>
<th>$\gamma=0.5$</th>
<th>$\gamma=1.5$</th>
<th>$\gamma=2.0$</th>
<th>$\gamma=2.5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attack</td>
<td>PSNR</td>
<td>Correlation Coefficient</td>
<td>PSNR</td>
<td>Correlation Coefficient</td>
</tr>
<tr>
<td>No attack</td>
<td>57.011</td>
<td>1.000</td>
<td>48.707</td>
<td>1.000</td>
</tr>
<tr>
<td>Salt and pepper noise</td>
<td>26.900</td>
<td>0.072</td>
<td>26.476</td>
<td>0.285</td>
</tr>
<tr>
<td>Cropping</td>
<td>8.159</td>
<td>0.009</td>
<td>8.170</td>
<td>0.066</td>
</tr>
<tr>
<td>Compression</td>
<td>47.149</td>
<td>0.228</td>
<td>45.543</td>
<td>0.612</td>
</tr>
<tr>
<td>Rotation</td>
<td>12.523</td>
<td>0.040</td>
<td>12.538</td>
<td>0.034</td>
</tr>
<tr>
<td>Resizing</td>
<td>62.220</td>
<td>0.999</td>
<td>58.836</td>
<td>1.000</td>
</tr>
<tr>
<td>Sharpening</td>
<td>39.100</td>
<td>0.814</td>
<td>38.354</td>
<td>0.994</td>
</tr>
<tr>
<td>Guassian Filter</td>
<td>56.452</td>
<td>0.993</td>
<td>55.303</td>
<td>1.000</td>
</tr>
<tr>
<td>Weiner Filtering</td>
<td>54.088</td>
<td>0.724</td>
<td>50.973</td>
<td>0.881</td>
</tr>
<tr>
<td>Median filtering</td>
<td>40.061</td>
<td>-0.014</td>
<td>39.591</td>
<td>0.047</td>
</tr>
</tbody>
</table>

Conclusion
In this work, spline based FRWPT is adopted for watermarking mammograms. The proposed scheme is linear for most of the test images used. Experimental results show that the proposed scheme is robust to most of the attacks and the correlation coefficient obtained is near ideal during resizing. The watermarking scheme is nonblind and imperceptible. This work can be further elaborated and a robust mammogram watermarking scheme using the curved wavelet transform will be proposed and performance analyses will be done.

References


Authors Biography

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