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BETTER REPRESENTATION OF THE LIMITS OF RGB AND CMYK COLOUR SPACES

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Abstract

Limits of RGB colour spaces are normally displayed as triangles in the CIE Yxy colour space. This type of diagram has the advantage that additive colour mixtures from two light sources actually all lie in a straight line. But CIE-Yxy colour space does not have uniform colour distances. So, a representation in other colour spaces with better equal spacing, such as CIE-Lab, shows better how good or bad the colour spaces really are.

Limits of an offset CMYK colour space were usually determined only at the six corners of the primary colours and the first-order mixed colours in CIE-Lab. It is much more meaningful to determine the limits of the most saturated colours in 10% increments.

The new visualisations were created using the Python library www.colour-science.org. The possibilities and limitations of this library will also be briefly explained.

Keywords: *sRGB, Adobe-RGB, PSOcoated_v3, CMYK, Colourspace-Borders, CIE-Yxy, CIE-Luv, CIE-Lab*

Introduction

In the daily work in the graphic arts industry, the conversion of colour spaces is often necessary and essential. In particular, the conversion of additive colour systems into subtractive colour systems is technically extremely demanding. These RGB colour spaces are commonly used according to their frequency of use in the graphics industry: Adobe RGB (see *Adobe RGB (1998) Color Image Encoding, 199 8, p. 9 ff.), sRGB (IEC-61966-2-1-1999-AMD1-2003.Pdf,* n.d.) and *CIE-RGB* (Vesely et al., 2019, p. 6). The expansion of the colour spaces is limited. If the limits of the RGB colour space used deviate too much from the limits of the CMYK colour space used for printing, software must offset greater colour deviations according to its algorithms. As software has not yet been able to perfectly reproduce human colour vision, major errors are to be expected. In day-to-day work, the aim should therefore be to use an RGB working colour space that deviates as little as possible from the subsequent CMYK output colour space. Fig. 1 shows the CIE standard colour space (Richter, 1996, p. 65 ff) and within it different RGB colour spaces. Similar representations are familiar to anyone who deals with colourimetry in any form. This type of diagram is often used to indicate how large the colour space is that is being enclosed.

Is it really enough to specify the colour space for offset printing using only six points, namely the three chromatic primary colours CMYK and the first-order mixed colours as shown in Fig. 4? In this study, all mixtures of a solid colour with another colour were determined in 10% increments. The results were processed with the Python library colour-science.org. There, the data for offset printing was simply converted from CIE-Lab to CIE-Yxy. The data was then displayed in the CIE-Yxy diagram using colour-science. In order to use the more equidistant CIE-Luv (*ISO/CIE 11664-5:2023,* n.d., pt. 5) and CIE-Lab (*ISO/CIE 11664-5:2023,* n.d., pt. 4), the usual RGB colour spaces had to be divided into smaller steps.

Methodology and equipment

Almost all the following graphics were created with an open-source library for Python. Python was used in the Anaconda environment (*Anaconda*, n.d.), both on Linux and PC, which in this case did not result in any changes. The name of the library for colour management is www.colour-science.org (*Colour Science for Python*, 2015). This library is very extensive and helpful. Its use would be a great relief for many researchers in the field of colour research. Unfortunately, it is not yet widely used.

