Abstract — The process of color recognition plays a central role in extracting information from the surrounding environment. Throughout the beginnings of mankind, this process has proved to be a preponderant factor in the quality control of textiles and consumables, as well as in the control of environmental parameters. With the increase in population and consequent industrialization, greater pollution control and environmental monitoring are necessary. However, this type of activity requires the handling of expensive equipment with complex and time-consuming procedures. The introduction of smartphone and its global success marked a turning point in the development of new environmental monitoring methodologies. Due to their set of sensors and smartphones software can be applied in colorimetric and spectrometric practices. With this objective, a hypothetical solution is proposed for the use of the smartphone as a low cost colorimetric sensor. This work presents the state-of-the-art of the first practices of colorimetry until the inclusion of smartphones in this field. Following this field it is presented the implementation adopted for colorimetric studies using a smartphone. An analysis of the performance of smartphone is made for solutions of various colors and concentrations. The main objective is to test the performance of the implemented solution for the various scenarios simulated by the usage of alimentary dyes and daily life liquids, such as coffee, wine, and fruit juices.

Keywords — Colorimeter, Smartphone, Colorimetry, Quality analysis, Wine, Coffee, Fruit Juice.

I. INTRODUCTION

Color recognition is a process present in human daily lives, that is made almost involuntarily and without self-consciousness. Nevertheless, it represents a major role concerning to extract information about the surrounding environment.

Over the years colour recognition has played a major role in the textile, food and dye industries, constituting one of the main metrics for product quality analysis. Colorimetric studies are also applied in study fields such as environmental monitoring and food safety, biological monitoring, among others. With the population increase, industrialization, and consequent pollution, it is very important to conduct colorimetric studies to monitor the environment to ensure the safety of populations and their ecosystems [1].

However, most of the times this kind of studies involve specialized and expensive equipment, such as colorimeters and spectrometers, that require time-costly procedures and specialized trained personnel [2].

The introduction and widespread of smartphone among the global population marked a turning point in what concerns to colorimetric studies and sensing platforms [3], [4].

Due to mass production of consumer electronics devices and market competition has provided users with cost-effective, compact, and high-performance products with high-end components including digital cameras, graphics processing units, and various sensors. This opened up the opportunity for researchers, and even citizen scientists, to develop novel imaging, sensing, and diagnostics platforms using smartphones as an underlying platform [5].

This work aims to provide a simple colorimetric platform that can be applied to colorimetric quality control of consumable liquids, distinguished by its easiness of use, mobility, and simplicity.

The state of art of colorimeters can be split off into two main groups: the history of colorimeter’s evolution, and the exploitation of the smartphone as a colorimetric platform.

The first colorimetric studies where introduced by Wilhelm August Lampidus (1772-1882) in 1832. These studies were used to determine Niquel’s concentration and relied on color’s comparison of a reference solution and a test one. This kind of approach was time-consuming and did not offer enough precision for colorimetric studies. In 1854, based on Beer-Lambert Laws, Dubosq introduced the first colorimeter. This colorimeter allowed to compare the color of two solutions through a monocular, which marked a turning point in terms of colorimetric studies. However, Dubosq’s colorimeter and its derivatives still relied on a subjective comparison method to calculate the concentration of a solution. In 1933, was introduced the first photoelectric colorimeter, which allowed to perform more precise studies in the colorimetric field [6].

Despite the usefulness of colorimeters, there are some constraints related to its global access, i.e., time-consuming procedures, high prices, lack of mobility. The evolution of electronics technology and the introduction of smartphones would then mark a turning point in the creation of new methodologies in this sensory platform. In terms of colorimetry, there are already several studies performed with a smartphone as main colorimetric sensor. Among the colorimetric studies performed with smartphone it can be highlighted two main types of approaches. The first one consists on the detection of color changes of paper test strips with a smartphone. The second relies on the creation of extra hardware to attach to the smartphone [7]. The last approach allows to isolate the smartphone from external light sources perturbances.
In 2014 Ali K. Yetisen presented a smartphone algorithm with inter-phone repeatability for the analysis of colorimetric tests. The app transformed the smartphone into a reader to quantify commercial colorimetric urine tests with high accuracy and reproducibility in measuring pH, protein, and glucose. In this work, the authors provide an algorithm that allows to create a calibration curve based on reference test strips [8]. The calibration curve presented on the application is device independent.

