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COLOUR MANAGEMENT IN THE PROCESS OF OBJECTS' DIGITALIZATION USING THE REVOSCAN DEVICE[1]

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Summary

This article presents the results of a research project carried out by the Terramap Sp. z o.o. company, which resulted in the development of a measuring device to digitize in 3D, allowing data acquisition and processing. A characteristic feature of the devised system is the automatic acquisition of information about both the geometry (spatial digitization) of the object and the colour information on the object within the RGB colour space (high-resolution digital photographs). The dedicated software, designed for the device makes it possible to plan and control the process of data acquisition, followed by data processing, and the development of the material ready for presentation. Implementation of the research results, by constructing the device and its software on the basis thereof, allowed us to significantly accelerate the digitization work, and thus reduce the unit cost of 3D digitalization.

In order to properly manage colour in the processing of data obtained using the device, we have applied a procedure to calibrate the colour of the material obtained. Studies and tests that we have conducted have shown the validity of the measures designed to control the colour of the resulting product. This publication presents the procedure used for colour management, applied in the process of creating a photorealistic 3D model, as well as the results of our research into automating the process.

Keywords

Digitization • 3D modelling • colour calibration

1. Introduction

The problem of colour management is an extremely important element in the process of digitization of museum collections. Experts appointed by the National Institute of Museology and Preservation of Collections (Narodowy Instytut Muzealnictwa i Ochrony Zbiorów), in the paper titled "Cyfrowe odwzorowanie muzealiów – parametry techniczne, modelowe rozwiązania" [Digital mapping of museum objects – techni-

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cal parameters, model solutions] [Bunsch et al. 2012], have pointed out that "Museums, caring for their collections of paintings, sculptures, objects of applied arts, and any items related to the wider material culture, must undertake a much more difficult challenge, already at the documentation stage. (...) They must not only provide the information about the stored resources, but also facilitate the reception of their aesthetic components." The same authors draw attention to the fact that, because of the need to register the nuances of colour of a given museum object, and allow them to be perceived by the user of the documentation, the problem of colour management is one of the most challenging areas of digitization activities [Bunsch et al. 2012].

The mathematical basis for the issues of colour calibration in monitors, scanners, printers, and digital cameras, was presented in the work of Vrhel and Trussel [Vrhel and Trussel 1999]. The problem of the calibration of colour images processed in the course of digitization is also discussed in the work of Boiangiu and Ştefănescu [Boiangiu and Ştefănescu 2014], who pay particular attention to the fact that even the most professional imaging devices require calibration. One of the important issues of colour management process is the possibility of the automation thereof, at various stages of image processing [Joshi et al. 2005].

2. Basic problems of colour management

In his book "Colour in computer graphics" W. Pastuszak [2000] states that "Each colour can be fully and unambiguously defined by the three attributes: the shade of the colour (hue, or value), saturation and brightness." Thus, the concept of colour as such is broader than the notion of the shade or hue of colour, although in everyday use, they function interchangeably. Therefore, according to the author, the shade of the colour is one of the attributes of colour. An important aspect of the problem is the fact emphasized by the same author, that everyone perceives colour differently. The issue of the definition of hue (shade of the colour) versus the definition of colour is also noted in the lectures on "The problem of hue and colour" by J. Tarasiuk [2012].

In turn, the colour space (gamut) determines the colour reproduction capabilities by specific devices such as digital cameras, monitors, printers, etc. It can also be defined independently of the device [Tarasiuk 2012]. The colour space is a mathematical – three-dimensional – model of the electromagnetic spectrum in the range between 380–780 microns. The digitization process uses two basic models of colour space: Adobe RGB and sRGB. The sRGB model was designed for online publication by Microsoft in 1996, and it is possible to map it on most of the monitors. The Adobe RGB model is more akin to the human eye, which is why it is recommended for use in professional applications [Bunsch et al. 2012]. However, note that only professional-grade monitors, dedicated to graphic applications, are able to reproduce the full range of the Adobe RGB model.

The Colour Management System (CMS for short) has been developed and is still being perfected by the International Colour Consortium. The latter is a suite of technical equipment, software, as well as rules and procedures aimed at ensuring the best possible colour reproduction [Tarasiuk 2012].

