Automated Gain Control for Temporally Recursive Detail Reconstruction with Variable Video Input Sharpness

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Abstract

Modern video signal processing systems need to be highly adaptive in their processing configuration due to the broad range of input signal quality levels. In many cases the input quality is not known. In this paper, we report on our research on adaptivity to the sharpness level of the video content. Based on our work on temporally recursive detail reconstruction, which we presented in [1], we developed a system to measure the sharpness level in the input signal and for subsequent automatic gain control. Further we measure the current level of image enhancement and stabilizes it over time, approximating a predefined target enhancement level. Our proposed system helps to avoid over-enhancement of high quality input signals while adjusting the gain for low quality input signals in order to achieve an adequately enhanced output signal.

1. Introduction

Video signal processing systems for image enhancement have to be well configured to generate output signals with a pleasant quality. This configuration is typically adjusted to a certain type of input quality. In case of different input qualities the configuration has to be manually adjusted to realize an acceptable output quality. In [1] we presented a temporally recursive detail reconstruction system to generate an output signal with a perceived higher detail level and increased sharpness by accumulating high frequency information from multiple input frames. The gain of the computed detail signal inside this system mainly defines the level of image enhancement and has to be manually adjusted to the input signal quality or sharpness. On the one hand over-sharpening in case of high detail input has to be avoided and on the other hand a sufficient enhancement must be realized in case of low quality input. With a predefined detail gain it is not possible to reach both goals at the same time. Hence, either the viewer has to setup the detail gain depending on the current input signal quality and change the configuration when having a different input quality, or a compromise has to be found, yielding a suboptimal output quality for most input signals. In best case the image enhancement setup should be adopted to the input quality, so that the final enhancement level is similar for all kinds of input quality. Furthermore, using temporally recursive detail reconstruction, the image enhancement level can vary from frame to frame within the same sequence, as additional details are generated and added to the last result. Thus realizing a stable enhancement level over time is a further goal for an automated setup of temporally recursive processing.

Previous work on automated control of image enhancement methods focuses on analyzing the sharpness in the input sequence and using this measure for automated control of the image enhancement system setup. Common approaches for sharpness level estimation compute the average edge spread (e.g. [2] and [3]) or analyze the sharpness in the spectral domain (e.g., [4] and [5]). Others estimate the sharpness in the spatial domain without initial search for edge positions (e.g. [6] and [7]). Also methods combining spectral and spatial approaches are available for sharpness level estimation [8]. There are only few methods measuring the output enhancement level and adjust the processing depending on the computed measure. In [9] a method for combined noise reduction and sharpness enhancement is presented that measures the output quality and carries out a second enhancement processing with adjusted parameters depending on the computed quality.

The contribution of this paper is to present a method for automated gain control for temporally recursive detail reconstruction as presented in [1]. The proposed system on the one hand relies on an estimated input sharpness level and on the other hand measures the enhancement level of the detail reconstruction output in comparison to the current input. Thus, a target enhancement level can be approximated in a final weighting of the difference between input and detail reconstruction output. Furthermore the final enhancement level is stabilized over time using the differences between target and actual enhancement level of previous frames. A further contribution is the introduction of two methods for sharpness level estimation and the analysis of their behavior for several input blur levels. The output behavior of the final system is analyzed and compared to the basic system from [1] with a predefined detail gain.

The rest of the paper is organized as follows: In section 2 a basic system for temporally recursive detail reconstruction as presented in [1] is described and the problem of changing output behavior for varying input quality levels is outlined. Our proposed method for automated gain control for this system is described in detail in section 3. In section 4 results for the integrated sharpness estimation methods are depicted and output results with activated automated gain control are compared to output results of the basic system with a static gain level. We conclude with section 5.

2. Temporally Recursive Detail Reconstruction

2.1. Basic System

In [1] we presented a system for temporally recursive robust detail reconstruction from 2D and S3D video sequences. An initial upscaling is assumed to be carried out in a previous processing step, so that input and output signal have the same size. The basic system for reconstruction from 2D sequences is depicted in Fig.1. To accumulate the details from multiple input frames, the previous result Z, containing the already computed details from preceding frames, is motion compensated and fed back to the input. For robustness reasons the motion compensation result is mixed with the input signal depending on the local reliability of the motion compensation. The high pass information (details) of the current input signal X is extracted by comparing X and mixing output W. This detail signal Y is multiplied with a detail gain factor and added to W, generating the output signal Z. This signal contains details from the current and previous frames of the input sequence. In case of S3D input (not depicted here) details from multiple frames of left and right views can be accumulated in a temporally recursive manner. For further details please refer to [1].