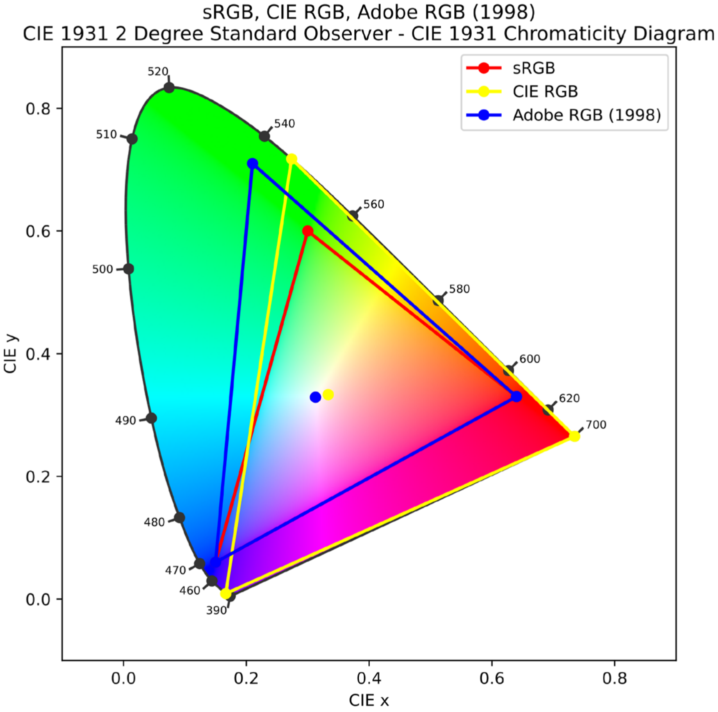
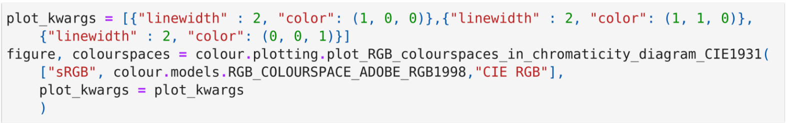


Fig 1. Color spaces in CIE-Yxy-Diagramm

Fig. 2 shows briefly how easy it is to create the diagram in Fig. 1 with colour-science. To generate these diagramms, various programme libraries have to be loaded. Then some definitions such as the used data format and the size are defined. Then the line width and the colours of the graphs are defined. The actual command is then completed in three lines. The programme code is still relatively simple. It gets more complicated later on.



```
plot_kwargs = [{"linewidth" : 2, "color": (1, 0, 0)},{"linewidth" : 2, "color": (1, 1, 0)},
    {"linewidth" : 2, "color": (0, 0, 1)}]
figure, colourspaces = colour.plotting.plot_RGB_colourspaces_in_chromaticity_diagram_CIE1931(
    ["sRGB", colour.models.RGB_COLOURSPACE_ADOBE_RGB1998,"CIE RGB"],
    plot_kwargs = plot_kwargs
    )
```

Fig 2. Code in colour-science.org for CIE-Yxy-Diagramm

The diagram Fig. 3 is similarly easy to create in Python. It shows the CIE-Yxy-Diagramm with the MacAdam ellipses. Each of the MacAdam ellipses shows an area within which a person with normal vision cannot distinguish colours. The Diagramm shows, that these ellipses have very different sizes. Colour distances in the diagram are never equally spaced. This, of course, raises the question: how useful is the first representation with the RGB colour spaces?

