

WATERMARKING FOR MULTI-MODAL MEDICAL IMAGING MODALITIES

In this work proposed watermarking methods are applied different modalities of same organ with is studied by inserting actual patient details as watermark in to X-ray, CT, MRI and Ultra-sound.

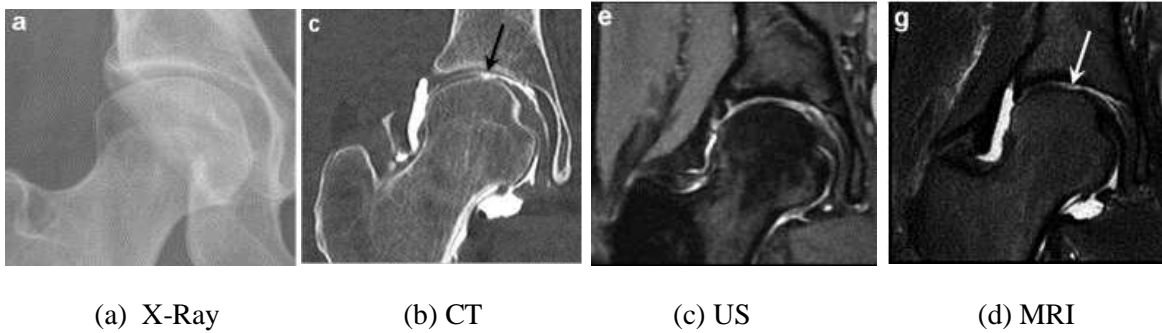


Figure 6.1 X-ray, CT, US and MRI Images of Knee

Consider the same knee organ of size 512x512 pixels in different medical imaging modalities as shown in Figure 6.1.

Watermark Formation from Patient’s Information

Patient details such as name, age, gender and disease as shown in Figure 6.2 are used for the preparation of watermark and are embedded into all the modalities mentioned above.

The performance is measured using Structural Similarity and robustness. Proposed methods for MIW are validated by applying attacks filtering, compression, cropping and noise respectively.

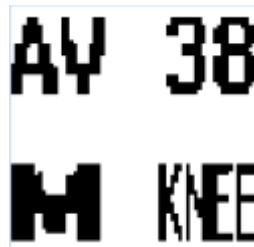


Figure 6.2 Watermark Formation from Patient Data

6.1. Multi-Modal Medical Image Watermarking

Cover image of knee organ is considered and patients' information such as name, age, gender and description prepared as watermark inserted independently in to various modalities and concave watermarked images are obtained by using watermarking embedding algorithm. Watermark is extracted from watermarked image using extraction algorithm.

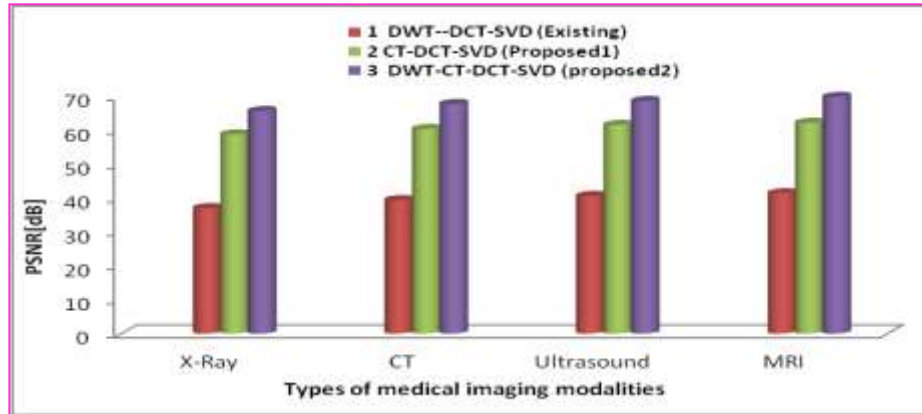
The parameters such as PSNR, NCC, and Structural similarity are used for the evaluation. Performance using robustness and imperceptibility are tabulated in the Table 6.1.

Table 6.1 Performance Evaluation of Multi-Modal Medical Image Watermarking Methods

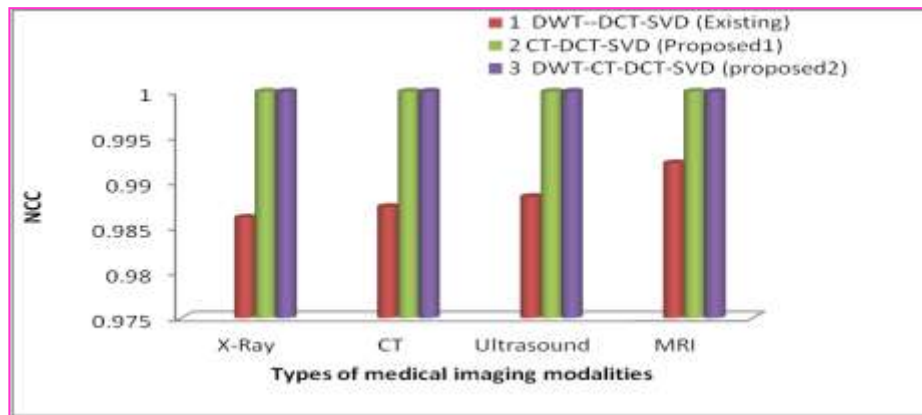
Imaging Modality	Watermarked image								
	DWT-DCT-SVD(Existing)			CT-DCT-SVD(Proposed1)			DWT-CT- DCT-SVD(Proposed2)		
	PSNR [dB]	NCC	Structural Similarity	PSNR [dB]	NCC	Structural Similarity	PSNR [dB]	NCC	Structural Similarity
X-Ray	37.12	0.9884	0.9981	58.93	1	0.9984	65.82	1	0.9989
CT	39.52	0.9921	0.9986	60.54	1	0.9990	67.92	1	0.9992
Ultra-sound	40.75	0.9984	0.9988	61.72	1	0.9993	68.82	1	0.9994
MRI	41.54	0.9986	0.9991	62.35	1	0.9994	69.99	1	0.9998

Table 6.1 infers that proposed algorithms are working better than the existing in case of multi modal watermarking. All the cases watermark distortion is less i.e. more robust as per Figure 6.3(c). It can be seen by observing structural similarity columns. Watermarked image is more imperceptible i.e. inclusion of watermark will not affect the appearance of the watermarked image.

