Neural network-based digital image spectrophotometer

User manual

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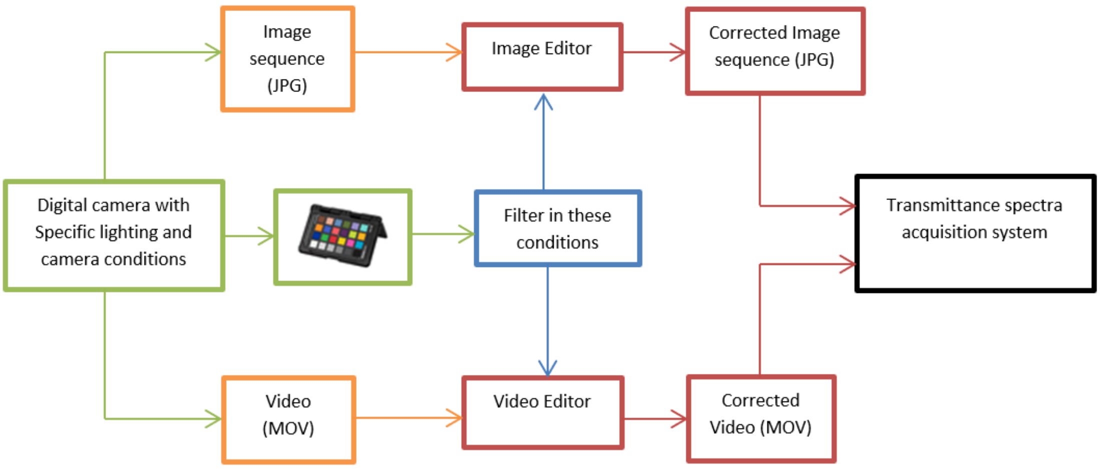
Currently, optical characterization of materials is carried out by means of a spectrophotometer. This device is used to measure the transmittance spectrum of these materials, and any subsequent changes by following the corresponding kinetics.

However, the use of this device carries with it certain disadvantages. Firstly, it is only capable of studying a very small area (in the square millimeter range) of the material at a time. If any transmittance change in the material is not homogeneous, a lot of information is lost, or it is possible that the results found do not give the correct information. In addition, although the price is becoming more affordable, it is still relatively high.

As an alternative, the transmittance spectra acquisition system developed in this manual has been developed to overcome these disadvantages.

This system is intended to obtain static or kinetic transmittance spectra in the visible range from digital images or videos. A neural network created for this purpose is used to generate the transmittance spectrum in the visible range (400-700 nm) from just three LAB color coordinates. For a reliable operation of the system, the obtention of true color coordinates is a prerequisite. For this purpose, an initial color correction of the image or video files is made. Therefore, two steps can be differentiated in the process: a first one where adequate color filtering is made to obtain real color coordinates, and a second one where the artificial intelligence process take place to generate a whole visible range spectrum. The two processes, and their corresponding steps, are visually summarized and briefly described in the following schemes:

a. Real **c**olor coordinates obtention from digital images or videos**.** The steps to be followed or parts to be taken into account are briefly described below.



a.1 Selection of lighting conditions: Specific lighting and camera settings are selected and maintained through the whole process

a.2 Color profiles creation: Color profiles are created to modify the images and videos taken. Image or video editor software are used in each case.

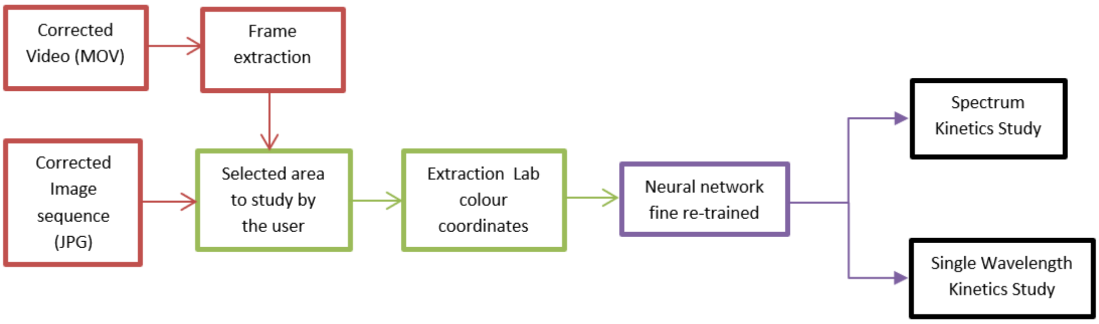
a.3 Image sequence and video: files to be studied (sequence of images or video) are obtained by the user (under the same illumination and camera conditions initially established).

a.4 Files correction through editors: Through the previous image or video editor, the files taken by the user will be corrected, storing the real LAB color coordinates.

a.5 Transmittance spectra acquisition system: These corrected files are the inputs for the second stage, the generation of transmittance spectra.

Each of these steps are explained in detail in Section 1.

b. **Transmittance spectra reconstruction through neural-network processing.** The corrected images and videos are processed in order to obtain the result expected by the system. The corresponding steps are briefly described below.



b.1 Upload corrected files: The files to be studied are uploaded to the system.

b.2 Area selection and extraction of LAB color coordinates: The user will be able to select the area, from the set of images or video, that he/she wishes to study. Then, the average value of the LAB coordinates of the area selected by the user will be calculated.

b.3 Neural network fine re-trained: a neural network capable of generating a transmittance spectrum (in the visible range (400-700 nm)) from LAB coordinates has been created.

b.4 Selection of experimental technique: The results from the neural network will be displayed according to the experimental technique chosen by the user. On the one hand, using "Spectrum Kinetics", the resulting transmittance spectra will be displayed graphically for each image or frame studied (referred to the selected area). On the other hand, if "Single Wavelength Kinetics" is selected, the user will enter the wavelength value to be studied, and the result will graphically show the evolution of the transmittance value for that wavelength for each image or frame (referred to the selected area).

This processing system has been carried out using Python language, Anaconda software. An interface has been created for an agile communication between the system and the user.

Section 2 describes how this interface works and instructions for the user.

1. Obtention of color coordinates: use of Colorchecker Chart.

The Colorchecker color chart (Figure 1) is routinely used in photography as a reference for the color “correction” of images or videos, and the obtention of their “true” color coordinates, based on a predefined set of calibrated colors. This process is different for images or videos. Therefore, although they are similar processes, a specific section, with details of the corresponding steps, is included for each case.

Figure 1. Color Chart Colorchecker Passport Photo 2.

1.1. Obtention of color coordinates: images.

For the correction of images using this color chart, two programs are necessary: An Image editor (CaptureOne was used in our case) and Colorchecker Camera Calibration (it can be downloaded from the official Calibrite website: https://calibrite.com/es/software-downloads/?noredirect=es-ES).

The following are the steps necessary to correct an image in certain lighting conditions (in case of using another image editor, the steps could be different):

1. Set the lighting conditions and camera settings ((ISO, shutter speed, etc.). These conditions and settings must be kept throughout the study.

2. Take a picture of the 24 color drop-down part of the colorchecker chart, under these lighting conditions an camera settings. The image should be similar to the one shown in figure 2, in which the 24 color samples are clearly visible. This image must be saved in a specific file format and kept throughout the correction process (in our case JPG, as it gives us greater versatility and is lighter than RAW).

Figure 2. Image of 24 color samples on Colorchecker color chart.

3. Open the image editor CaptureOne and load the color chart image previously obtained. On the drop-down menu that appears on the left (the different options offered by CaptureOne), under "Color", under "Basic Characteristics", in the option "ICC Profile" select "No color correction" and under "Curve" select "Linear response", as shown in figure 3. These options will eliminate the changes made by the camera on the image and will leave it without any type of filter. Once these changes have been applied, this image is downloaded and saved, ONLY AT THIS STEP, in TIFF format.

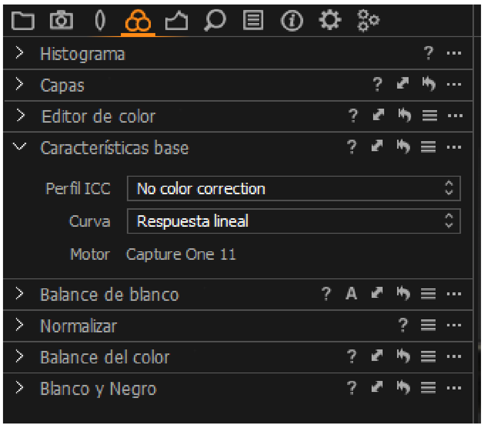


Figure 3. Options to generate image without filters.

4. Close the CaptureOne program and open "Colorchecker Camera Calibration", which presents an interface like the one shown in figure 4.