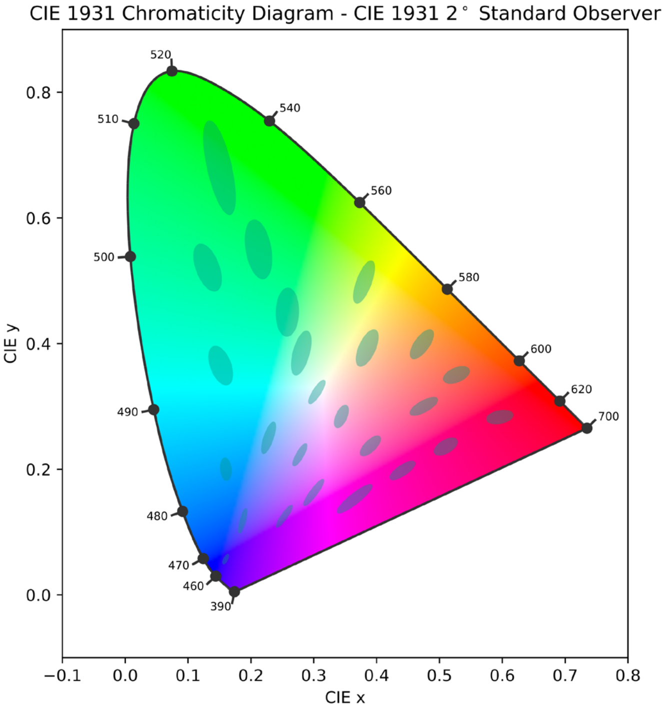


Fig 3. MacAdam-Ellipses in CIE-Yxy-Diagramm

In Fig 4, is entered a colour space for offset printing according to PSO-coatedV3 in the diagram, but only the pure CMYK primary colours and the first-order mixed colours. This representation can often be found on the Internet (López-Baldomero et al., 2022, p. 8). To obtain the colour values by converting the CMYK values into Lab values and from there into CIE Yxy values the Scribus colour management was used. In this CIE standard colour space, additive colour mixtures always run in a straight line from one light source to the next. This is why you can do the same with RGB colour spaces. Can this also be done with printing colours?

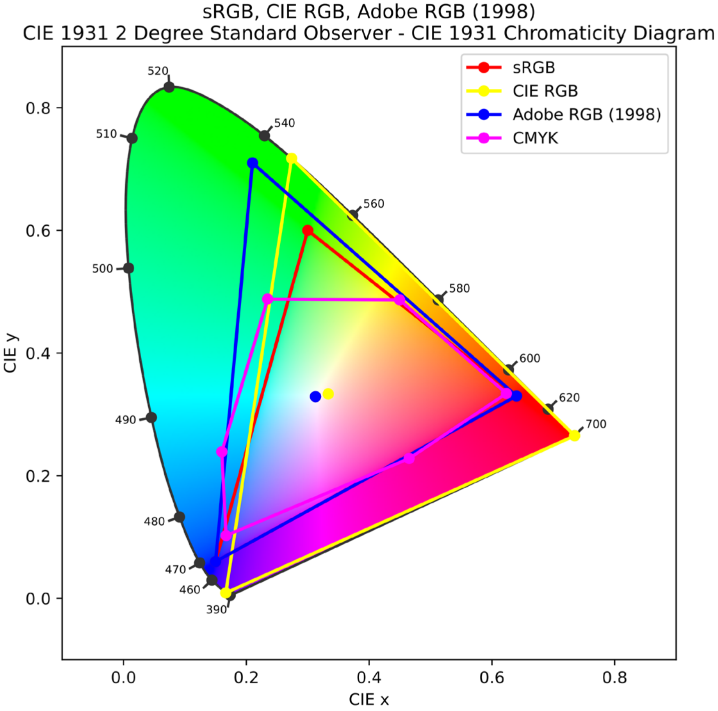


Fig 4. CIE-Yxy with RGB-Spaces and the usual representation of CMYK

Presentation of research results (Analysis)

In Fig 5. is shown why diagrams like Fig. 4 should not be used. The orange-coloured curve in the diagram shows the mixed colours, for example, 10% cyan and 100% yellow, 20 C and 100 Y, 30 C and 100 Y, also via the colour management of Scribus and colour-science in CIE-Yxy. The result is something similar to a triangle, but it is rounded and curved. It is particularly noticeable that there is also a corner in greenish yellow, which is completely missing if we only draw the graph through 6 points. This shows once again that it is not possible just to draw in subtractive colours and assume that the mixtures result in a straight line. The diagram shows that this is not the case. The colour space of offset printing inks should always specified by using more than 6 corner points. Every CIE-Yxy standard diagram in which subtractive colour mixtures are entered in only 6 points cannot be correct.

