SEPARATING NONLINEAR IMAGE MIXTURES USING A PHYSICAL MODEL TRAINED WITH ICA

Mariana S.C. Almeida

Luís B. Almeida

Instituto de Telecomunicações IST

Lisbon, Portugal

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Mariana S.C. Almeida

Luís B. Almeida

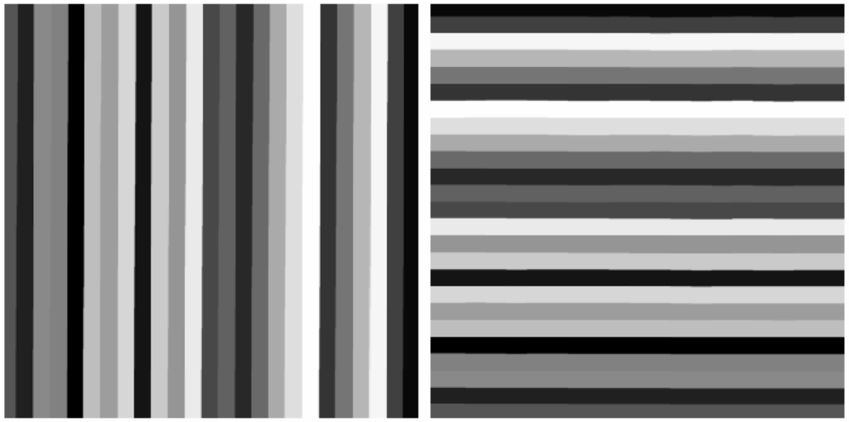
Instituto de Telecomunicações IST

Lisbon, Portugal

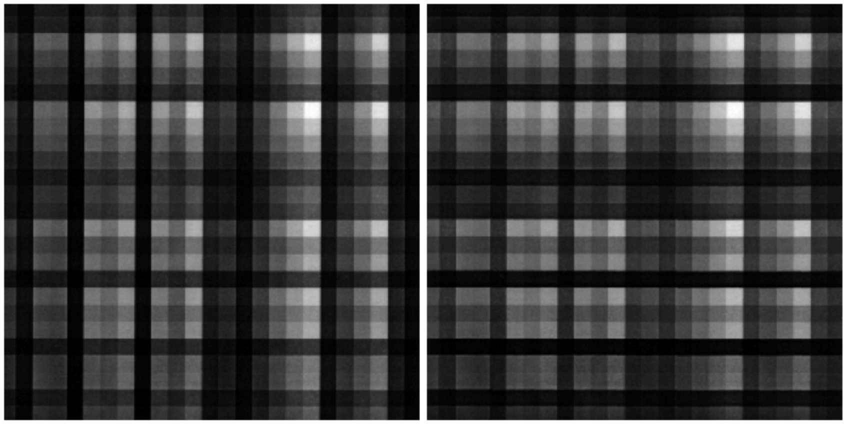
Outline

- Nonlinear mixture of images
- MISEP ICA method (brief review)
- Physical model of the mixing process
- Inverse model for separation
- Experiments and results
- Conclusions