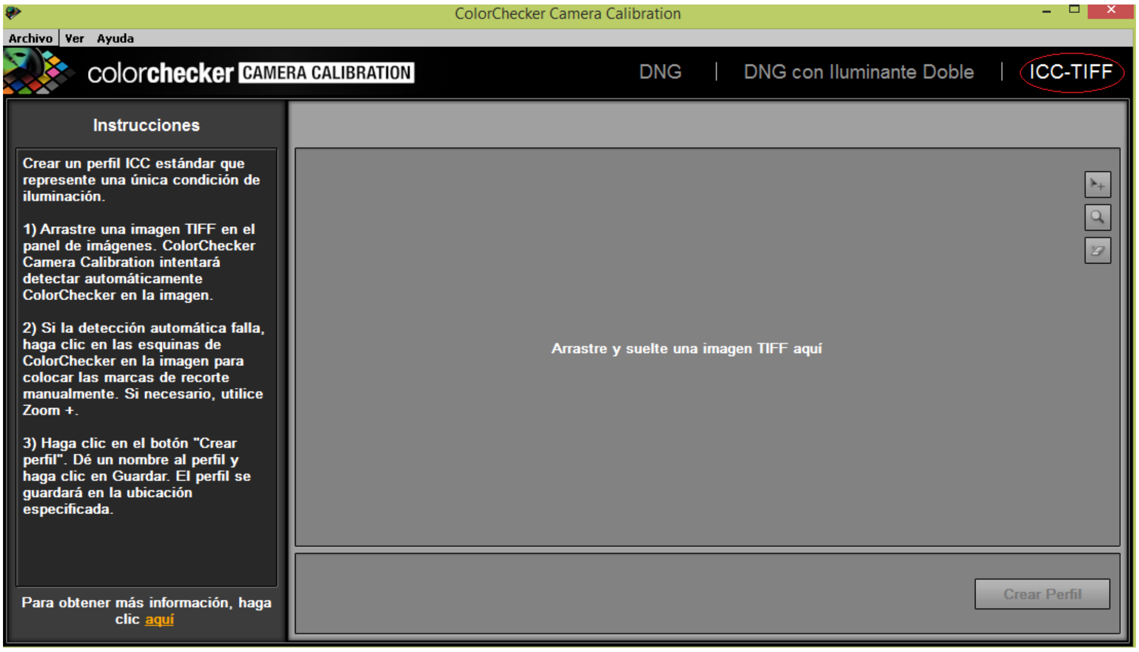


Figure 4. Main interface of the "ColorChecker Camera Calibration" software.

5. Open the image saved in TIFF format (it can be dragged and dropped onto the main screen). Then, the different squares that appear in the image are adjusted, so that they fit exactly with the 24 color samples of the image, as shown in figure 5. Finally, click on the option "Create Profile" and save it with an identifying name, which will be recognized later (it is advisable to place a name with the lighting and camera conditions in which the photograph was taken). This profile, which is called ICC Profile, is the one that will be applied to future photographs taken under these conditions. For this example, it has been saved with the name "ICC1".

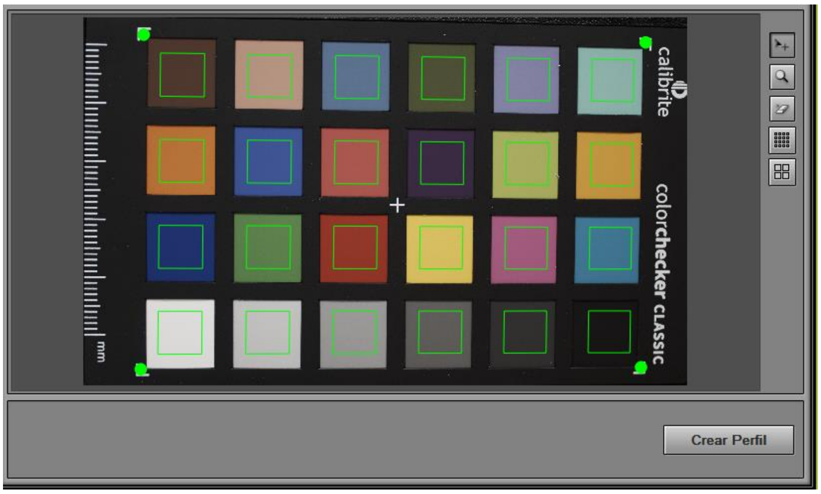


Figure 5. Adjust ICC profile.

6. Close "ColorChecker Camera Calibration". Proceed to take a new image, in the same format as the previous one (in our case JPG) and with the same lighting conditions and camera settings. Open "CaptureOne" and open this new image. To correct this new image, in the same option of step 3, "Basic Characteristics", under ICC Profile, select the one created previously, which will appear with the name you have given it (ICC1 in this

case). To do this, click on the option "others". Figure 6 shows our example (ICC Profile = ICC1). In the "Curve" option, the automatic mode is selected.

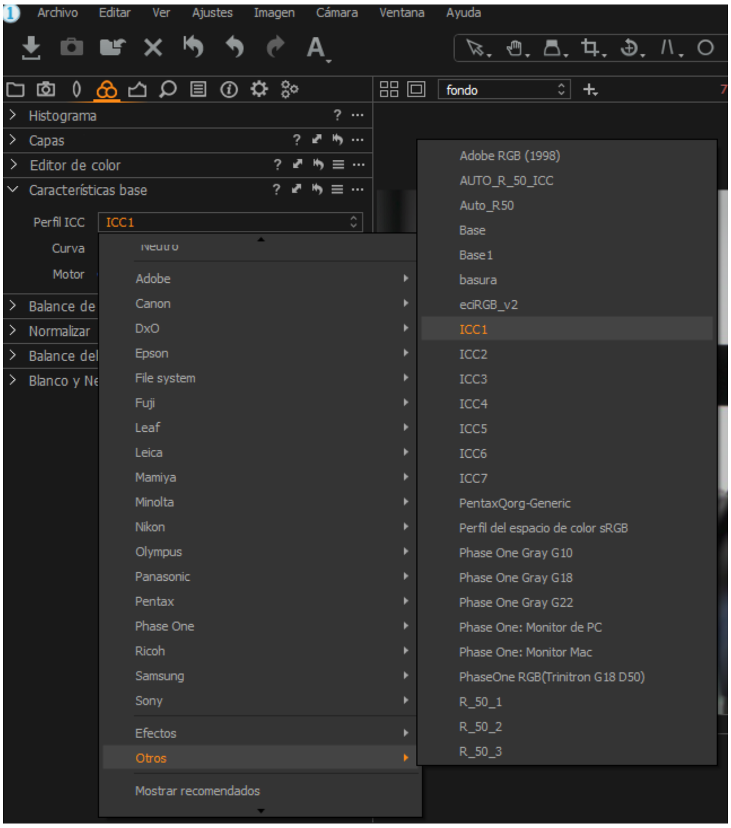


Figure 6. ICC profile in CaptureOne.

7. The image is now corrected and can be downloaded in the same format (JPG). This image is now ready for processing and obtaining the true color coordinates of any pixel of the image.

1.2. Obtention of color coordinates: videos.

The correction of a video using this color chart can be carried out using several video editors. In particular, we have used "DaVinci Resolve". With this software, it is possible to create the base profile for certain lighting conditions and camera settings, and then, in the same software, to correct videos made under the same conditions.

For this software, it is possible to download a free version, which has the necessary options to carry out this process, at the following link:

https://www.blackmagicdesign.com/es/products/davinciresolve.

The following are the steps to follow in order to perform a video corrections (in the case of using another video editor, the steps could be different):

1. Set the lighting conditions and camera settings ((ISO, shutter speed, etc.). These conditions and settings must be kept throughout the study.

2. Take a video of the 24 color drop-down part of the colorchecker chart, under these lighting conditions an camera settings (a video between 5 and 10 seconds will be enough). The video should record this scene statically. The image shown in the video should be similar to the one shown in figure 2, in which these 24 color samples are clearly visible. This video must be saved in a certain format and kept during the whole correction process (in our case it is saved in .MOV format).

3. Open the video editor "DaVinci Resolve", creating a new project. This software presents several tabs, located in the lower area of the screen (Figure 7). In the third tab (Edition), in the second column, click on the right mouse button and select multimedia. The directory opens and the video created in the previous step can be selected. Then drag the video to the timeline in the lower right corner, thus creating a new Timeline, on which the filter for correcting subsequent videos will be created. After these steps, the screen is displayed as shown in figure 7.

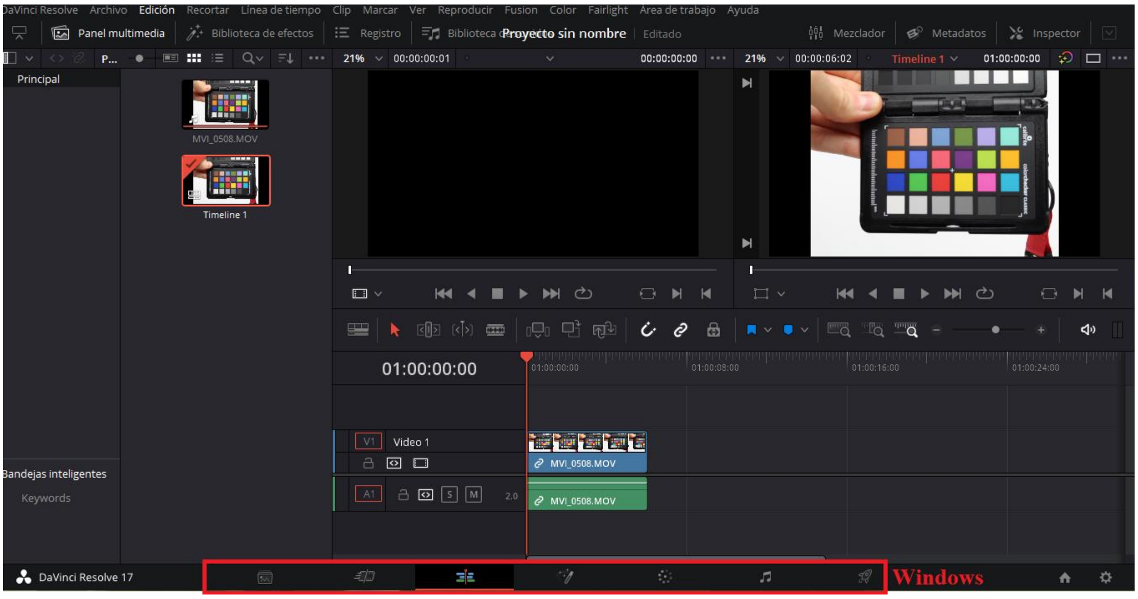


Figure 7. Main screen in DaVinci Resolve "Edition" window.

