Technical description of the i²e image enhancement library
Technical description of the i2e image enhancement components.

The i2e image enhancement library is a C/C++ Win32 library that can be used in any 32-bit Windows environment. It provides all the file and image processing functions which are needed to enhance images coming from digital cameras or scanners. It is available as a DLL that can be used from almost any programming environment (including C/C++, VB, C#, MC++, PowerBasic, Delphi, Access, and many more).

The i2e image enhancement library lets the user scale the image enhancement pipeline which is suitable for his application. This way he can configure for example a basic image enhancement pipeline which runs on a MMS cell phone or a more complete enhancement pipeline with all features for a high end film scanner. There are several enhancement stages in the pipeline which can be enabled or disabled.

The enhancement stages and technologies can be divided in two classes. The base processing stages act globally on the whole image. In addition to these global enhancement stages there are some specialized stages which act locally on the image.

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<th>Global image enhancement processing stages</th>
<th>Local image enhancement processing stages</th>
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<td>Adaptive Brightness and Contrast Enhancement</td>
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<td>ACE</td>
<td>Adaptive Color Enhancement</td>
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<td>ICC</td>
<td>ICC input and output profiling</td>
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</table>

(*) in development

In addition to these enhancement stages the library allows a statistical analysis of the whole film which is specially appropriate for negative film scanners allowing to scan in a single channel mode.

Main subroutines of the library

The main subroutines of the i2e library are:

- **Initialize**
  System initialization, memory allocation, ...
- **SetProcessing**
  Selection of the desired processing stages (e.g. SHE on/off, ...)  
- **SetParameters**
  Selection of the processing parameters (e.g. strength of sharpening, ...)  
- **StartOrder**
  Initialization for order analysis  
  Loading of film- or camera-type statistics

**Image analysis loop**

- **AddImage**
  For all images in the order  
  Downsampling and storing of the images  
  Accumulation of image and order statistics
- **EndOrder**
  Analysis of accumulated image and order data  
  Updating of film- or camera-type statistics

**Image processing loop**

- **ProcessImage**
  For all images in the order  
  Processing of the images based on image and order analysis
- **Exit**
  Memory deallocation, ...
Processing pipeline of the i2e software library

**Initialize**
System initialization, memory allocation, ...

**SetProcessing**
Selection of the desired processing stages (e.g. SHE on/off, ...)

**SetParameters**
Selection of the processing parameters (e.g. strength of sharpening, ...)

**StartOrder**
Initialization for order analysis
Loading of film- or camera-type statistics

**AddImage** *(For all images in the order)*
Downsampling and storing of the images
Accumulation of image and order statistics

- end order
  - no
  - yes

**EndOrder**
Analysis of accumulated image and order data
Updating of film- or camera-type statistics

**ProcessImage** *(For all images in the order)*
Processing of the images based on image and order analysis

- ICC1 input color space -> i2e color space ✔
- ABE Adaptive Brightness and Contrast Enhancement ✔
- ACE Adaptive Color Enhancement ✔
- SHE Shadow and Highlight Enhancement ✔
- MCE Memory Color Enhancement ✔
- LSE Local Sharpness Enhancement ✔
- LNR Local Noise Reduction ☑️
- xxx special enhancement (LAR, EPU, RER, ...) ☑️
- ICC2 i2e color space -> output color space ✔

- end order
  - no
  - yes

**Exit**
Memory deallocation, ....

On the following pages you will find a technical explanation of the different enhancement methods.
The adaptive Brightness and Contrast enhancement stage uses SVM (Support Vector Machine) object recognition technology to classify the images and so determine the optimum settings for white- and black-point level and for the gamma correction. The underlying SVM classification models have been trained with a large sample image set. The special class dependent corrections are automatically extracted out of this image database, but they can also be manually adapted if this is needed.

The advantage of this technology is that difficult scenes like snow-, night-, portrait, flash-, and other images are detected and so the optimal corrections can be made.

### Examples:

| White point: | Skin tone -35% correction |
| Black point: | Pure black +0% correction |
| Gamma: | Center weight 70% = -15% correction |

| White point: | White -0% correction |
| Black point: | Pure black +0% correction |
| Gamma: | Snow = +25% correction |

### 1st step: training and classification of a representative image set

The library comes already with well determined black point / white point and gamma models. So this first step is not a necessary step for the user of the library. However it is possible to adapt the behavior of the ABE enhancement later on for special applications.

