A METHOD FOR SEMI-AUTOMATIC CHROMATIC EQUALIZATION ON MULTIPLE IMAGES IN GRASS

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Abstract:

This paper presents a method for color equalization of a *n*-number of images using a semi-automatic regression-based method. The images equalization will be based on contiguous images where one will be considered the "master" and the other the "slave" depending on which will be used as reference and which will be changed respectively. The idea behind this procedure is to match user-input-points which are supposed to have the same chromatic characteristics. The problem of unsightly patch lines often arises when texturing 3D models with digital images taken with different lighting conditions and camera settings.

The example which is used shows the validity of such procedure. It is a Chapel by Giotto in Padova, Italy called "Cappella degli Scrovegni". After doing a 3D model from a laser scan inside the structure, digital images of the frescoed chapel walls where draped over it thus applying texture. The textured model presented odd color differences especially visible along the patch-line between two images which were draped next to each other in the model.

Our method implies for the operator to add control points which the program identifies as having to be have equal chromatic characteristics. It then uses grey levels for the three RGB color bands around the points to bring frequencies distribution of the slave to the master and thus compute a trasformation look up table for each pair of points.

Grass's characteristics of scripting and open-libraries permit the implementation of such a module. This open source program will therefore be used as the base tool for programming.

1 Introduction

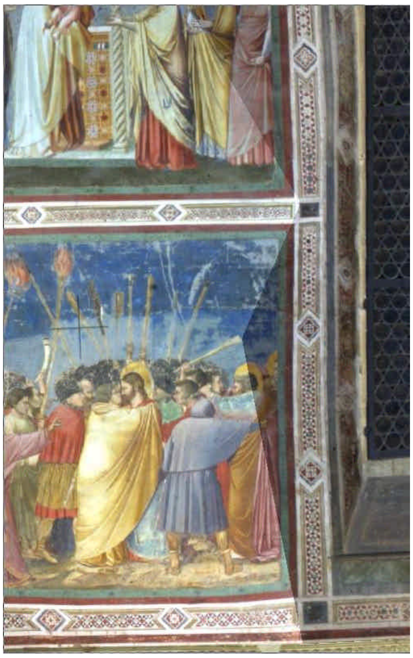


Image 1 – a critical point on texture mapping

Color perception by the human eye has been subject to study since man has begun to appreciate art and visual representations of real elements both for pleasure and for work. Even more so, color has become of central interest when computers started to express reality as digital images, both as simple 2D images and now also in 3D representations. Chromatic consistency becomes a harder task as more and more factors contribute to its variations, such as sensor difference, illuminant distribution and camera settings. A lot of the research lately has dealt mostly with equalizing two snapshots of the same object; one taken as reference (master) and and one to be equalized (slave). Both master and slave images though, are identical objects subject to different light exposure.

In this paper the problem discussed is how to equalize several images in order to execute a texturing of a 3D model with chromatic coherence. The problem is therefore slightly different than usual image equalization: instead of having an identical image we have contiguous images with only a small overlapping part which can be used to compare luminance and chromatic characteristics. The modeling was done by laser scanning inside the Cappella degli Scrovegni. The scans where then aligned with adequate software and the model was exported using a common 3D format. The model was then imported in another software for adding sky and terrain in order to accomplish a virtual reality setting. When rendering the chapel model with texture, it was clear that the images had chromatic differences and lacked the necessary homogeneity. In the places of the model where two different images are patched together, the patch-line was unnaturally evident due to color discrepancies between the two adjacent images (see illustration 1).

The work proposes therefore a procedure implemented in an open-source programming environment making use of an already existing program used for GIS and image analysis purposes. Such procedure includes the intervention of an operator during the process to input control points between image pairs. These control points will be used to calculate the necessary transformation parameters to give to the slave image to make it become more similar to the master, therefore eliminating the color discrepancy mentioned.

2 Study object

The object taken into consideration for this study is a national architectural monument named Cappella degli Scrovegni (Scrovegni's Chapel). It is considered a very important element of the Italian cultural heritage, as its frescoes have been painted by Giotto. Visits inside the Chapel are timed 15 minutes and are limited to a certain amount of people each time. There is a sophisticated apparatus for monitoring humidity and temperature to alert any change that can damage the frescoes. The laser scan was carried out after visiting hours, with the permission of the Sovrintendenza (supervisoring body of heritage elements). The images were taken in artificial light with a camera inside the chapel. Fifteen images were necessary to drape the whole model in order to view it realistically using the adequate software. The challenging characteristics of the chapel were its chromatic variability due to non-uniform lighting and geometric differences. The former is obvious when looking at the frescoed walls and ceiling, the latter is seen when modeling flat walls, arcs, and the varied geometries next to the altar. These characteristics contribute to the modification of illumination in space therefore of chromatic coherence.