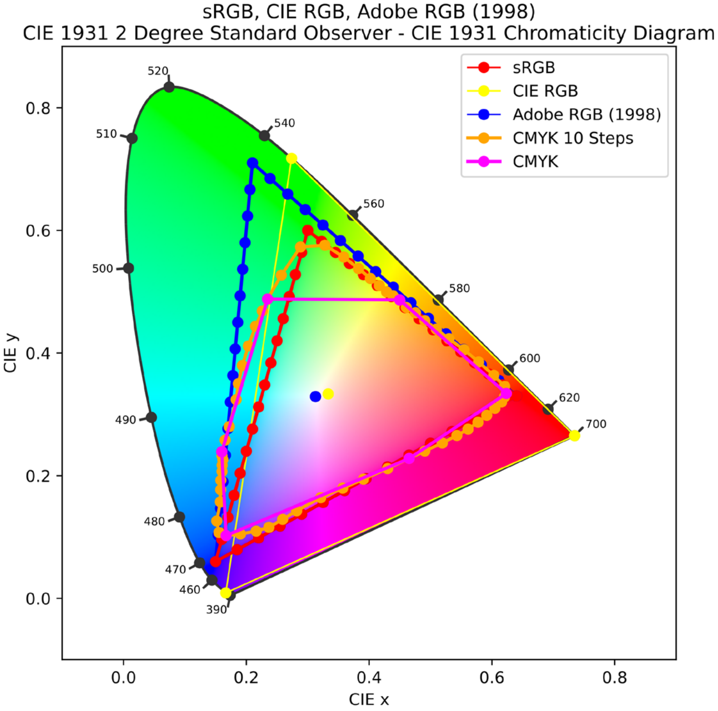


Fig 5. CIE-Yxy with RGB-Spaces, the real borders of CMYK according to PSOcoatedV3 and sRGB, Adobe RGB in more steps

In Fig. 6 another colour space is shown in which the MacAdam ellipses have a bit more uniform sizes than in the CIE-Yxy diagram, namely the CIE1976UCS diagram. UCS stands for Uniform Colour Space. This colour space is also known as CIE-Luv (*ISO/CIE 11664-5:2023*, n.d., pt. 5), as the axes of the diagram are labelled. For comparison purposes, in this Figure more interpolation points of the RGB colour spaces are calculated and as predicted these really do lie on a straight line. Unfortunately, this is often not explicitly mentioned in specialised literature.

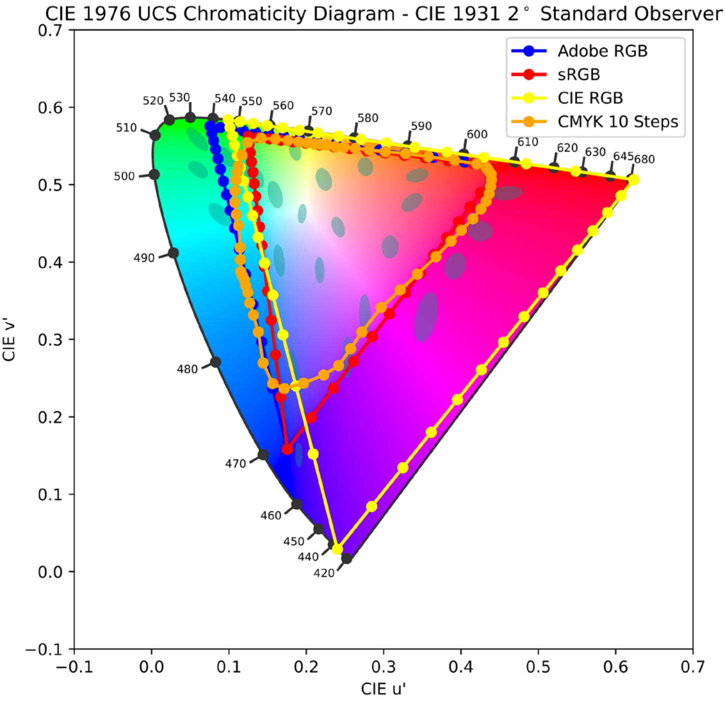


Fig 6. MacAdam-Ellipses, Adobe RGB, sRGB, CIE-RGB and CMYK according to PSOcoatedV3 in CIE-Luv-Diagramm

