HVS & Watermarking

What does hiding mean?

- Keep it secret. The hidden object is put in a place which is unknown to not authorized people. If an object location is unknown it is unlikely that it can be seen.
- Make it small. The hidden object is made so small that nobody is able to see it. The ability of people to perceive an object is limited by its dimension.
- Make it similar. The hidden object is made so similar to the surrounding environment that it is not possible to distinguish it.
- Make it spread. The object to be hidden is sub-divided into pieces which are spread around. In this case is the whole object that can not be perceived.

Human Visual System

Original "Lena"

"Lena" AWGN (variance 0.01)

Human Visual System

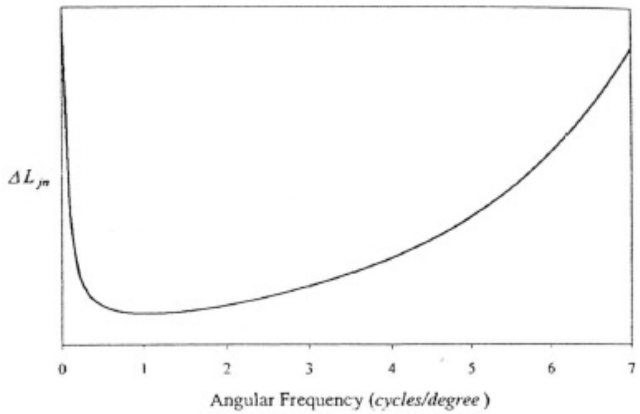
- Disturbs are much less visible on highly textured regions than on uniform areas
- Contours are more sensible to noise addition that highly textured regions but less than flat areas
- Disturbs are less visible over dark and bright regions (Weber law)

Human Visual System

Human Visual System

- A small square of uniform luminance L+Delta is superimposed over a uniform backgroud of luminance L: Delta is then increased until the small square is perceived by an human observer, as differing from the background. The Just Noticeable Difference is the minimum amount by which stimulus intensity must be changed in order to produce a noticeable variation in sensory experience.

- The Just Noticeable Difference increases for very low and very high luminance values.



Human Visual System

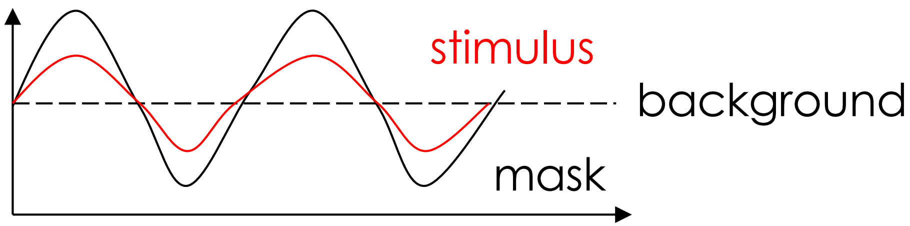
- Weber's law states that the ratio of the just noticeable difference to the background intensity is a constant. So when you are in a noisy environment you must shout to be heard while a whisper works in a quiet room. And when you measure the just noticeable difference on various intensity backgrounds, the threshold increase in proportion to the background.

- According to Weber's law the ratio of the just noticeable difference and the luminance is constant and equals 0.02 for a wide range of luminances.

- More complex experiments are needed to model the behaviour of the eye in the presence of textured patterns.

Human Visual System

- The maximum sensibility of the Human Visual System (HVS) to luminance changes is achieved for medium level
- When more stimuli are present masking occurs
  - The new stimulus is masked by the presence of a background sinusoid



- Masking is maximum when the stimulus and the masking signal have the same frequency, phase and orientation
- Masking plays a major role in determining the visibility of a watermark

Frequency masking

$$|f_{iw}| = |f_i| + a w_i |f_i|$$

a is as large as possible subject to the invisibility constraint

f is typically a transformed coefficient (DCT, DFT, DWT)

Problems

- inter-frequency masking is neglected
- frequency masking lacks spatial localization

Frequency masking

Example in “Improved wavelet-based watermarking through pixel-wise masking” by Barni et al. IEEE Transactions on image processing, vol. 10, no. 5, May 2001