3 Materials

The set of images where this procedure will be tested were taken in 1999 with the analogic WILD P31 metric camera. They were successively used as photogrammetric source to build a 3D model using Photomodeler. This program builds both a 3D model and does the necessary texturing using the images which were used to extract the geometry of the objects photographed. This resulted in a 3D model which was then exported in VRML format for viewing. The chromatic discrepancies are easily spotted thus decreasing the value of the final product.

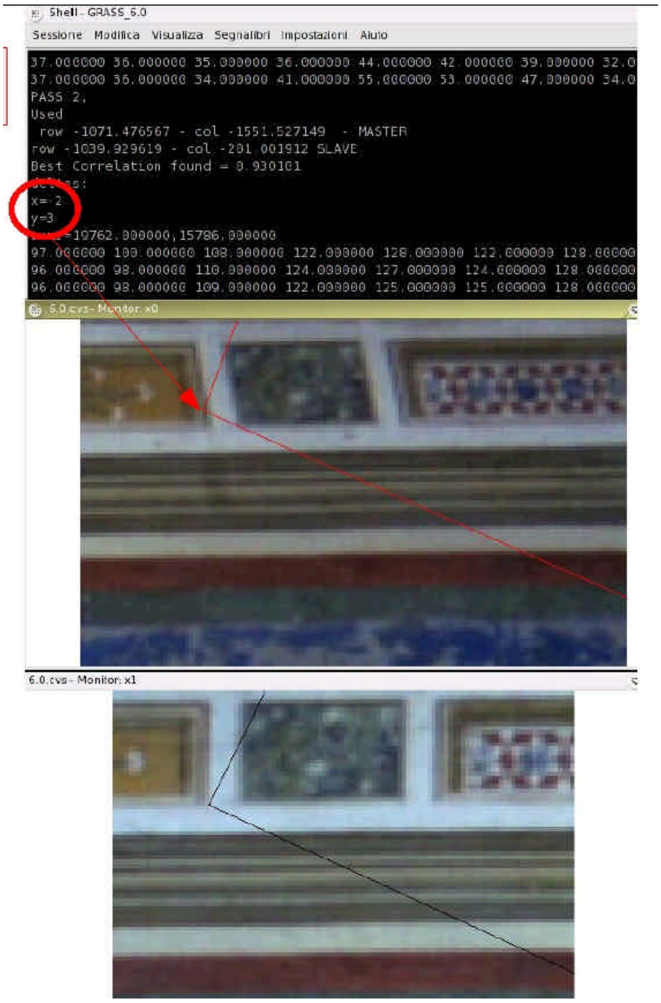
VRML format consists of a file with .wrl extension which contains the model geometry and reference to color and texture. The images which the model is draped of are in separate images, in this case with a jpeg compression format. This permits the user to load and process the single images separately and then substitute the processed-equalized images with the old ones. The VRML model will thus load the new images, and results will be automatically revealed in the final 3D model.

The procedure and algorithms were implemented making use of libraries and environment from GRASS – Geographic Resources Analysis System, an open-source software. This application was chosen because of the availability of its code, written in C, and its libraries for dealing with raster objects and image processing. The procedures for common operations such as opening images and fixing control points were already implemented, thus permitting us to focus our attention to the actual image equalization process. The GRASS environment also provides visual user interfaces for implementing the modules both from command lines and from GUI. The display manager in GRASS also permits to organize images in folders to deal with large numbers of image patches to equalize. This latter part helps in the non-automatic part of the process, where the user has to take CCLs in image pairs.

3 Methods

3.1 Description

As was mentioned in the introduction, the process is semi-automatic, therefore it needs user input. The solution proposed in this paper plans to set up a complete module in GRASS to deal with image equalization not only from the point of view of calculation, but also from the perspective of a user which has to go thru the single steps of the process. The user input is represented by the digitization of the lines which divide patched images in the model (see image 1); the vertices of these lines will be used as control points. This can be compared by its analogy with Ground Control Points (GCP) when doing an image warp. Since in this case we are in a chromatic dimension and not in a spatial dimension we will call these points Chromatic Control Points (CCP). Just like GCPs are locations which should have the same spatial coordinates in different images, CCPs are analogous points in two images which should have the same chromatic values in the two images because they represent the same space in the model.



```
37.000000 36.000000 35.000000 36.000000 44.000000 42.000000 39.000000 32.0
37.000000 36.000000 34.000000 41.000000 55.000000 53.000000 47.000000 34.0
PASS 2,
Used
 row -1071.476567 - col -1551.527149  - MASTER
row -1039.929619 - col -201.001912 SLAVE
Best Correlation found = 0.930101
deltas:
x=-2
y=3
[illegible]=19762.000000,15786.000000
97.000000 100.000000 108.000000 122.000000 128.000000 122.000000 128.00000
96.000000 98.000000 110.000000 124.000000 127.000000 124.000000 128.000000
96.000000 98.000000 109.000000 122.000000 125.000000 125.000000 128.000000
```

Image 2 – Correction of user input by correlation matrix comparison – the red circle indicates pixel distance to correct according to highest correlation in the window considered

The part above described is important because it will set the reference data from which the algorithm will calculate the equalization parameters. One problem is represented by image deformation due to the camera orientation relative to the object, which is of course different for the two images. This kind of deformation is corrected when the image is draped over the model by the VRML viewer, but in our case we work with the 2D original images, thus we have to overcome such a problem as is illustrated in the next paragraph.