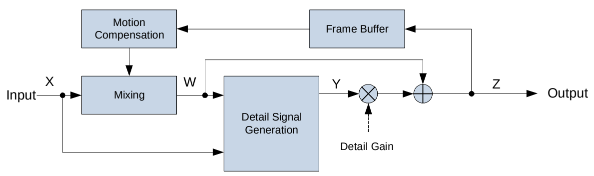


Figure 1 Basic system for temporally recursive detail reconstruction

2.2. Output Behavior at Variable Input Sharpness

The described system generates an output signal with additional details and a higher sharpness level. This is achieved by accumulating high pass information of multiple input frames. The amplitudes of these detail signals strongly depend on input quality and sharpness level. For high sharpness input signals the detail signal has a higher amplitude due to the large amount of high frequency information. In contrast to this, for low sharpness input signals a detail signal with a low amplitude is generated due to the missing high frequency information. The level of enhancement, which will be defined in section 3.4 of this paper, can be controlled by adjusting the detail gain. With the same detail gain strongly varying output enhancement levels are achieved for input signals with different sharpness levels. This effect is depicted in Fig. 2. The detail gain was adjusted for generating moderately enhanced output signals for upscaled SD content. For these input signals enhancement levels between 1,25 and 1,4 are reached. Using upscaling methods generating synthetic transitions (DRC), slightly higher enhancement levels are achieved with the same detail gain in comparison to High Resolution Spline upscaling (HRS). When using the same detail gain in case of HD input signals, a much higher enhancement level of 1,5 - 2,0 is reached for the output signal, depending on input characteristics and sharpness level. The output signals look "over-sharpened" or "over-enhanced". In contrast to this, when adjusting the detail gain to reach moderate enhancement of HD content, input signals with a lower sharpness level will not be sufficiently enhanced when using the same detail gain. Hence, it is necessary to adjust the detail gain for each input sharpness or quality to generate output signals of a desired enhancement level. For reasonably handling input signals with variable quality and sharpness levels it is necessary to extend the system by an automated gain control. For each level of input quality a desired enhancement level should be reached for the output signal.

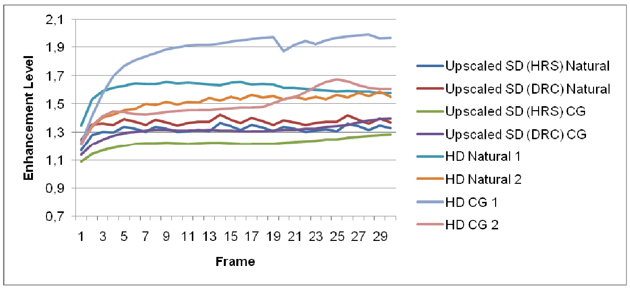


Figure 2 Enhancement Level for Upscaled SD and HD Input Signals, Detail Gain = 0,5

3. Automated Gain Control

In this section a system for automated gain control is presented, providing a method for gaining a desired enhancement level for variable input sharpness and quality levels.

3.1. Proposed System

In Fig. 3 the proposed system for temporally recursive detail reconstruction with automated gain control is depicted. The additional processing blocks are depicted in yellow. Parallel to computing a detail signal Y as described in section 2 the input sharpness level is estimated. Based on this, the detail gain is computed, resulting in a high detail gain for low sharpness levels and a low detail gain for high sharpness levels. This detail gain is the same for the whole signal. The detail signal Y is multiplied by the computed detail gain and added to the mixing output W, generating a signal U containing additional details. Then the enhancement level up to this processing step is computed by comparing the local contrasts of U and current input X in discriminated areas of a defined local contrast range as described in section 3.4. To be able to finally