4. Once the Timeline has been created (by default its name will be "Timeline 1") move it to the fifth tab, called "Color", figure 8. In the central area of the screen, a series of options will appear (indicated in red). Please select the second one, called "Color Match", indicated in figure 8.

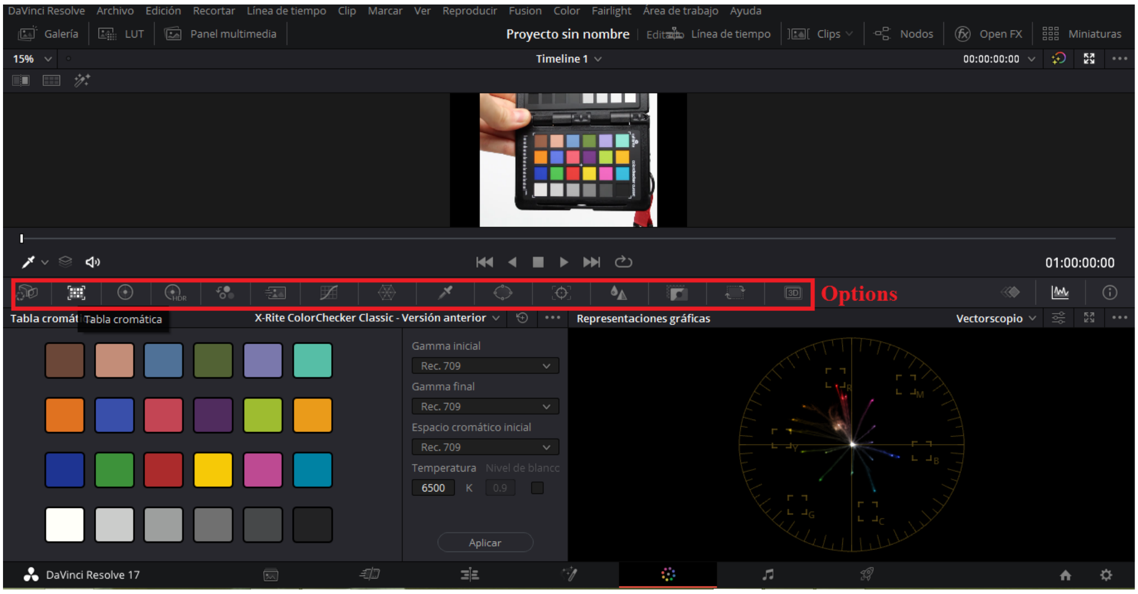


Figure 8. Color Window DaVinci Resolve.

5. In this window, by clicking on the little arrow marked in red (figure 9), a series of possible color cards to use appear. The one to be used must be selected. In our case, it is the "X-Rite ColorChecker Classic".

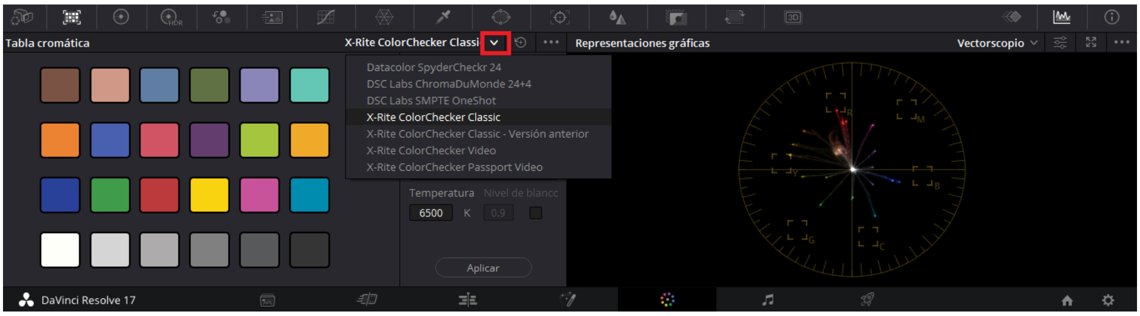


Figure 9. DaVinci Resolve color chart selection.

6. By clicking on the little red arrow shown in figure 10, Color Chart is selected. In figure 10, you can see how, instantly, a mask appears over the video image, with boxes for the 24 color samples. Similarly, as it was made for image correction filter, this mask must be adjusted to these 24 samples of the video (hence the importance of creating the video statically, so that these samples are in the same position throughout the recording and the adjustment is done correctly).

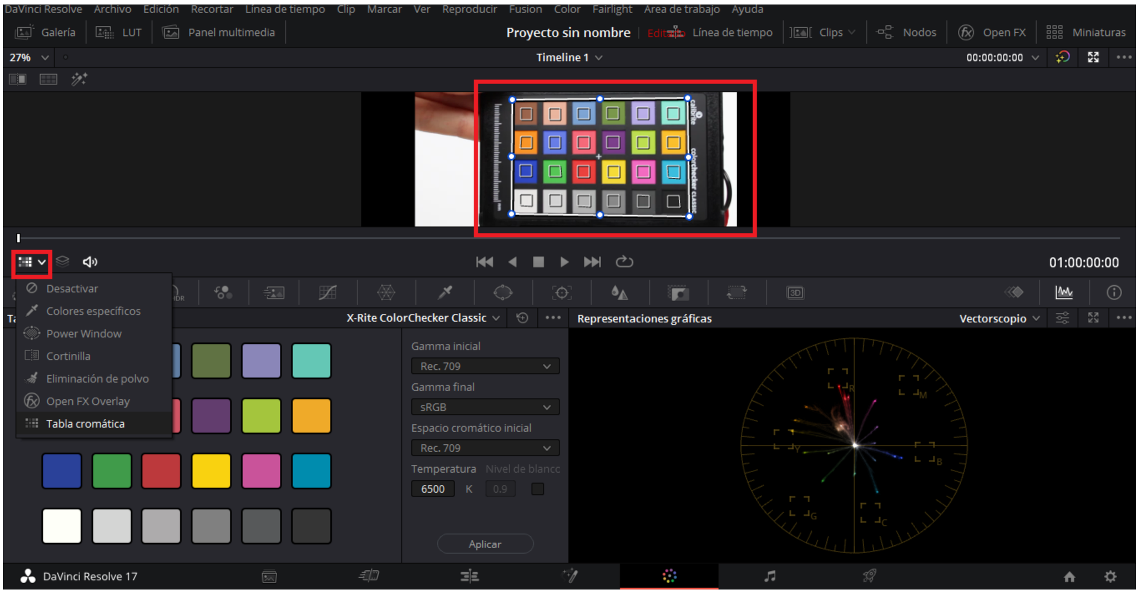


Figure 10. Alignment color chart to the video image.

7. Figure 11 shows the options to configure the conditions under which the video has been obtained and how the final result will be obtained. In "Source gamma", the curve used by the digital camera to record the video must be selected. In this way, the software will be able to linearize this curve and use it to make the appropriate corrections later on. This information can be obtained in the camera's settings or even in its manual. In our case it is “Canon Log”. In “Target Gamma”, choose the color space in which the color information will be displayed or saved. In our case, “sRGB” is selected. Under “Target

Color Space”, “Rec.709” can be retained. Under “Temperature” a temperature must be selected at which the colors remain neutral, which is why it is kept at 6500 K. If warm colors are desired, this temperature should be lowered, and for cold colors it should be raised. Finally, the white level can be kept at 0.9, but it is advisable to set it to 1.0, in order to have the widest possible range of colors. After selecting these options, they are applied, and as a result the color differences in percentages, between the corrected recording and the colors that should really appear, are displayed, as shown in figure 11.