- DWT domain

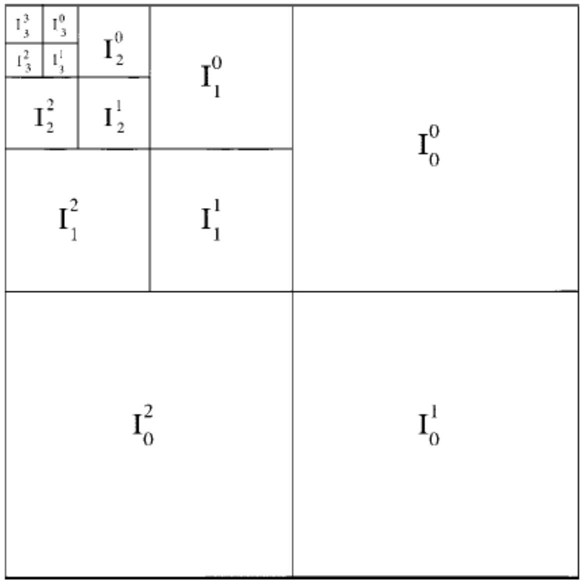
- Given the watermark that has to be embedded into the wavelet coefficients it defines and exploits the just noticeable threshold of modification that each coefficient can sustain without degrading the visual quality of the image (following three perceptual rules)
- Detection based on Newman-Pearson theorem

Frequency masking

- Watermark: pseudo-random sequence of -1 and +1 m is arranged in 2D, where 2Mx2N are the dimensions of the host image

$$x^{\theta}(i,j) = m_{(\theta MN + iN + j)}$$

- Embedding into sub-bands I_0



$$\tilde{I}_0^{\theta}(i,j) = I_0^{\theta}(i,j) + \alpha \omega^{\theta}(i,j) x^{\theta}(i,j)$$

w is a weighing function considering the local sensitivity of the image to noise. It is this weighing function that allows to exploit the masking characteristics of the HVS.

Frequency masking

- The choice of embedding the watermark only into the three largest detail subbands is motivated by experimental tests, as the one offering the best compromise between robustness and invisibility.
- Inserting the watermark into these subbands could give a lower robustness (e.g., compression or low-pass filtering) but given the low visibility of disturbs added to these frequencies a higher level of watermark strength is allowed thus compensating for such a bigger fragility.

Frequency masking

- The quantization step of each coefficient is computed as the weighted product of three terms (following three perceptual rules):

$$q_l^\theta(i,j) = \Theta(l,\theta)\Lambda(l,i,j)\Xi(l,i,j)^{0.2}$$

- Using this quantization step will imply that disturbs having value lower than its half are assumed not to be perceivable. Thus the weighing function will be set to:

$$w^\theta(i,j) = \frac{q_0^\theta(i,j)}{2}$$

which is equal to the quantization step of the DWT coefficient to which the watermarking code has to be added.

Frequency masking

- First rule: the eye is less sensitive to noise in high resolution bands and in those bands having orientation of 45°

$$\Theta(l,\theta) = \begin{Bmatrix} \sqrt{2} & if \quad \theta = 1 \\ 1 & otherwise \end{Bmatrix} \cdot \begin{matrix} 1.00 & l = 0 \\ 0.32 & l = 1 \\ 0.16 & l = 2 \\ 0.10 & l = 3 \end{matrix}$$

Frequency masking

- Second rule: the eye is less sensitive to noise in those areas of the image where brightness is high or low: this second term takes into account the local brightness based on the grey-level values of the low pass version of the image

- High brightness region

$$\Lambda(l,i,j) = 1 + L(l,i,j)$$

$$L(l,i,j) = \frac{1}{256} I_3^3 (1 + \frac{i}{2^{3-l}}, 1 + \frac{j}{2^{3-l}})$$

- Dark region

$$L'(l,i,j) = \begin{cases} 1 - L(l,i,j) & se \quad L(l,i,j) < 0.5 \\ L(l,i,j) & altrimenti \end{cases}$$

Frequency masking

- Third rule: the eye is less sensitive to noise in highly textured areas but, among these, more sensitive near the edges: gives a measure of texture activity in the neighborhood of the pixel.