Colour calibration is performed by applying the appropriate colour model and colour space in the development process of the picture. For the purpose of the effective colour management in the digital imaging, the ICC colour profiles are used (short for "International Colour Consortium"). ICC is a colour management system that allows you to parameterize peripheral devices used for imaging (printers, scanners, displays, digital cameras), so that the printed colours of the image would be faithful to the original (ICC 2016). Profiles are produced as a result of the measurement of colour, shown by the specific devices. In order to create a profile, and thus to calibrate colour images, you can use the template of colours plus the software dedicated to creating colour profiles.

If you select the RAW recording format in the digital camera, the files that appear on the memory card or on your computer are not yet properly photographs. These are the raw data collected during the exposure of the light-sensitive camera sensor, and metadata about the camera settings at the moment when the picture was taken. After taking the picture, there is the possibility to "develop" it, i.e. modify the white balance, adjust the exposure, the colour saturation, and the contrast, and select colour intensity. For the professional processing of images, colour calibration of the photograph is necessary, as it guarantees that a faithful representation of the subject is obtained.

3. Description of the device

The aim of the completed project was to build an automatic measuring device (Figure 1) that would digitize small-sized objects, enabling the acquisition and processing of data about the colour and the geometry of these objects [Prochaska, Mitka 2016]. In the course of the project, studies have been carried out on the whole process of digitizing 3D objects of small size, from the stage of obtaining spatial data about the object, through the processing of that data, all the way to the publication of a virtual model of the object.

Photos by B. Mitka

Fig. 1. View of the device

In the basic configuration, the device performs digitization of the objects in the form of a sequence of spherical, cylindrical or elliptical photographs, depending on the geometry of the object, which is the subject of the measurement. In addition to the location of the camera, resulting from the "approach plan" defined by the operator, it is also possible to manually specify the location of the camera for a single image within the range of the working area. The solution that further increases the capabilities of the device is the option to disconnect the measuring columns from the table, with a simultaneous rotation of the vertical measuring column by 90 degrees. This results in the ability to obtain images automatically (i.e. according to the "approach plan" defined by the operator) for surface objects of vertical or horizontal orientation, such as for instance reliefs.

An integral component of the constructed device is the HP Z420 graphics station, along with two 24-inch graphics-supporting monitors HP ZR2440w with a resolution of 1920x1200 pixels produced in the IPS technology. In order to reproduce the colours as faithfully as possible, the monitors were calibrated using the X-Rite i1 Pro spectrophotometer (X-Rite 2014), taking into account the surrounding lighting conditions in the operator's workplace.

Colour management in the process of data acquisition and processing is facilitated by the module of image exposure, allowing control of other settings from the level of the device's software, including, among other things, the white balance settings of the camera. Manual setting of the colour temperature parameters of the lighting used, at the stage of obtaining the source material of RAW images, allows the user to acquire data about the colour, which is as close as possible to the actual colour. At the same time, the calibration procedure performed during the measurement includes, inter alia, the registration of images containing the X-RITE colour template (Figure 2).

Photo by B. Mitka

Fig. 2. Colour template used in the X-RITE device

4. Colour calibration procedure applied in the RevoScan device

The validity of using a dedicated colour profile for each individual object has been demonstrated by the test, which consists in developing the same image using different profiles. In the figure below (see: Figure 3) we have shown the effect of developing images saved in RAW format, coming from Nikon D800 (ISO 100, f/16, 1s, 35 mm), using the AdobeRGB colour gamut recording for the following ICC colour profiles: Adobe Standard (Figure 3a), CameraStandard (Figure 3b) and a dedicated profile obtained using the X-Rite template (Figure 3c). Photos were developed using the CameraRaw 9.1 application, which is an addition to Adobe Photoshop CS6 software.

Photos by B. Mitka

Fig. 3. a) Left: image developed using the Adobe Standard profile; b) Middle: image developed using the Camera Standard profile; c) Right: image developed using the profile based on the template

The relatively small visual differences between the images seen on the printed version result from the proper white balance settings and low ability for colour mapping by printing devices in the RGB colour space. For colour calibrated graphic display monitor, differences in various colour tones are much more noticeable.