In 2014 Qingshan Wei et al. presented an environmental study about spatial sapping of mercury contamination in water samples using a smartphone. For this purpose, the authors created an integrated opto-mechanical attachment to the built-in camera module of a smartphone to digitally quantify mercury concentration using a plasmonic gold nanoparticle (Au NP) and aptamer based colorimetric transmission assay that is implemented in disposable test tubes [9].

B. Dissertation objectives

The main objectives of this work can be summarized in the following topics:

- Development and implementation of a simple cost-effective colorimeter.
- Qualitative analysis of colorimeter’s performance
- Color differences detection according solution’s concentration.
- Proposal of calibration curves for practical cases of study;
- Detection of color differences in alimentary liquids;

II. THEORETICAL BACKGROUND

A. Basic colorimeter

The colorimeter is based on Beer-Lambert's law, according to which the absorption of light transmitted through the medium is directly proportional to the medium concentration. The typical (simplified) structure of a colorimeter contains a light source, light’s aperture, color filter, a sample holder and a photovoltaic cell. In a colorimeter, a beam of light with a specific wavelength is passed through a solution via a series of lenses, which navigate the colored light to the measuring device. This analyzes the color compared to an existing standard solution. A microprocessor then calculates the absorbance or percent transmittance. If the concentration of the solution is greater, more light will be absorbed, which can be identified by measuring the difference between the amount of light at its origin and that after passing the solution [10].

B. CIE color space

In order to obtain a color mixture that covers the entire visible wavelength area the CIE introduced in 1931 the CIE XYZ color space. The X, Y, Z values do not represent any physical spectral distribution and can be obtained by the following expressions [11]:

\[ X = k \int_{\lambda_{\text{min}}}^{\lambda_{\text{max}}} \phi(\lambda) \bar{x}(\lambda) \, d\lambda \]  
\[ Y = k \int_{\lambda_{\text{min}}}^{\lambda_{\text{max}}} \phi(\lambda) \bar{y}(\lambda) \, d\lambda \]  
\[ Z = k \int_{\lambda_{\text{min}}}^{\lambda_{\text{max}}} \phi(\lambda) \bar{z}(\lambda) \, d\lambda \]

Where \( \phi(\lambda) = S(\lambda) \cdot T(\lambda) \) or \( \phi(\lambda) = S(\lambda) \cdot R(\lambda) \). \( S(\lambda) \) represents the spectral distribution of the signal. \( T(\lambda) \) and \( R(\lambda) \) are the transmittance and the reflection factors. The \( \bar{x}(\lambda) \), \( \bar{y}(\lambda) \) and \( \bar{z}(\lambda) \) are the color matching functions from CIE presented in Figure 1.

![Color matching functions from a standard 2º observer.](image)

The \( k \) value is a constant value obtained by the following expression:

\[ k = \frac{100}{\sum \lambda S(\lambda) \bar{y}(\lambda) d\lambda} \]

C. RGB color space

The RGB color space is an additive color space based on RGB color model. One of the most common RGB color spaces is the sRGB, and it is the color space used for the experience. The linear RGB color space can be obtained from the CIE XYZ by the following expression [12]:

\[ \begin{bmatrix} r \\ g \\ b \end{bmatrix} = \begin{bmatrix} 3.240 & -1.537 & -0.499 \\ -0.969 & 1.886 & 0.042 \\ 0.056 & -0.204 & 1.057 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \]

Where the r, g, and b represent the red, green and blue channels. Considering that V represents the sRGB channels and v the linear RGB channels, the conversion from linear RGB to sRGB can be made by the following expression [12]:

\[ V = \begin{cases} 12.92 \times v & \text{if } v < 0.00313 \\ 1.055 \times v^{1/2.4} - 0.55 \text{ c.c} \end{cases} \]
D. HSI color space

The HSI color space is a color representation based on human color perception. The coordinates for this color space can be obtained from RGB linear color space by the following expressions [12]:

\[
H = \begin{cases} 
\delta & \text{if } B \leq G \\
360^\circ - \delta & \text{if } B > G 
\end{cases} 
\]  
(7)

\[
\delta = \cos^{-1} \left( \frac{0.5 \times (R - G) + (R - B)}{\sqrt{(R - G)^2 + (R - B)(G - B)}} \right) 
\]  
(8)

\[
S = 1 - \frac{3}{(R + G + B)} \times \min(R, G, B) 
\]  
(9)

\[
I = \frac{1}{3} \times (R + G + B) 
\]  
(10)

Where the H variable represents the Hue, S the saturation and I the Intensity. This color space is also considered as a cylindrical representation of color due to its coordinates.