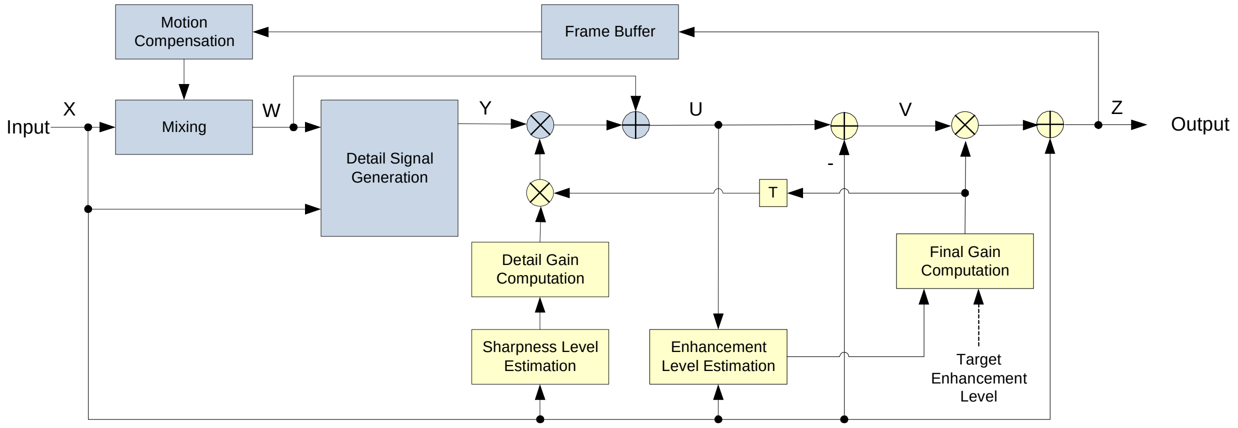


Figure 3 Proposed system: Temporally Recursive Detail Reconstruction with Automated Gain Control

control the enhancement level, a difference signal between U and X is computed, which shall be weighted by a final gain factor and added to the current input. To compute this final gain the current enhancement level is compared to a target enhancement level. A final gain smaller than 1 is chosen, if the current enhancement level exceeds the target enhancement level. Otherwise a final gain higher than one is chosen to increase the final enhancement level. To achieve a temporal stabilization of the final enhancement level, also the previous enhancement level differences are regarded for computing the final gain. The computed final gain is further stored and multiplied with the detail gain when processing the next frame. Thus, the initial detail signal weighting is adjusted to the resulting final gains of the previous frames to achieve a detail signal which results in a better approximation of the target enhancement level. In the following, the different blocks of the proposed system will be described in detail.

3.2. Sharpness Level Estimation

The sharpness level of the current input image is estimated by analyzing the average edge steepness. Two different methods are proposed for this purpose. The first method filters the input image with 3 Gaussian low-pass filters of different standard deviations. Depending on the minimum description length criterion the optimal filter standard deviation is computed for each pixel. The mean optimal filter standard deviation inside the selected edge areas describes the input signal sharpness. The second method computes the mean ratio between maximum gradient and local contrast inside selected edge areas. As depicted in Fig. 4, this ratio is higher for sharp edges than for blurred edges. Hence, it describes the input sharpness level as well.

3.2.1. Edge Area Selection

The two proposed methods for input sharpness level estimation both compute a mean edge sharpness value in selected edge areas. Hence, in a first step this area has to be detected. Edge areas are described by large luminance gradients. The gradients in x- and y direction are approximated using central differences.

$$X_x(x,y) \approx 0.5\big(X(x+1,y)-X(x-1,y)\big)$$
$$X_y(x,y) \approx 0.5\big(X(x,y+1)-X(x,y-1)\big) \quad (1)$$

From these values the absolute gradient is computed using

$$\left|(X_x, X_y)\right| = \sqrt{X_x^2 + X_y^2} \quad (2)$$

The final edge area is selected by a simple threshold decision. If the absolute gradient at a certain image position (x,y) exceeds a threshold thr_{grad}, the image position (x,y) is