The RevoScan device uses the following procedure for colour calibration and colour control of the generated 3D models:

1. When the object is placed on the table of the device, photographic lamps are set (either continuous or flashing light) in order to obtain the most uniform illumination of the object possible, using a shadow-less tent.
2. In the module, which controls the operation of the camera, parameters of the image exposure are set, i.e. the focusing distance, aperture size, the time of exposure, light sensitivity of the camera matrix, and the white balance. For the white balance

parameter, colour temperature is set depending on the colour temperature of the lamps that will be used.

3. A set of calibration images is then taken, containing the template of colours as well as the geometric template for the calibration and verification of the resulting geometry of the object.
4. The image, along with its colour template, is saved to Digital Negative (DNG) format. DNG is an open, lossless format for digital negatives, containing unprocessed data from a digital matrix (RAW), developed by the Adobe Systems. Adobe provides a free converter to DNG from RAW formats of many different manufacturers cameras (Figure 4). Having a photograph in DNG format, you can use the software supplied along with the colour template for creating a colour profile. Open format is also perfectly suitable as a universal way for archiving raw images.

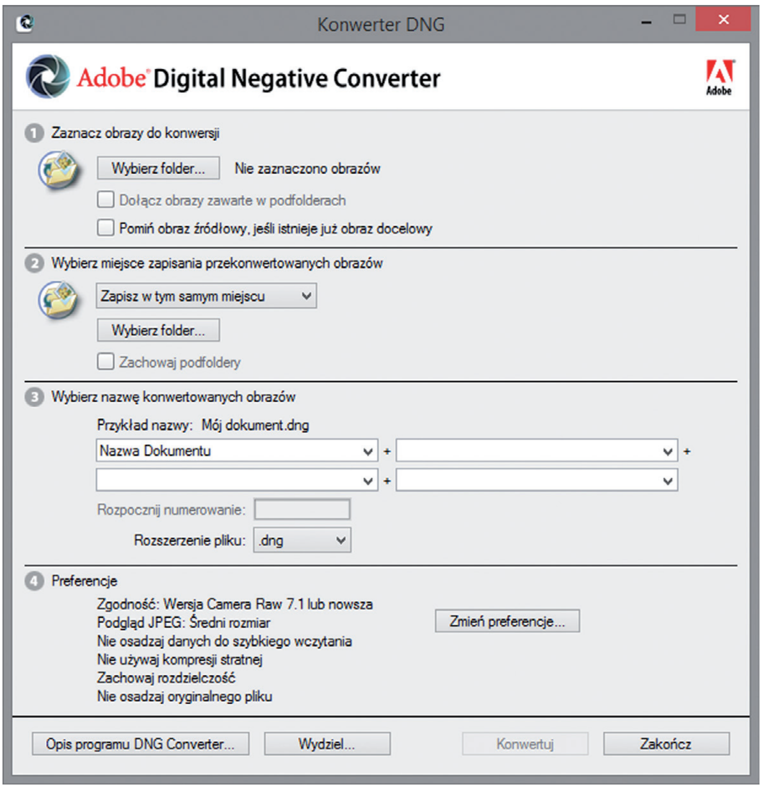
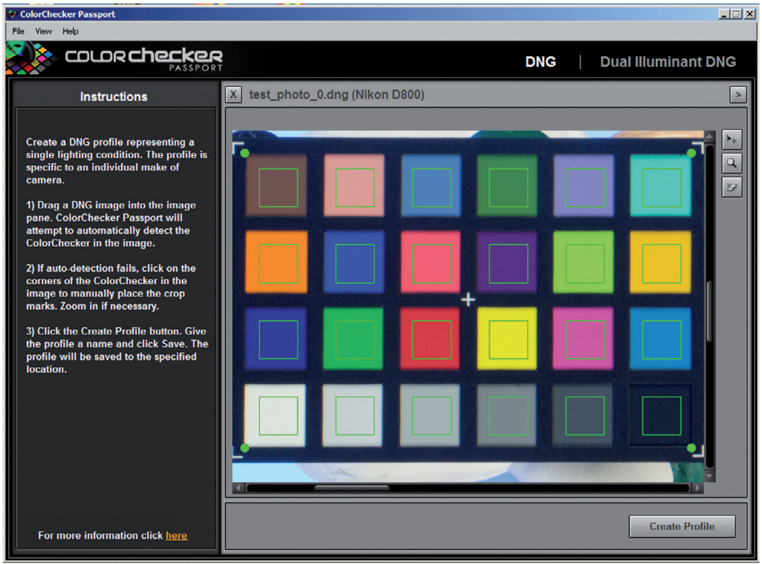


