Does interpolation affect diagnosis?

Quantitative assessment of the effects of interpolation on uncompressed and compressed medical images.

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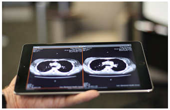
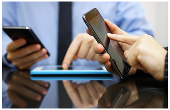
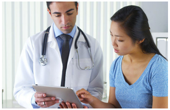
Motivation

- Remote medical record access has gained popularity in the healthcare industry as it enables remote diagnosis, quicker access to a specialist, remote monitoring and makes the communication between physicians regarding a patients' medical history faster.
- Lossless and lossy image compression.
- The resolution at which medical images are displayed on output devices often differs from the original (mobile devices)



Interpolation

Interpolation is extensively used by radiologists to rescale images. It involves producing a larger/smaller version of an image, by adding new - artificial pixels to the existing image.

Interpolated pixels are obtained by convolution of an interpolation filter. This involves combining the known pixels with some weighted functions (convolution kernels) that satisfy certain properties.

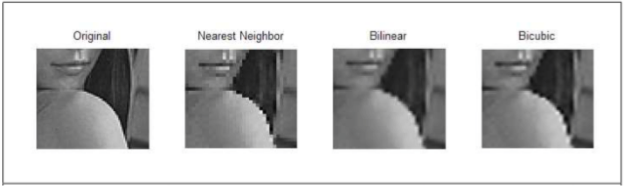
Interpolation is only an approximation and therefore an image will always undergo some loss-of-quality when interpolation is performed.

Interpolation algorithms

The performance of an interpolation technique depends on the approximation order and the support of the convolution kernel. In practice, the choice of the interpolation method is a trade-off between quality and computation time.

Most common interpolation algorithms:

- Nearest neighbour
- Bilinear
- Bicubic
- Gaussian



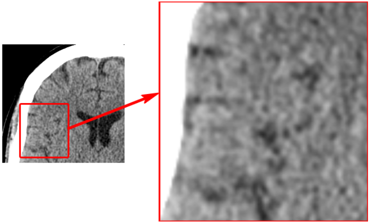
Effects of interpolation

The most common artifacts resulting from interpolation include blurring, edge distortion, ringing near sharp edges.

Even for the same image, different interpolation techniques may produce images that differ significantly. As a result, interpolation may have an impact on diagnostic image quality. [Blunser].

Some distortions are more visible to human eye than others!

“Pixelated” images, the result of the “blockiness” effect, are of poor quality due to the loss of detail especially near edges. The figure below shows the original and a magnified region of a brain CT image using bilinear interpolation technique with the scaling factor of $4:1$. The visible artifacts in the magnified image include blurring and distortions around the edges.



Quality assessment of interpolated images

Subjective Image Quality Assessment

The best way to compare the effects of interpolation algorithms is to run time-consuming **subjective tests** involving a number of radiologists assessing the quality of each interpolated image.

Objective Image Quality Assessment

A faster way to measure the performance of interpolation techniques would be to use some **objective quality measures** that predict image quality automatically using a numerical algorithm.

Quality assessment of interpolated images

Quality of interpolated images is difficult to assess!

Why?

- There is no one-to-one mapping between the original image and the interpolated image!
- No objective model has been yet established for medical images.

Workarounds

- Some attempts to make this comparison possible include creating a lower resolution image from the original image (using some downsizing technique), interpolating the lower-resolution image and comparing it to the original image.
- Another approach involves downsizing the magnified image by averaging pixels to match the original image resolution. The downsized image is then compared to the original image.
- Another attempt may involve acquiring the same image at different resolutions.

Objective quality assessment of images

Most common algorithms:

- Mean Squared Error (MSE)
- Peak Signal-to-Noise Ratio (PSNR)
- Structural Similarity (SSIM) index [Wang]

Do we trust them?

- Although MSE is shown to poorly correlate with visual quality, it should not be taken for granted that any perceptual objective quality measure must be better!
- According to the relevant literature, SSIM index and other objective measures show better performance than MSE for natural image/video content for consumer electronics applications based on subjective tests. [Wang, et al.]
- In a recent study on the quality of compressed medical images, SSIM shows better correspondence with subjective radiologists' responses than MSE.[Kowalik-Urbaniak et al.]

The Mean Squared Error (MSE)

MSE is related to the L^2 distance between image functions. The MSE between the compressed image g and the original image f is given by:

$$\text{MSE}(f, g) = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} (f(i,j) - g(i,j))^2 \,.$$

Note: Larger MSE errors correspond to worse image quality!

