

Comparison and Evaluation of Popular Syntax Highlighting Themes in Terms of Color Correlated Temperature Values

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Abstract

Digital screens containing artificial light sources emit intensely blue light, which is known to be hazardous to human eye health. Software developers are among the people who are most affected by this blue light. Color themes are used to color code in software development processes. The developers chose the color theme based on their personal tastes or the popularity of the theme, Without being aware of the danger of blue light. In this study, Color Correlated Temperature (CCT) was utilized to calculate the quantity of blue light contained in popular color themes chosen by developers. It was observed that the average CCT values of both the dark and light versions of the examined themes were above the D65 threshold and contained intense blue light. Theme developers should consider the risks that blue light poses to human eye health while creating their themes.

Keywords Blue light hazard, CCT, Code highlighting, Eye health

1 Introduction

Software developers spend long hours in front of the screen while reading, writing, or debugging code [1]. The complexity of the source code that composes the software requires high concentration and effort in terms of coding the algorithm or understanding the algorithm of the coded one. The fact that code readability is of great importance in this whole process has been well expressed by Abelson *et. al.* (1996) in their seminal book *Structure and Interpretation of Computer Programs*, 'Programs must be written for people to read, and only incidentally for machines to execute.'[2].

Syntax highlighting (SH), based on the different coloring of code elements, is an important tool to visually improve the readability of source code and the context of the text. Modern IDEs offer built-in and installable color themes. Users tend to go with the default theme. They choose the theme according to their popularity and personal taste when they want to change.

Coloring plays an important role in syntax highlighting. Coloring allows perceptual segregation of code [3]. Thus, colors provide a clear model of the perceived concept. Colors clearly indicate the differences between various programming language elements and provide clues to the programmer.

The artificial light produced by digital screens, a critical component of software development, contains blue light hazard (BLH). It is sufficient to use CCT to assess the amount of blue light in the artificial light. Predicting CCT value of the light source requires solving a non-linear optimization problem [4]. Different methods have been developed to calculate CCT value [5, 6, 7, 8, 4, 9, 10].

Blue light, which is known with its phototoxic [11] / photochemical [12] adverse effect shows its effects on individuals depending on various parameters such as the time exposed to artificial light producing device (at night, while going to bed, etc.) [13] and frequency [14], dose/intensity [12], distance [15], time/past [16], age [17]. These effects may cause harm with serious side effects on health such as cancer (breast [18], prostate and colorectal [19]), psychological (depression [20], anxiety/ severity [20] problems, mental health [21], mood disorder [22], more frequent engagement on quiet and mobile devices [23], behavioral problems [24]), body function disorders (increase in temperature and heart rate [25], obesity [13], diabetes [18], cardiovascular disease [21], hormone balance disorder [26], systemic disorder [27], balance disorder, headache [28], long term cumulative effect [29]). It has been reported that blue light increased melatonin suppression [30], leading to a deterioration in the circadian rhythm, which is seen as biological clock [31], caused a delay in phase [32], and had adverse effects such as reproduction/early adolescence [18]. The negative effect on circadian rhythm causes accumulated sleep loss [27], decreases quality of sleep such as sleep interruption/inefficiency [26], sleep difficulty/delay [28] and daytime sleepiness [24]. It has been shown that smart phone use especially without room light affects sleep disorder [33]. As a result of all these, neurocognitive function losses have been reported [21] such as phase shifts in circadian rhythms [34], loss of academic performance [24], cognitive daytime dysfunction [35], decrease in the ability to learn [13], decrease in the ability to concentrate and remember [36], and decrease in comfort and work productivity [37].

It can be expected that adverse effects will be reduced if screen producers use model estimations to adjust the spectral power of self-illuminated devices by finding out how the products they make will influence melatonin levels and adjusting them to the circadian rhythm [38]. However, this is very difficult to achieve due to concerns such as the perception of image quality. Therefore, we as individuals will have to resort to different methods to minimize the harmful effects of devices while using them. These are filter use [39], special lens use [40], special glass use [39], screen specific night/reading mode [41] and software adjusting color temperature [42].