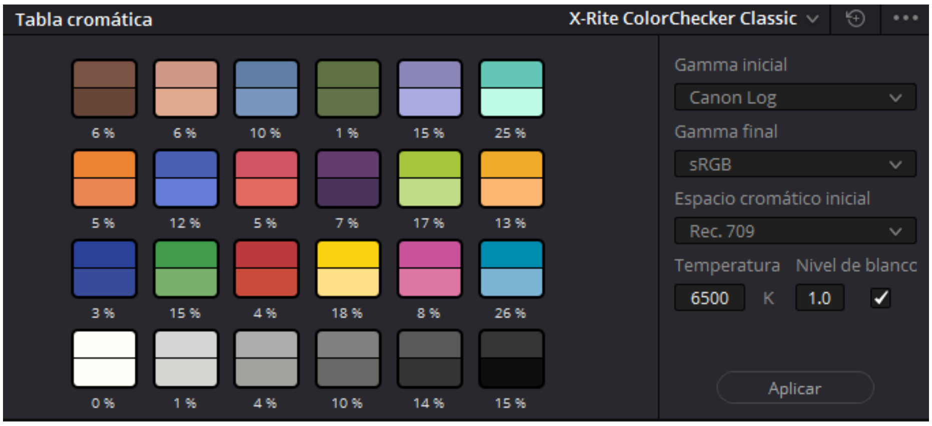


Figure 11. DaVinci Resolve Color Chart Settings.

8. This is a first correction applied to the video via the ColorChecker color chart. However, to be more precise, a couple of extra corrections can be applied to reduce the error as much as possible. Therefore, the next step is to go to the "Power Windows" option marked in figure 8, which would be tab number 10, marked in red in figure 12. In this new screen, we choose the function marked with a red box also in figure 12, which will allow us to select a part of the video image. Then, in the video image, we select the samples of the 3rd row of the color chart, as shown in figure 12. These samples represent the six basic colors, which will be adjusted in the next step.

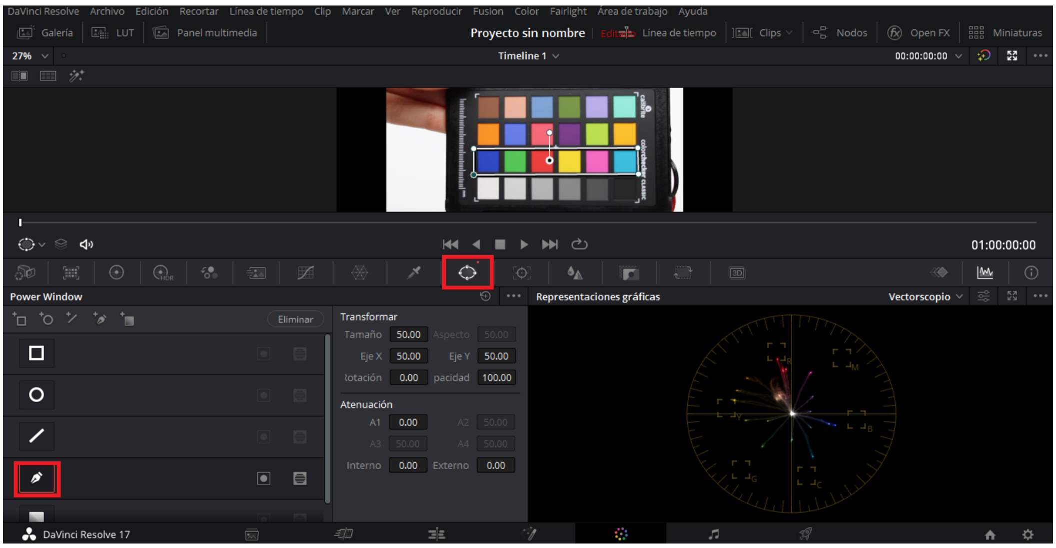


Figure 12. Selection of the six primary colors in DaVinci Resolve color chart.

9. Next, click on the highlight function, marked in red in figure 13. In this way, only the 6 primary colors marked are kept, in order to adjust them correctly. In the graphical representation figure, we can see how each primary color falls into the vectorscope. For each color to be the real one, it must fall within the squares of the graph. Therefore, the final correction will be to introduce each primary color in these squares.

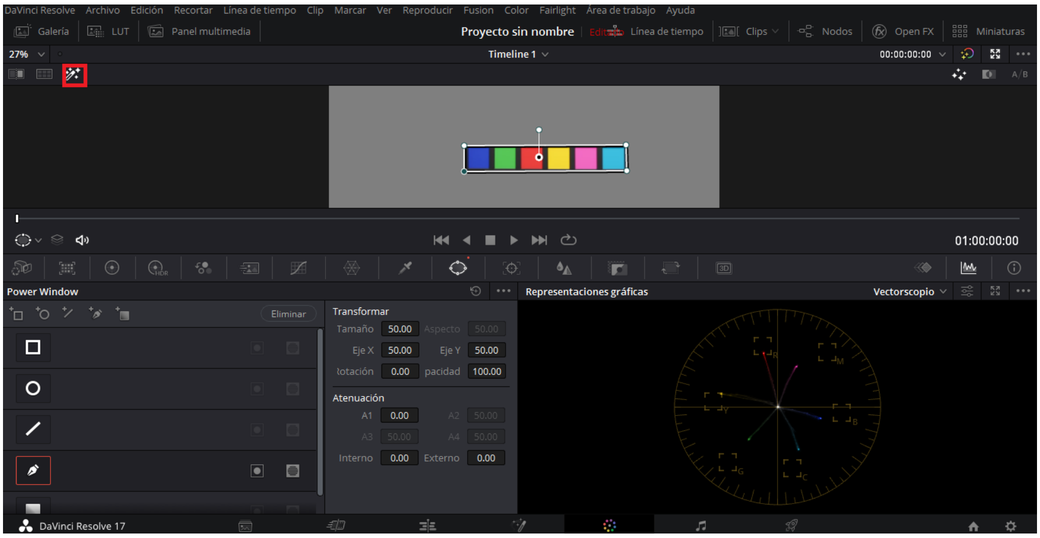


Figure 13. Highlight 6 primary colors in chart color DaVinci Resolve.

10. The next step is to go to the 7th tab, called "Curves", marked in red in figure 14. In the second graph (Hue vs. Hue), all the points located at the bottom left are pressed, and these points appear on the graph, each representing a primary color. These points have to be moved up or down, so that, in the vectorscope, the points of each color are aligned with their corresponding box.

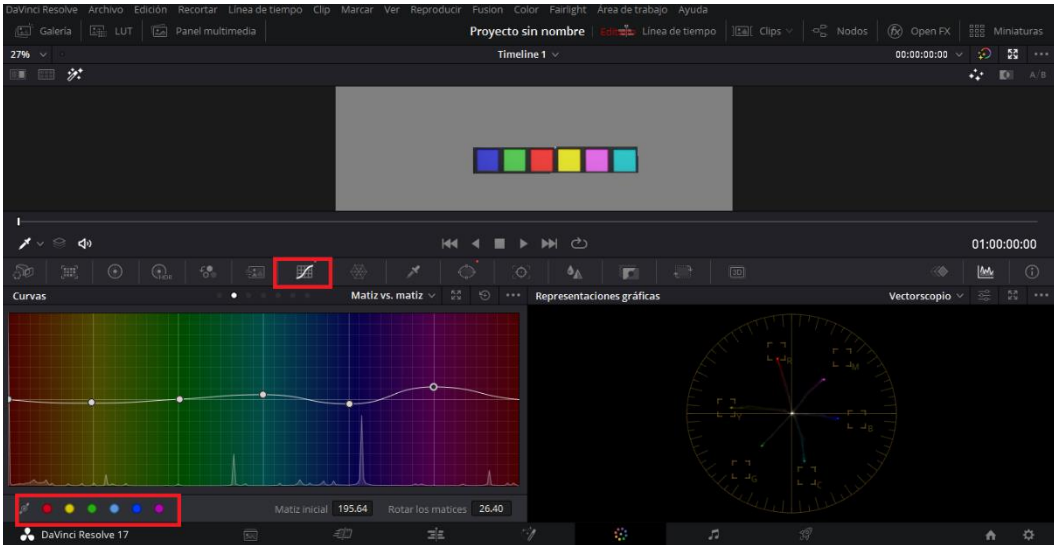


Figure 14. Curve adjustment "Hue vs Hue" in DaVinci Resolve.

11. In the "curves" option, in the "hue vs. saturation" curve, click again on all the points, which identify each color, at the bottom left. In the graph, move them up or down until, in the vectorscope, the points of each primary color are located inside their corresponding box, as shown in figure 15.