Furthermore, the diagram shows that sRGB and AdobeRGB differ less in this diagram than in CIE-Yxy. Why this CIE-Luv colour space, is used, which is rather uncommon in the graphic arts industry? The more common CIE-Lab colour space (*ISO/CIE 11664-5:2023,* n.d., pt. 4) is not available in this simple way at colour-science. This is not satisfying although there are convincing reasons for this. The colour space limits in CIE-Lab are dependent on brightness. They can only be cumbersome and calculated with the help of optimum colours. These colour space limits are usually called MacAdam limits (Martínez-Verdú et al., 2007). These Mac-Adam limits were calculated for different brightness levels in 1 % steps. Finally, all these MacAdam limits were then superimposed and calculated into a single graph, as shown in Fig.7.

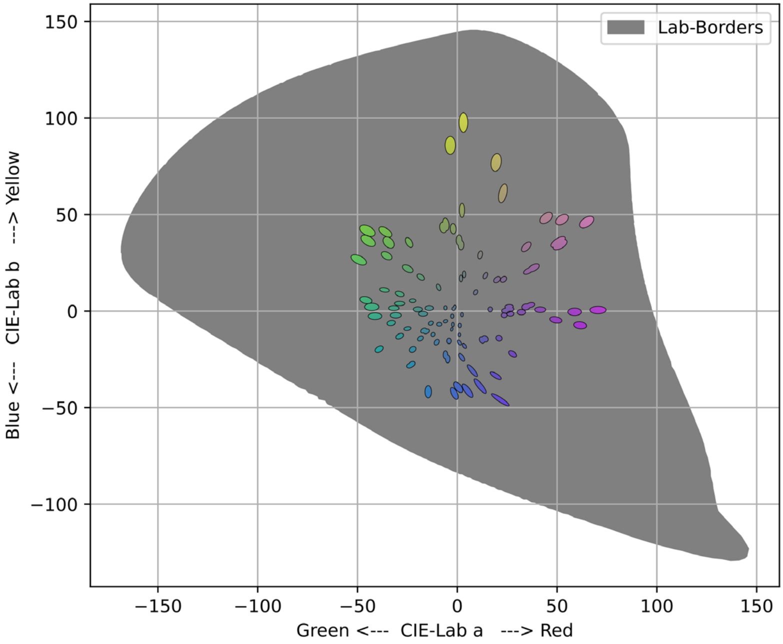


Fig 7. Summarised MacAdam limits with MacAdam ellipses according to Luo/Cui/Rig (2000)

Fig. 7 shows the boundaries of the Lab colour space and ellipses according to Luo, Cui and Rig from the year 2000 (Luo et al., 2001, p. 2). They also contain the MacAdam ellipses as well as those from other experiments. The RGB colour spaces can now be entered in these CIE-Lab colour space boundaries.

