Where monoscopic images (e.g. blocks of text) are reproduced on stereoscopic displays, the resolution can be increased for the viewer as follows:

it is necessary to start with an image with double the quantity of lines and columns as that of the stereo displays. Offset sub-rasters are derived from this and output on the displays for the left and right eye. Inter-pixel information is produced in this way, which is combined in the brain to form a higher resolution than that of an individual display. This fusion is effected by means of disparity compensation in the visual cortex. This image combination corresponds to a super-resolution with two images, as a result of which image sharpness improves and image noise is reduced. Moreover, further raster separations are presented with which horizontal or vertical image structures are preferentially emphasized or displayed with greater sharpness, for example for overlaying lettering.

2. CONSTRUCTING THE SUB-RASTERS

It is necessary to use a stereoscopic display consisting of at least two sub-displays of the respective resolution \(nxm\) pixels. The monoscopic original image \(P\) must possess at least double the quantity of lines and columns as that of the sub-displays. If \(P\) displays more than double the quantity of lines and columns, it has to be scaled to the desired size. Two checkerboard-like sub-rasters with the resolution (quantity of pixels) of the stereo screens in each case are then extracted from the original image \(P\) of \(2nxm\) pixels (see Figs. 1 and 2).

Definition:
This separation is referred to as the “Diagonal separation”. Let \(P = \{p_{i,k}\}, i = 1,...,n; k = 1,...,m\). Then the sub-rasters \(A\) and \(B\) are selected:

\[
A = \{p_{2i,2k}; i = 1,...,n; k = 1,...,m\}
B = \{p_{2i+1,2k+1}; i = 1,...,n; k = 1,...,m\}
\]

For displays with more than 2 views (autostereoscopic displays, e.g. lenticular lens displays), it is necessary to select the sub-raster separation alternately for the successive views. The views are usually determined in such a way that two adjacent ones are captured by the eyes of the viewer.
3. BAND-LIMITING OF THE HIGH-RESOLUTION IMAGE PRIOR TO THE RASTER SEPARATION

A suitable low-pass filtering stage is required prior to the separation into sub-rasters in order to avoid Moiré patterns. Prior to the conversion from the overall raster $P$ to the checkerboard sub-raster $A \cup B$, the following passband limiting has to be carried out: the band-limiting should not be matched to the individual rasters $A$ and $B$, since in this case the frequency response is cut off unnecessarily severely, but to the raster $A \cup B$ instead, as this is the raster which is put together in the visual cortex.

A suitable 2-dim band-limiting filter is constructed as follows. It is necessary to select a 1-dim low-pass filter with a coefficient number $n$, which halves the frequency response. In this respect, $n$ should be as large as possible for the purposes of precise passband-limiting, and is only restricted by computing time requirements. However, a two-dimensional separable filter should not be used for super-resolution on stereo displays. In its place, a cross-shaped filter has to be constructed from the one-dimensional low-pass filter mask by means of superimposition of the horizontal and the vertical filter masks (see Figs. 3 and 4). This allows through double the width of frequency spectrum in the diagonal directions and therefore greater image sharpness (see comparisons in Fig. 5-8). Suitable super-resolution techniques are described in [5]-[10].

4. ALTERNATIVE RASTER SEPARATION

There are some images in which horizontal or vertical structures appear preferentially. In the case of overlaid narrow lettering (proportional lettering), it is critical to present the vertical edges in high resolution in order to divide the letters clearly from each other.

The following sub-raster separation is proposed for this case (Fig. 4 and Fig. 5):

$$A = \{p_{2i,2k}\} \quad B = \{p_{2i+1,2k}\}; \quad i = 1, \ldots, n; \quad k = 1, \ldots, m$$

Here, the sub-rasters are displaced horizontally with respect to each other. The corresponding passband filtering is produced from the resultant raster $A \cup B$ as follows: in this case, only one filter with a vertical filter mask is required. A 1-dim band-limiting filter (low-pass), which halves the spectrum, is sufficient in this respect (Figs. 3 and 4). The horizontal direction remains unfiltered, since the original resolution is in any case given by the pixel density in the line direction.

Fig. 2.: Fusion of the two sub-rasters in the visual cortex to form one image with double the quantity of pixels.

Fig. 3.: Simple examples of band-limiting filters. Top: Separable filter. Center and bottom: Non-separable filters, as used for super-resolution. The sum of the coefficients has to be normalized to 1.

Fig. 4.: 2-dim frequency responses of the low-pass filters. The fine line corresponds to a separable filter, the heavy line to a non-separable filter. Left: Diagonal separation; Right: Horizontal separation. In all cases, the non-separable filter produces a broader frequency response.
Definition: This separation is referred to as the “Horizontal separation.”

In order to reproduce horizontal lines in high-resolution, it is necessary to proceed in a similar manner with a raster and filter arrangement rotated by 90° and obtain the “Vertical separation.”

A further enhancement of the image quality is possible if areas with differing direction of preference are differentiated within the image. To do this, the original image is subdivided into regions, e.g. rectangular blocks. Which of the 3 possible raster breakdowns has to be preferred is decided independently in each block. The raster scheme is then adapted locally to the image structures. Criteria comprise horizontal or vertical image structures, which are determined by means of edge detectors. In the area of overlaid narrow lettering, the horizontal separation has to be given preference.

5. CONCLUSION

The method presented utilizes the information of the two imaging displays - provided for the left and the right eye - for the purposes of enhancing the pixel resolution. It can be applied to any desired stereo systems and is suitable, for example, for overlaying lettering or computer graphics in mono or stereo images. The results show greater image sharpness than in the case of conventional reproduction (Figs. 6 – 8).

6. REFERENCES

Fig. 6.: Increased resolution of a test image generated by diagonal separation. The letters are recognizable to different degrees in the two sub-images and are put together to form legible text on stereo displays.

Fig. 7.: Increased image resolution of a monoscopic pair of images generated by diagonal separation.
Fig. 8.: Magnified extract from Fig. 7. The noise structures and filter artifacts (ringing) are different in the two images and average out on stereo displays, as a result of which the image quality increases compared to the individual image.