The dark theme trend in syntax highlighting themes shows an organic movement in theme selection in the context of eye health. Popular themes make subjective evaluations stating that they are better for eye health [43]. An objective evaluation cannot be made in the context of eye health for syntax highlighting themes, which are chosen based on popularity and personal tastes. CCT can be used to express the amount of blue light a Syntax highlighting theme contains. The higher the average CCT produced by the Syntax highlighting theme in the coloring of the selected code, the more blue light it has. In this study, we aim to the theme for syntax highlighting selection based on Color Correlated Temperature in terms of blue light hazard.

2 Material and Methods

In this study, the sample source selected with each popular coloring theme was colored, and the average CCT values of the obtained contents were calculated and compared (Figure 1).

Depending on the font chosen for each character of the code, a representative bit-process character box is created. Each character box is made up of pixels colored in the theme’s foreground and background colors. CCT value is calculated for these colors. For the entire colored code, the average CCT value that we call "Correlated Colored Code Temperature" (CCCT) is calculated. In this way, a novel quantitative criterion has been introduced to compare code coloring themes by using CCCT values specified as theme specified.

The first step was to choose a theme. Themes are generally classified into two theme groups according to the use of dark/light background colors in the user interface: dark/light themes. Theme selection is dependent on editor selection. The VS Code programming editor was chosen for our research. Developers use a variety of programming languages to create the code for their projects. Because analyzing the influence of the chosen theme on all codes would be impractical, operations were conducted out on a sample source code. For this purpose, a C programming language source code taken from the Git source code, which is a fairly modern code base, was chosen. The HTML output for the colorized version of the code with the chosen theme, as well as a code representation based on it, was created. Different fonts are preferred by developers. The influence of different fonts on the calculation was not investigated in this study. The BDF transformation and subsequently the font representation have been created for the selected font. The Ohno’s method has been used to determine the CCT using code and font representation.