To minimize the influence of distortion, we utilize a method which also has the advantage of correcting the user input. When the user selects the two control points, in the master and in the slave image, he is likely to position the points not exactly in the corresponding place, unless he really takes a long time to compare and choose by zooming almost at pixel size scale. To speed things up and decrease the distortion problem, the point placed in the second image (slave image) is tested by comparing a set of correlation values between a window around such a point and the relative one on the master image. The window in the slave image is shifted around the point to gather all the correlation values, while the one in the master image is kept with the CCP in the middle. The value in the resulting correlation matrix which is higher is the most probable corresponding point in the slave image. Therefore the window used to equalize the chromatic characteristics will be the one corresponding to the higher correlation value (see image 2).

The first part of the module therefore deals with acquisition of these points by the user and the correction of errors that the user makes. The following steps have been programmed in GRASS in order to implement the process:

- STEP 1 – import all the images to be equalized – to make things easier the importing module will use the r.in.gdal utility on every image found inside a specified folder. Thus the user specifies the folder name and every file inside will be processed by the r.in.gdal module, saving time and effort. The images will keep the original name;

- set up the three RGB images acquired from each band when importing into groups for GRASS imagery processing in a folder in GRASS's display manager;

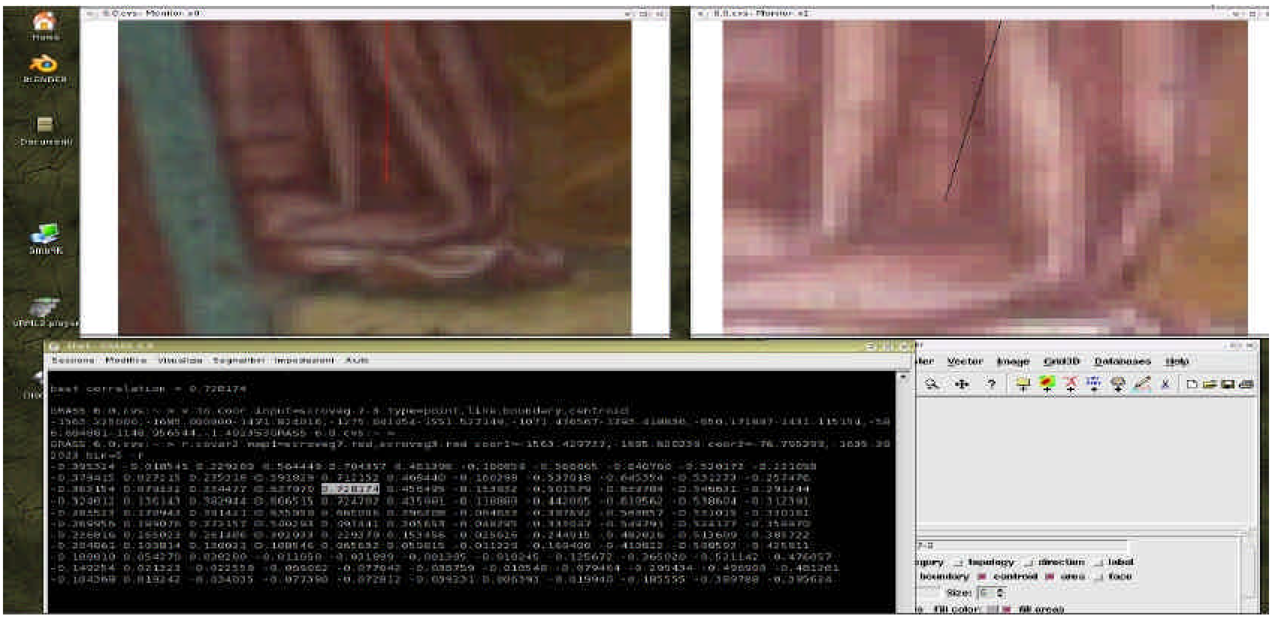
- use a menu entry called "*equalize images – take CCP*" on the "image" menu to operate on two or more viewed images in order to take CCPs;

- the CCPs are taken on image pairs, and the digitized points are automatically named following a naming convention <original name>_<image number>_<corresponding image>

Once the user accessed the first part of the module he has images imported and can proceed to take CCPs. He then chooses any kind of visualization he wants from the display menu (grey levels or RGB with the appropriate module) to take CCAs using the digitizing module available from the display manager.