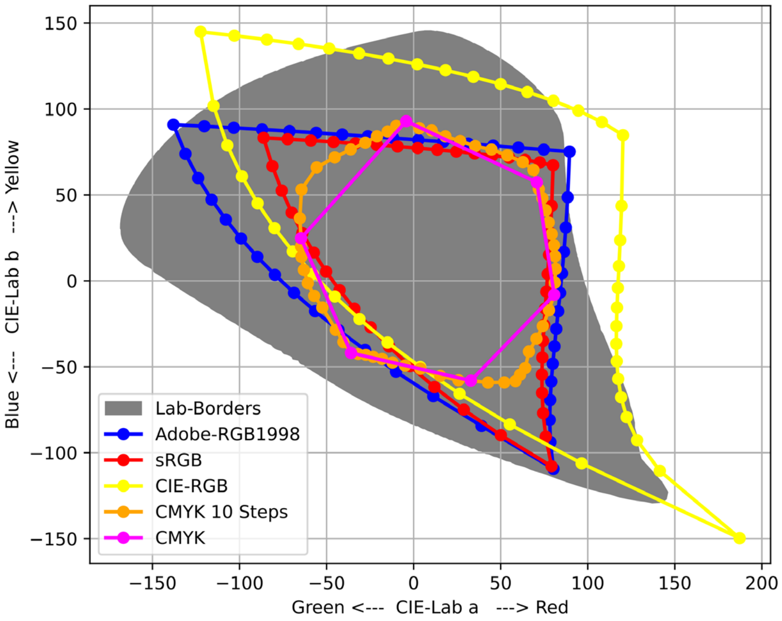
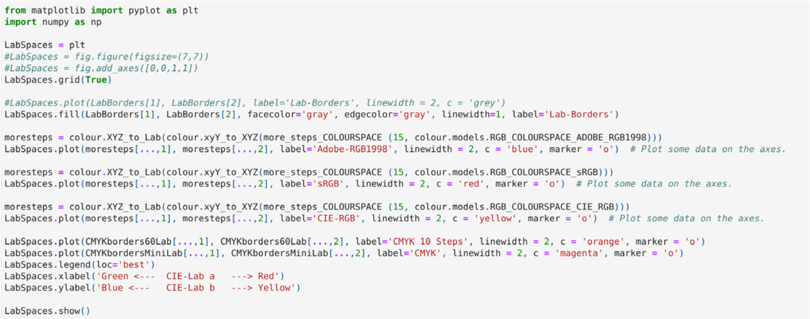


Fig 8. CIE-Lab with RGB-Spaces, the real borders of CMYK according to PSOcoatedV3 and sRGB, Adobe RGB in more steps

Fig. 8 shows the three RGB colour spaces examined and the CMYK colour spaces in the CIE Lab colour space. Firstly, it is remarkable that CIE-RGB sometimes goes far beyond the limits of CIE-Lab.The Lab colour space becomes less and less accurate the closer a colour is to the limits. In any case, further investigation is required to determine whether this is perhaps a software error of colour-science. Overall, however, it could also show that it is very easy to make any technical definitions. But just because it looks good in the first diagram does not necessarily mean that it is a good working definition in reality.

Secondly, it is worth noting that AdobeRGB actually almost completely encloses the offset printing colour space. Remarkably enough sRGB is not that much worse. The sRGB space even has the advantage that it allows far fewer colour definitions that cannot be realised in offset printing. This means fewer systematic errors in the colour space transformation. But this comes at the price of not being able to display a small range of the blue-green colours. Particularly the dark blue areas were expected to be particularly problematic. Apparently, this is not the case.

In office environments, most people work with PCs and Microsoft programmes. Adobe RGB is almost only used by graphics agencies or in the graphics industry. The vast majority of people therefore work with sRGB without realising it. So, most print shops therefore often also have to process files in sRGB. This usually works better than one would expect



```
from matplotlib import pyplot as plt
import numpy as np

LabSpaces = plt
#LabSpaces = fig.figure(figsize=(7,7))
#LabSpaces = fig.add_axes([0,0,1,1])
LabSpaces.grid(True)

#LabSpaces.plot(LabBorders[1], LabBorders[2], label='Lab-Borders', linewidth = 2, c = 'grey')
LabSpaces.fill(LabBorders[1], LabBorders[2], facecolor='gray', edgecolor='gray', linewidth=1, label='Lab-Borders')

moresteps = colour.XYZ_to_Lab(colour.xyY_to_XYZ(more_steps_COLOURSPACE (15, colour.models.RGB_COLOURSPACE_ADOBE_RGB1998)))
LabSpaces.plot(moresteps[...,1], moresteps[...,2], label='Adobe-RGB1998', linewidth = 2, c = 'blue', marker = 'o')  # Plot some data on the axes.

moresteps = colour.XYZ_to_Lab(colour.xyY_to_XYZ(more_steps_COLOURSPACE (15, colour.models.RGB_COLOURSPACE_sRGB)))
LabSpaces.plot(moresteps[...,1], moresteps[...,2], label='sRGB', linewidth = 2, c = 'red', marker = 'o')  # Plot some data on the axes.

moresteps = colour.XYZ_to_Lab(colour.xyY_to_XYZ(more_steps_COLOURSPACE (15, colour.models.RGB_COLOURSPACE_CIE_RGB)))
LabSpaces.plot(moresteps[...,1], moresteps[...,2], label='CIE-RGB', linewidth = 2, c = 'yellow', marker = 'o')  # Plot some data on the axes.

LabSpaces.plot(CMYKborders60Lab[...,1], CMYKborders60Lab[...,2], label='CMYK 10 Steps', linewidth = 2, c = 'orange', marker = 'o')
LabSpaces.plot(CMYKbordersMiniLab[...,1], CMYKbordersMiniLab[...,2], label='CMYK', linewidth = 2, c = 'magenta', marker = 'o')
LabSpaces.legend(loc='best')
LabSpaces.xlabel('Green <---   CIE-Lab a   ---> Red')
LabSpaces.ylabel('Blue <---    CIE-Lab b   ---> Yellow')

LabSpaces.show()
```