Fig. 4. Interface of the Adobe Digital Negative Converter application

Using the ColorChecker Passport software, you create and save the colour profile for the digitized object. The software is supplied together with the colour. Its use is very intuitive – it is sufficient to drag-and-drop the photo along with the colour template in the DNG format onto the working area of the application. The ColorChecker Passport application automatically detects the colour template in the photo, and when you click the "Create Profile", it creates the colour profile (Figure 5).



Source: authors' study based on ColorChecker Passport application

Fig. 5. ColorChecker Passport application with a colour template detected automatically

The next step is to develop all the source images. This is accomplished in a single process, using Adobe Photoshop CS6 with the Camera Raw 9.1. plug-in. All source files in RAW format (for Nikon cameras, they have the NEF extension), after they have been developed, are saved to JPG format and are the basis for generating a photorealistic 3D model. Due to the number of images obtained in the processing of data, manual calibration corrections are not performed on the individual source images.

The last stage of the verification of colour of the digitized 3D model of the object is to compare its photorealistic 3D model to the original, with appropriately selected parameters of the rendering engine display. Practical experiences resulting from the dozens of 3D models executed so far show that when lighting and white balance are set properly, and when colour calibration has been performed on the basis of individually generated colour profiles, the 3D models obtained correspond to the colours of the original in a satisfactory manner (Figure 6 a–c).

Source: authors' study

Fig. 6. a) Left: model executed without the colour calibration; b) Middle: image after the calibration and the automatic separation of the background; c) a 3D model executed based on the colour-calibrated images

5. Studies on the possibility of automating the process of acquiring colour-calibrated photos

The procedure presented above for calibrating colour photographic material harvested for the 3D modelling of objects is largely based on manual operations, requiring the intervention of the device's operator. Striving for the maximum automation of all activities related to the digitization process of three-dimensional objects, as a part of this research project, we have also conducted the study and testing of the feasibility of automated colour calibration.

The following is a procedure for automating the process, developed within the framework of the present study. The whole process needs to be structured, i.e. RAW files developed to TIFF or JPEG, along with the colour profiles, should be placed in the proper directory structure.

The process of obtaining colour-calibrated images can be divided into several stages:

1. Obtaining the colour profile:

   After setting the scene, and performing the white balance adjustment, the picture of an object is taken. Colour template is placed within the frame. The image is then downloaded from the camera to your computer drive, written and stored in a suitable location in the directory structure. The format of the picture depends on the manufacturer's camera. Let us assume that the image is given a name *calibration_photo_1.NEF.*
2. Converting the image named *calibration_photo_1.NEF* to the DNG format, using the DNG Converter software. As a result, we obtain the file named *calibration_photo_1.DNG*:

From the menu of commands (CMD)> "Tools\\dngconverter\\Adobe DNG Converter.exe", "-c -d " + fullDestPath + " " + fullPathToPhoto, we have created the class named DngConvStarter (singleton) which automatically (that is, without the need for the operator's involvement) launches the converter program. Below we present the method, which launches the Adobe DNG Converter.exe software in response to the command:

```
async public static Task AsyncExecute(string fullPathToPhoto, string fullDestPath)
{
RunModule("Tools\\dngconverter\\Adobe DNG Converter.exe", "-c -d " + fullDestPath + " " + fullPathToPhoto);
}
```