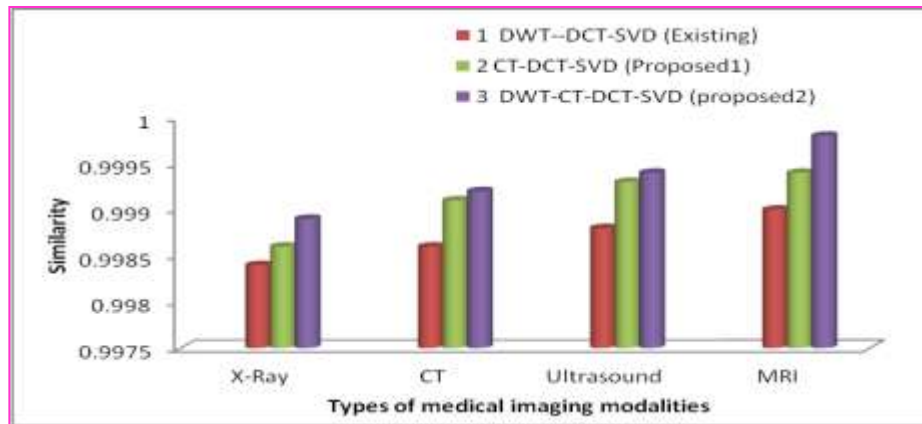
This can be justified by the improved parameters of PSNR and NCC prefers to the column1 and column3 of Table 6.1. MRI is more robust and less perceptible compare to other modalities which can be observed from Figure 6.3(a) and (b).



(a) PSNR



(b).NCC



(c) Structural Similarity

Figure 6.3 Performance Comparison of Four Modalities








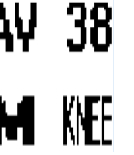

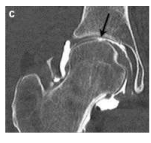
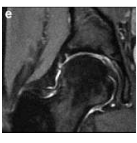


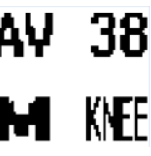




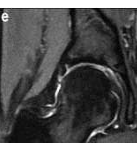



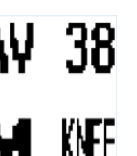






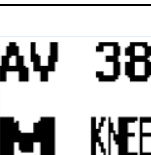


S.No.	Method	Image(s)	Medical imaging Modalities			
			X-Ray	CT	Ultra-Sound	MRI
1	-	Original image				
2	-	Original Watermark				
3	DWT-DCT-SVD (Existing)	Watermarked images				
		Extracted Watermark				
4	CT-DCT-SVD (Proposed1)	Watermarked images				
		Extracted Watermark				
5	DWT-CT-DCT-SVD (Proposed2)	Watermarked images				
		Extracted Watermark				

Figure 6.4 Simulation Results of Watermarked Images and Extracted Watermarks of Multi-Modalities

Figure 6.4 shows the Simulated Results of Watermarking. It is clearly shows that extracted watermark and reconstructed watermarked images are more roust as per rows6 and 8 and rows5 and 7 respectively. Proposed methods are performing we in case of multi modal image watermarking.

6.2. Attacks

In this work, proposed methods are evaluated with watermarking images with attacks. The performance is measure using robustness and imperceptible.

6.2.1. Filtering

Table.6.2. and Table.6.3 indicates that PSNR and NCC are increased in both the methods compared to the existing and hence these methods are more robust to filtering attacks. Out of three, median filtering is more robust and high pass is least robust and average filter performance is in between for all the modalities.

Similarly NCC is used to observe the correlation between watermarked and reconstructed image after filtering. The hike in NCC indicates that image is imperceptibility enhances in these methods. Structural similarity is used to measure the distortion in the reconstructed watermark. From Table 6.4, the increased value of structural similarity indicates that proposed algorithms are more robust than the existing.