Mixing problem



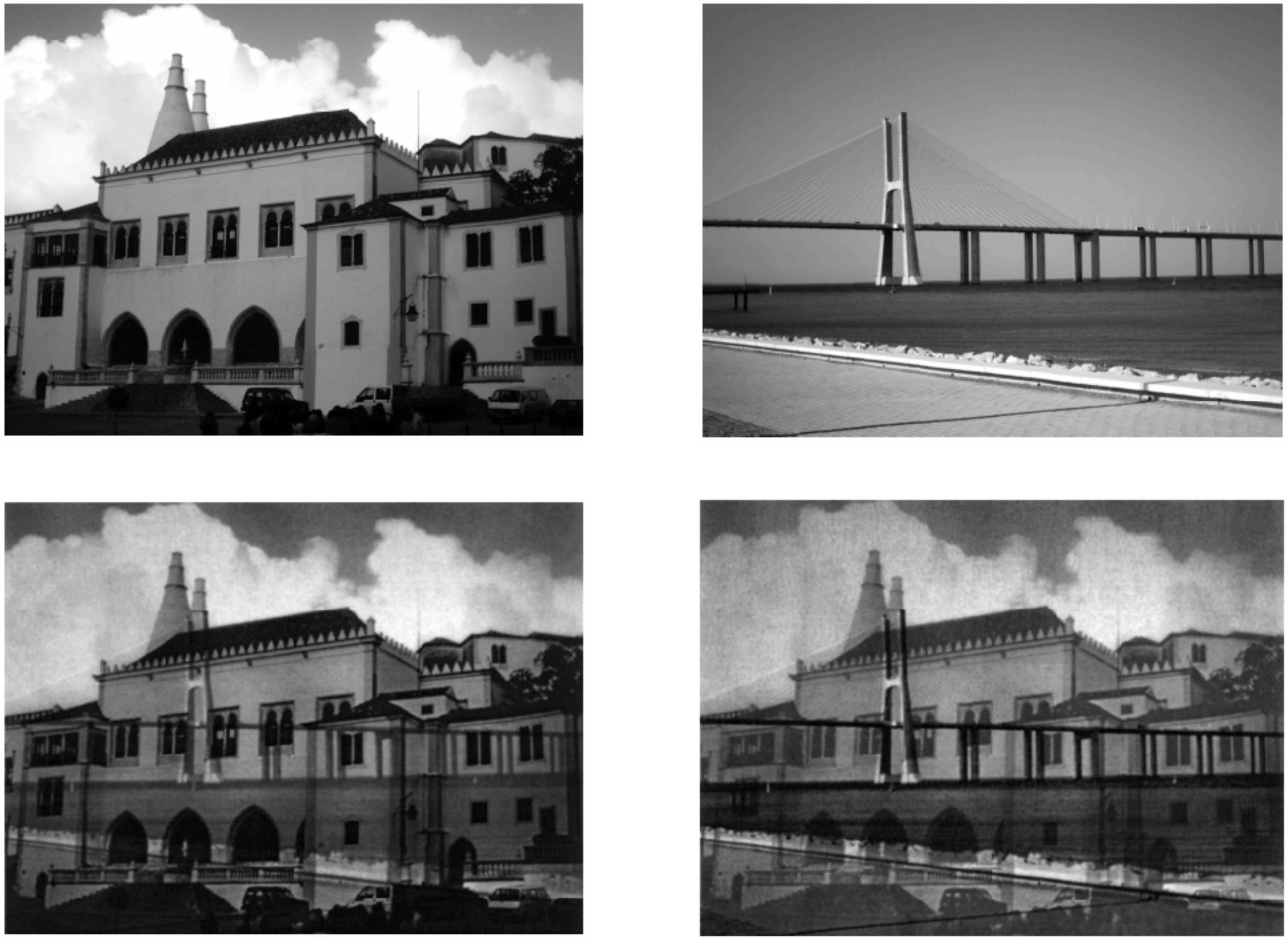
Sources



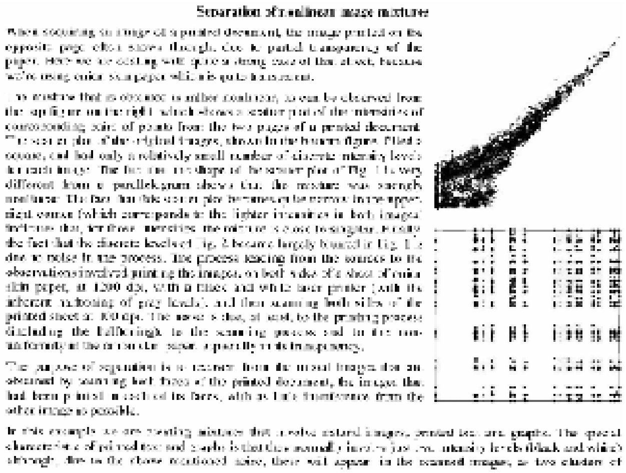
Mixtures

- Mixture of the front- and back-page images of a document when acquired with a scanner
- The mixture is nonlinear and noisy
- Five different pairs of mixtures were studied

