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Blue Sky Detection for Content-based Television Picture Quality Enhancement

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Abstract—Using high-resolution flat panel displays for TV systems, the visibility of signal impairments has grown. As a solution, content-based image processing can be used for obtaining higher levels of picture-quality improvement, thereby outperforming traditional TV image-enhancement methods. This paper presents a new algorithm and feature model for blue sky detection, which enables content-adaptive enhancement of TV video sequences. The algorithm analyzes the image, creates adaptive position and color models, and classifies the sky areas of the image using a pixel-accurate soft segmentation. Such a probabilistic measure matches well with the requirements of typical video enhancement functions in TVs. We have evaluated the proposal for typical and critical natural scenes, and obtained a clear improvement over state-of-the-art techniques.

I. INTRODUCTION

Currently, the parameter settings of TV image processing algorithms are often globally constant or adapted to some simple local pictorial features. This leads to a sub-optimal picture quality, as compared to a system that locally adapts the processing to the content of the image. Such content adaptation can be enabled if video objects of interest are detected, and image areas belonging to each object are segmented [1].

Sky is an example of visually important objects. The smooth appearance of sky makes noise and other artifacts clearly visible in these regions. Besides picture-quality improvement, sky detection can also be used for 3D depth-map generation, and for semantic-level applications such as content-based image and video retrieval. Fig. 2 shows an example of segmentation-based image enhancement.

A first proposal on sky detection [2],[3], calculates a "sky belief map", followed by a hard decision on connected areas for the final sky detection. A second method [4],[5] assumes that sky regions are smooth and are found around the top of the image. Here, an initial sky probability is calculated based on color, texture and vertical position, and the features of highly probably areas are used to compute a final sky probability. While the first method yields useful results in annotating sky regions, its segmentation result lacks the spatial consistency due to the crisp classification decision. The second method is suitable for video applications, but due to modeling simplicity often results in false detections.

II. ALGORITHM DESCRIPTION

We propose a system that builds upon the second method, and considerably improves false detection/rejection rates. The improvements are primarily due to an extensive multi-scale texture analysis, adaptive thresholds and a spatially-adaptive

color model. Next to position and color features, the key assumption of our system is that sky has a smooth texture and shows limited luminance and chrominance gradients, that are different in the horizontal and vertical directions.

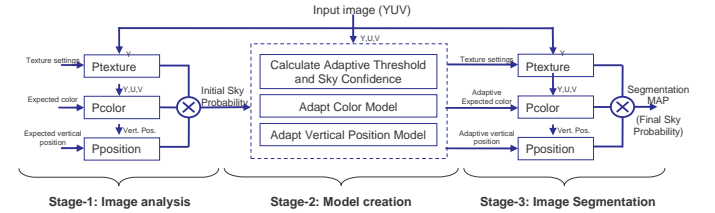


Fig. 1: Sky detection system overview

Fig. 1 depicts the overview of the algorithm. "Image analysis" stage computes an initial sky probability using color, position and texture features. "Model creation" stage creates adaptive models for the vertical position and the color of the sky areas. Finally, "Image segmentation" stage, employs these models to compute a pixel-accurate segmentation of the sky regions. The following explains these stages in more detail.

A. Image Analysis

Using predefined settings for the color, vertical position, texture, and horizontal and vertical gradients, an initial sky probability is calculated for each image pixel as

$$P_{sky} = P_{color} \times P_{position} \times P_{texture} \times Q_{sky}. \quad (1)$$

The color and vertical position probability are calculated similar to [4],[5]: P_{color} is computed by a three-dimensional Gaussian function in the YUV color space, having a fixed variance, and centered at a predetermined color. $P_{position}$ is defined by a function that emphasizes the upper parts of the image.

For the texture probability $P_{texture}$, a multi-scale analysis is performed on the image, using an analysis window of 5×5 pixels. The image is analyzed in different scales and the results are combined to compute the multi-scale texture measure. The analysis utilizes the following two measures. (I) P_{SAD} : Sum of Absolute Differences between horizontally and vertically adjacent pixels in the window (SAD_h and SAD_v), for removing textured areas. (II) P_{GRAD} : horizontal and vertical gradients (G_h , G_v) for eliminating areas with excessive gradients. The gradient values are computed by taking the difference between the average values of the opposite halves of the analysis window. The gradient analysis also exploits the often occurring luminance-increase and color-desaturation in the vertical (top to horizon) direction in blue sky images for a better elimination of sky reflections and other non-sky objects.

$$P_{texture} = P_{SAD} + P_{GRAD} \quad (2)$$

$$P_{SAD} = \exp\left(-\left(\left[SAD_h + SAD_v - T_{SAD}\right]_0^\infty\right)^2\right) \quad (3)$$

$$P_{GRAD} = \exp\left(-\left([T_{vl} - G_v]_0^\infty + [G_v - T_{vu}] + [G_h - T_h]_0^\infty\right)^2\right) \quad (4)$$

Here, T_{SAD} is a noise-dependent threshold value, while T_{vl} , T_{vu} , T_h are threshold values for limiting the gradients.