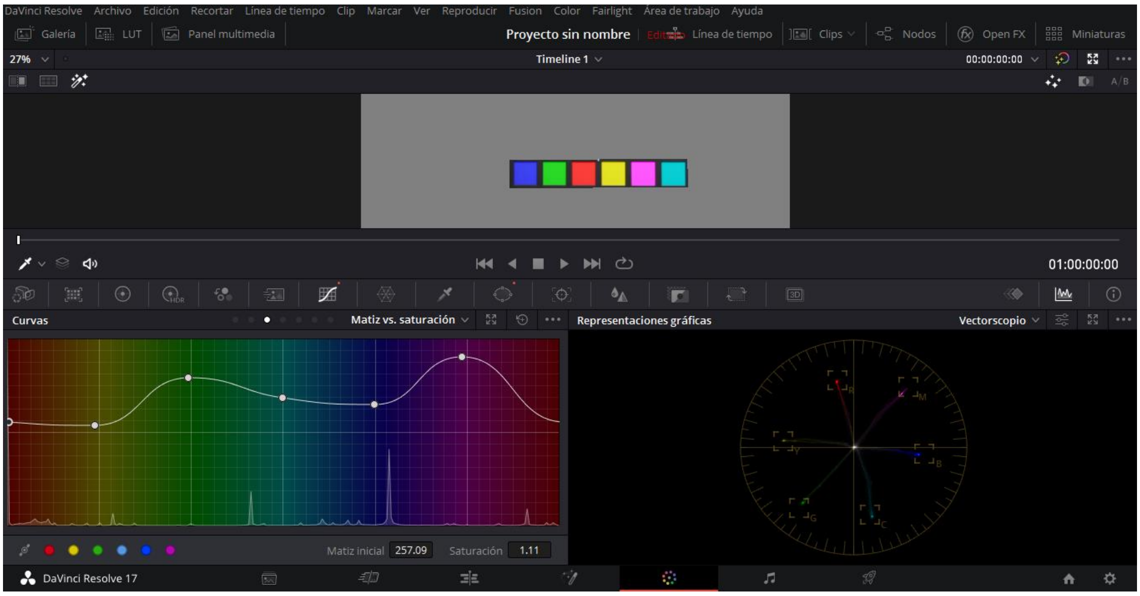


Figure 15. Hue vs. saturation curve adjustment DaVinci Resolve.

12. Go back to the "Power Window" option and click on the function marked in figure 12 to remove the function. We would now have this video completely corrected and the colors displayed would have the correct color coordinates. This video is the one that will be used as a filter for the videos that are run under the same lighting conditions and camera settings. Therefore, a different file should be saved each time lighting conditions or camera settings are changed.

13. Once a new video to be corrected has been created, the first step is to open the previous "filter" corrected file. In the "Color" option, where we were in figure 8, at the top, click on the "NODES" function, which opens a screen like the one shown in figure 16.

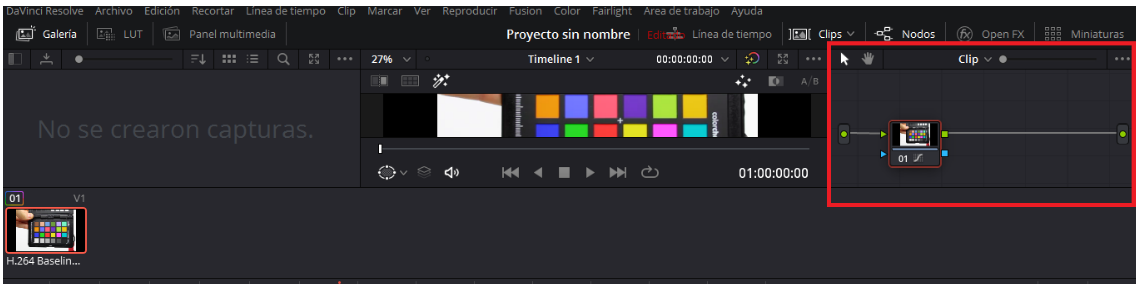


Figure 16. DaVinci Resolve Nodes screen.

14. Pressing on the main node with the mouse right button, add a node in series (always in series, so that the changes made in this first node are transferred to the video to be corrected). In this new node, the video to be corrected is added and finally downloaded.

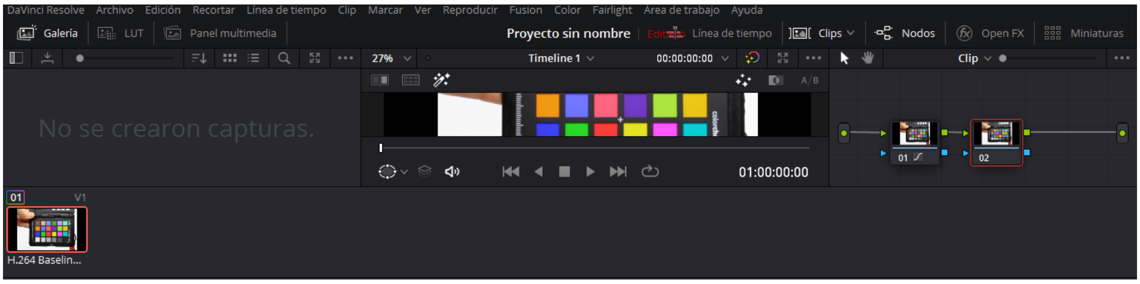


Figure 17. Nodes in series to make new video corrections.

Thus, once the base file has been created for each lighting conditions and camera settings, correcting new images or videos is a quick and agile process. These corrected images and videos will be the ones that can be used for the transmittance spectra acquisition system created.

2. Transmittance spectra acquisition system.

The developed system is a spectrophotometer that can obtain transmittance spectra in the visible range from digital images or videos. To do that, it generates a whole spectrum from their corresponding three color coordinates (thus the need to work with “real” color coordinates, obtained through the process described in the previous section). The process of generation (reconstruction) of the spectra is based on a neural-network, developed in Python language. One of the programming environments offered by the Anaconda application has been used, in particular Spyder, although the programmed script can be run in similar environments. However, this must be local; it cannot be run online in environments such as "Colab", as some of the libraries used will not work, such as "Tkinter", which is necessary to create the interface. The script and all necessary documents and files related to the program are located in “github” in the following link:

https://github.com/antoniocs11/Spectrophotometer.git

The following subsection 2.1 describes the libraries needed to run the script, while subsection 2.2 describes the user interface created and instructions to use it as a spectrophotometer.

2.1. Spyder software and required libraries.

To open the corresponding programming environment, first download the "Anaconda" application (select the last version), available at the following address: https://www.anaconda.com/download , selecting your computer's operating system. Once installed, a set of programming environments are pre-installed, such as "Jupyter Notebook", "Spyder", "RStudio", and so on. In our case, "Spyder" will be used.

Before loading the system-related script, a set of extra libraries must be installed, as only some of them are installed by default. Below are the set of all libraries used and code to install them:

import cv2

import os

import datetime as dt

import pandas as pd

import numpy as np

from skimage.io import imread

from skimage.color import rgb2lab, lab2rgb

import matplotlib.pylab as plt

import tensorflow

import joblib

from keras.models import load_model

from matplotlib.backends.backend_pdf import PdfPages

from matplotlib.backends.backend_tkagg import FigureCanvasTkAgg

from matplotlib.pyplot import figure

*from tkinter import **

from pathlib import Path

from tkinter import filedialog

from PIL import Image

from colormath.color_objects import LabColor, sRGBColor

from colormath.color_conversions import convert_color

from scipy import signal

import csv

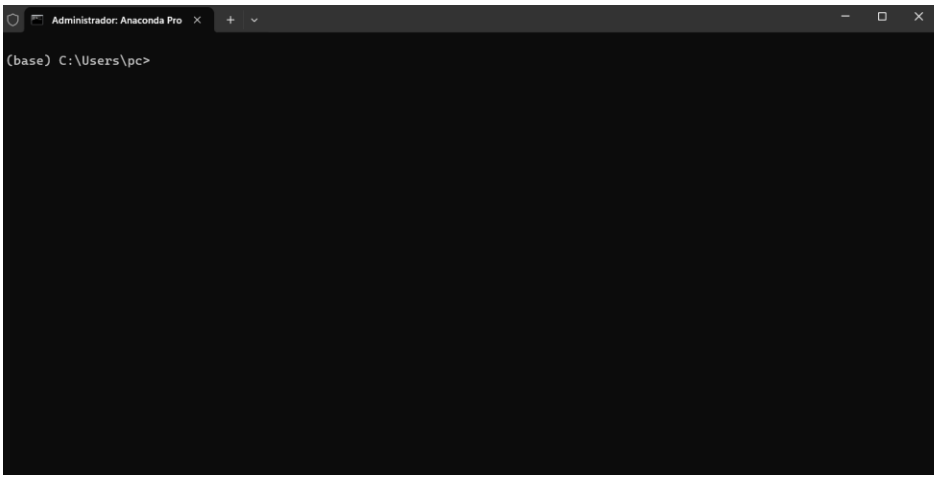
from tkinter import messagebox

import tkinter as tk

import matplotlib.colors as mcolors

The vast majority of libraries are installed by default when installing anaconda software. However, there are several that must be installed manually. Regarding the ones used in this particular script, "tensorflow", "colormath" and "opencv" must be installed manually. The steps are described below:

- All libraries are installed in “Anaconda prompt”, which comes pre-installed with Anaconda. Therefore, the first step is to open this window:



- “Tensorflow” library: this library is installed introducing the following command: “pip install tensorflow”.
- “Colormath” library: this library is installed introducing the following command: “conda install conda-forge::colormath”
- “Opencv” library: a file that includes this library must be downloaded. In the following link (https://www.youtube.com/watch?app=desktop&v=ZdMwt9ZZaSc) a video

explaining how the installation takes place is shown. During the installation process, the user will download a file including the desired library, which will be saved in a specific folder. Subsequently, in Anaconda Prompt, this file will be installed, implementing the "Opencv" library to the software.

Before opening the script and starting to run, it is necessary to save the file containing the neural network (Neural_network.h5) in the same folder where the program script is located.