Table 6.2 PSNR Comparison of Filtering Attacks

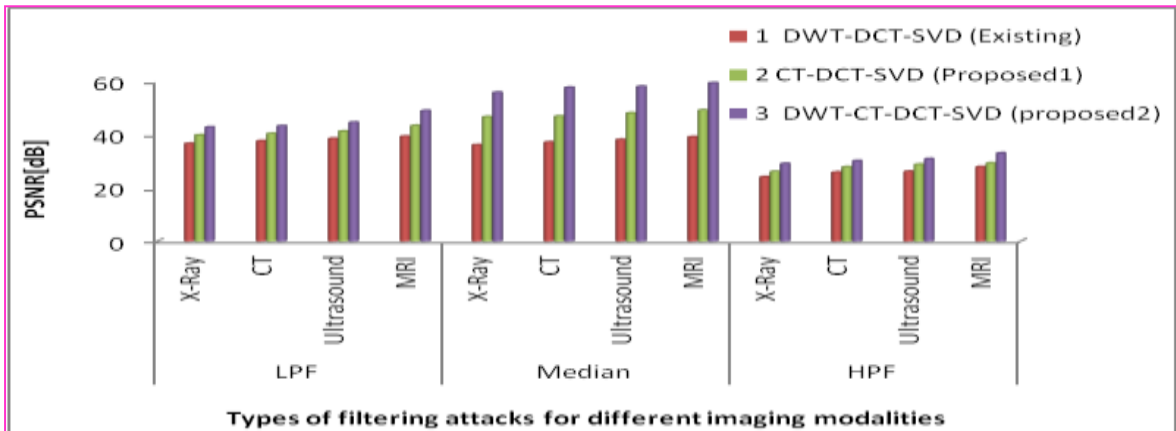
Attacks – Filtering	PSNR [dB]											
	LPF				Median				HPF			
	X-Ray	CT	Ultra Sound	MRI	X-Ray	CT	Ultra Sound	MRI	X-Ray	CT	Ultra Sound	MRI
DWT-DCT-SVD (Existing)	36.74	37.74	38.64	39.45	36.22	37.26	38.22	39.26	24.18	25.95	26.22	27.97
CT-DCT-SVD (Proposed1)	39.94	40.48	41.38	43.48	46.80	47.03	48.22	49.30	26.18	27.92	28.91	29.35
DWT-CT-DCT-SVD (Proposed2)	42.93	43.39	44.73	49.15	56.01	57.85	58.21	59.59	29.18	30.25	31.01	33.18

Table 6.3 NCC Comparison of Filtering Attacks

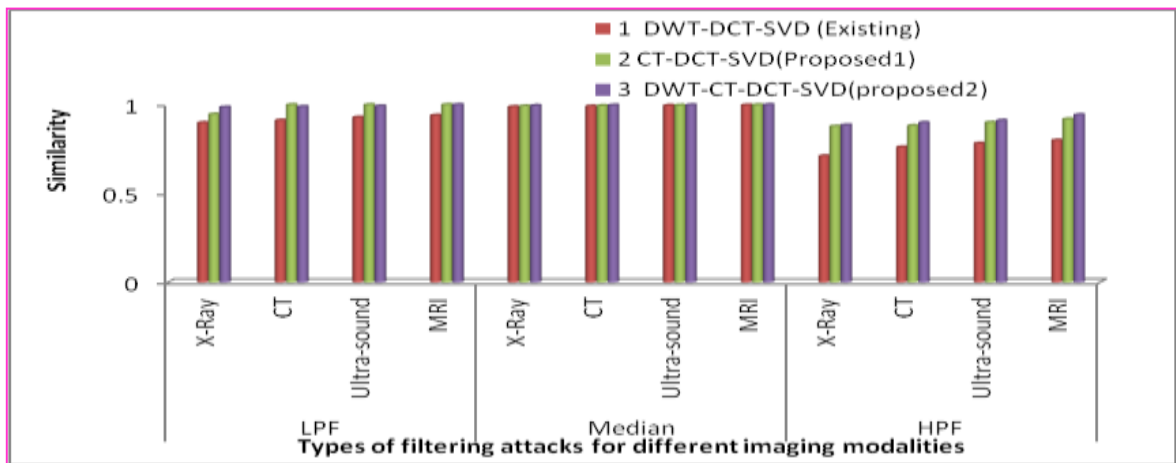
Attacks – Filtering	NCC											
	LPF				Median				HPF			
	X-Ray	CT	Ultra-Sound	MRI	X-Ray	CT	Ultra-sound	MRI	X-Ray	CT	Ultra-sound	MRI
DWT-DCT-SVD (Existing)	0.8912	0.9112	0.9223	0.9335	0.8987	0.8999	0.9113	0.9445	0.7221	0.7235	0.7715	0.7862
CT-DCT-SVD (Proposed1)	0.9657	0.9751	0.9862	0.9941	0.9919	0.9929	0.9949	0.9999	0.8208	0.8342	0.8881	0.8913
DWT-CT-DCT-SVD (Proposed2)	0.9857	0.9868	0.9898	0.9929	0.9992	0.9995	0.9997	1	0.8291	0.8595	0.8921	0.9021

Table 6.4 Structural Similarity Comparison of Filtering Attacks

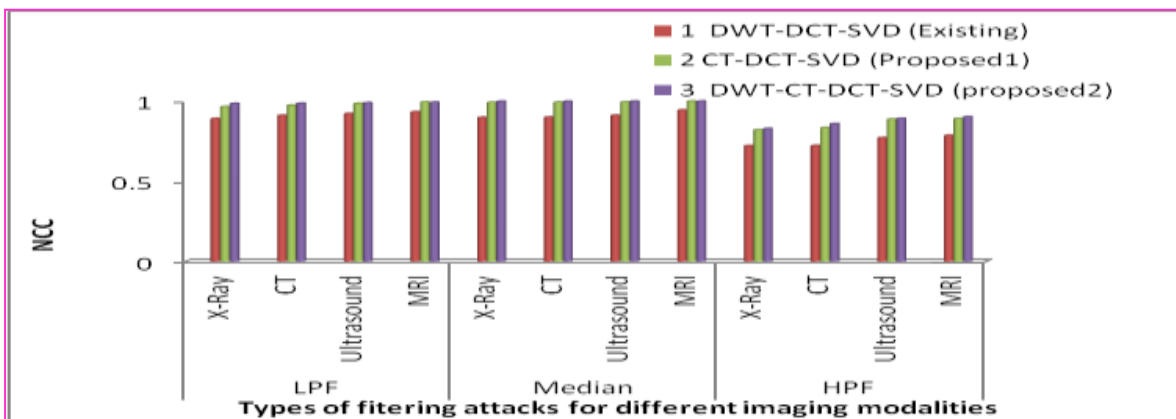
Attacks – Filtering	Structural Similarity											
	LPF				Median				HPF			
	X-Ray	CT	Ultra-sound	MRI	X-Ray	CT	Ultra-sound	MRI	X-Ray	CT	Ultra-sound	MRI
DWT-DCT-SVD (Existing)	0.8985	0.9121	0.9291	0.9399	0.9884	0.9914	0.9958	0.9978	0.7112	0.7615	0.7823	0.7997
CT-DCT-SVD (Proposed1)	0.9455	0.9993	0.9995	0.9998	0.9923	0.9945	0.9967	0.9989	0.8778	0.8816	0.8999	0.9191
DWT-CT-DCT-SVD (proposed2)	0.9859	0.9889	0.9919	0.9999	0.9953	0.9973	0.9985	0.9996	0.8852	0.8991	0.9113	0.9431