Mixing problem



Mixing problem



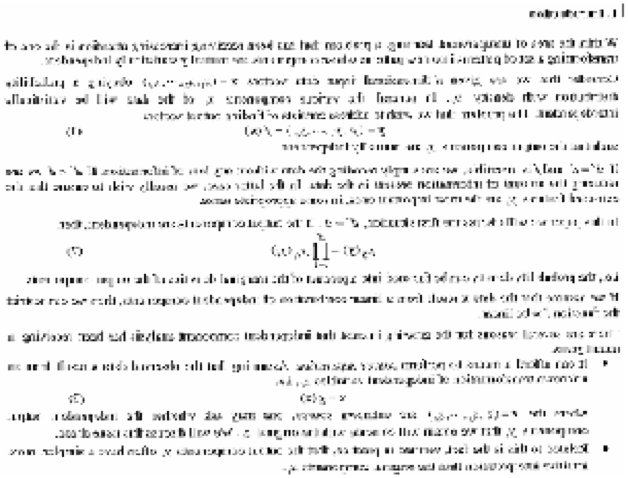
Separation of nonlinear image mixtures

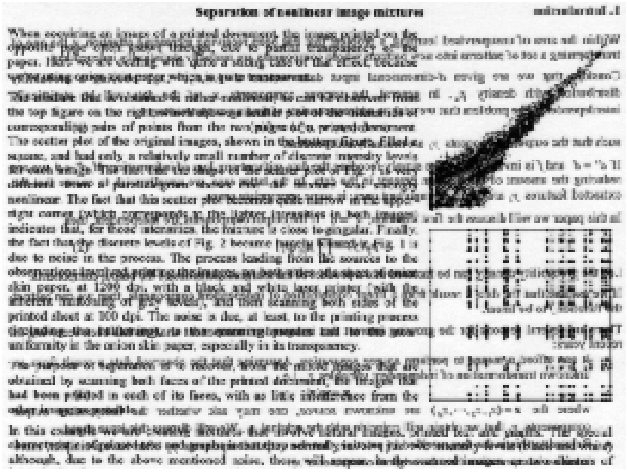
When acquiring an image of a printed document, the image printed on the opposite page often shows through, due to partial transparency of the paper. Here we are dealing with quite a strong case of that effect, because we're using onion skin paper, which is quite transparent.

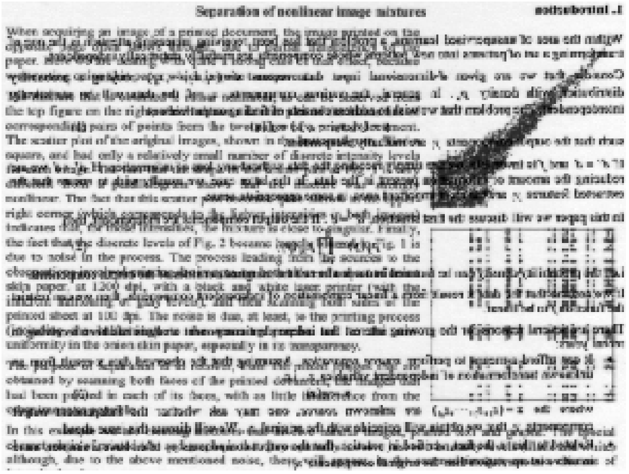
The mixture that is obtained is rather nonlinear, as can be observed from the top figure on the right (which shows a scatter plot of the intensities of corresponding pairs of points from the two pages of a printed document. The scatter plot of the original images, shown in the bottom figure, filled a square, and had only a relatively small number of discrete intensity levels for each image. The fact that the shape of the scatter plot of Fig. 1 is very different from a parallelogram shows that the mixture was strongly nonlinear. The fact that this scatter plot becomes quite narrow in the upper right corner (which corresponds to the lighter intensities in both images) indicates that, for those intensities, the mixture is close to singular. Finally, the fact that the discrete levels of Fig. 2 became largely blurred in Fig. 1 is due to noise in the process. The process leading from the sources to the observations involved printing the images on both sides of a sheet of onion skin paper, at 1200 dpi, with a black and white laser printer (with the inherent halftoning of gray levels), and then scanning both sides of the printed sheet at 100 dpi. The noise is due, at least, to the printing process (including the halftoning), to the scanning process and to the non-uniformity in the onion skin paper, especially in its transparency.