The classification models are distributed later on with the library. They will be responsible for a reliable classification of the images.
2\textsuperscript{nd} step: analysis and correction of the images

This part will be made with every image when it runs through the ABE processing stage.

- **Image normalisation**: Makes the image independent from the source (digital camera, scanner …)
- **Feature extraction**: For black point white point gamma correction
- **Classification**: black-, white point and gamma type classification using the SVM models
  - **Black point type**: Green plant, Blue water, Brown earth, ...
  - **White point type**: Skin, Sky, Artificial light, ...
  - **Gamma type**: Snow, Night, Counter-light, ...
- **LUT calculation**: WP, BP, Gamma
- **Image processing**: ABE enhanced images (brightness and contrast)
ACE Adaptive Color Enhancement

The adaptive color enhancement can remove linear and nonlinear casts. Nonlinear means that the color cast in the shadows can be different then the cast in the highlights. It is possible to work in a single image color enhancement mode or in a order based color enhancement mode. The order based mode will make a statistical analysis of image groups. For digital cameras this can be images shot in a short lap of time using the same camera settings. For a scanner this are the negative exposures grouped from underexposed to overexposed. It is so possible to work with a negative film scanner in a one channel mode, which means that ACE will automatically correct the different mask colors of different film types.

ACE is in fact using the same classification engine as ABE to differentiate a normal color cast situation (where the black and white point have a neutral color balance) from special cast situations like artificial light, portrait with skin tone white point, colored black point (for example in the green trees)...

Examples of uncorrected digital camera images which require special color corrections:

<table>
<thead>
<tr>
<th>White point</th>
<th>Black point</th>
<th>Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artificial light (yellow)</td>
<td>Pure black +0% correction</td>
<td>The white point is strongly colored. ACE detects this as a artificial light scene. ACE should not correct this color cast in the white point.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>White point</th>
<th>Black point</th>
<th>Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue sky</td>
<td>Brown bushes.</td>
<td>This image has nearly no neutral tones. Even the black point and the white point are strongly colored. ACE has to detect the white point as sky and the black point as brown bushes.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>White point</th>
<th>Black point</th>
<th>Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin tone (flashed)</td>
<td>Brown artificial light</td>
<td>This image is difficult to correct as it is a mixed light situation with artificial light and flash. The forehead is the brightest point. This point has to be recognized as a skin tone white point.</td>
</tr>
</tbody>
</table>
ACE processing pipeline

Original uncorrected images

Image normalisation and order statistics
Makes the image independent from the source (digital camera, scanner ...) and removes film slope for images coming from negatives

Feature extraction
For black point white point gamma correction

Classification
black-, white point and gamma classification using the SVM models

Black point type
- Green plant
- Blue water
- Brown earth
- ...

White point type
- Skin
- Sky
- Artificial light
- ...

Gamma type
- Snow
- Night
- Counter-light
- ...

Multipoint colour cast analysis
For black point white point gamma correction

LUT calculation

Image processing

ABE enhanced images (brightness and contrast)
SHE  Shadow and Highlight Enhancement

The SHE enhancement is one of the most important image enhancement steps. The enhancement results are obvious especially in the shadow areas where much more detail will be shown. SHE also acts on the highlights which are near saturation. A good example are flash portrait images shot at night. Here SHE tries to bring back some skin details in the overexposed “flash head”

Examples:

<table>
<thead>
<tr>
<th>Digital camera image</th>
<th>SHE enhancement on</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Original image" /></td>
<td><img src="image2.png" alt="SHE enhanced image" /></td>
</tr>
</tbody>
</table>

- Additive and multiplicative density correction
- Noise removal
- Edge enhancement
- MCE enhancement
The MCE Memory Color Enhancement is a local color enhancement of key colors which have to be pleasant for the human eye. These are colors of skin, sky, vegetation and others. For these colors we have memorised a pleasant reference colour in our mind. Because of this we call them memory colors. Skin tones should for example be rather warm tones, vegetation should show a nice saturated green and especially not be to bluish. The sky should be more bluish than grey. For these colors we define attractive Memory Color Points which pull non pleasant colors closer to more pleasant colours.

We also define repulsive Memory Color Points which tend to push of unpleasant colors like magenta colour casts towards more pleasant colors.