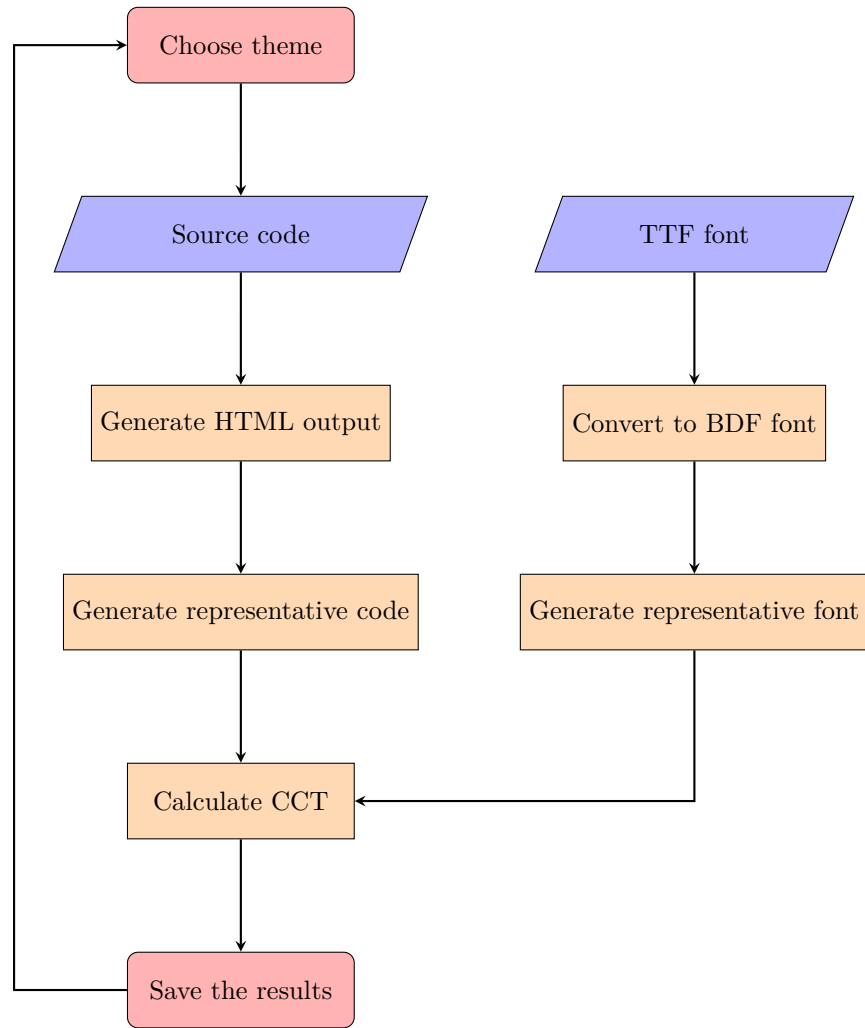


Figure 1: Flow chart

The analyzes were performed in a mixed environment with components written in different programming languages and running on Windows and Linux. In this context:

- PowerShell has been used to convert the colored codes to HTML format.
- The Ruby programming language has been used to parse the HTML format and obtain the bitmap for the font.
- CCT calculation has been done with the Python programming language.

- The entire process has been made up of subscripts implemented with the Bash shell programming language.

All analysis programs developed within the scope of the study and the data produced are presented in an open source form in a Github repo [44]. Rationales behind all the selections in the analysis were explained in further sections.

2.1 Selection of analysis inputs

The following choices have been made in order to carry out the targeted analyses of the research.

- Editor choice: Programming editor where development was made.
- Theme selection: The color theme set in the programming editor for coloring.
- Sample source code selection: It is the source code file that is the subject of syntax coloring.
- Font selection: Fixed-width font set in the programming editor for displaying the source code.

2.1.1 Editor Selection

In order to determine the coloring themes, which are the subject of this research, and to obtain the codes colored with these themes, a suitable programming editor should be determined, which will enable concrete and comparative analysis. The following criteria were taken into account in the selection of the programming editor:

- To be public.
- Multi-platform (e.g. Windows, OS X, Linux) support.
- To provide data on the popularity of themes installed as plugins.
- It offers possibilities for obtaining coloring information.

Considering these criteria, the Visual Studio Code (VS Code) editor developed by Microsoft and offered as open-source on the Github platform has come to the fore as the most suitable option among alternatives.

- According to Stack Overflow’s 2021 developer survey[45], he is the first on the list of preferred editors by a very serious margin; Visual Studio IDE, which uses a similar infrastructure to VS Code, is in second place in the same survey.
- It works on Windows, OS X, and Linux.
- It offers theme statistics[46] through the VS Code market.
- It has the ability to analyze colors.

2.1.2 Theme Selection

Based on VS Code theme statistics[46], the most popular 17 themes have been chosen. Some of these themes have dark and light versions. Since the dark theme is mostly used[47], the number of examples of this theme was chosen more than the light theme. Since there is no API to retrieve VS code Market information programmatically, theme information was obtained for each theme by web scraping. Information on themes selected within the scope of the study are shown in Table 1.

2.1.3 Programming language and source code selection

Since it will not be possible to work with all common programming languages for analysis, the C language was preferred as an example language. The main reason for this preference is that, according to the TIOBE index, which tracks programming language usage rates, six of the top ten programming languages (C, Java, C++, C#, Javascript, PHP) are in the "C programming language family" in terms of syntax as of the date of this study[48], and in this regard, the code coloring of the C programming language represents the general situation with a sufficient approximation. The following criteria have been used to pick sample source code produced in the C programming language.

- Should be a fairly modern and professional code base that reflects current practices.
- Should contain most syntax elements of the C programming language.
- The number of lines of code (LOC) must be large enough (e.g. a few thousand rows) for the sample to be large.