(a) PSNR



(b) NCC



(c) Structural Similarity

Figure 6.5 Performance Comparison of Filtering Attacks

It is also observed that from Figure 6.5, proposed algorithms are more robust and imperceptible for filtering attacks as shown in Figure 6.6-6.7. MRI and US are more robust to filtering attacks compared to X-ray and CT.







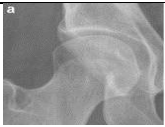





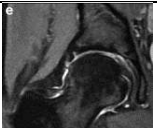
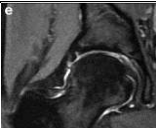
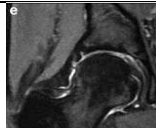
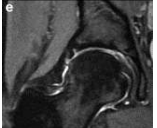
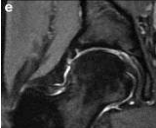
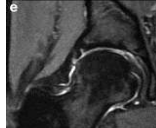
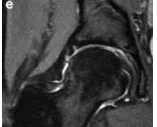
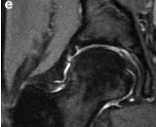
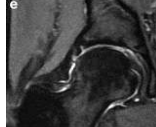
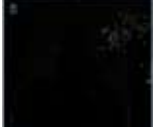

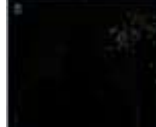
Modality	Attacks	Existing		Proposed1		Proposed2	
		Watermarked Image	Extracted Watermark	Watermarked Image	Extracted Watermark	Watermarked Image	Extracted Watermark
X-Ray	Watermarked		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	Low-Pass		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	Median		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	High-Pass		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
US	Watermarked		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	Low-Pass		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	Median		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	High-Pass		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE

Figure 6.6 Simulation Results of X-Ray and US Modalities of Filtering Attacks











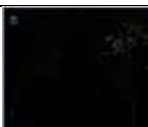
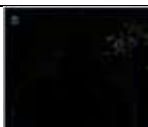





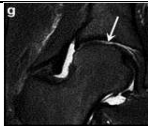
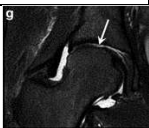





Modality	Attacks	Existing		Proposed1		Proposed2	
		Watermarked Image	Extracted Watermark	Watermarked Image	Extracted Watermark	Watermarked Image	Extracted Watermark
CT	Watermarked		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	Low-Pass		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	Median		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	High-Pass		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
MRI	Watermarked		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	Low-Pass		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	Median		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	High-Pass		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE

Figure 6.7 Simulation Results of CT and MRI Modalities of Filtering Attacks

6.2.2. Compression Attacks

In this section compression attacks multi modal watermarking methods are studied. JPEG, JPEG2000 and pyramidal compression methods are applied on watermarked images and their effects are tabulated in Table 6.5 - 6.7. In all the cases performance is improved compared to

the existing methods and also filtering affect clearly understood that robustness and imperceptibility decreases with respect to un-attacked watermarking as per Figure 6.8 (a), (b) and (c). Simulation results are shown in Figure 6.9 – 6.10.

Table 6.5 PSNR Comparison of Compression Attacks

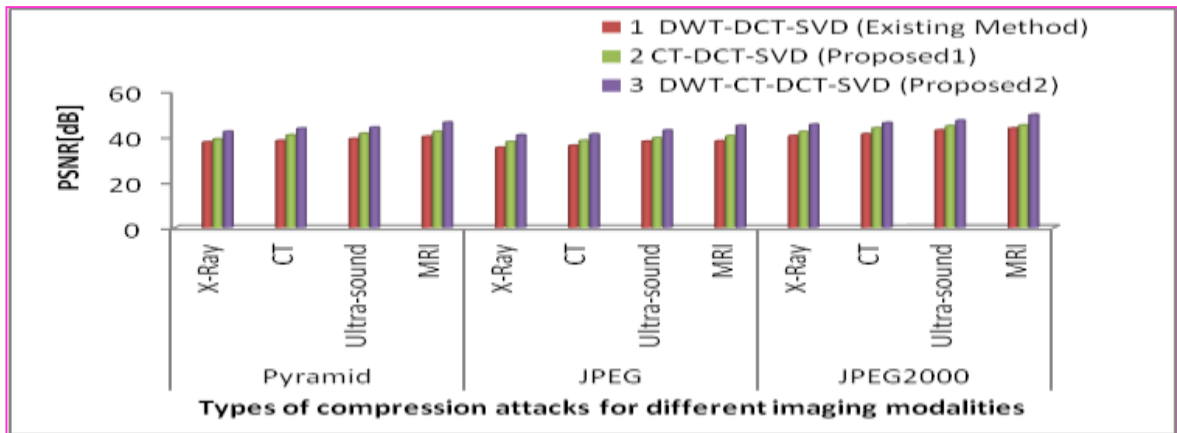
Compression	PSNR											
	Pyramidal				JPEG				JPEG2000			
Imaging Modalities	X-Ray	CT	Ultra-sound	MRI	X-Ray	CT	Ultra-sound	MRI	X-Ray	CT	Ultra-sound	MRI
DWT-DCT-SVD (Existing)	37.67	38.31	39.15	40.08	35.26	36.11	37.96	38.13	40.42	41.23	42.91	43.73
CT-DCT-SVD (Proposed1)	39.00	40.80	41.45	42.28	37.78	38.36	39.47	40.36	42.21	43.88	44.78	45.08
DWT-CT-DCT-SVD (Proposed2)	42.28	43.67	44.11	46.33	40.79	41.17	42.87	44.94	45.41	46.12	47.20	49.74