Fig 9. Most parts of the python-code

Fig. 9 shows the essential parts of the source code for Fig 8, the diagram before. In the shown code 15 steps in each case are defined. The whole definition of the boundaries of the CIE Lab colour space is missing, the input of the data for the offset printing colour space is missing and the function more_steps_COLOURSPACE, which divides the straight lines of the RGB colour spaces into several parts. However, the data for the offset colour spaces, the limits of the Lab colour space and the code for the missing functions can be requested from the author.

Conclusions

1. Colour space of offset printing inks must be drawn in diagrams using more than 6 corner points.
2. In CIE-Luv colour space the additive mixtures of two colours also lie on a straight line like in CIE-Yxy.
3. CIE-RGB has wide ranges that cannot be displayed at all in CIE-Lab and are therefore probably not perceptible.
4. Using the sRGB colour space instead of the Adobe RGB colour space should not have too many disadvantages. Only colours of the very saturated light greenish blue could be displayed a little less saturated.

References

1. *Adobe RGB (1998) Color Image Encoding*. (1998).
2. *Anaconda*. (n.d.). Anaconda. Retrieved 17 May 2024, from https://www.anaconda.com/download
3. *Colour Science for Python*. (2015, December 1). Colour Science. https://www.colour-science.org/
4. *IEC-61966-2-1-1999-AMD1-2003.pdf*. (n.d.). Retrieved 17 May 2024, from https://cdn.standards.iteh.ai/samples/10795/ae461684569b40bbbb2d9a22b1047f05/IEC-61966-2-1-1999-AMD1-2003.pdf
5. *ISO/CIE 11664-5:2023*. (n.d.).
6. López-Baldomero, A. B., Rubiño, M., Ortiz, C., & Salas, C. (2022). New software for comparing the color gamuts generated by printing technologies. *Optik*, *261*, 169194. https://doi.org/10.1016/j.ijleo.2022.169194
7. Luo, M. R., Cui, G., & Rigg, B. (2001). The development of the CIE 2000 colour-difference formula: CIEDE2000. *Color Research & Application*, *26*(5), 340–350. https://doi.org/10.1002/col.1049
8. Martínez-Verdú, F., Perales, E., Chorro, E., De Fez, D., Viqueira, V., & Gilabert, E. (2007). Computation and visualization of the MacAdam limits for any lightness, hue angle, and light source. *Journal of the Optical Society of America A*, *24*(6), 1501. https://doi.org/10.1364/JOSAA.24.001501
9. Richter, K. (1996). *Computergrafik und Farbmetrik: Farbsysteme, PostScript, geräteunabhängige CIE-Farben*. VDE-Verl.
10. Vesely, S. L., Dolci, S. R., Vesely, A. A., Vesely, M. E., & Dolci, C. A. (2019). *Encoding of colors*. 020002. https://doi.org/10.1063/1.5123563