The purpose of separation is to recover, from the mixed images that are obtained by scanning both faces of the printed document, the images that had been printed in each of its faces, with as little interference from the other image as possible.

In this example we are treating mixtures that involve natural images, printed text and graphs. The special characteristic of printed text and graphs is that they normally involve just two intensity levels (black and white) although, due to the above mentioned noise, there will appear in the scanned images, as two clusters of

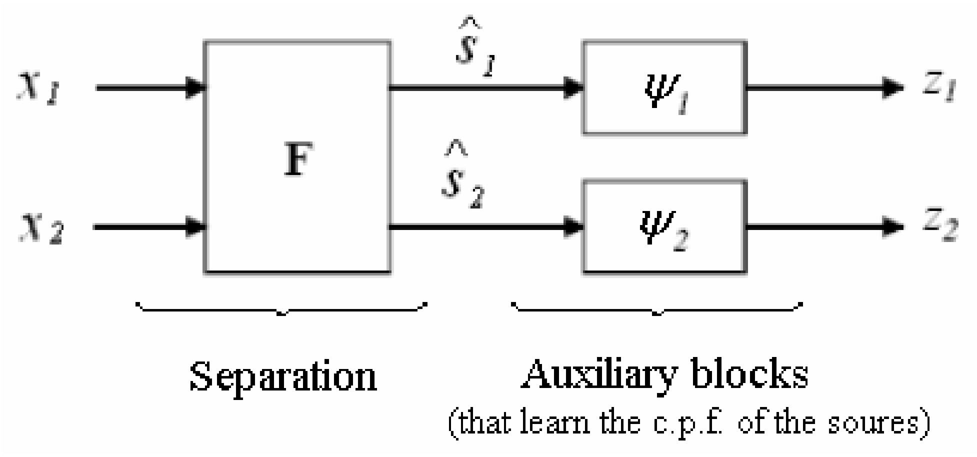






MISEP method

- Performs nonlinear ICA by minimizing mutual information



- Generalizes *Infomax* in two directions
  - □ Allows nonlinear functions in the separation block F
  - □ Adaptive output nonlinearities

