Addressing Lighting Issues in 3D Model Colorization

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Abstract: The digitization of existing sites is a really efficient way to obtain a very large amount of data (shape, geometry, appearance…). Photogrammetry and/or 3D scanner devices coupled to a camera offers a good solution to obtain a digital reconstruction of an archaeological site or an object of interest in order to present it to users via different media (web presentation, virtual reality, immersive system, ...). But both in photogrammetry and in lasergrammetry, in order to get a complete model of a wide site and to minimize the so-called geometric shadows, it is necessary to perform a large number of acquisitions from a variety of viewpoints.

In natural uncontrolled climatic and light conditions, such as archaeological and architectural outdoor sites, the magnitude of the acquisition time induces risks of changes in the lighting conditions (like effects due the sun positions or the weather changes). The variations of the brightness, the lightning, and the acquisition parameters can induce wide differences in the visual appearance of a given scene. Without additional processing, obtaining a visually correct rendering of the appearance for digital models remains an open issue in this field of multi view rendering.

The paper promotes a method, compatible with fieldworks, that produces visual representations of sites with consistent and homogenous colorization. Image stitching and weighting methods are adapted to perform per pixel colorizations, considering all possible colors sources (photographs) in order to color each point of the model. Each contribution is weighted using a quality measure based both on geometric configuration and pictures content (e.g. avoiding exposure problems).

In addition, a lighting prototype for 3D scanners is proposed to fill the gaps in current systems for acquisition in no light conditions.

Keywords: *3D laser scanner—color acquisition—multi view colorization—lighting problems*

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Introduction

Visual Appearance of a Material

Visual appearance is probably one of the most critical parameters affecting an observer's perception, as well as their judgment or initial understanding of what is being presented to them. Appearance is therefore a subjective property inaccessible to direct measurement for Leloup et al. (2012). To quantify it, it is necessary to determine the physical parameters or optical properties that can be measured (Schenkel, 2017).

It is possible to characterize the optical properties of materials according to four paradigms related to behavior toward light: *color* and *texture* (which depend on the spectral and spatial distribution of the reflected light), as well as the *brightness* and *translucency* (which depend on the geometric or angular distribution of the reflected/refracted light). In addition, these different attributes are not independent, influencing each other, which complicate the appearance measurement of a material.

- Color is the interpretation of a visual system stimulation. By nature, the perceived color is subjective and can therefore depend on different factors like the background, its distance from the observer, the ambient color, the lighting conditions, the environment. Objectively, the color measurement is based on the spectral reflection factor, which can be obtained directly using a spectroradiometer, and indirectly with a camera.
- Texture reflects the effects of local variation and non-uniformity of the object surface, in connection with the various external factors, the lighting direction, and the observation distance. In terms of visual response, this characteristic results in a perception of roughness, softness, waviness … (Eugène, 2008).
- Brightness refers to the shininess of a surface in opposition to a mat object, or to its ability to change its appearance following the observation or illumination angle. By definition, it is a measure, at the level of visual perception, of the property of a surface to reflect light in preferential directions. It is commonly characterized using two tools: the glossmeter and the gonio-spectrophotometer.
- Translucency reflects the internal optical behavior of the materials. In fact, the color appearance will vary depending on the light scattered (its color), reflected (its brightness) and transmitted by the object. It depends essentially on the way in which the photons will scatter and varies from transparent, passage of light without dispersion but with a possible absorption depending on its wavelength, to completely opaque, passing through the phenomenon of transluminescence (i.e. subsurface scattering).

Taking into account the different light sources in the materials rendering is important for obtaining photorealistic results. The ideal solution for this is then to fully characterize the different distribution functions: Bidirectional Reflectance Distribution Function (BRDF), Bidirectional Transmittance Distribution Function (BTDF), and Bidirectional Scattering-Surface Reflectance Distribution Function (BSSRDF). The principle of their measurements consists in illuminating a surface and in measuring the luminance in the direction of the sensor, for a sufficient number of pairs of directions to adequately sample (in number and in distribution) the parameter space (Schenkel, 2017).