3. Creating the colour profile.

   The converted image named ***calibration_photo_1.DNG*** is dragged and dropped onto the working area of the ColorChecker Passport application. Similarly as above, the class of PassportStarter has an in-built method for launching the ColorChecker Passport program. The process of creating the colour profile is performed in a separate thread; therefore it is working in the background and is not blocking the operation of other applications:

```
async public static Task AsyncExecute(string fullPathToPhotoToColorCalibration)
{
string args = string.Format("/Select, {0}", fullPathToPhotoToColorCalibration);
ProcessStartInfo pfi = new ProcessStartInfo("Explorer.exe", args);
System.Diagnostics.Process.Start(pfi);
RunModule("Tools\\passport\\passport.exe", "");
DirectoryInfo d = new DirectoryInfo(@"ICC\");
FileInfo[] files = d.GetFiles("*.dcp");
if (files.Length > 0)
{RunModule("Tools\\dcp2icc\\dcp2icc.exe", "ICC\\" + files.Last().Name + " 5000");
if (File.Exists("ICC\\" + files.Last().Name))
File.Delete("ICC\\" + files.Last().Name);
}
}
```

   The AsyncExecute method first brings up a window with the converted picture (DNG), and then runs a program to create a colour profile, and finally writes the profile in the ICC format.

4. Processing of RAW images.

   The last step is to process ("develop") RAW images, using the created colour profile. After careful reviewing and analysis of tools available for developing photos, we have decided that the DCRAW software performs best. At the time that the photo is being taken, demanding the calibration of colour, the application automatically develops (processes) the image based on the previously created ICC profile. The process does not require the presence of the operator.

The key features of the DCRAW application include:
- It is free software (open source);
- Is written in C programming language;
- It is portable (using only the standard C libraries);
- It is expanded;
- It has the ability to develop images using the ICC profile to TIFF or JPEG;
- Because we possess the source code, we can modify the software and adapt it to our needs;
- It fulfils the most important criterion – it allows the user to automate its operations.

The DcrawStarter class (singleton) is responsible for running the version of the DCRAW application, compiled under the Windows operating system, in a separate thread. Below is an asynchronous method of launching an automatic process of developing photos:

```
async public static Task AsyncExecute(string fullPathToPhoto, string destPath,
string fullPathToColorProfile, string format)
{
if (format.Equals("tiff, jpeg") || format.Equals("jpeg, tiff"))
{
RunModule("Tools\\dcraw\\dcraw.exe", "-v -p " + fullPathToColorProfile + " " +
fullPathToPhoto);
RunModule("Tools\\dcraw\\dcraw.exe", "-v -T -p " + fullPathToColorProfile + "
" + fullPathToPhoto);
RunModule("Tools\\cjpeg\\cjpeg.exe", "-v -outfile " + fullPathToPhoto.
Replace("nef", "jpeg") + " " +            fullPathToPhoto.Replace("nef", "ppm"));
if (File.Exists(fullPathToPhoto.Replace("nef", "ppm")))
File.Delete(fullPathToPhoto.Replace("nef", "ppm"));
}
else if (format.Equals("jpeg"))
{
RunModule("Tools\\dcraw\\dcraw.exe", "-v -p " + fullPathToColorProfile + " " +
fullPathToPhoto);
RunModule("Tools\\cjpeg\\cjpeg.exe", "-v -outfile " + fullPathToPhoto.
Replace("nef", "jpeg") + " " + fullPathToPhoto.Replace("nef", "ppm"));
if (File.Exists(fullPathToPhoto.Replace("nef", "ppm")))
File.Delete(fullPathToPhoto.Replace("nef", "ppm"));
}
else
{
RunModule("Tools\\dcraw\\dcraw.exe", "-v -T -p " + fullPathToColorProfile + "
" + fullPathToPhoto);
}
}
```

The method writes the processed photos in either the TIFF or JPEG format, to an appropriate folder, and gives them an assigned file name.

6. Conclusions

The colour profile (ICC) and the applied colour space (gamut) cause significant visual differences when processing (developing) digital photos. The results generated using standard colour profiles are not satisfactory – the image still do not fully correspond to the original. Performing the colour calibration of an image, by taking the photo of the colour template with the same lighting conditions and the same camera settings (ISO, aperture, exposure time, focal length) significantly improves the reproduction of object colours, and its digital representation in the form of pictures, and then the 3D model generated from the calibrated images. In order to create the correct colour profile, you can use the applications that came with the colour template. Colour calibration of images is essential in digitization of museum objects. The process of obtaining colour-calibrated photos can be automated through the use of appropriate software and custom-made scripts to support it.

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