Table 6.6 NCC Comparison of Compression Attacks

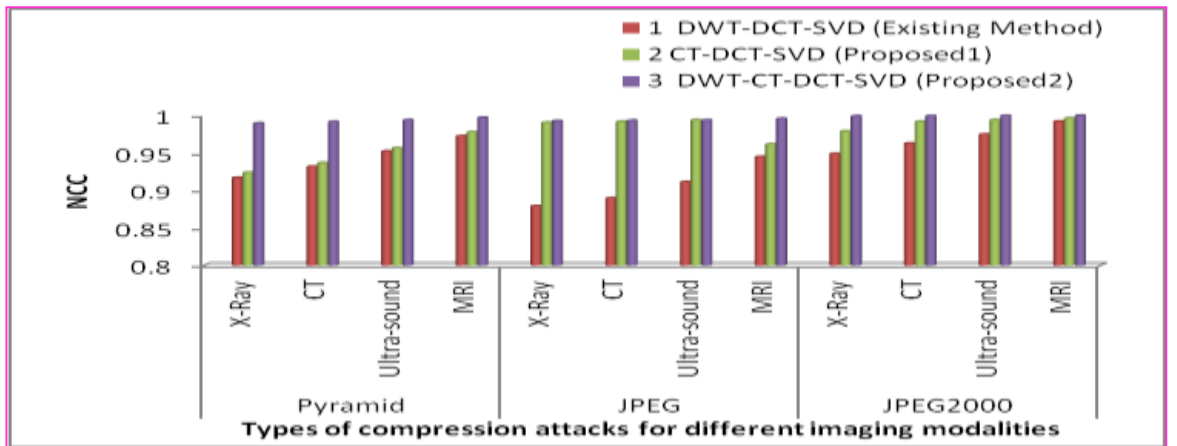
Compression	NCC											
	Pyramidal				JPEG				JPEG2000			
Imaging Modalities	X-Ray	CT	Ultra-sound	MRI	X-Ray	CT	Ultra-sound	MRI	X-Ray	CT	Ultra-sound	MRI
DWT-DCT-SVD (Existing)	0.9168	0.9315	0.9521	0.9721	0.879	0.8895	0.9112	0.9445	0.9486	0.9624	0.9743	0.9917
CT-DCT-SVD (Proposed1)	0.9234	0.9365	0.9561	0.9773	0.9901	0.9913	0.9934	0.9612	0.9786	0.9912	0.9934	0.9958
DWT-CT-DCT-SVD (Proposed2)	0.9892	0.9912	0.9934	0.9967	0.9923	0.9928	0.9932	0.9953	0.9986	0.9988	0.9991	0.9995

Table 6.7 Structural Similarity Comparison of Compression Attacks

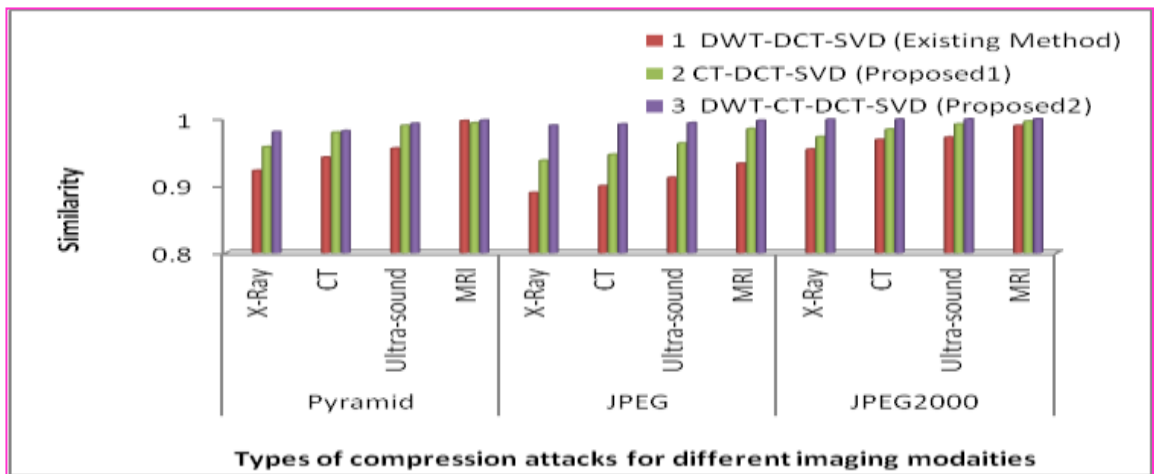
Compression	Structural Similarity											
	Pyramidal				JPEG				JPEG2000			
Imaging Modalities	X-Ray	CT	Ultra-sound	MRI	X-Ray	CT	Ultra-sound	MRI	X-Ray	CT	Ultra-sound	MRI
DWT-DCT-SVD (Existing Method)	0.9223	0.9421	0.9553	0.9963	0.8894	0.8994	0.9119	0.9329	0.9538	0.9683	0.9718	0.9891
CT-DCT-SVD (Proposed1)	0.9576	0.9791	0.9892	0.9931	0.9372	0.9462	0.9628	0.9843	0.9724	0.9836	0.9913	0.9954
DWT-CT-DCT-SVD (Proposed2)	0.9798	0.9811	0.9922	0.9971	0.9894	0.9912	0.9931	0.9968	0.9983	0.9985	0.9988	0.9991