III. COLORIMETER IMPLEMENTATION

A. General Description

The main objective of the experimental setup is to provide a cost-effective colorimeter accessible to the common population. The colorimeter has as main components a 3-D printed attachment, an iPhone 4, and plastic fiber optics fixed on a sample holder. The choice of the iPhone was made due to his simple exterior form and its high-quality optical components (flash and camera). The 3-D printed attachment can be easily fixed to the smartphone and support the optical fiber attached to the sample holder, as presented in Figure 2. It has two circular apertures, one pointing to the camera and the other to the LED of the smartphone. The circular apertures allow to fix the optical fiber and create an optical circuit between the camera and the LED. Although, is also possible to use another external light source to create an optical path. For that, it is only necessary to point the optical fiber responsible to conduct the optical signal to the desired light source.

B. Color Sensor

The experimental setup uses the camera onboard an iPhone for color determination. The use of the smartphone’s camera mitigates the need for the usage of other hardware to detect color differences from the optical signals. Once it is not possible to control the camera’s software it is important to note that the camera has features such as exposure compensation, auto-focus, and white balance, which mimic the human eye but are detrimental in terms of color measuring. The color measuring is also dependent on the spectral sensitivity of the iPhone’s camera, presented in Figure 3.

![Image](image_url)

Figure 3 - Spectral Sensitivity of iPhone's camera [extracted from [3]]

The spectral sensitivity is considered for a qualitative analysis during the experimental work.

C. Material for the colorimetric study

For the colorimetric studies, it was chosen food dye and some consumable liquids, like coffee and fruit juice. The main reason for this choice is based following facts:

- Accessibility for the general population;
- Easy and time-effective procedure to prepare solutions;
- Preparation of solutions with different colors and concentrations;
- Simulation of hypothetical scenarios;

The food dyes are available in three colors: red, yellow and blue. Mixing the three types of dyes it is possible to create several solutions of different colors and adapt them to the proposed colorimeter. The hypothetical scenarios simulated with dyes consisted on the simulation of coffee and wine colors. At the end of the experience, it is also used, coffee, fruit juices, and wine.

D. Light Sources

One of the principal components of a colorimeter is the light source. In this work, two different light sources are used for different purposes. The first light source is the LED present on the iPhone. The usage of smartphone’s LED has as main scope the mobility and independence of the sensor, allowing to perform colorimetric studies in point of care situations. Although the software in the camera does not allow to control LED’s light intensity. This issue represents a constraint to the kind of colorimetric study to perform in terms of risk of camera’s saturation. The use of the LED of the smartphone has
as main scope the mobility and independence of the sensor, allowing to perform colorimetric studies in remote areas. However, the software of the camera does not allow you to control the light intensity of the LED. This problem represents a restriction on the type of colorimetric study to be performed since not all solutions have the same level of transparency. There so, for solutions that present some level of transparency, there is a huge risk of saturation of the camera’s sensor. To reduce the risk of the camera’s saturation it is used the light LED lamp. The objective is to readjust the distance of the lamp to the optical fiber in order to avoid sensor saturation. Another relevant topic about the colorimetric studies is the spectral composition of the light sources. The information about the absorbance of the spectrum is essential to understand if the results obtained with the smartphone are valid for the related experience.

For that purpose, the spectral composition of iPhone LED, presented in Figure 4, and the LED lamp present in Figure 5 were measured with S09500 Oceanview spectrometer. In both figures, it is noticeable that both light sources present different spectral distributions.

The videos and photographs are then transferred from the camera phone to a personal computer and analyzed using custom software developed in the MATLAB (MathWorks Inc.) environment. Using MATLAB it is possible to extract all frames present in the video and select the desired zone of interest with MATLAB crop toolbox. This selection reduces the size of the image which facilitates the post-processing. Image reduction is also an advantage in the cases where the smartphone performs all colorimetric image processing and necessary calculations for a calibration curve. The obtained images contain a colored circle resultant from the incident optical signal, as presented in Figure 7.