**Memory Color example:**

In this example the vegetation colour changes from a dark bluish green to a warmer more pleasant green. The shadows enhancement also increases the brightness of the dark vegetation scenes.

This is an example of the MCE sky detector. The magenta-bluish color of the sky will be automatically shifted to a more pleasant blue sky color.

On the next page you will find a good example of Memory Color Enhancement MCE color correction used in combination with Shadow and Highlight Enhancement SHE.
### The combined power of SHE and MCE

<table>
<thead>
<tr>
<th>Original Image</th>
<th>SHE and MCE Enhancements</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Original Image]</td>
<td>This is the original digital camera image. The foreground is overexposed by the small camera flash and the background is nearly black.</td>
</tr>
<tr>
<td>![SHE Lighten Shadows]</td>
<td>SHE will lighten up the shadows to bring out the details of the book shelves. The overexposed “flash head” is made slightly darker to bring back the skin details. MCE detects skin color in this image.</td>
</tr>
<tr>
<td>![MCE Enhance Skin]</td>
<td>MCE detects skin color in this image. The skin color is enhanced locally.</td>
</tr>
<tr>
<td>![Final MCE Image]</td>
<td>Now the MCE Memory Color Enhancement will now drag the detected skin color to a more pleasant color.</td>
</tr>
</tbody>
</table>
The LSE algorithm is performing a variable sharpening of the image depending on our object recognition algorithms. It is so possible to locally sharpen vegetation and edges and even smoothen objects like sky or faces. This algorithm will achieve specially good results on images coming from cameras with noisy CCD’s. It is also helpful to sharpen low resolution images coming from camera equipped cell phones.

In the following example you can see the advantage of LSE sharpening in comparison to a traditional sharpening.

<table>
<thead>
<tr>
<th>Detail: This is a zoomed part of the original digital camera image.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detail: The traditional sharpening will also increase the grain in the sky. This grain is normally due to camera noise.</td>
</tr>
<tr>
<td>Detail: LSE will drastically reduce noise in some critical image parts</td>
</tr>
<tr>
<td>Detail: The LSE sharpened image shows the same sharpening effects like a traditional sharpening on some important parts (vegetation, edges ..) while reducing substantially the noise in the sky.</td>
</tr>
</tbody>
</table>
LNR  Local Noise Reduction

The LNR algorithm is performing a special noise reduction on some parts of the image. This algorithm mainly reduces thermal noise in the spatial domain. This filter is specially useful to get rid of heavy noise which could for example be an obstacle for a good shadow enhancement. The filter may also be used to reduce quantization noise due to high compression. The big difference to a standard noise reduction filter is edge preserving and that it only acts on selected parts of the image and does not simply make the whole image unsharp.

ICC  ICC input and output profiling support using ICM (Image Colour Management)

The i2e library includes also the possibility to translate images from a defined input color space to a defined output color space. When using the library to enhance images coming from a negative film scanner it is so for example possible to generate a input profile which corrects reproduction errors due to fact that the spectral sensitivity of the CCD does not match exactly the film- and lamp house characteristics. On the output side the image can be exported in some standard color space like sRGB or mapped directly to the printer color space using a measured printer ICC profile. Colour-Science has all necessary tools to build ICC profiles for scanners and printers.
**Projects**

**LAR  Local Jpeg Artefact Removal**

The LAR algorithm removes DCT (Discrete Cosine Transform) quantization noise which is generated with the Jpeg compression. This algorithm is very useful if small images coming from MMS (Multimedia Messaging System) should be printed in good quality. The highest resolution for MMS cell phones is today 480x640 pixels and the images are normally compressed to about 40 kb compared to about 1Mb for a good image from a digital camera.

![original image (zoomed) showing strong jpeg artefacts](image1)

![image (zoomed) after jpeg artifact removal](image2)

**EPU  Edge Preserving Upsampling**

Another major problem when trying to print small images is the fact that conventional resizing algorithms like bicubic show bad results if you have to upsample (make an image bigger) small images.

To upsample small images from MMS cell phones you have to use special edge preserving techniques.

**RER  Red Eye Removal**

Due to always smaller cameras the flash moves always closer to the objective. A result of this miniaturization are the red flash eyes. We are working on the implementation of a fully automatic red eye removal algorithm in the i2e library.

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