(a) PSNR



(b) NCC



(c) Structural Similarities

Figure 6.8 Performance Comparison of Compression Attacks










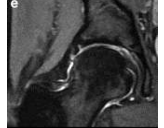
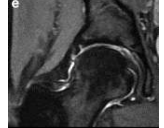
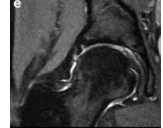
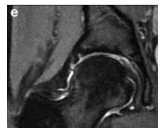
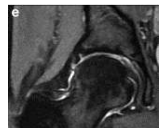
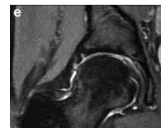
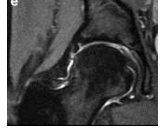
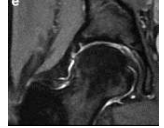
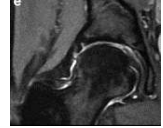
Modality	Attacks	Existing		Proposed1		Proposed2	
		Watermarked Image	Extracted Watermark	Watermarked Image	Extracted Watermark	Watermarked Image	Extracted Watermark
X-Ray	Pyramidal		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	JPEG		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	JPEG2000		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
US	Pyramidal		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	JPEG		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	JPEG2000		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE

Figure 6.9 Simulation Results of X-Ray and Ultra-Sound Modalities of Compression Attacks










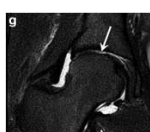
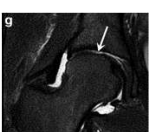
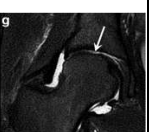


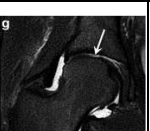

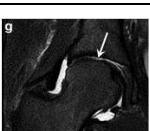

Modality	Attacks	Existing		Proposed1		Proposed2	
		Watermarked Image	Extracted Watermark	Watermarked Image	Extracted Watermark	Watermarked Image	Extracted Watermark
CT	Pyramidal		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	JPEG		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	JPEG2000		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
MRI	Pyramidal		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	JPEG		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
	JPEG2000		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE

Figure.6.10 Simulation Results of CT and MRI Modalities of Compression Attacks

6.2.3 Noise

The proposed two algorithms are validated by using Gaussian Noise. PSNR, NCC and structural Similarity are tabulated in Table 6. 8 - 6.10. It is observed that proposed algorithms are more robust and imperceptible for noise attacks and percentage improvement is high compared to existing as shown in Figure 6.11. The extracted watermark and reconstructed watermarked images after noise attack are shown in Figure 6.12. It is observed that all the modalities are robust and imperceptible.

Table 6.8 PSNR Comparison of Noise Attack

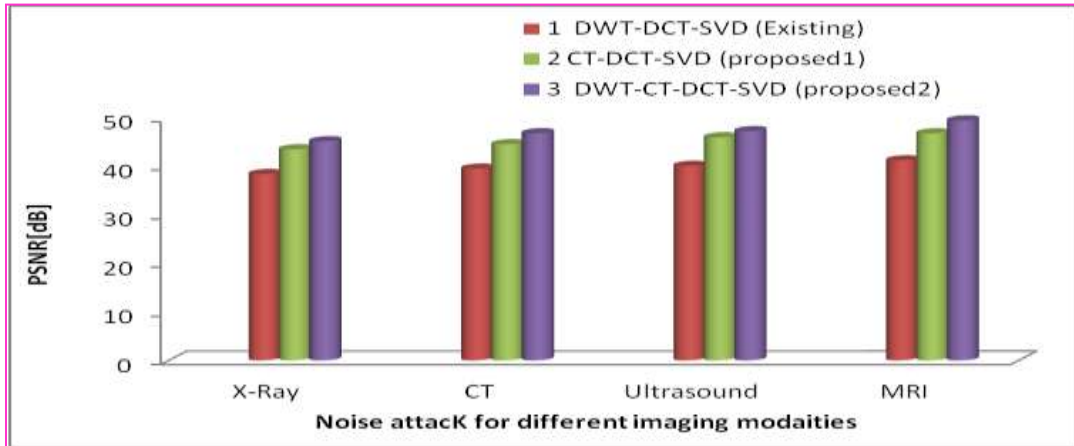
Performance Metrics	Noise			
	PSNR [dB]			
Imaging Modalities	X-Ray	CT	Ultra-sound	MRI
DWT-DCT-SVD (Existing)	38.3665	39.4717	40.0668	41.1859
CT-DCT-SVD (Proposed1)	43.4674	44.5103	45.9307	46.7491
DWT-CT-DCT-SVD (Proposed2)	45.118	46.7655	47.1974	49.4015