By inspecting the Figure 7 it is possible to notice that the image contains areas of different color intensity. This phenomenon is justified by the diffusion of the light beam when goes through the camera lenses. This means that not all circular color zones are useful for the colorimetric study. To overpass this issue, the image is then submitted to post processing in MATLAB. This post processing consists in the following steps:

1. Image conversion from sRGB to CIE Lab color space;
2. Image color segmentation with kmeans++ algorithm present on Statistics and Machine Learning of MATLAB;
The k-means++ algorithm is an iterative, data-partitioning algorithm that assigns n observations to exactly one of k clusters defined by centroids. The k is a predefined number chosen before the algorithm starts. In this context, the number of clusters will represent the number of different colored areas. Considering that the obtained images have four areas with different color intensities, it was considered four clusters for color separation. Then, the three best clusters are selected to calculate the median RGB value of the optical signal. The obtained RGB values are then converted to the normalized RGB and HSI color spaces.

To validate the results obtained by the smartphone, it was used the Oceanview S09500 spectrometer, to measure the spectra of the transmitted signals with a resolution of 1024 pixels and an integration time of 10 seconds. Then, the experimental data were interpolated to the spectral region between 380 and 720 nm with a spectral step of 5 nm. From the spectral data, it was possible to calculate the CIE XYZ color coordinates and converting them to the RGB color space.

IV. EXPERIMENTAL RESULTS

A. Experiments with an integrated light system

The first experiments consisted of the analysis of the response of the colorimeter to solutions with different concentration prepared with the red and the blue dye. One of the main objectives of the experiments is to analyze the limitations imposed by the different types of spectral absorptions of the dyes. The experimental procedure consisted on the acquisition of the transmitted optical signal with the iPhone 4 and a spectrometer for the solutions of different concentrations. For that purpose, it was prepared a red and a blue solution with 4 mL of water and 0.1 mL of dye each. The concentration of the initial solutions was increased by adding 0.1 mL of dye between each data acquisition. The procedure was stopped when the iPhone could not detect any color differences between the previous assay. In Figure 8 are displayed the values of the normalized value of RGB channels obtained to the experience with the blue solution.

The Figure 8 shows that the blue and red channels of both color measurement systems exhibit a linear response with the increase of dye’s concentration. Hence there was applied a linear fit to the iPhone channels to demonstrate that the channel’s response can be modulated by a linear function. The obtained expressions are presented in Table I.

Table I – Analytical functions that describe the response of the normalized values in function of a solution’s concentration. F represents Vc/Vt. The variables g and b represent the normalized values of green and blue channels.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Model</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>$g = 2.2309 \times F + 0.5369$</td>
<td>0.95</td>
</tr>
<tr>
<td>Blue</td>
<td>$b = -2.1718 \times F + 0.4482$</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Considering the $R^2$ values present in Table I it can be assumed that linear functions can be a good approach to create a calibration curve for this kind of solution.

Applying the same procedure for the red dye, it was obtained results are presented in Figure 9.

From the results presented in Figure 9, it is possible to conclude that the values obtained with the spectrometer do not present any variation with the increase of dyes concentration. On the other hand, the iPhone presents a slight variation for the first three assays. The difference observed from the results of the spectrometer and the iPhone can be justified from the loss of information during the calculation processes and the color corrections applied by the camera’s software. Therefore, for this dye, it was not possible to establish a reliable calibration curve.

B. Experiment with different color solutions:

The main purpose of this experiment is to demonstrate that the camera of the iPhone can detect optical signals resulting from the transmission of different color solutions. The obtained results are shown in Table II.
The variables \( r, g, b \) represent the camera’s saturation.

The conducted experimental studies consisted in the analysis of the response of normalized channel values of iPhone as a function of a solution’s concentration. For the experimental work it was prepared a brown and violet solutions. These two solutions were then submitted to a gradual dilution until the camera’s saturation. To dilute the initial solutions, 5 mL of water were added between each data acquisition. These experimental assays focused on the simulation of colorimetric study of coffee and red wine. In the Figure 11 are presented the results obtained for the study of a brown solution.