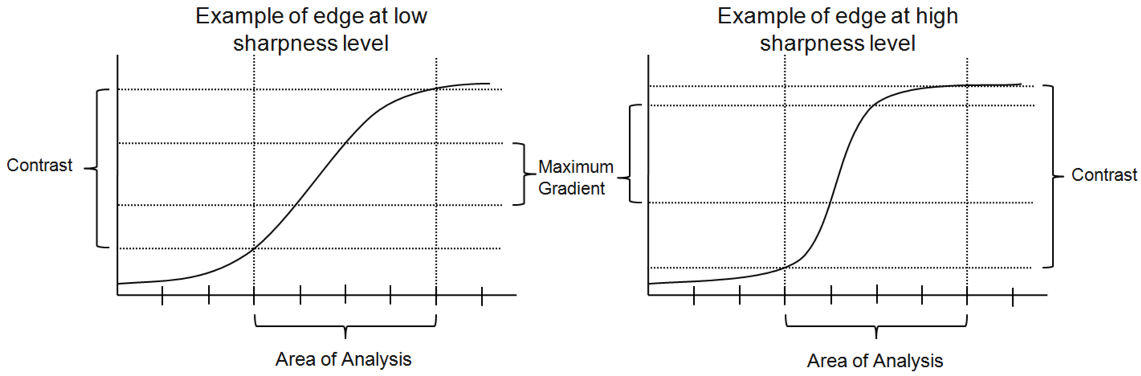


Figure 4 Contrast and Maximum Local Gradient for Edges of High and Low Sharpness Levels

defined to be an edge area. For different input sharpness levels, different thresholds have to be chosen, as edges in low sharpness input images are described by smaller gradients than in high sharpness images. Therefore, thr_{grad} is selected depending on the maximum gradient in the input image. We propose to set thr_{grad} to half of the maximum gradient.

3.2.2. Mean Optimal Local Filter Variance

The first method for sharpness level estimation computes the mean optimal variance for Gaussian filtering inside the detected edge area. This measure indicates the sharpness of an edge, as for steep edges a smaller optimal standard deviation is detected than for blurred edges. The optimal variance for Gaussian filtering is computed based on the minimum description length criterion as described in [7]. The input signal X is separately filtered using three different Gaussian filter kernels of variance σ_1^2 - σ_3^2, generating three Low-Pass filter results $X_{\sigma 1}$- $X_{\sigma 3}$. For each pixel inside the selected edge area the mean differences between current input X and the filter results $X_{\sigma n}$ are computed inside a local IxJ block area centered at (x,y).

$$\varepsilon_{\sigma_n}(x,y) = \frac{1}{I \cdot J}\sum_i \sum_j \left| X(x+i,y+j) - X_{\sigma_n}(x+i,y+j) \right| \quad (3)$$

For each filtered image then the local description length is computed using the following equation.

$$dl_{\sigma_n}(x,y) = \left(\frac{\lambda}{\sigma_n^2}\right) + \varepsilon_{\sigma_n}(x,y) \quad (4)$$

For each pixel (x,y) inside the selected edge area three description length values are computed and compared. The filter variance σ_n^2 inducing the minimum description length value is assumed to be the optimal variance for Gaussian filtering at position (x,y). Finally the mean optimal variance $\bar{\sigma}$ inside the selected edge area is computed. Typically ranged between $\square_{min}$ and $\square_{max}$ it is mapped to a range between 0 (low sharpness) and 1 (high sharpness).

$$sharpnessLevel = \begin{cases} 0, & \text{if } \bar{\sigma} > \sigma_{max} \\ 1, & \text{if } \bar{\sigma} < \sigma_{min} \\ 1 - \dfrac{\bar{\sigma} - \sigma_{min}}{\sigma_{max} - \sigma_{min}}, & \text{else} \end{cases} \quad (5)$$

3.2.3. Mean Gradient / Contrast Rate

The second method for sharpness estimation computes the mean rate between maximum local gradient and local contrast inside the selected edge area. For each pixel (x,y) located inside the selected edge area a local IxJ block area centered at (x,y) is selected. Typical values for I and J are 3-7. Inside this area the maximum absolute gradient and the difference between maximum and minimum luminance value are detected. The ratio ϑ between these values describes the edge sharpness, as depicted in Fig. 4.

$$\vartheta = \frac{\max\left(\left|\left(X_x(x+i,y+j), X_y(x+i,y+j)\right)\right|\right)}{\max\left(X(x+i,y+j)\right) - \min\left(X(x+i,y+j)\right)}, i \in I, j \in J \quad (6)$$

The mean ratio inside the selected edge area describes the input sharpness level and is typically in a range between $\square_{min}$ and $\square_{max}$. Thus, this value is mapped to the range between 0 and 1, having the same meaning as the sharpness level based on the optimal local filter variance.