- First contribution is the local mean square value of the DWT coefficients in all detail subbands (representing the distance from the edges), while the second is the local variance of the low-pass subband (representing the texture)

$$\begin{aligned}
&\Xi(l,i,j) \\
&= \sum_{k=0}^{3-l} \frac{1}{16^k} \sum_{\theta=0}^{2} \sum_{x=0}^{1} \sum_{y=0}^{1} \left[I_{k+l}^{\theta}\left(y + \frac{i}{2^k}, x + \frac{j}{2^k} \right) \right]^2 \\
&\cdot \operatorname{Var}\left\{ I_3^3\left(1 + y + \frac{i}{2^{3-l}}, 1 + x + \frac{j}{2^{3-l}} \right) \right\}_{\substack{x=0,1\\ y=0,1}}
\end{aligned}$$

Frequency masking

- Absolute difference bewteen original and watermarked image magnified by a factor 8

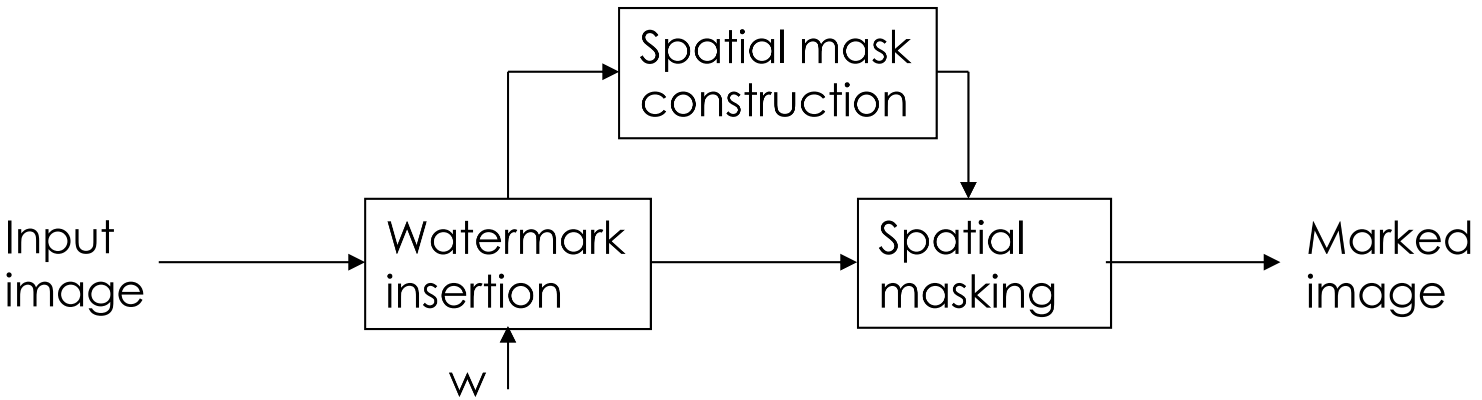
Frequency masking

- Maximum watermark strength achievable by the three visual masking methods subject to the invisibility constraint. The values reported in the table refer to the average alpha over the whole image

Image	Our method	Variance based Mask	Constant Mask
Pepper	1.68	1.38	1.64
Boat	2.10	1.15	1.81
Airplane	1.98	0.78	1.74
Lena	2.14	0.96	1.78

- This allows more robustness

Spatial masking



$$I_W = I + MW$$

M is the masking image which for each pixel gives a measure of the perceptibility of the watermark in that particular point

Spatial masking

To achieve the desired marking level, a larger energy is used

so that the target average watermark strength is obtained.

Goals

- to increase the invisibility for a given watermark energy
- to increase the watermark strength for a given level of perceptibility
- to increase robustness against the most common image processing techniques

Spatial masking

The masking characteristics of the HVS are exploited to conceal the watermark in high-activity regions

Effectiveness

Robustness is achieved through the use of a higher watermark energy and because through masking the code is hidden in regions which are less affected by common image processing techniques

Heuristic masking

- The watermark is hidden more easily in high activity regions
- Edges are more sensitive to disturb
- Dark and bright regions can bear more watermark energy than medium-gray regions

Problem

The main problem is the no differentiation between textured regions and edgy regions

➡ techniques based on multiple channel models of the HVS

Watermarking versus Compression

The duality between the problem of data hiding and that of compression consists in the fact that, while in compression technology the aim is to remove from the multimedia document all those data which are perceptually less important, in data hiding technology the goal is, on the contrary, to add to the multimedia document some data in such a way that they result to be perceptually unimportant.

Watermarking versus Compression

- Goal of compression: to subtract from images perceptually unimportant information
- Goal of watermarking: to add to images perceptually unimportant information

⇒ Compression can disturb watermarking

⇒ Watermarking can learn from compression

Watermarking versus Compression

- Compression must be very fast
- Data hiding not always have to satisfy stringent time requirements and does not require side information to be transmitted

Thus it is likely that data could be perceptually hidden inside multimedia documents more effectively than they could be removed by compression algorithms.