![Figure 11 - Response of iPhone normalized channel values to concentration decrease of brown solution. The variables \( r, g, b \) represent the normalized red, green and blue channels.](image)

The data presented in Figure 11 demonstrates that the green and red channels present a regular symmetric response with the decrease of solution’s concentration. As expected, the normalized values of the channels will stabilize and tend to the saturation limit of the camera’s sensor. Due to the occurred spectral absorbance, the blue channel presents values are close to zero for all the experiences. There so, in future work, only the green and red channels can be considered for calibration curves for colored brown type solutions.

For the violet solution, the obtained results are presented in Figure 12.

![Figure 12 - Response of iPhone normalized channel values to concentration decrease of violet solution. The variables \( r, g, b \) represent the normalized red, green and blue channels.](image)

As seen in Figure 12 the normalized channel values exhibit a regular response to the increase of the dilution factor. Analogously to the previous experience, as the concentration of the solution decreases, the red and green channels tend to the saturation values of the camera sensor. On the other hand, the blue channel presents a slight variation with concentration.

<table>
<thead>
<tr>
<th>( C_r )</th>
<th>( C_y )</th>
<th>( C_b )</th>
<th>Color</th>
<th>R</th>
<th>G</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02</td>
<td>0</td>
<td>0</td>
<td>Red</td>
<td>234</td>
<td>50</td>
<td>67</td>
</tr>
<tr>
<td>0.07</td>
<td>0</td>
<td>0</td>
<td>Darker red</td>
<td>228</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>0.02</td>
<td>0.02</td>
<td>0</td>
<td>Orange</td>
<td>240</td>
<td>157</td>
<td>0</td>
</tr>
<tr>
<td>0.014</td>
<td>0.011</td>
<td>0.003</td>
<td>Brown</td>
<td>244</td>
<td>215</td>
<td>1</td>
</tr>
<tr>
<td>0.016</td>
<td>0</td>
<td>0.025</td>
<td>Yellow</td>
<td>228</td>
<td>242</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>0.013</td>
<td>0.01</td>
<td>Green</td>
<td>29</td>
<td>244</td>
<td>34</td>
</tr>
<tr>
<td>0</td>
<td>0.02</td>
<td>0.05</td>
<td>Sea Green</td>
<td>246</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0.02</td>
<td>Light Blue</td>
<td>8</td>
<td>203</td>
<td>253</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0.11</td>
<td>Blue</td>
<td>2</td>
<td>62</td>
<td>253</td>
</tr>
<tr>
<td>0.016</td>
<td>0</td>
<td>0.025</td>
<td>Violet</td>
<td>216</td>
<td>148</td>
<td>243</td>
</tr>
</tbody>
</table>

As observable in the Figure 10, for the different colors, the coordinates \( H \) are relatively distanced from each other. With this fact, it can be concluded that the developed colorimeter can be applied to colorimetric studies that require the detection of a large gamut of colors, such as the colorimetric pH assays.

C. Experiments with an external light source

As referred before, it is impossible to control the intensity of iPhone 4’s LED light due to present software. To overcome this restriction, it was used a LED lamp in order to control light’s intensity through the adjustment of the distance of the lamp to the optical fiber. The main purpose of the usage of the lamp is to allow the study of solutions that exhibit a certain level of transparency.

The results presented in the Table II were then converted to HSI, in order to provide a better understanding of color variation. The Figure 10 presents the experimental \( H \) color coordinates displayed in a HSI color chart.

![Figure 10 - \( H \) coordinates displayed in a HSI color chart plane.](image)
decrease, which allows to conclude that this channel can be not considered for the implementation of calibration curves for these type of solutions.

D. Coffee experience

After the results of the previous sections, it has been proved that the implemented colorimeter is able to perform colorimetric studies that involve color detection based on the solution’s concentration. Thus, the next experience consisted on the analysis of color changes due to the increase of coffee concentration. The assay was performed by first adding 4 grams of coffee in 100 mL of water. To increase the initial solution’s concentration, it was added 2 grams of coffee between each data acquisition. In the end, it was added a total of 18 grams of coffee to 100 mL of water.

After processing the obtained images and proceeding to the normalization of RGB values, were obtained the graphics present in Figure 13:

![Normalized channel values vs concentration](image)

Figure 13- Response of the normalized RGB to the increase of coffee concentration. Where r, g, and b represent the normalized red, green and blue channels.