$$sharpnessLevel = \begin{cases} 0, & \text{if } \bar{\vartheta} < \vartheta_{min} \\ 1, & \text{if } \bar{\vartheta} > \vartheta_{max} \\ \dfrac{\bar{\vartheta} - \vartheta_{min}}{\vartheta_{max} - \vartheta_{min}}, & \text{else} \end{cases} \quad (7)$$

One of the mentioned methods is used for sharpness estimation inside the proposed system. The gradient / contrast rate based method has the lower computational complexity, as after discriminating the edge area only the maximum local gradient and the contrast have to be computed inside a local area. The gradient and contrast information are also needed for edge area selection and enhancement level estimation respectively. Thus, evaluating a local block area and computing the mean of the ratios over the discriminated edge area is the only additional effort for this method. In contrast to this, the effort for the optimal local filter variance based method is higher. The input signal has to be filtered with three different blur kernels and each filter result has to be compared to the input within a local area. The resulting sharpness levels of the two methods are compared for an input signal with several blur levels in section 4.1.

3.3. Detail Gain Computation

The detail gain is computed depending on the estimated sharpness level and the final gain of the previous frame processing.

$$detailGain = \left(\frac{3\rho}{2} - sharpnessLevel \cdot \rho\right) \cdot finalGain_{t-1} \quad (8)$$

In our system the basic detail gain ρ is set to 0.6. For low sharpness levels the detail gain gets a high value while for high sharpness levels it gets a low value. Furthermore, the detail gain is amplified in case the final gain of the previous frame processing was higher than 1 and reduced in case the final gain was lower than 1. This results in an adjusted approximation of the target enhancement level in comparison to the previous frame processing already in this processing step.

3.4. Enhancement Level Estimation

For estimating the enhancement level the local contrasts of the enhanced image U and the current input X are compared. A ratio ξ of the contrasts is computed for each pixel

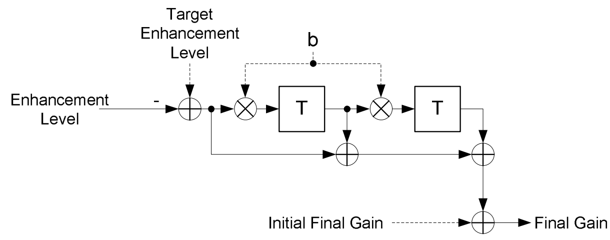


Figure 5 Final Gain Computation

(x,y) inside a local IxJ block area which is centered at (x,y).

$$\xi = \frac{\max\left(U(x+i,y+j)\right)-\min\left(U(x+i,y+j)\right)}{\max\left(X(x+i,y+j)\right)-\min\left(X(x+i,y+j)\right)}, i \in I, j \in J \quad (9)$$

Furthermore an area is discriminated in which the local contrast of X has a value inside a defined contrast range. This area shall exclude steep edge areas and homogeneous regions. In our system the area of local contrasts between 10 and 50 (for a maximum luminance value of 255) is discriminated.. Inside this area the mean of the contrast ratios is computed and defined as enhancement level.

3.5. Final Gain Computation

The computation of the final gain, weighting the difference signal V between current input X and enhancement result U, is depicted in Fig. 5. The final gain shall be reduced in case the target enhancement level is lower than the computed enhancement level and amplified if the target enhancement level is higher than the current enhancement level. The goal is to approximate the target enhancement level in the final output signal Z. To realize this, the computed enhancement level is subtracted from the target enhancement level and this difference is added to a predefined initial final gain (1 in our system). For stabilizing the final enhancement level over time also the differences between target enhancement level and current enhancement level of previous frames are analyzed for final gain computation. The difference computed in t-1 is weighted with b and the difference computed in t-2 is weighted with b^2. In our simulations we set b to 0.7.

4. Results

4.1. Sharpness Level Estimation

For analyzing the results of the two different sharpness estimation methods, a computer generated HD input sequence was filtered with several Gaussian low-pass filters of different standard deviations between 0.1 and 2.5. The resulting sharpness levels are depicted in Fig. 6.