In the light of these criteria, the source code[49] of the `grep` subcommand[50] was chosen as an example in the source code repository[51] of the Git[52] version tracking system. This sample code, which has a total of 2025 lines, can be accessed in the Git repository with the command below.

```
git show 0a6adc26e2efd2dcfb3e65407623287e08989a63:grep.c
```

2.1.4 Font Selection

Among the many monospace fonts, the study was carried out only with a font installed on the system and available as a default. As explained in the 2.1.1 section, colored codes are obtained with the VS Code programming editor on the Windows 10 operating system. During the research, the Consolas[53] fixed-width TrueType font, displayed in Figure 2 by default in this environment, is also used as a default 14 pixel size. Since it is predefined, this font selection is considered to reflect the common situation experienced by developers.

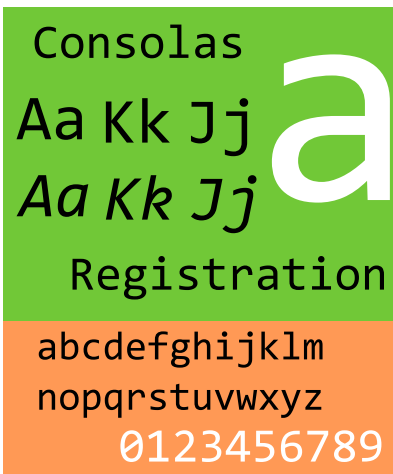


Figure 2: Consolas font

2.2 Syntax colored code representation

2.2.1 Converting colored codes to HTML format

To produce colored code in HTML format, the "Copy With Highlight" command that has been added to VS Code at version 1.10 was used. Accessible from the editor's command palette, this command copies the selected source code content to the clipboard in a colored format. Since the editor has no feature to save the colored source code to a file in HTML format, the copied content in the clipboard must be saved to a file manually. For this purpose, the below procedure has been performed by using the PowerShell terminal on the Windows platform where the study was carried out.

- Copy colored code to clipboard in VS Code editor.
 - Open the file and select all source code.
 - Run the "Copy With Highlight" command from the command palette.
- Save clipboard contents to file in HTML format with commands run in PowerShell terminal.
 - Set the format of the clipboard content to HTML.

```
Get-Clipboard -TextFormatType Html | Set-Clipboard
```

- Save clipboard contents to file.

```
Get-Clipboard >source.html
```

For example, if we consider a C source code in the following content:

```
#include "cache.h"
...
```

Here is a simplified view of the "raw" file produced for such a code:

```
Version:0.9
StartHTML:0000000105
EndHTML:0000186320
StartFragment:0000000141
EndFragment:0000186284
<html>
<body>
  <!--StartFragment-->
  <div style="color: #d4d4d4;background-color: #1e1e1e;
font-family: Consolas, 'Courier New', monospace;font-weight: normal;
font-size: 14px;line-height: 19px;white-space: pre;">
    <div><span style="color: #c586c0;">#include</span>
    <span style="color: #569cd6;"> </span>
    <span style="color: #ce9178;">"cache.h"</span></div>
    ...
  </div>
</body>
</html>
```

Figure 3: The raw HTML output of colored sample code

The following observations can be made to these examples:

- There is some meta-information at the beginning of the file. These lines must be removed for the content to be a valid HTML file.
- Each line has been converted into a `div` blockquote in HTML.
- Colorings are transformed into color-coded `span` parts.
- Font family ('Consolas') and size ('14px') are defined at the beginning.
- Line height ('19px'), which will be used to compute a full height character box, is defined.
- Background color, which will be used for space characters, is defined.


```

#include "cache.h"
#include "config.h"
...
static void std_output(struct grep_opt *opt, const void *buf, size_t size)
{
    fwrite(buf, size, 1, stdout);
}

```

Figure 4: Sample code without coloring

```

#include "cache.h"
#include "config.h"
...
static void std_output(struct grep_opt *opt, const void *buf, size_t size)
{
    fwrite(buf, size, 1, stdout);
}

```

Figure 5: Colored code

2.2.2 Parsing the HTML format

After the colored code was obtained in HTML format, the raw file was converted to a valid XML file and parsed with a script written in the Ruby programming language. At this stage, which is carried out with the Nokogiri library[54], which is widely used in the Ruby programming language, it is parsed into an inter representation file in JSON format.