The results presented in Figure 13 show that the red and green channels exhibit the largest sensitivity to the color change of the optical signal. Despite having small variations of green and red channels, it can be considered that they exhibit a linear response with the increase of coffee’s concentration. Considering this kind of response, it was applied a linear model fit function to the extracted data. The expressions obtained and $R^2$ are present in the Table III.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Model</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>$r = 0.0043 \times C + 0.4765$</td>
<td>0.972</td>
</tr>
<tr>
<td>Green</td>
<td>$g = -0.0043 \times C + 0.4765$</td>
<td>0.972</td>
</tr>
</tbody>
</table>

Another approach that allows to determine a calibration curve is the representation of the quotient between the red and green channels as a function of the coffee’s concentration. Applying this method, it was obtained the graphic presented in Figure 14.

![Response of the quotient between red and green channels with respect to coffee’s concentration](image)

Figure 14 – Response of the quotient between the red and green channels with respect to coffee’s concentration.

Applying the best polynomial fit to the present data it was obtained the following expression:

$$Q = 0.0004 \times c^4 - 0.00143 \times c^3 + 0.1792 \times c^2 - 0.856 \times c + 2.7543$$

Where Q represents the quotient between the red and green channels, and c the concentration of coffee in (g/mL). For the equation 1 it was obtained a $R^2 = 0.9964$, meaning that, for this interval of concentration it can be applied a fourth-degree polynomial model that allows to calculate the coffee’s concentration with a low error.

For the last, the obtained RGB values were converted to the HSI color space. This color space also provides an intuitive representation of the color variation resultant from the transmitted signals, as shown in Figure 15.

![HSI Polar representation of the H values as a function of the coffee concentration](image)

Figure 15 – HSI Polar representation of the H values as a function of the coffee concentration.
The H response to the coffee’s concentration is also presented in a graph of Figure 16.

![Graph showing the H response to coffee concentration](image)

Figure 16 – Response of H coordinate to the coffee’s concentration.

Figure 16 shows that H variable presented a regular response to the increase of coffee concentration. Given this fact, it was also applied a polynomial fit to the obtained data, given by:

\[ H = 0.13 \times c^2 - 4.72 \times c + 45.29 \]  (2)

With a value of \( R^2 = 0.9977 \), H curve reached the best \( R^2 \) value among all the calibration curves suggested. Thus, for this concentration range, the calibration curve obtained from the variable H is potentially the best method to calculate the coffee concentration, and to offer a lower error.

E. Experience with red fruit nectars

“Anthocyanins are responsible for the brilliant red color and its different hues in many fruits and berries. Attractive color is one of the main sensory characteristics of fruit and berry products, and this important quality parameter strongly affects consumer behavior. Unfortunately, the color of red juices is unstable and easily susceptible to degradation leading to a dull, weak, and brownish juice color. The color stability of anthocyanins is influenced by pH, storage temperature, presence of enzymes, light, structure and concentration of the anthocyanins, and the presence of other berry compounds such as other flavonoids and phenolics” [13]. To prove that the implemented solution can be applied to the study of red fruit juices, a colorimetric study was performed with four different red juices, presented in Figure 17.

![Image showing four different red juices](image)

Figure 17- 1 – Red Fruit Nectar; 2- Plum nectar; 3- Classical Red Fruit Nectar 4- Grape nectar

From Figure 17, it is possible to observe that the presented juices exhibit similar colors. After applying the experimental procedure, it was obtained the results presented in Table IV.

<table>
<thead>
<tr>
<th>N°</th>
<th>R</th>
<th>G</th>
<th>B</th>
<th>Color of Optical signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>233</td>
<td>202</td>
<td>101</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>237</td>
<td>179</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>242</td>
<td>207</td>
<td>144</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>238</td>
<td>180</td>
<td>147</td>
<td></td>
</tr>
</tbody>
</table>

Table IV- RGB color values of the four juices presented in Figure 17. The first column represents the number of juice presented in Figure 17. The R,G,B columns are RGB channel values. The last column represents the associated color of the optical signal.

From the results presented in Table IV it is possible to conclude that the implemented solution can distinguish colors for the transmitted signals of the four juices. Converting the results presented in Table IV to the HSI color space, it is also possible to detect color differences for the obtained H values, as shown in the graph bar of Figure 18.

![Graph showing H values for the solution four juices presented in Figure 17](image)

Figure 18 – H values for the solution four juices presented in Figure 17.

With this experience, it was demonstrated that the implemented solution can be applied in quality control assays of red juices.