The Structural Similarity Index (SSIM)

The SSIM index, introduced by Wang and Bovik, assumes that the human visual system (HVS) is highly sensitive to structural information/distortions (e.g. JPEG blockiness, “salt-and-pepper” noise, ringing effect, blurring) in an image and automatically adjusts to the non-structural (e.g. luminance or spatial shift, contrast change) ones. Another assumption of the SSIM index is that images are highly structured and there exist strong neighbouring dependencies among the pixels, which the MSE totally ignores. The SSIM index measures the difference/similarity between two images by combining three components of the HVS: luminance, $l(f, g)$, contrast, $c(f, g)$ and structure, $s(f, g)$. The (local) SSIM is given by:

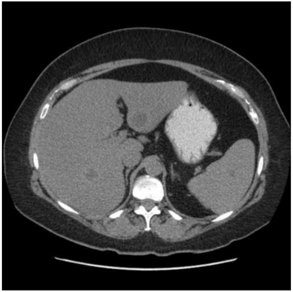
$$SSIM(f, g) = \left(\frac{2\mu_f \mu_g + C_1}{\mu_f^2 + \mu_g^2 + C_1} \right) \cdot \left(\frac{2\sigma_f \sigma_g + C_2}{\sigma_f^2 + \sigma_g^2 + C_2} \right) \cdot \left(\frac{\sigma_{fg} + C_3}{\sigma_f \sigma_g + C_3} \right) \tag{1}$$

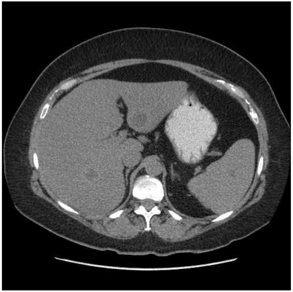
$$SSIM(f, g) \leq 1 \tag{2}$$

Note: The larger the SSIM index the better the quality of the image!

Methodology

- 30 Body CT and 30 Brain CT images were analyzed.
- The compression ratios used are 2:1 to 35:1 using JPEG and JPEG2000 compression methods.
- The images are magnified at two factors 2:1 and 4:1. The magnified images are then interpolated again back to their original size (512×512 pixels) using the same interpolation technique. The resulting images are compared to the original images using MSE and SSIM.
- The scaling procedure is as follows: scale using a given interpolation algorithm along X and Y directions such that the aspect ratio is conserved. Restore to the original image size using the same interpolation algorithm.





Body CT image. Left: JPEG CR: 12:1. Right: Interpolated (4:1), Bicubic method (and resized back to original size).

Note the blurring effect!

Body CT image. Left: JPEG CR: 33:1. Right: Interpolated (4:1), Bicubic method (and resized back to original size).

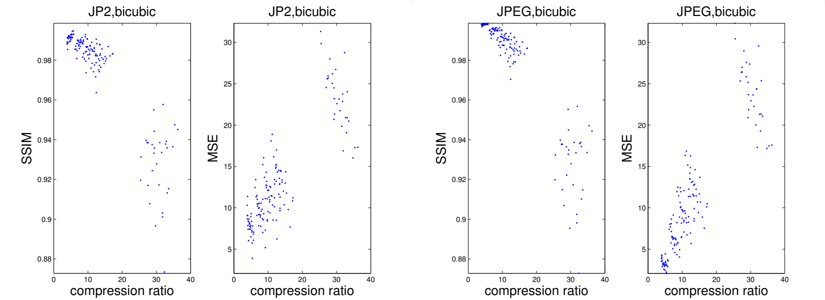
Note the smoothing effect!

	SSIM		MSE	
Comp.Ratio	Comp	Comp-Interp	Comp.	Comp.Interp
4.0400	0.9976	0.9842	0.9675	8.7540
6.7400	0.9893	0.9769	4.5378	10.7328
9.4400	0.9790	0.9685	9.5219	13.4287
12.4400	0.9637	0.9530	13.1632	16.2499
32.3400	0.8860	0.8810	25.5157	26.1432
5.3400	0.9987	0.9910	0.5741	5.5446
8.4600	0.9939	0.9865	2.4312	6.6900
11.4200	0.9878	0.9814	4.6703	8.1125
14.7200	0.9790	0.9730	7.3719	10.1080
33.5500	0.9321	0.9285	16.2139	17.2491

Tables of quality scores corresponding to JPEG2000 compressed and interpolated images. Interpolation factor 4:1

	SSIM		MSE	
Comp.Ratio	Comp	Comp-Interp	Comp.	Comp.Interp
4.0400	0.9980	0.9967	2.9803	3.8544
6.7400	0.9916	0.9910	8.7282	8.0860
9.4400	0.9829	0.9824	13.4688	12.4236
12.4400	0.9703	0.9704	17.5007	16.2789
32.3400	0.8708	0.8728	30.3006	29.5871
5.3400	0.9988	0.9981	1.5491	2.2239
8.4600	0.9953	0.9947	4.4847	4.3288
11.4200	0.9905	0.9901	7.3539	6.7298
14.7200	0.9824	0.9825	10.3304	9.4307
33.5500	0.9130	0.9147	21.7836	21.0887

Tables of quality scores corresponding to JPEG compressed and interpolated images. Interpolation 4:1



Rate distortion plots corresponding to Body CT images. With higher compression ratio the quality of images (compressed-interpolated) gets worse according to the most common measures of image fidelity.

Exactly what we expect!

So, why interpolated-compressed images receive a better score than (only) compressed images at the same compression ratios?