Color information has been produced from CSS declarations given inline in the HTML output. In the parsing of CSS declarations, it has been preferred to parse with regular expressions without using a particular library, taking into account the monotony of the declaration. At the end of this stage, an inter representation output in JSON format containing the following information has been produced.

- Fixed-width font information used in code: A dictionary of font family and font size
- Colorized content groups: An array of color and content string groups

2.3 Generating the Font Representation

The most common font technology used in computer applications today is TrueType[55]. Developed by Apple in the late 1980s, this technology enables vector-based scalable font families that allow a character to be displayed on the screen in a wide variety of sizes with high precision. Fixed-width TrueType fonts (TTF) are widely used in programming editors and regular applications. The fixed-width font is a user preference among programmers as crucial as choosing a color theme. "Monaco", "SF Mono", "Cascadia Code", "Consolas", "Fira Mono". Considering the existence of a large number of [56] fixed-width fonts, with examples like "Menlo," it should say that font preference is as important as color theme, especially in the aesthetic perceptions of a user looking at a colored source code [57, 58].

In this research, it is necessary to determine the pixel density of a particular character in the selected font to calculate CCT values. For this purpose, the TTF font chosen must be converted to bitmap format in a suitable size. "Glyph Bitmap Distribution Format (BDF)", a widely used format in its field, was chosen as the bitmap format. The main reasons for selecting the BDF format are:

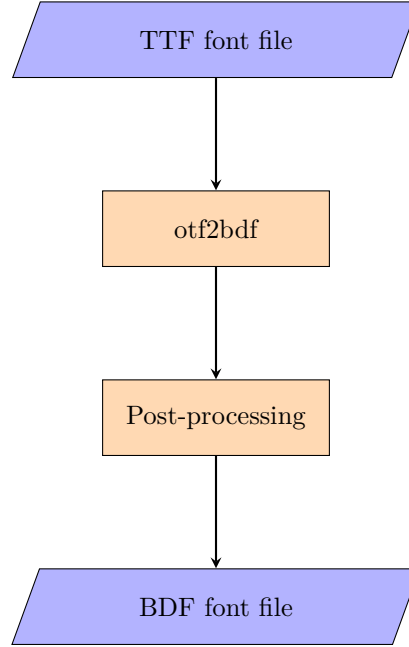
- Standard: Although bitmap fonts are not used as much as TTF today, BDF (with PCF alternative) is a common standard used when needed.
- Simplicity: BDF is a simple text-based format that it can quickly parse.
- Tooling: Necessary tools are available to handle BDF fonts.

Before the theme analysis, a "Font representation" was generated in the later stages of the study based on the technologies described above for the selected font in the programming editor. A "font representation" is a file in JSON format that contains all the font data that it will need to analyze that font. While some of this data is transferred from the BDF font definition, some consist of data calculated by the methods described in the following sections, such as "Character bit density."

2.3.1 Conversion to BDF font

The developers used the `otf2bdf` tool [59] developed as part of the FreeType project [60] to convert the TTF font to BDF format, as shown in the flow diagram (Figure 6). In the generated BDF file, simple post-processing has been made to remove some fields in the BDF format to ensure compatibility with the next parsing steps.

Figure 6: TTF to BDF conversion



2.3.2 Calculation of CCT contribution of a character box

In syntax coloring, each syntax group (e.g. an identifier, a keyword) in the source code is displayed with the font glyph selected in color set in the theme. As stated at the beginning of Chapter 1, each character in the source code character series creates a character box with a height of the line in which it is located and accordingly, the entire colored source code content is interpreted as a character box sequence of these boxes. The character box sequence of "static" is given in the Figure 7.



Figure 7: Colored character boxes array

The average CCCT value is calculated in two steps.

1. The average CCT value of each character box is calculated by considering the CCT contribution of the foreground and background colors of the font glyph in the box and the pixel area ratios covered by these colors in the box. In the example in Figure 7, the foreground color is green and the background color is white.
2. The CCT contribution of each character box depends on the frequency of the character box. For example, in the 6-character content given in Figure 7, the character box of the **a** character is 2 times, and the box of the **s** character is passed once.