In practice, the acquisition of BRDF is therefore very poorly suited to real sites under natural and variable environmental conditions. Indeed, ensuring the sampling and the coverage of the acquisitions requires the use of specific equipment, in particular for controlling the sensor. In addition, a real scene is not limited to a constant point light source, but also includes indirect sources (like reflection on surfaces) and variabilities depending on climatic conditions and sun movements. It is thus not obvious to acquire a sufficient amount of input data to reduce ambiguities relating to all of these variables, while keeping this quantity within an achievable limit. Finally, the proposed approximations require specific data, methodology, or equipment when acquiring the data. It is therefore almost impossible to completely characterize a BRDF at each point of any scene under variable natural conditions. The problem is relatively similar for the data acquisition necessary for the estimation of other functions (BTDF, BSSRDF) useful for photorealistic rendering.

Alternatively, methods have been proposed for working in outdoor scenes without heavy installation. However, this imposes many restrictions. Bernardini and Rushmeier (2002) use different approximations of BRDF based on a reduced number of measurements and on the adjustment of a lighting model. Love (1997) bases his solutions on a model of the sky and the sun, for acquisitions carried out under a clear sky, while Yu and Malik (1998) extend this idea by using photographs of the sky and the surroundings. Gibson et al. (2001) simulate a certain number of virtual light sources positioned around the scene to deduce the properties of the surfaces. Debevec et al. (2004) introduce a measuring device to precisely determine the light source, thus improving the results. Sato et al. (2003) use the presence of shadows in a scene to determine the lighting and BRDF of flat surfaces. Nielsen and Brodersen (2004) focus on estimating the properties of polished materials under complex but constant uncontrolled lighting, without a priori consideration of its position. Lalonde et al. (2012) propose a method for estimating the complete illumination of the sky using the information available in a single exterior image (the appearance of the sky, the presence of shadows on the ground or even the shading of vertical surfaces). This solution remains limited for photographs of details due to lack of information.

One solution is to use photographic images. In this case, the apparent texture is plated on the digital object by applying an inverse projection. The appearance capture for the same surface is then limited to taking a set of photographs, partially taking into account the luminous properties. In addition to geometric considerations, on-site scanning must take into account factors influencing photographs.

Factors Influencing the Photographic Result

Some principal factors influence the photographic result.

Influence of Natural Lighting

For most surveys, the measurements are spread over time, which makes it impossible to acquire all the pictures under the same conditions due to changes in natural luminosity (like sun and cloud movements, variability in light intensity). In addition, direct sunlight is responsible for most observable critical situations (like shadows, excessive illumination, reflections on surfaces that cannot be fully characterized). Ideal conditions then consist rather in a diffuse light, which conveys the color information (without taking up the information on the state of the surface) and which can be obtained with a uniform sky. However, in practice, the variations in intensity, hue, direction, of the light from a partially or completely diffused sky are infinite. In practice, the same problem appears on architectural acquisition. Fig. 1 gives the colorization of a model part based on five different color sources, acquired independently from different points of view, without taking into account light changes.

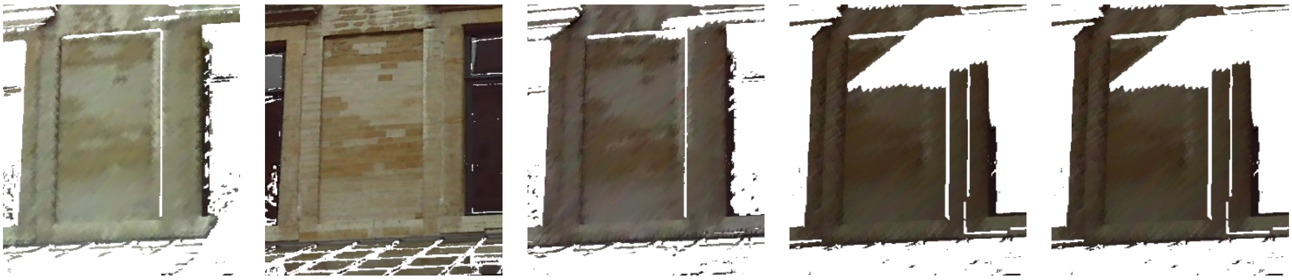

Fig. 1. Influence of natural lighting on photographic results. Colorization of a model part with five different color sources (© Arnaud Schenkel)

Influence of Exposure

Defining the appropriate exposure is a fundamental problem in obtaining a photograph. The correct exposure however remains a subjective opinion; it depends on the desired effect. Digital cameras have a limited dynamic range. As a result, when part of the scene has values below or beyond this range, it cannot be rendered correctly and the portion of the resulting image will be uniformly black (underexposed) or white (overexposed), without rendering details.