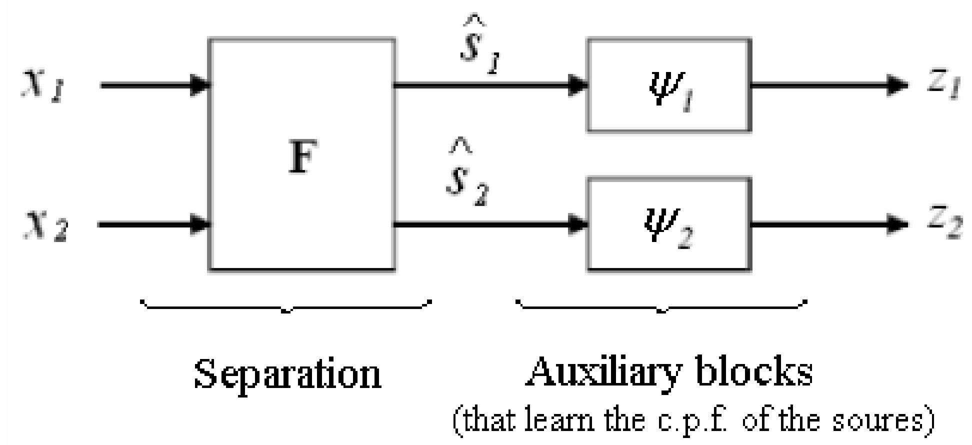
Mixing model

- Based on the *halftoning* process of the printers
  - □ The printer produces small black dots
  - □ The gray level is given by the fraction of area covered by the dots
  - □ We model the dots by a random binary variable
  - □ With suitable assumptions, a bilinear mixing model can be derived

$$\begin{cases} x_1 = \boldsymbol{\alpha} s_1 + \boldsymbol{\beta} s_2 + \boldsymbol{\gamma} s_1 s_2 + \boldsymbol{\delta} \\ x_2 = \boldsymbol{\alpha} s_2 + \boldsymbol{\beta} s_1 + \boldsymbol{\gamma} s_2 s_1 + \boldsymbol{\delta} \end{cases}$$

s_i - *sources* $\quad$ x_i - *mixtures*

Inverse (separation) model

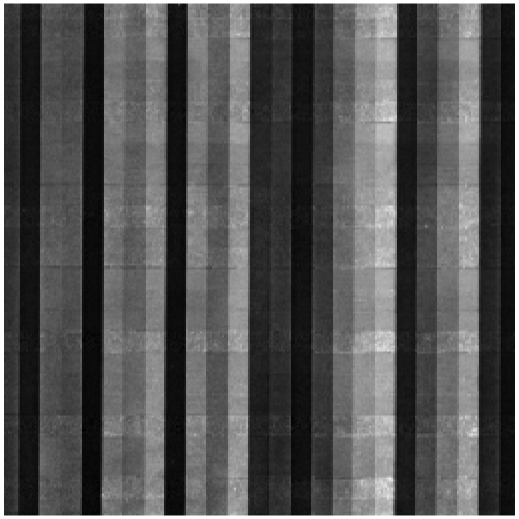


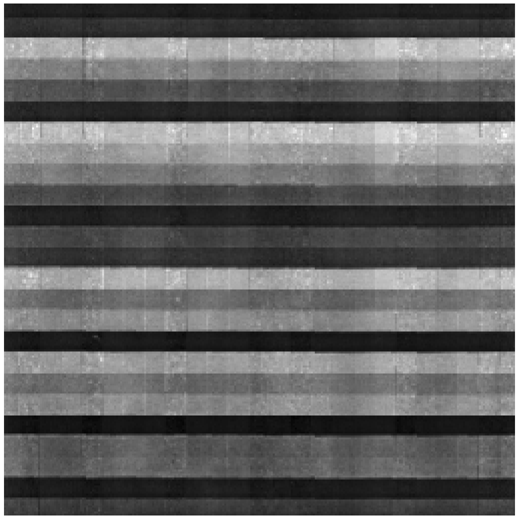
- F implements the inverse of the physical mixture model
- This inverse can be found algebraically
- Equations not shown here due to complexity
- This inverse has the same four parameters as the physical mixture model
- These four parameters are what needs to be estimated by the MISEP method