For filter standard deviations between 0.5 and 1.4 the method based on the mean local filter variance estimation tends to a linear output behavior as indicated with the dashed line. For these types of input sharpness the estimated sharpness level is a good indicator for the actual

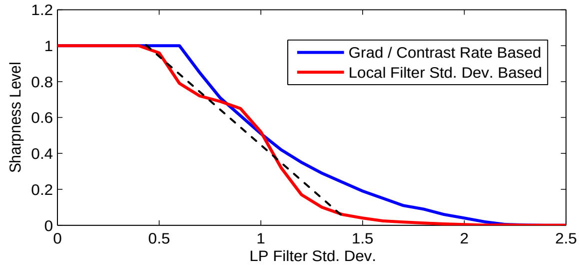


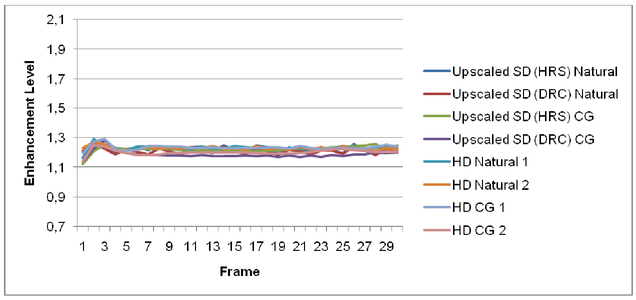
Figure 6 Sharpness Levels for Gaussian Low Pass Filter Results

input sharpness. Input images which are blurred stronger are detected as blurred but no further sharpness differentiation is possible.

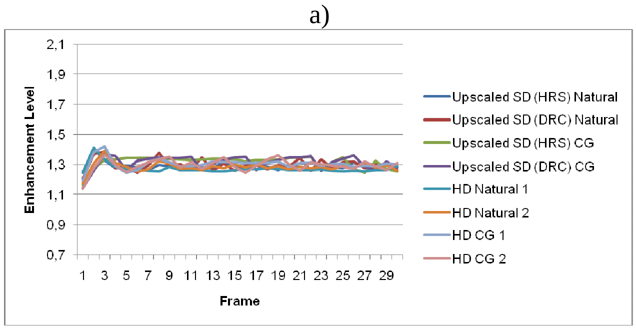
The results of the gradient / contrast ratio based approach show a hyperbolic behavior for low-pass filter results with standard deviations between 0.6 and 2.3. For such sharpness levels it can be well used as basic information for setting the detail gain.

4.2. Output Behavior

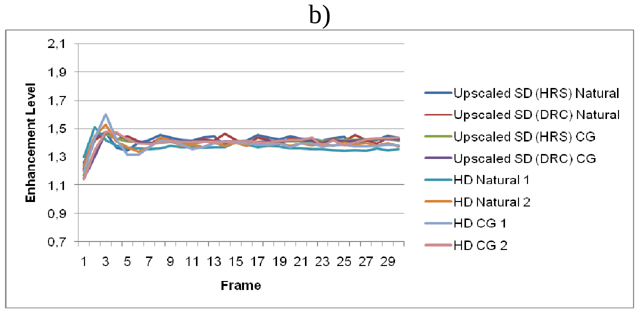
Realizing the same predefined target enhancement level for typical kinds of input quality is the goal of the pro-



a)



b)



c)

Figure 7 Final Enhancement Levels for Upscaled SD and HD Input Signals. a) Target Enhancement Level = 1,2. b) Target Enhancement Level = 1,3. c) Target Enhancement Level = 1,4.

posed method for automated gain control. Hence, for analyzing the output behavior, the enhancement level as described in section 3.4 is measured for the output signal Z in comparison to the current input X. For comparison, the same input sequences that were already used for analyzing the basic system output behavior in section 2.2 were processed. Three different reasonable target enhancement levels of 1.2, 1.3 and 1.4 should be realized with the automated gain control. The resulting enhancement gain for each input signal is plotted in Fig. 7. As becomes visible in comparison to Fig. 2, for each input sequence the target enhancement rates are approximated with only weak outliers of +/- 0.06 at maximum. This shows that with the proposed system it is possible to realize a well defined enhancement level for typical input qualities and sharpness levels.

5. Conclusion

In this paper a method for automated gain control for temporally recursive detail reconstruction with variable video input sharpness was presented. We showed that using the same detail signal gain for different types of input signal quality results in strongly varying output enhancement levels using the system presented in [1]. This results in either over-enhancement of high detail inputs or only weak enhancement of low quality inputs. With the proposed system the enhancement levels for all types of typical input signals can be adjusted to a target enhancement level within a reasonable range. This enhancement level can be defined by the user, so that it is possible to achieve a well defined processing gain for all typical types of input signal quality without further quality dependent manual adjustment.

6. References

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