In most cases the user must therefore favors either shadows or highlights. An alternative solution is High Dynamic Range (HDR) photography, which involves acquiring the full dynamic range by acquiring a series of photographs with different exposures and combining them into a well-exposed image. Mertens et al. (2009) identify several methods to merge the different contributions. However, the HDR acquisition is time-consuming and will not solve all the problems.

Complementary to the lighting, the appearance of a site is also influenced by the shadings. Shadows occur when light from a source is partially or completely blocked by an object and tends to change the shape and perceived color of objects. This is a special case of the problems of underexposure. Several image enhancement techniques, such as gamma correction, histogram equalization, evenness of brightness, or change of contrast can help solve the problem, and with less loss of detail than for overexposures.

Influence of Additional Lightings

In a no light or in a low light environment, the difficulty is to expose the sensor sufficiently to light to collect the information from the scene. In general case, uniform ambient lightning conditions are ideal to capture the visual aspect of object surfaces, avoiding exposure and shadow problems. The use of artificial lighting sources makes it theoretically possible to circumvent the problem of adjusting camera parameters (exposure, aperture, ISO). The addition of artificial light in a scene allows for shorter exposure times, smaller apertures, and lower sensitivities, while capturing enough light to produce clear, noiseless images. The use of lighting, however, has a significant impact on the characteristics of the scene. It disproportionately brightens the objects in the scene, especially as they are close to the camera, and fades quickly. Despite these disadvantages, it remains an effective solution in low light conditions.

With photogrammetry, data acquisition can be easily coupled with a flash light or a portable diffuser. In the case of a mobile system, the lighting of the same part of the geometry will therefore not be uniform across all of the pictures due to the viewpoints configurations. With 3D scanning, there is no problem with geometric acquisition. For color, only a small number of devices use an external camera compatible with flashlight, but most of them integrate the sensor directly inside the device, making them hardly compatible.

In such conditions, it is often impossible to install standard suitable lighting devices in a large and complex survey, without creating new obstacles and thus new artifacts: geometrical related to occultations or colorimetrical related to shadows.

Model Colorization Problem

The first problem to colorize a 3D model is to detect the correspondences between pixels and 3D points for all the geometric samples. Knowing all the intrinsic and extrinsic parameters of the camera, we can determine when a point is mapped inside an image, as well as the pixel-3D point correspondence. In addition, there are different approaches for recalculating the reverse projection necessary for these calculations for an uncalibrated photo in 3D space. In this manner, it is possible to assign a pixel color to each sample of the geometric model. The real problem arises when there are several sources that can provide this color information.

An intuitive approach is to choose the most appropriate source for each part of the model. Schenkel and Debeir (2015) identify several existing methods, such as multi-criteria selection from the best source, texture correction, blending approach, weighting of the different contributions… Without additional processing, when acquisition conditions vary over time, mixing such colored point clouds into one pattern usually produces an unpleasant rendering with a poor appearance, including apparent color discontinuities. Algorithms that require specific data or hardware were discarded. We also limit the methods to those suitable for point cloud on full-scale scene models and a reasonable computation time for real time application. We consider as the best existing candidate the class of weighing methods and we adapt then in order to take into account several important features impacting the colorization quality of the produced model.

Theoretically, the problem is only related to the acquisition of the object appearance, not to the determination of its geometry. Thus, it is general for the acquisition of colorized 3D models, and therefore present in both photogrammetry and 3D scanning processing, even if, in photogrammetry, the pictures content could influence the calculation and the quality of the 3D model.