Observations:

- In the case JPEG compressed medical images after a certain compression ratio, the interpolated images exhibit better visual quality than their compressed (not interpolated) counterparts. (smoothing effect, reduction of blockiness in JPEG).
- This may be true visually, however, the diagnostic quality of the image is worse due to loss of “information” caused by interpolation.
- Based on the standard objective quality scores, the blurred image (even though there is a smaller amount of original “information” that remained after interpolation) is of better quality than the image that was just compressed (and not interpolated) using JPEG. **This must be wrong!**
- This oddity is not observed for JPEG2000 compressed images.

Modified Image Quality Measure

We propose a measure of image quality for interpolated images using deterministic and statistical information of the signal.

The energy of the signal $f(x)$ is given by:

$$\int_{-\infty}^{\infty} |f(x)|^2 \, dt = \int_{-\infty}^{\infty} |\hat{f}(s)|^2 \, df. \tag{3}$$

where is the Fourier transform of $f(x)$:

$$\hat{f}(s) = \int_{-\infty}^{\infty} e^{-2\pi isx} f(x) dt. \tag{4}$$

By the Parseval's theorem, the Fourier transform can be used to measure the energy of a signal.
The energy spectral density of a signal $f(x)$ is defined as

$$S_{ff}(s) = |\hat{f}(s)|^2 \tag{5}$$

Suppose f is a reference image and g is a distorted image.
The ratio,

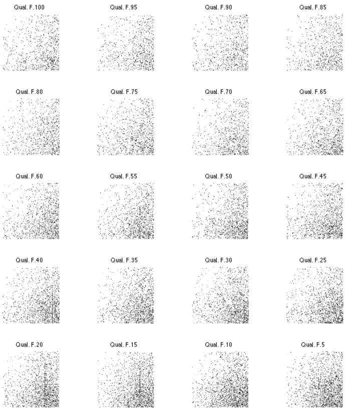
$$\frac{S_{ff}(s)}{S_{gg}(s)} \tag{6}$$

measures the amount of degradations in distorted images as compared to the given reference image.

The modified measure of image quality involves the use of SSIM and energy spectral density of high frequency coefficients.

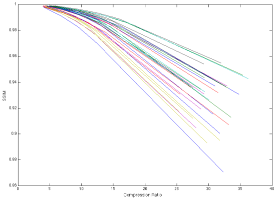
$$Qual_{ind}(f,g) = SSIM(f,g) * \frac{S_{ff}(s)}{S_{gg}(s)} \tag{7}$$

Using the modified measure, we observe that the quality of images is captured properly, i.e. interpolation lowers the quality of compressed images as compression increases.

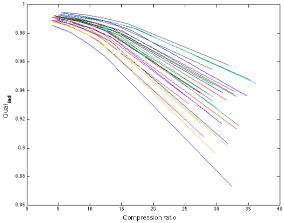


The magnitude of frequency domain coefficients of an interpolated, JPEG compressed body CT image at several quality factors. The darker the area the lower the magnitude. As expected, with the increase in compression, there are more (higher frequency) coefficients of lower magnitude.

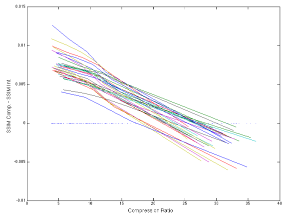
Rate distortion curves corresponding to 60 Body CT images for SSIM and $Qual_{ind}$:



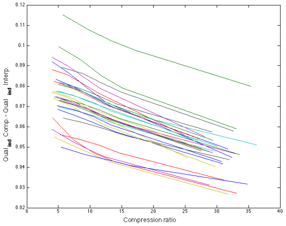
Rate distortion curves for 60 JPEG Body CT images corresponding SSIM.



Rate distortion curves for 60 JPEG Body CT images corresponding $Qual_{ind}$



SSIM quality score differences between interpolated compressed and compressed 60 Body CT images as several compression ratios. The difference becomes negative! It means that the compressed interpolated images seem to be of better quality their compressed (not-interpolated) counterparts!!!



Qual_{ind} quality score differences between interpolated compressed and compressed 60 Body CT images as several compression ratios.

MSE / SSIM versus the new modified Qual_{ind} measure

- For an interpolated image, the quality score is computed by comparing the interpolated-compressed image to the original image.
- Both methods predict that quality of interpolated images is worse for lower compression ratios.
- According to SSIM compressed-interpolated images are of better quality than compressed images at some compression ratios.
- This cannot be true since we are losing information by applying interpolation!

Using the newer measure Qual_{ind}, the quality of interpolated compressed image is predicted correctly!

Conclusions and future work

- Attempted to capture the loss of diagnostic information of interpolated compressed and uncompressed medical images.
- We propose a full-reference objective measure of quality for interpolated images, which considers deterministic and statistical knowledge about the image.
- The statistical properties are acquired from the frequency domain (high-frequency content) of the signal and are combined with the elements of SSIM.
- Future work will involve validation of the proposed image fidelity measure based on subjective radiological assessments using a modified Receiver Operating Characteristic (ROC) analysis.
- We aim to present a model that could serve as a predictor of quality of interpolated images at different rescaling factors for a given image modality and anatomical region.

Thank you!