Further, Q_{sky} equals 1 for initial sky probability. The parameters of this stage are chosen such that all desired sky appearances are captured.

B. - Model Creation

In this stage, we use the initial sky probability to create adaptive models for the color and the vertical position of the sky regions. This involves the following steps.

To begin, we segment the initial sky probability to generate a map of regions of high sky probability. Here, we use an adaptive threshold value based on the histogram of the initial sky probability. Furthermore, we compute a confidence metric Q_{sky} , that prevents small sky-blue objects from being accepted as sky, in images where no large areas with high sky probability are present.

Next, the average vertical position of the segmented initial sky probability is computed and used to determine an adaptive vertical-position probability model. The model results unity starting from the top of the image, and decreases in the vertical direction, with a steepness dependent on the calculated average vertical position.

The last step is to create a spatially adaptive color model that allows correct detection of sky regions when they cover a wide range of values within one image. The color model for each color component (Y, U, and V) is in the form of a small ($h \times w$) 2D matrix. The model represents the expected sky color at each image position. Each matrix, e.g. the luminance model M_Y in (5), is fitted to the values of the corresponding color component ($Y(r+i, c+j)$) of the image, using a Gaussian filter ($W(i, j)$) that is weighted with the segmented initial sky probability ($P_{sky}(r+i, c+j)$) [6]. This ensures that the color model is not influenced by parts of the image that are initially not considered to belong to sky.

$$M_Y(r, c) = \frac{\sum_{i=-h}^h \sum_{j=-w}^w (Y(r+i, c+j) \times P_{sky}(r+i, c+j) \times W(i, j))}{\sum_{i=-h}^h \sum_{j=-w}^w (P_{sky}(r+i, c+j) \times W(i, j))} \quad (5)$$

C. - Image Segmentation

In this stage, the created vertical position and the color models are employed to compute the final, pixel-accurate sky-probability (segmentation) map, similar to [4],[5].

The color probability P_{color} is calculated again using a 3D Gaussian function, this time centered at *spatially-varying* color values. To reduce false detections, the variance is smaller than that used for computing the initial color probability, and it is adaptive to the amount of noise in the image.

The inclusion and the type of the texture probability $P_{texture}$ depends on the application for which the segmentation result is used. For example, for noise removal in sky regions, we

found it necessary to reduce the sky probability around the edges of objects adjacent to sky, in order to retain the edge sharpness. $P_{position}$ and Q_{sky} were explained in the section on model creation.

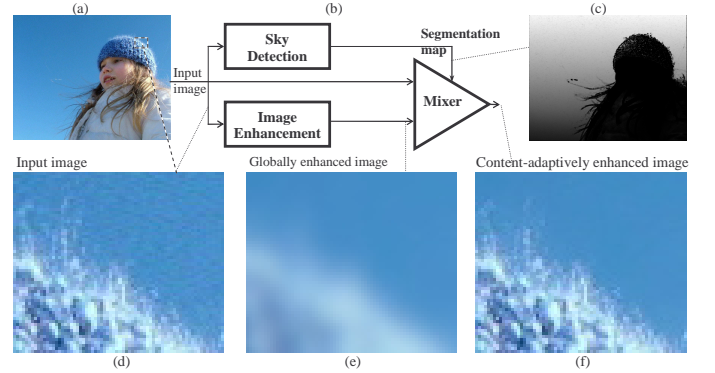


Fig. 2: Example of content-based noise reduction using the sky detection system (b): (a,d) Input image, (c) Segmentation map, (e) Globally processed image (simple averaging), (f) Content-adaptively processed image



Fig. 3: Examples of input images (left), and the sky segmentation maps (right)

III. EXPERIMENTAL RESULTS AND CONCLUSION

We have applied the proposed algorithm on more than 200 images, presenting a large variety of sky appearances. Compared with the existing algorithms, we have achieved considerable improvements in correctly detecting sky regions with large color ranges (due to a spatially-adaptive color model), and correctly rejecting non-sky objects (due to a multi-scale texture analysis). Furthermore, the segmentation results are spatially consistent (Fig. 3). As an example application, we also experimented with a content-based image enhancement system using the proposed sky-detection algorithm (Fig. 2). As can be seen in Fig. 2(d-f), the content-adaptive processing facilitates selective noise reduction in the sky areas, while other objects are unmodified.

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