Proposed Approaches to Improve 3D Model Colorization

The main goal is to obtain a rendering, with a coherent colorization, of architectural site models, which can be geometrically very complex and have significant volumes. The proposed solution consists of two essential elements:

- The improvements of the shootings in the field by improving the lighting condition of indoor sites in most situations (low or no lighting) by using a specific system producing omni-directional ambient lighting, without adding any geometric or colorimetric artefacts to be treated;
- The digital color processing for each geometry element of the model, considering all pictures acquired in the field, in order to guarantee as much as possible the uniformity of the model colorization by eliminating all the artifacts present.

Acquisition Lighting Improvement

For general lighting conditions, a conceptual prototype was developed considering different criteria:

- The lightning equipment should not be seen by the scanner, avoiding post-processing to eliminate these aberrant measurements;
- It should produce a diffuse light to avoid all lighting artifacts, and specifically over-exposures and hard shadows; and
- The produced lighting should cover the whole field of view of the scanner, both the 360° horizontal coverage and the device zenith.

The prototype was therefore designed to be positioned entirely inside the scanner tripod. It includes a series of bulbs coupled to diffusers positioned, either parallel to the ground to avoid overexposing it while uniformly illuminating the whole room, or in the zenith direction to diffuse the light all around the scanner itself. Fig. 2 shows our prototype, placed in a cellar where no natural light illuminates the surfaces, and some pictures of the walls and the roof lit with it.


a
b

Fig. 2 a) Lighting equipment prototype, placed in a cellar where no natural light illuminates the surfaces, and b) some pictures of the surrounding elements lit with it (walls and roof) (© PANORAMA).

It is however impossible to have a lighting independent of the distance; the light intensity will always decrease. It is therefore necessary to take this effect into account when coloring.

Model Color Processing

The proposed method consists in a colorization by vertex taking into account all the available sources of colors. Each contribution is then weighted according to a quality measure. The local quality depends on characteristics directly related to the pictures content and on characteristics related to the picture in relation to geometry.

A series of quality factors are defined to weight each contribution. Inspired by Callieri et al. (2008), Schenkel and Debeir (2015) suggest to use a geometric mean of these normalized measures to combine these scores. Thus, for each image, an evaluation of the quality of each pixel is obtained from the extraction of characteristics directly related to the content of the picture considered or related to the latter by considering its environment and the derivation of these characteristics to obtain a series of quality factors. The evaluation of a quality factor for a complete image composes a weighting mask.

Firstly, in the proposed process, the detection of problems related to the images content are limited to the shadow detections and the overexposures detections. The need to solve both problems is related to changes in brightness, which can induce unpleasant discontinuous stains by creating false edges. As illustrated in Fig. 3, a quality mask can be defined based on these detections: for an image, we define shadows and overexposed elements and determine the borders of these elements. The quality then depends on the distance of a pixel from these borders. More a pixel is far from an edge, better is the quality. Finally, the three kinds of areas (well-lighted, shadow, and overexposed) were weighted differently. A combination of these two elements makes it possible to obtain the mask of quality that we will consider.