2.2. User Interface.

When the script is executed, the interface shown in Figure 18 appears. There are six simple steps that the user will. Each one comprises, at the right side of the text area, a button with the letter "i" for information about that particular step.

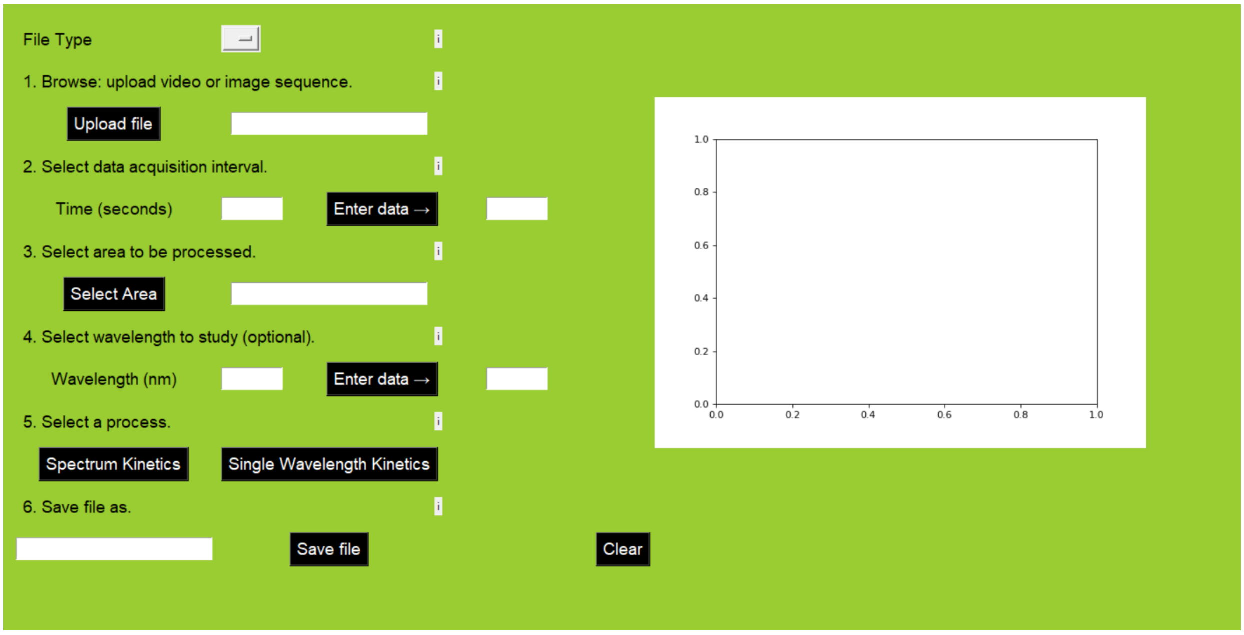
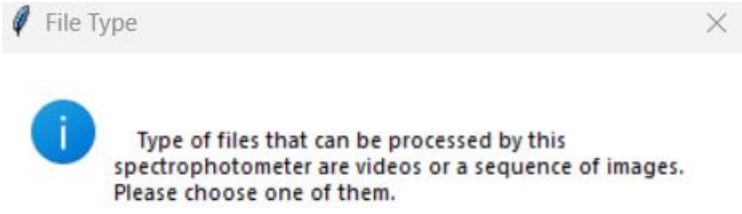


Figure 18. System interface created in Spyder.

FILE TYPE

The files that can be processed can be videos or image sets. The processing of these two type of files is different. Therefore, it is initially necessary to select which file type is going to be studied. First, click on the button that appears at the right of the text "File Type". The user can select either "video" or "Image_sequence":

The Info button will display this message when clicked:



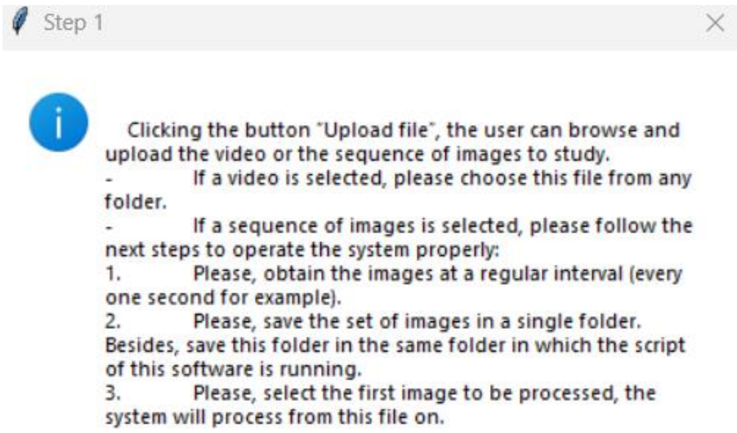
1. Browse: upload video or image sequence.

Clicking the button “Upload file”, the user can browse and upload the video or the sequence of images to study:

- If a video is selected, this file can be imported from any folder.
- If a sequence of images is selected, the folder where these images are located must be saved in the same folder where the script is located. The set of images to be processed is determined by selecting a specific image, The system will process the sequence of the files contained in the folder from this one on.

The path, where the selected file is located, will be shown in the interface:

In this step, the info button shows the following text:

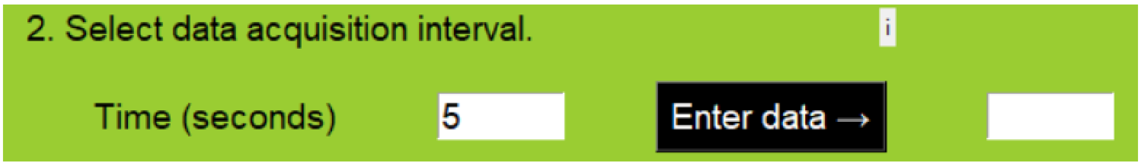


2. Select data acquisition interval.

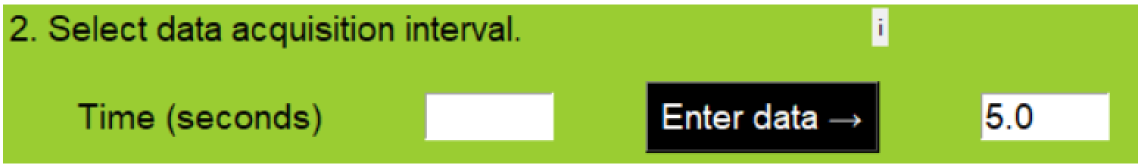
If video option is selected, the user will indicate the desired interval “t” (in seconds) for data processing. One frame every "t" seconds will be extracted from the video and processed.

If Image sequence is selected, the user will indicate the interval (in seconds) with which the images were taken.

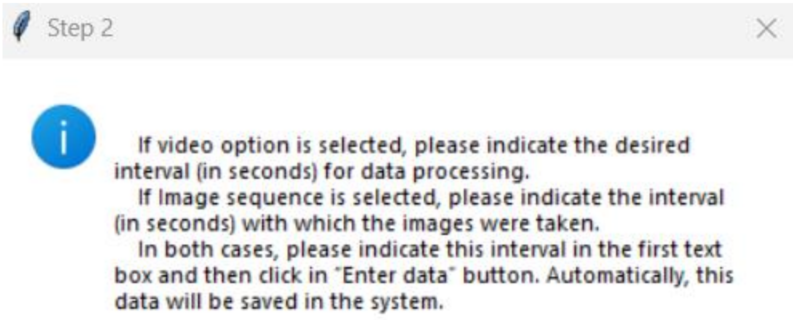
In both cases, please indicate this interval in the first text box.



Then, click in “Enter data” button and, automatically, this data will be saved in the system. This data will appear in the second text box of the line.



In this step, the button related to information shows the following text:



3. Select area to be processed.

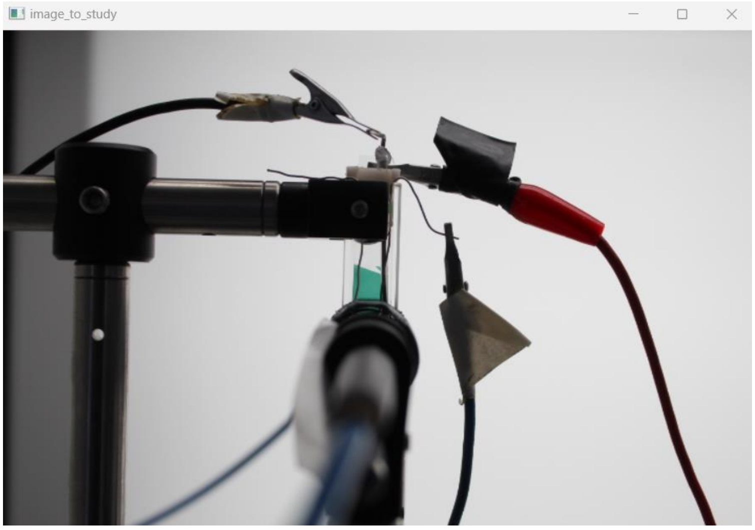
In first place, press the button “Select area”.

If the “video” option has been selected, note that the first step of the program will be the extraction of frames from the video. Simultaneously, it will save these frames in a folder called "data" that will be automatically created in the folder where the script is stored. Every time a new measurement is taken, the frames belonging to this folder will be automatically overwritten by the new ones. Due to this extraction intermediate step, this process could be slow (depending on the data acquisition interval selected).