Table 6.9 NCC Comparison of Noise Attack

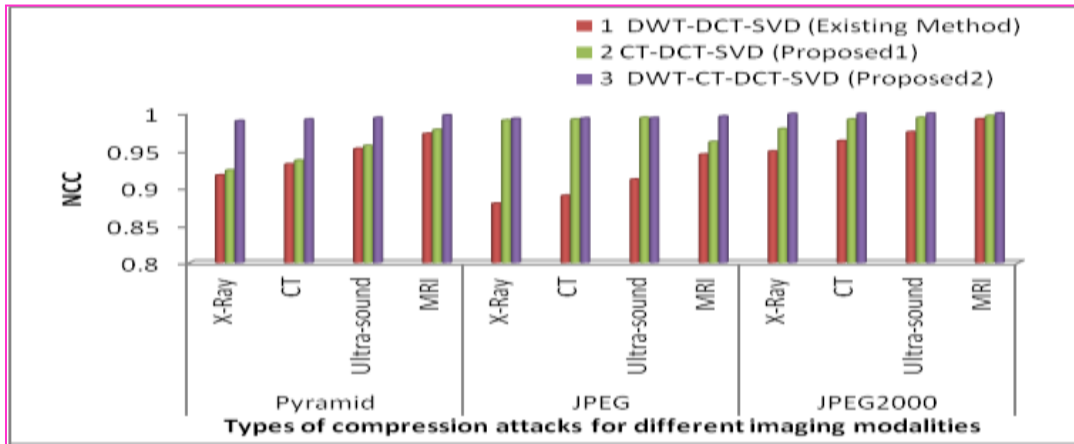
Performance Metric – NCC	Noise			
Imaging Modalities	X-Ray	CT	Ultra-sound	MRI
DWT-DCT-SVD (Existing)	0.3623	0.7521	0.8532	0.8964
CT-DCT-SVD (Proposed1)	0.9234	0.9443	0.9553	0.9782
DWT-CT-DCT-SVD (Proposed2)	0.9234	0.9445	0.9662	0.9885

Table 6.10 Structural Similarity Comparison of Noise Attack

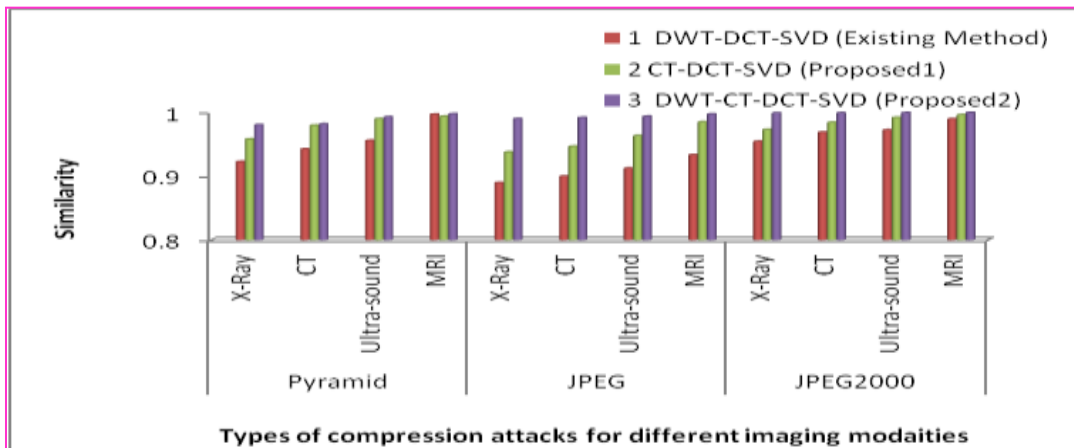
Performance Metric – Structural Similarity	Noise			
Imaging Modalities	X-Ray	CT	Ultra-sound	MRI
DWT-DCT-SVD(Existing)	0.3778	0.6553	0.8541	0.8772
CT-DCT-SVD (Proposed1)	0.8592	0.8699	0.8899	0.9119
DWT-CT-DCT-SVD (Proposed2)	0.9236	0.9491	0.9669	0.9889



(a) PSNR



(b) NCC



(c) Structural Similarity

Figure 6.11 Performance Comparisons of Noise Attack




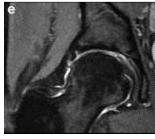
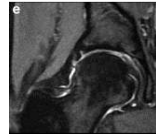
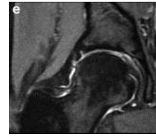

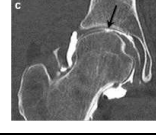
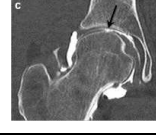
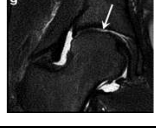


Attacks Gaussian Noise	Existing		Proposed1		Proposed2	
	Watermarked Image	Extracted Watermark	Watermarked Image	Extracted Watermark	Watermarked Image	Extracted Watermark
X-Ray		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
US		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
CT		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE
MRI		AV 38 M KNEE		AV 38 M KNEE		AV 38 M KNEE

Figure 6.12 Simulation Results of X-Ray, US, CT and MRI Modalities of Noise Attack

6.2.4. Geometrical Attacks - Cropping

Geometrical attacks such as scaling, rotation and cropping attacks are usually occurred during acquisition or transmission. Watermarked images are cropped and watermark is extracted from the reconstructed images using proposed algorithms. X-Ray, CT, Ultra-Sound, and MRI is used as cover images for these algorithms.

PSNR, NCC and Structural Similarity are tabulated in Table 6.11- 6.13. Performance comparison is shown in Figure.6.13. In case of geometrical attacks more distortion will occur and hence proper reconstruction will not be possible in case of watermark which can be observed in the Figure 6.14- 6.16. In case of cropping also PSNR and NCC improved and imperceptibility is high.