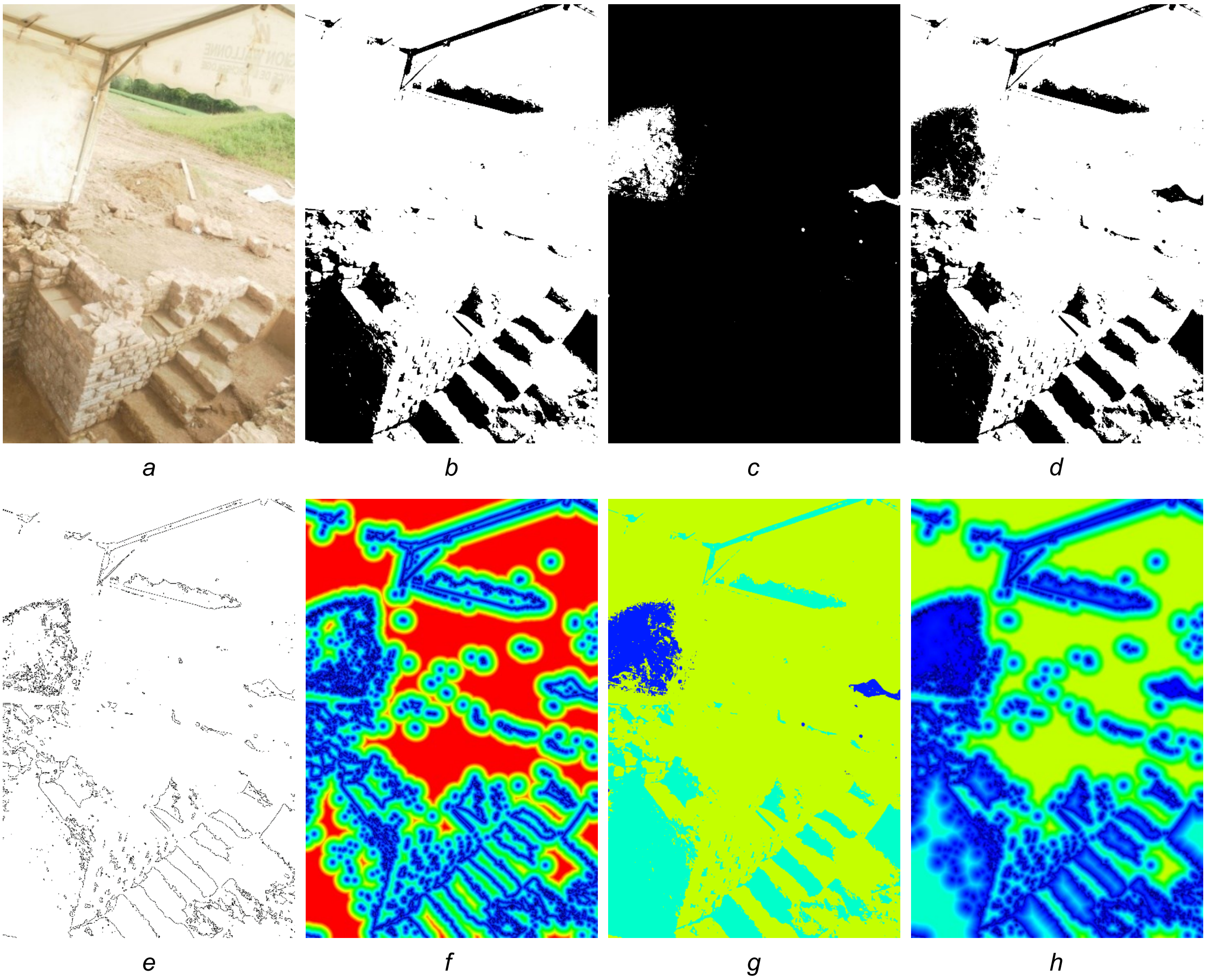

Fig. 3. Exposure quality mask, for an image: a) image considered; b) shadows detection; c) overexposure detection; d) combination of the segmented elements; e) borders extraction; f) distance map; g) weighting of the different zones types; h) resulting mask. (© Arnaud Schenkel)

For the shadow detection, an approach based on the distribution of intensities was promoted. More particularly, the detection is based on the value of the Pearson's moment coefficient of skewness, which measures its asymmetry, which can be associated with the histogram shape of an underexposed image, or showing shadows. Thus, in addition, the elaborated method also tends to detect clean shadows or dimly lit areas that cannot be unilaterally categorized as shadows. The difficulty of this detection is linked to the human perception of the problem: it is not easy to clearly limit the shadow areas of a complex scene with multiple lights. Humans will generally rely on the context of what they see (especially for the shaded shadow limits) to make their judgment and not only on the local colors present. Fig. 4 illustrates the ambiguity of the problem; different researchers have manually segmented the main shadows. The proposed solution gives good results (according to a visual evaluation) for fixed parameters.