3.2 Procedures

Images are referenced in a cartesian coordinate system with its origin at (0,0) corresponding to the bottom left corner of the bottom left pixel of each image. We are dealing with chromatic space, and therefore the CCPs will represent points with equal color characteristics in each image they are taken. The point will therefore have a unique ID value, color values , and an image coordinate. This last information is needed because of an eventual improvement of the module which will be discussed in the concluding part of the article. Color values accepted up to now will be simple RGB triplets.


Sessioni Modifica Visualizza Segnalibri Impostazioni Aiuto
Vector Image Grid3D Databases Help
topology direction label
boundary centroid area face
Size:
Fill color: fill areas

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best correlation = 0.728174
[illegible]
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Image 1 - Best correlation value in the correlation matrix

Once control points are taken, the correlation between master and slave windows is calculated (see image 2 and 3) to correct any user input mistake (see Eq. 1 and 2).

$$\rho_{i,j} = \frac{cov(X_i, X_j)}{\sigma_i \sigma_j}$$

Eq 1 - Correlation formula where:
Xi Xj = Value data for the two windows
Sigma i and j are the standard deviations
Cov = covariance

$$\boldsymbol{\rho} = \begin{pmatrix} \rho_{1,1} & \rho_{1,2} & \rho_{1,3} & \cdots & \rho_{1,n} \\ \rho_{2,1} & \rho_{2,2} & \rho_{2,3} & & \\ \rho_{3,1} & \rho_{3,2} & \rho_{3,3} & & \vdots \\ \vdots & & & \ddots & \\ \rho_{n,1} & & \cdots & & \rho_{n,n} \end{pmatrix}$$

Eq. 2 - Correlation matrix of a moving window

3.3 Algorithms for equalization

The user entered CCP which are then sampled to take pixel values along those lines. This saves time and effort as more points are sampled with less work.

It is obvious that this method is based on empirical calculations which use a sampling method to determine differences. It does not model the change in the strength and type of illuminant , it does not model the differences. It assumes that the chromatic variability follows a casual model, as it was noise. We know that this assumption is not correct, but it can still give interesting results without depending on prior information on the characteristic of the illuminants (their angle of incidence, their strength and color etc...) and its behavior when reflected on surfaces with different characteristics. These parameters can be modeled but would require the user to know a significant amount of information at the time of image acquisition. This is most of the time not the case because taking that kind of information requires specialized equipment, operators and software: most often we also deal with images taken some time back and successively digitized by scanning.

The method is very elaborate for taking the control areas. This is the case because the process needs to be told what colors have to be the same in two separate pictures. For human mind it is obvious when looking at the patch lines in the 3D model, and the logical step would be to tell the procedure to use as control values the points along the patch lines. The Virtual Reality Model L (VRML) model which the pictures were taken from has the wrl file which contains the 3d elements plus the coordinates where images have to be patched to the elements. GRASS is not a 3D model software, so it was not possible to work directly on the VRML file, but we had to import the images which the model uses, process them, and then put them back where the VRML will use them, this time chromatically equalized. Most image equalization research has focused on equalizing different images which were spatially equivalent and only differed in color. Such a case of course would eliminate the need for acquisition of control values between images. In our study the matter is a little more complex, and could be solved by enabling GRASS to acquire the 3D information associated to the images which drape the object directly from the VRML file.

The acquisition of CCAs was a solution to correct eventual errors from wrong digitization. If for example we used control points, the user had to get exactly the corresponding pixel in the two images: this is prone to error. Continuing with the GCP analogy, selecting a point which is one pixel away from where it should be to match the one on the reference image will only bring a mistake proportional to resolution, but in this case a different pixel can have a completely different value. Imagine an image like a chess board, and instead of a white pixel you get a black one. Such case would make the process useless and results futile.

With this method we sacrifice precise modeling for the sake of independence from light information. This approach is easier and also permits correction of any images without requiring any other parameter to be known. The assumption that the chromatic variability is casual is good enough for achieving homogeneity by correcting the differences among patch-lines thu improving a generic model without having to acquire more data.

3.3 Conclusions

The practical application of this research is evident on 3D texturing. The added value of equalizing images in order to eliminate differences where the colors should be the same is clear when comparing the model before and after image equalization. There are a few details which can be taken into consideration. For example it would be interesting to have the user put down vector lines as controls instead of points and have the program sample points along that line. This way two lines, one from the master image and one from the slave image, can be considered to run along the corresponding patch-line. This would enable the programmer to consider points along those lines sample points which must match in the regression equation. This would bring an increased smoothness in the blending of colors.

5 References

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