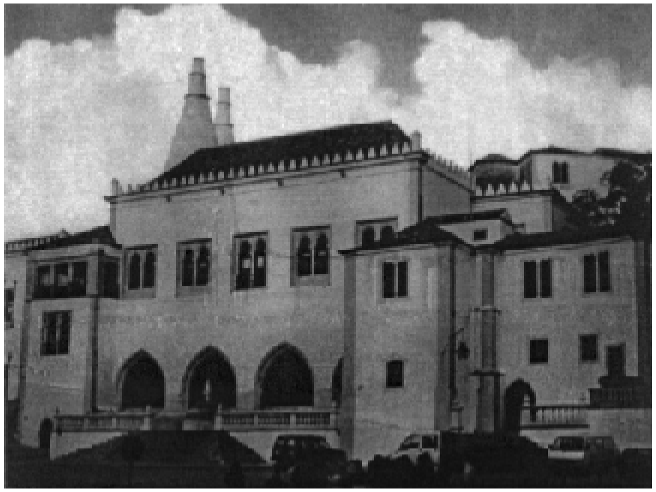
Experiments

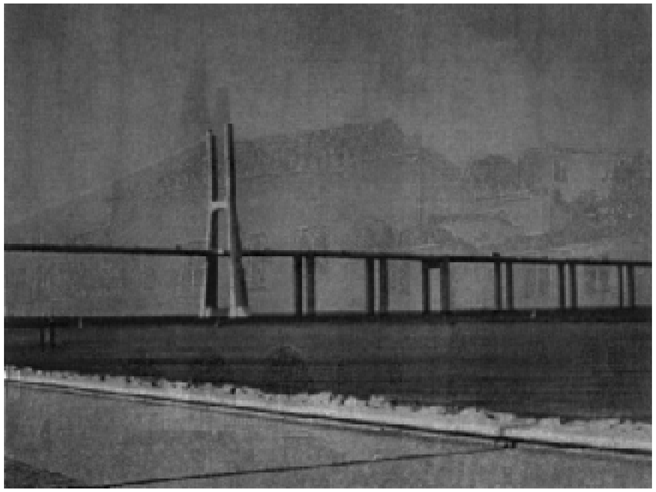
- The **F** Block was initialized near the identity function
- Auxiliary blocks were MLPs with 10 hidden units each
- MISEP was applied to each pair of mixtures during 1000 epochs.
  - A separation model was trained for each pair of mixtures
  - Training set: 1000 pairs of pixels, randomly selected

Results (1)