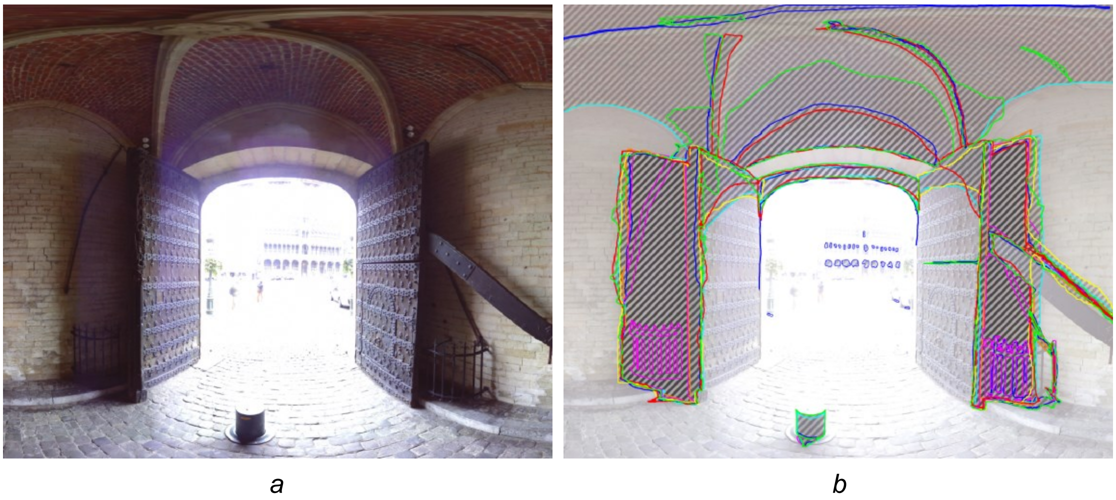
a
b

Fig. 4. Manual segmentation of shadows by different researchers: a) reference image; b) segmentation. Each segmentation is associated with a different color. The hatched areas represent the parts determined at least once as a shadow; its intensity varies according to the number of similar decisions. (© Arnaud Schenkel)

About the overexposures, the method combines the detection of shadows on a negative image and an adaptation of the thresholding proposed by Yoon et al. (2014) and based on human perception. Fig. 5 gives the results of these detections for an image.

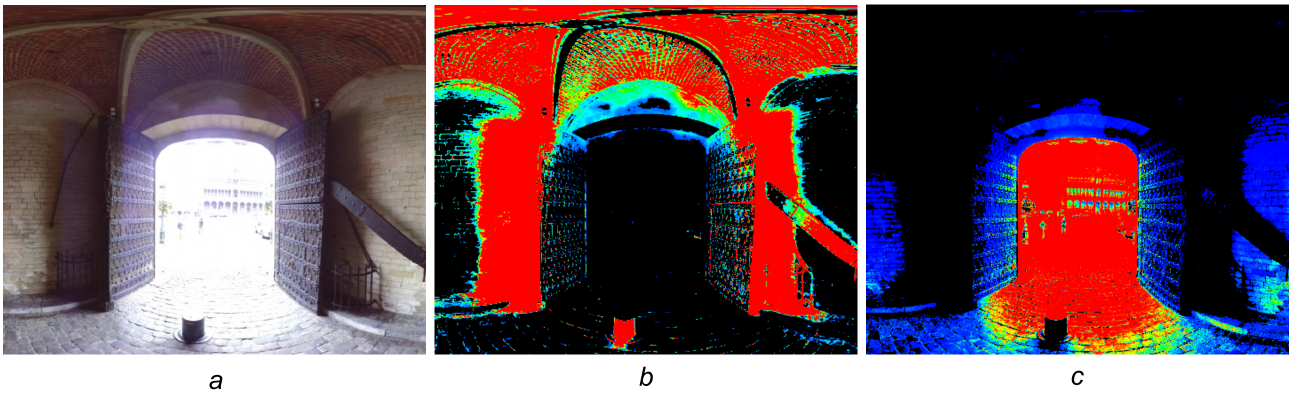
a
b
c

Fig. 5. Proposed shadow and overexposure detections: a) initial image; b) shadow detection discrimination map; c) overexposures discrimination map (© Arnaud Schenkel).

The second step of the proposed approach consists in extracting elements of the acquired geometry relative to the image considered. Two data are essential in this specific colorization process: the depth map and the normal map. These two sets of data are firstly necessary to determine which part of the dataset is visible from the camera, and secondly derived to extract different masks of quality.