Table 6.11 PSNR Comparison of Cropping Attack

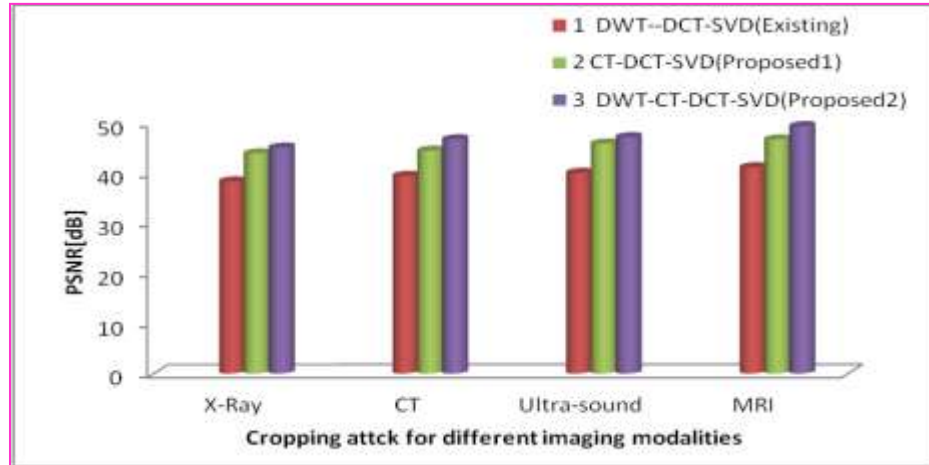
Performance Metric	Cropping			
	PSNR [dB]			
Imaging Modalities	X-Ray	CT	Ultra-sound	MRI
DWT--DCT-SVD (Existing)	38.3665	39.4717	40.0668	41.1859
CT-DCT-SVD (Proposed1)	43.9674	44.5103	45.9307	46.7491
DWT-CT-DCT-SVD (Proposed2)	45.118	46.7655	47.1974	49.4015

Table 6.12 NCC Comparison of Cropping Attack

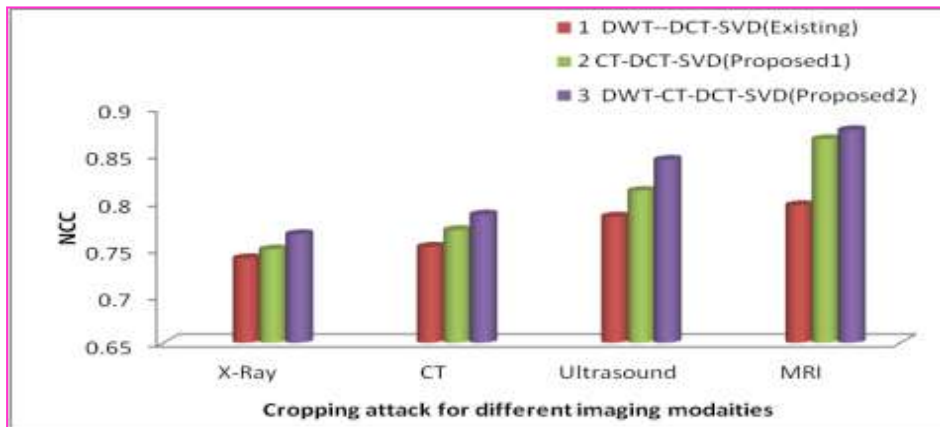
Performance Metric - NCC	Cropping			
	X-Ray	CT	Ultrasound	MRI
DWT--DCT-SVD(Existing)	0.7399	0.7521	0.7842	0.7963
CT-DCT-SVD (Proposed1)	0.7493	0.7698	0.8115	0.8665
DWT-CT-DCT-SVD (Proposed2)	0.7655	0.7863	0.8445	0.8761

Table 6.13 Structural Similarity Comparison of Cropping Attack

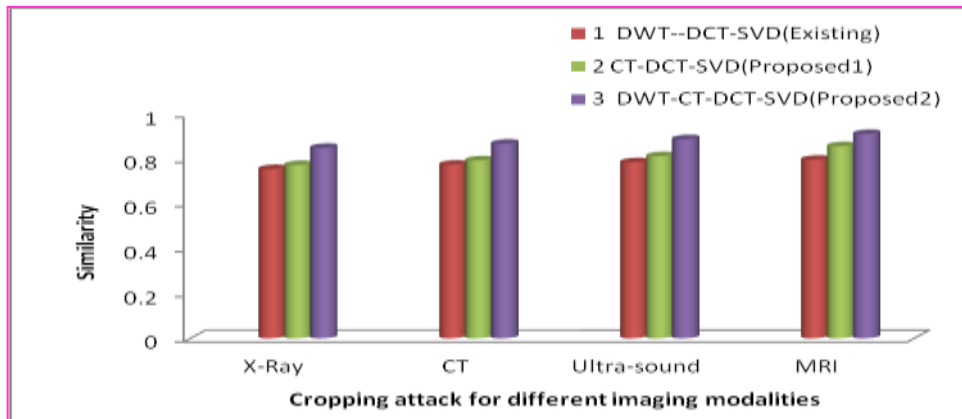
Performance Metric – Structural Similarity	Cropping			
	X-Ray	CT	Ultra-sound	MRI
DWT--DCT-SVD Existing)	0.7537	0.7732	0.7841	0.7954
CT-DCT-SVD (Proposed1)	0.7718	0.7924	0.8112	0.8554
DWT-CT-DCT-SVD (Proposed2)	0.8481	0.8668	0.8868	0.9102



(a) PSNR



(b) NCC



(c) Structural Similarity

Figure 6.13 Performance Comparison of Cropping Attack




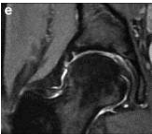

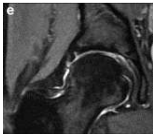



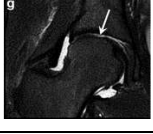


Attacks Gaussian Noise	Existing		Proposed1		Proposed2	
	Watermarked Image	Extracted Watermark	Watermarked Image	Extracted Watermark	Watermarked Image	Extracted Watermark
X-Ray		No Edge information		No Edge information		No Edge information
US		No Edge information		No Edge information		No Edge information
CT		No Edge information		No Edge information		No Edge information
MRI		No Edge information		No Edge information		No Edge information

Figure 6.14 Simulation Results of X-Ray, US, CT and MRI Modalities for Cropping Attack

6.3. Conclusions

The hybrid algorithms applied on multi modal medical images is performed well and improving robustness and imperceptibility. It can be used for providing the security of medical images since PSNR and Structural Similarity are improved very much.