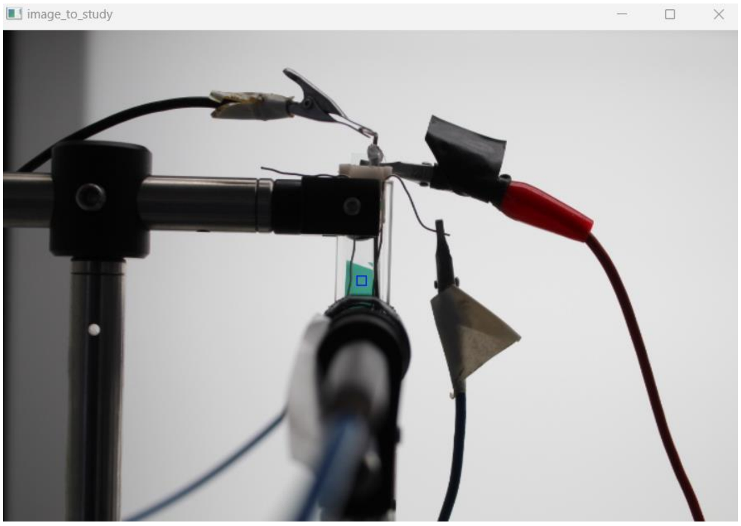
If “image_sequence” has been selected, the system will directly open the image selected by the user. Remember to store this folder in the same address where the script is located. This process is immediate and should not take long.

In order to select the image area to be studied (whether in video or image sequence option), please, press the button “Select area”. Then:

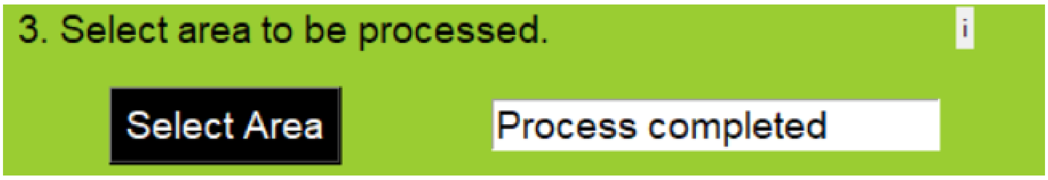
1. Wait until an image of the selected file appears in a pop-up window.



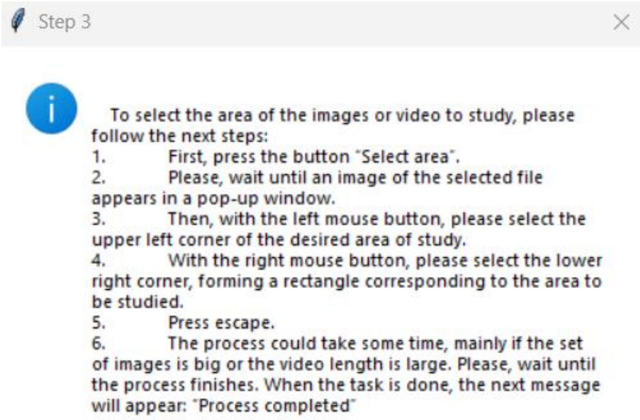
2. Then, with the left mouse button, select the upper left corner of the desired area of study.
3. With the right mouse button, please select the lower right corner, forming a rectangle corresponding to the area to be studied.



4. Press “ESC” key.
5. The process could take some time, mainly if the set of images is big or the video length is large. Please, wait until the process finishes. When the task is done, the next message will appear: “Process completed”.



In this step, the button related to information shows the following text:

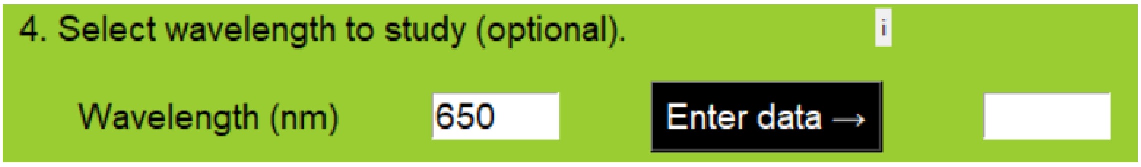


4. Select wavelength to study (optional).

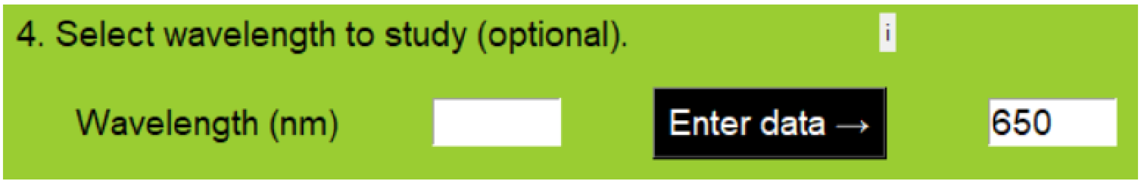
The experimental techniques available in this spectrophotometer comprise the transmittance spectrum kinetics in the entire visible range (**Spectrum kinetics**) or, on the other hand, single wavelength kinetics (**Single wavelength kinetics**).

Therefore, if the study of the obtained files is to be performed for a certain wavelength (**Single Wavelength Kinetics**), the user can specify this value in nanometers (between 400 and 700 nm). The value must be a multiple of 5.

The steps to introduce this variable are the following. First, the user will introduce this value in the first text box:

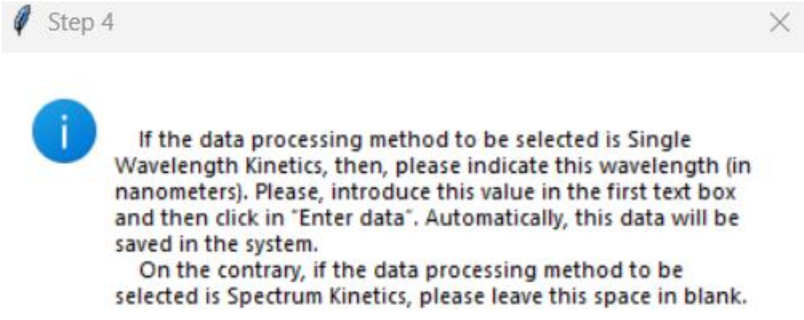


Next, clicking "Enter data" button, this data will be saved in the system. This data will appear in the second text box of the line.



If the data processing method to be selected is Spectrum Kinetics, please leave this space in blank.

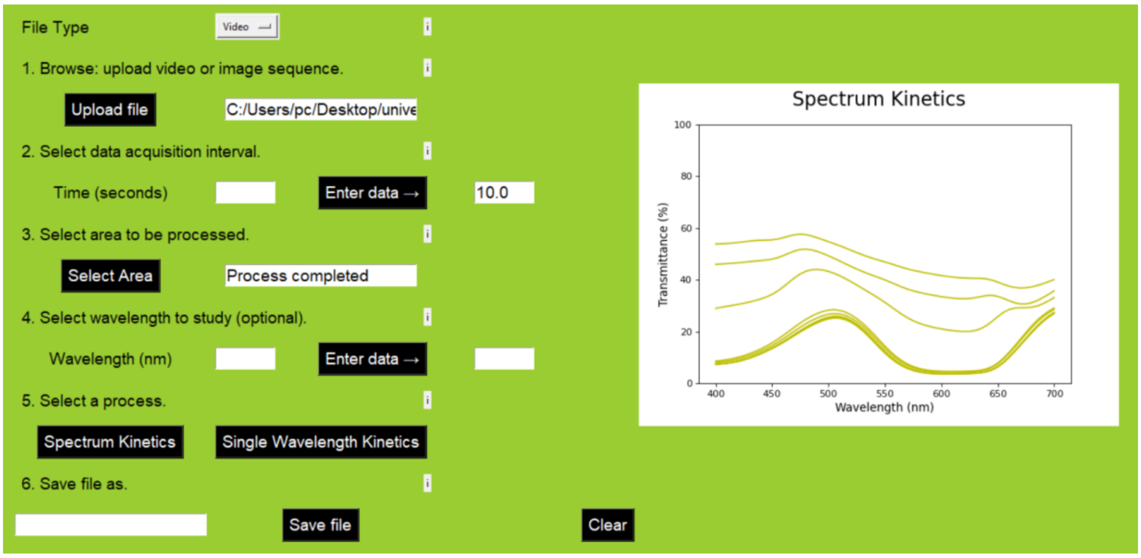
In this step, the button related to information shows the following text:



5. Select a process.

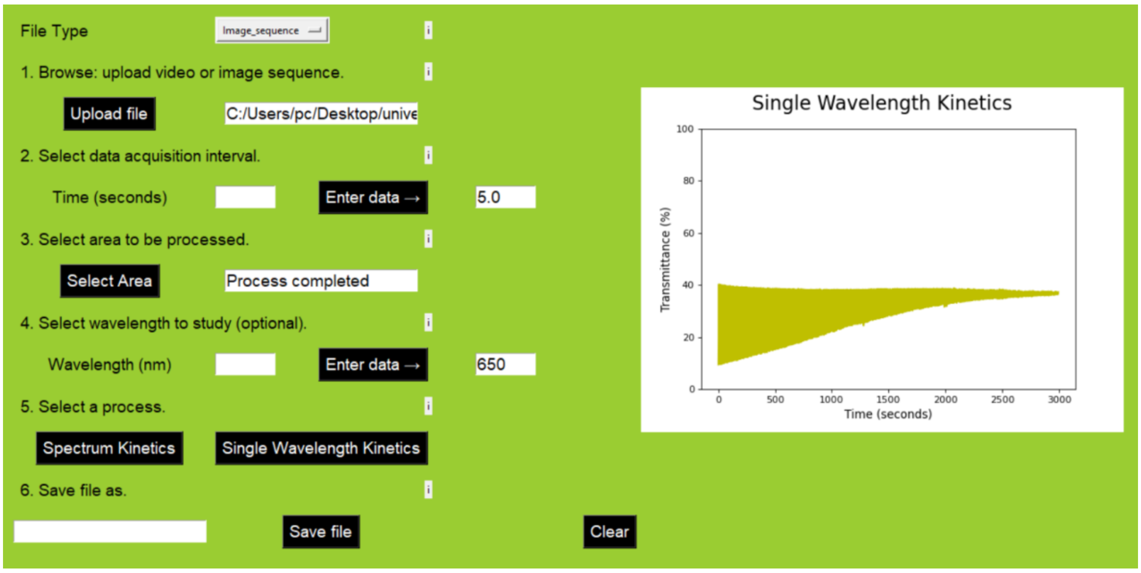
As mentioned previously, two different experimental techniques can be selected by clicking the corresponding button:

1. Spectrum kinetics: Transmittance spectra in visible range of the selected area will be shown in one graph. If a video file has been processed, a set of spectra (one spectra every “t” seconds, being “t” the previously defined “data acquisition interval”) will be displayed in the graph. If a sequence of images has been processed, a set of spectra (one spectrum per image) will be displayed in the graph.
   This process will be finished when the graphical result of the process is shown in the interface graphic. Thus, the final result offered by the spectrophotometer can be visualized before saving the resulting file.



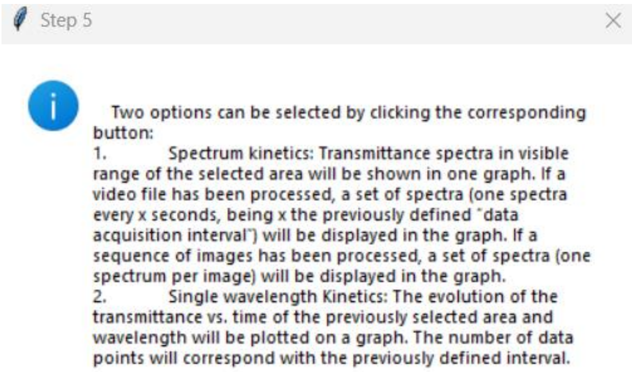
2. Single wavelength Kinetics: The evolution of the transmittance vs. time of the previously selected area and wavelength will be plotted on a graph. The number of data points will correspond with the previously defined interval.

   This process will be finished when the graphical result of the process is shown in the interface graphic. Thus, the final result offered by the spectrophotometer can be visualized before saving the resulting file.



The time required for these processes will be defined by the number of frames or images to be processed. Even so, it should be a relatively fast process.

In this step, the button related to information shows the following text:



6. Save file as.

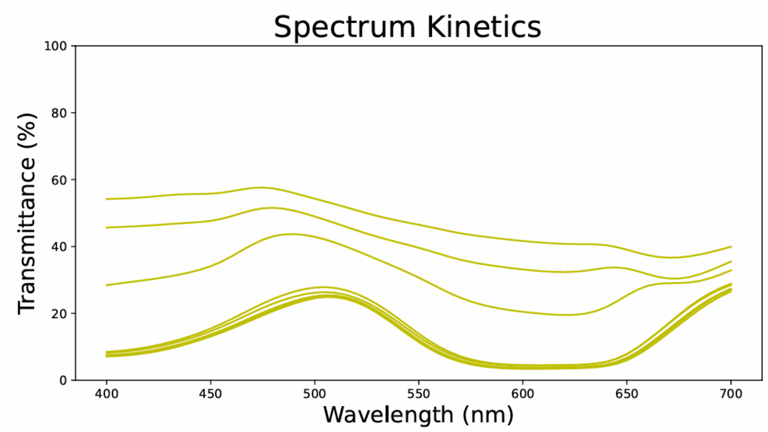
For properly saving the obtained results, please follow next steps:

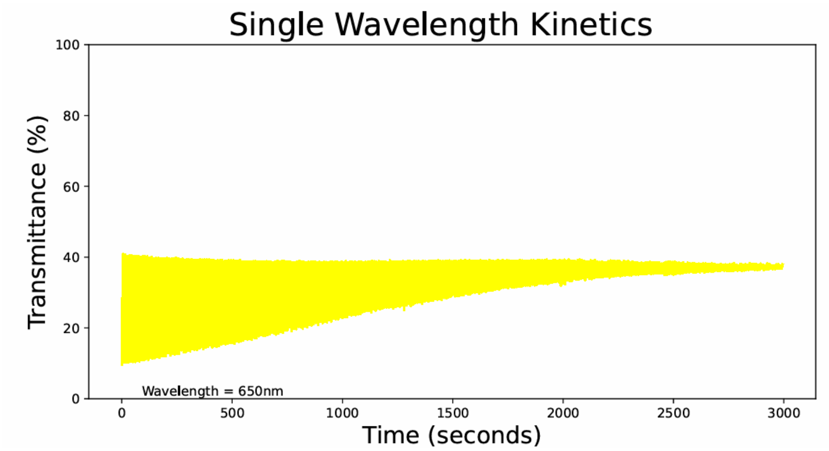
1. Introduce the desired file name in the text box.

2. Then, press the button "Save file". Data will be saved in the same folder in which the software script is. Three different format files with the same information will be created

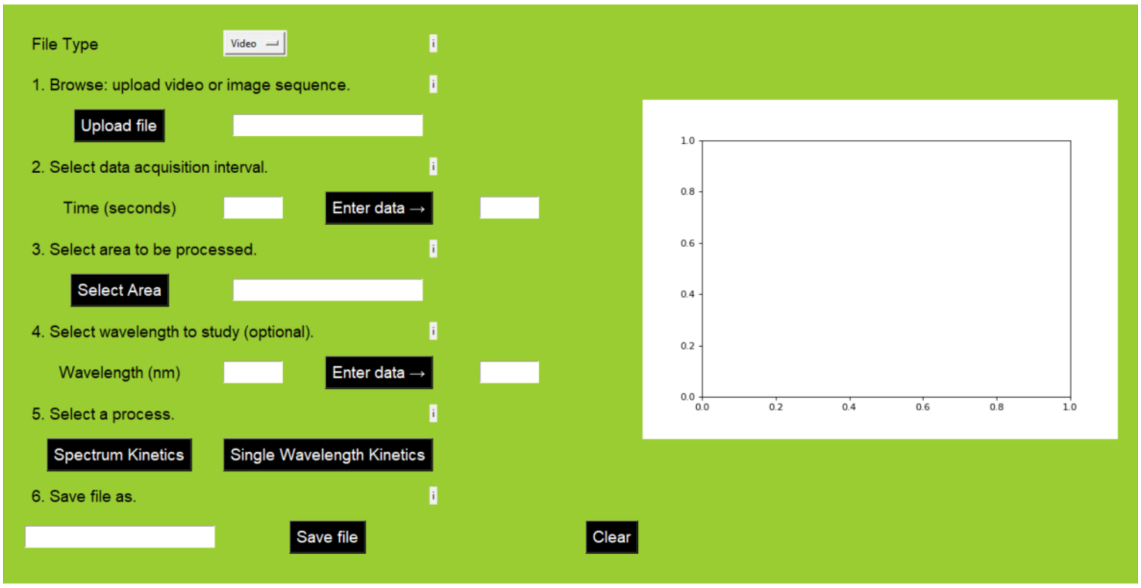
and saved: “.PDF”, “.TIFF” and “.csv”. When the task is done, the next message will appear: “Saved”:

Next, two graph results (in “PDF” format) are shown (one per method):

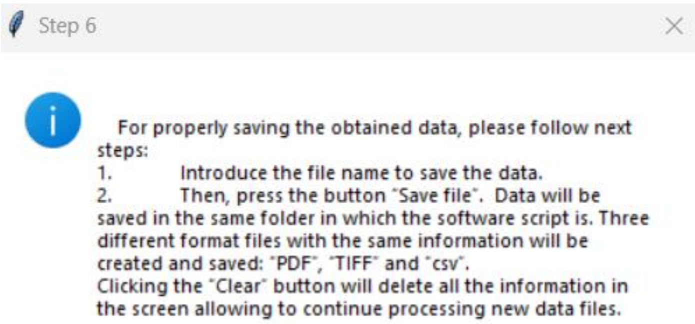




Clicking the “Clear” button will delete all the information in the screen allowing to continue processing new data files.



In this step, the button related to information shows the following text:



Enjoy your new spectrophotometer!