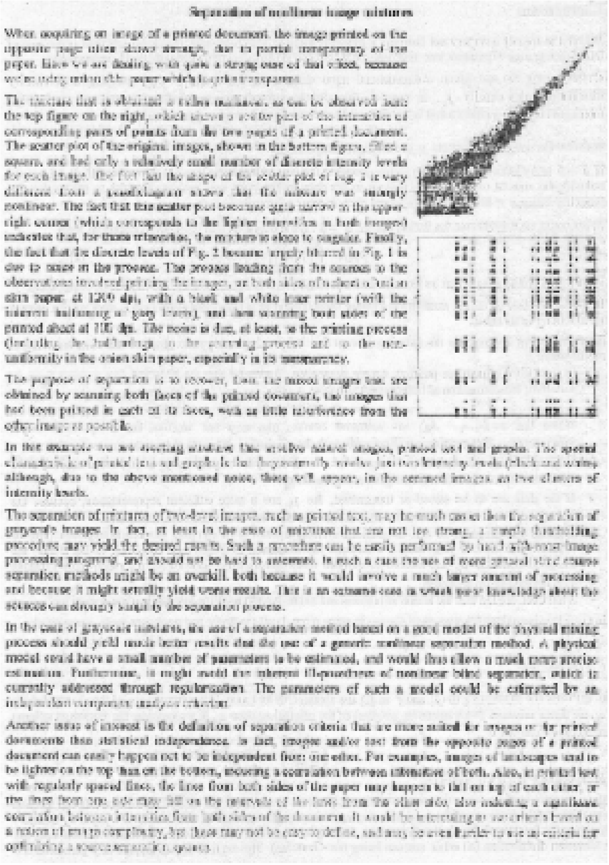


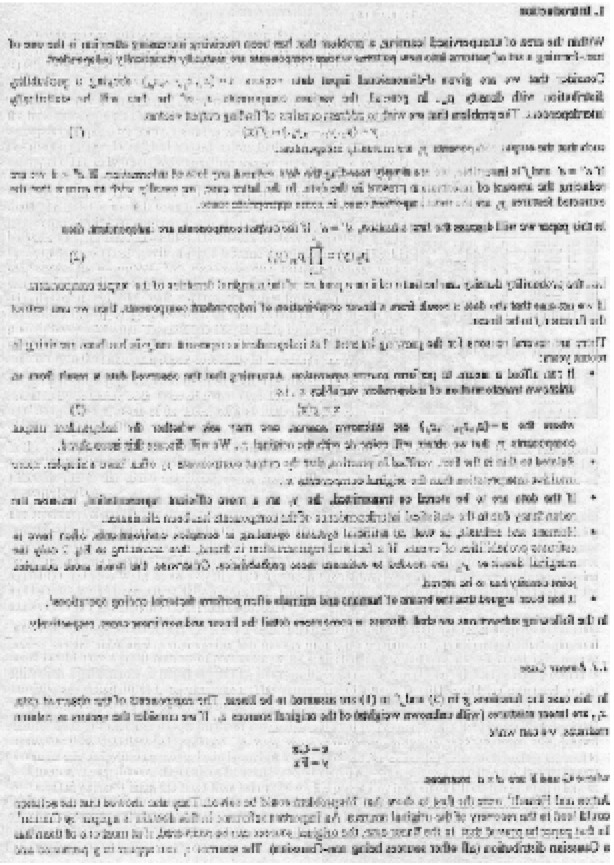






Results (2)

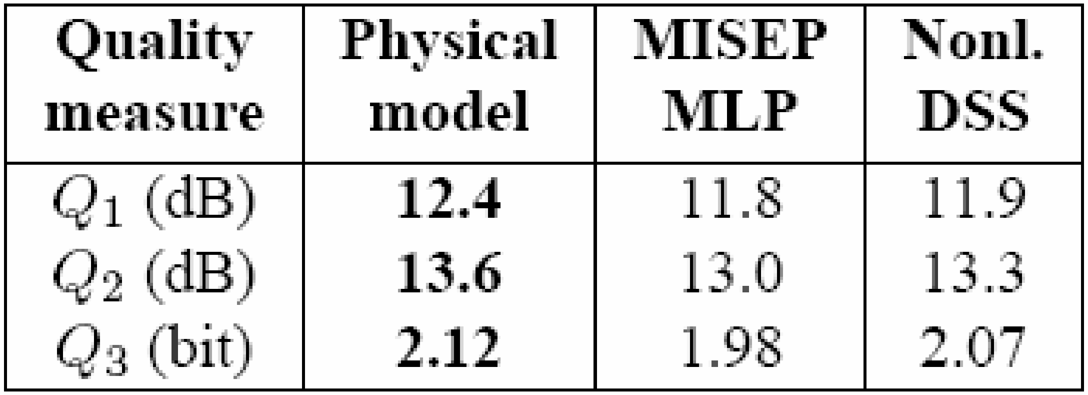




Objective quality measures

- Three quality measures were computed
  - Q1 – SNR between extracted and original source
  - Q2 – Same as Q1, but compensated for possible nonlinear intensity distortion
  - Q3 – Mutual information between extracted and original source

Results



Quality measure	Physical model	MISEP MLP	Nonl. DSS
Q_1 (dB)	**12.4**	11.8	11.9
Q_2 (dB)	**13.6**	13.0	13.3
Q_3 (bit)	**2.12**	1.98	2.07

MISEP MLP – MISEP using an MLP in the separation block (L.Almeida JMLR 2005)

Nonl. DSS – Nonlinear Denoising Source Separation (M.S.C Almeida ICA 2006)

Conclusions

- A physical model for the mixing process of scanned images was presented
- The inverse model was trained using MISEP (ICA)
- The separation quality is better than those obtained with previous methods for the same data (according to objective quality measures)
- The physical model fits the mixture process well
- MISEP is appropriate for estimating the model parameters