In general, sources close to a surface are more representative and better reflect the details than distant viewpoints. The distance between a color source and the geometry reflects both the amount of light reaching the object, the ratio between the pixel number and the surface area, or the illumination due to a light source (e.g. additional lights). Therefore, the quality of a color source is considered especially as a function of the distance.

Then the orientation of the photos in relation to the model was considered. The quality of a color source is greater when the image plane is parallel to the geometry, and varies according to the incidence of the viewing angle of the surface. The angle between the surface normal and the optical axis thus reflects a local quality of the pictures. Orientation quality factor discredits bad oriented color elements.

Within a 3D model, there are essentially three geometrical characteristics depending on the view where the visibility of a surface can change: the silhouettes, the edges of the surfaces, and the crease. The elements related to these points in the pictures present certain characters of uncertainty, both in terms of position in space and in terms of color consistency (these pixels in the image can potentially represent several non-contiguous regions). Taking into account such discontinuities in geometry allows better rendering of a model; silhouette quality factor discredits blurred and anti-aliased pixels.

Fig. 6 gives an illustration of the considered quality masks, related to one picture.

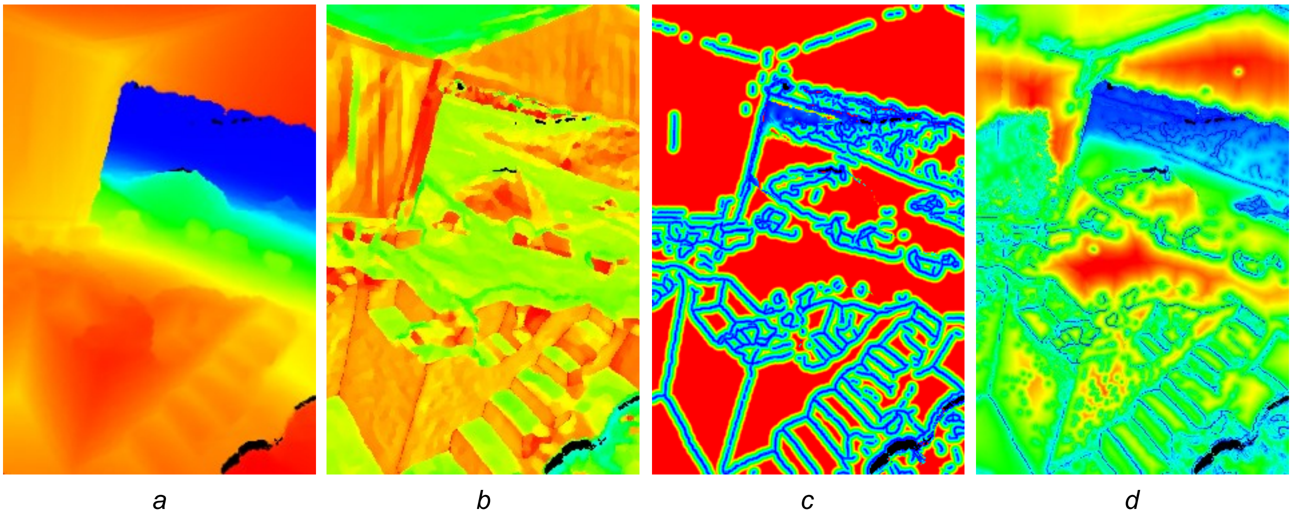

Fig. 6. Quality masks, calculated for the image used in Fig. 3: a) distance; b) orientation; c) silhouette; d) combination of all quality factors (© Arnaud Schenkel).

Results

To obtain a consistent colorization of a model, it is necessary to have a redundancy of colorimetric information. A low level of overlap between images and between scans will induce increased risks of having visible transitions, non-homogeneity in colorization and differences in colors due to changes in brightness or hue between photographic acquisitions. The proposed method makes it possible to remove most of the visual artifacts, when a 10 % overlap is present in each set of images.

The result obtained thus gives a smoothing of the transitions and a uniform colorization, both at the level of a scan and at the level of the complete object.