F. Experience with red wine

The color of red wine is associated with its maturation age and relative quality, being one of the most important parameters for the quality analysis. In general, wine color is the first characteristic that stands out in the eyes of the consumer, playing a key role in the consumer choice process, which tends to choose wines with stronger color and a lower subjective transparency level. "Phenolic compounds, which are responsible for the color of wines, are transferred from the skin and seeds of grapes and diffuse into the must and wine during the maceration stage. The bright red color of young wines is mainly due to free anthocyanins, self-association, and the pigmentation of anthocyanins with other phenols present in..."
these wines such as flavanols, flavonols and hydroxycinnamic acids” [14].

To prove that the implemented solution can be applied to colorimetric studies of red wines, an experiment was carried out with five different red wines. The wines differ by their year of production, price, wine grape varieties, maturation time, and recommended consumption time. The first two have a recommended consumption time between one and two years, the third between 3 years, and the last two should be consumed within 5 years of the production date. For the five wines, the obtained results are presented in Table V.


<table>
<thead>
<tr>
<th>Wine</th>
<th>R</th>
<th>G</th>
<th>B</th>
<th>Color of the optical signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>236</td>
<td>81</td>
<td>97</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>239</td>
<td>74</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>235</td>
<td>45</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>236</td>
<td>1</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>235</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

By the obtained results presented in Table V it is possible to conclude that colorimeter also can differentiate the colors of the different wines. The red (R) channel remains almost constant for the different wines. In contrast, the green (G) and the blue (B) channels present different values according to the type of wine. For this experience, it was also applied a color conversion from the values presented in Table V to HSI color space. However, the calculated H values did not present any noticeable variation. Therefore, the HSI color space did not provide any relevant information to correlate with the type of red wine studied. To provide a better understanding of the results, the values presented in Table V were converted to the normalized RGB color space and displayed in Figure 19 as a bar chart.

From the graph presented in Figure 19 it is noticeable that the wines that have a longer consumption period (IV, V), present higher values for the normalized red channel and almost null values for the green and blue channels. The other three wines (I, II, III), which have a lower recommended consumption period, present similar values for both three channels. This means that the normalized RGB values can be associated with the consumption period of the wine.

V. CONCLUSIONS

From the overall experience, it can be concluded that the implemented colorimeter accomplished most of the defined objectives. In the experiences performed with the alimentary dyes it was possible to differentiate distinct colored solutions and define hypothetical calibration curves.

For the experience with two primary dyes there are two points that can be highlighted. The first consists on the response obtained for both spectrometer and the iPhone. Both presented a linear response to the increase of blue dye concentration, mean that the results obtained are congruent with each other. It was also possible to define hypothetical calibration curves with $R^2$ close to one. The other point is that same did not happen for the red dye, meaning that the proposed colorimeter is not applicable for this type of solution.

The experiments performed with several colored solutions also demonstrated that it is possible to distinguish the resultant optical signals through the plot of the H coordinate in an HSI color chart. Therefore, the implemented colorimeter can be applied to colorimetric studies that involve the detection of several colors in response to a parameter variance, as it happens in pH colorimetric studies.

Regarding the experiments with the external lighting system, it can be concluded that they consisted on a good pilot test to determine if the colorimeter could detect color differences as a function of the concentration of brown and violet solutions. In this experience, the normalized RGB channels presented a regular response to the concentration decrease without the presence of any evident outlier point.

The experience of coffee corroborated the data obtained for a brown dye solution. Analogously to observed with a brown solution, the normalized RGB channels also presented a regular response to the increase of coffee concentration. In this case, it was a linear response that can be mathematically described by linear functions. The obtained $R^2$, with a value of 0.972, was also close to one. For the other two approaches, it was also obtained a high $R^2$ value, respectively 0.9964 for the quotient of the red and green channels and 0.9972 for the H value. A higher $R^2$ value will also mean that there is a higher probability of getting a lower error in the measure of coffee’s concentration.

For the last, the experiments of fruit juices and the wines demonstrated that the colorimeter can be applied to quality control of consumable liquids. One similar aspect of both liquids is the presence of the compounds that influence the color of the liquid. In these particular case study, it was possible to obtain different color signals resultant from the
absorption of the different type of wines and juices. Therefore, it remains as a possibility the use of this colorimeter to practical wine or juice assay.

REFERENCES


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