The proposed method was evaluated on acquisitions made using two scanners, a Riegl LMS-Z360i coupled to a camera equipped with a flash and a scanner FARO 3D S350 with an integrated camera. The method provided quality colorizations for all the acquisitions, as well for small surveys (e.g. Merbes-le-Château, including 4 scans and 32 photos) as complex surveys (e.g. City Hall of Brussels, including 97 scans and 5841 photos).

Fig. 7 gives a comparison of the results obtained for the acquisition of the El Castillo Cave (Spain), comprising 177 scans and 1770 photographs using flash light. The cave is relatively dimly lit, requiring additional lighting. The site has a complex geometry, composed by large pieces and long corridors. The photographs in this dataset are particularly impacted by the use of additional light, presenting areas that are largely underexposed when they are distant from the camera.

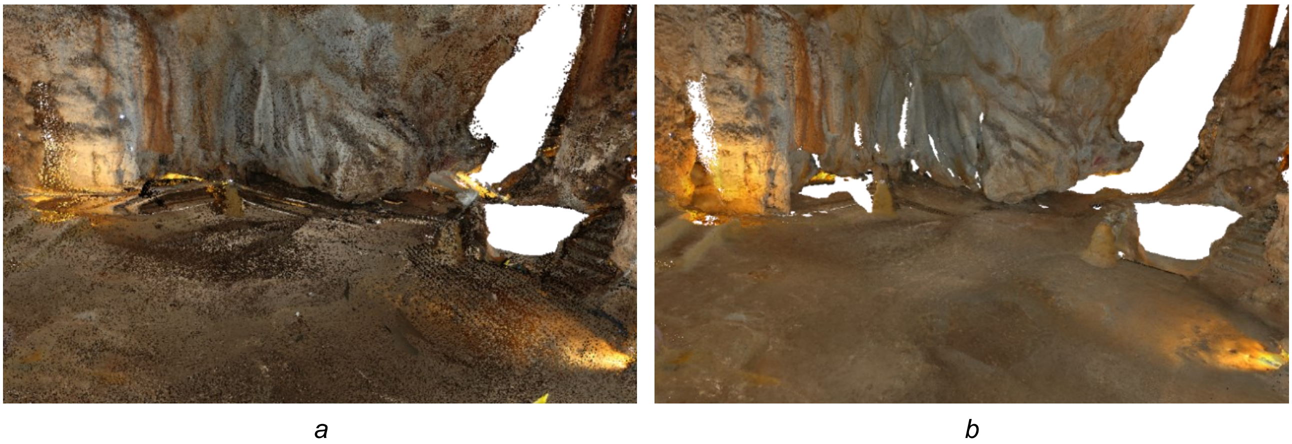

Fig. 7. Results on El Castillo Cave dataset based on a point cloud rendering: a) scanner software colorization and b) our proposition (© Arnaud Schenkel).

The survey of Merbes-le-Château was made outside. The acquisitions were therefore impacted by climate change, resulting in the presence of overexposed and shaded areas. Fig. 8 shows the difference in results obtained with and without detection of exposure problems. This effect is mainly seen at the stairs and at the ground.


a

b

Fig. 8. Comparison of the results based on a point cloud rendering: colorization a) without and b) with the exposure problem detection (© Arnaud Schenkel).

Additional results are available on PANORAMA website: http://panorama.ulb.ac.be/.

Conclusion

The promoted method allows to quickly obtain a visually pleasing rendering, by ensuring, for each geometry, the use of the same color sources in each overlapping zone during the colorization process. The developed method allows to keep the model suitable for different studies, while allowing to consider other types of corrections and improvements proposed in the literature. This method is easily integrated to the field acquisition process to rapidly observe gaps during fast site scanning, without requiring the use of brightness control techniques. The developed prototype tries to fill the hardware lack of sufficient integrated lighting in the content of indoor acquisition where no natural light is available or possible (saddlers, cellars, caves, etc.) and where the total pitch-black limit the HDR mode usage. The prototype will be enhanced with a power controller to manage the intensity following the volume to be enlighten. Portability (power battery, deployment, compactness) will also be improved.

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