To sample the calculation made in the first step, take into account the character box given in Figure 9a for the **a** character. This character's BDF font definition and the bit pattern in the definition are as in Figure 8.

```

STARTCHAR 0061
ENCODING 97
SWIDTH 525 0
DWIDTH 7 0
BBX 5 7 1 0
BITMAP
70
88
08
78
88
88
F8
ENDCHAR

```

0	1	1	1	0	0	0	0
1	0	0	0	1	0	0	0
0	0	0	0	1	0	0	0
0	1	1	1	1	0	0	0
1	0	0	0	1	0	0	0
1	0	0	0	1	0	0	0
1	1	1	1	1	0	0	0

(b) Bit map

(a) BDF definition

Figure 8: Consolas font of character 'a' in BDF

Renklendirilmiş kaynak kodun HTML temsiline bildirilen **line-height** değeri ve Şekil 8b'deki bit eşlemi birlikte dikkate alınacak olursa **a** karakteri için Şekil 9b'deki karakter kutusu elde edilir. Bu karakter kutusunun içerik dizisinde *i*'nci karakter kutusu olduğu kabul edilerek kutuya ait $CCT(charbox_i)$ ile gösterilen ortalama CCT katkısı Eşitlik 1 ile tanımlanır.

$$CCT(charbox_i) = \frac{Count_i^1 \times CCT_i^{fg} + (Width_i \times Height_i - Count_i^1) \times CCT_i^{bg}}{Width_i \times Height_i} \quad (1)$$

Bu ifade:

- $Count_i^1$ karakter kutusundaki 1'lerin sayısını
- $Width_i$ ve $Height_i$ sırasıyla karakter kutusunun genişlik ve yüksekliğini
- CCT_i^{fg} ve CCT_i^{bg} karakter kutusundaki her bir pikselin ön ve arka plan renklerine ait CCT değerlerini

göstermektedir.

İkinci adımda, her bir karakter kutusu için ilk adımda hesaplanan CCT değerlerinin ortalaması alınmalıdır. Karakter kutusu dizisinin N boyutlu olduğu kabul edilecek olursa tüm içeriğin ortalama CCT değeri Eşitlik 2 ile elde edilir.

$$CCT_{average} = \frac{\sum_{i=1}^N CCT(charbox_i)}{N} \quad (2)$$

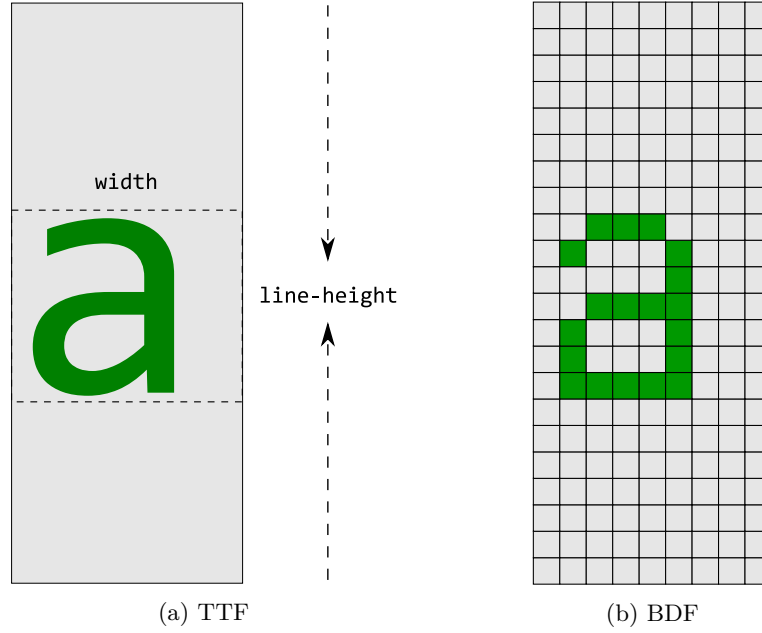


Figure 9: Character box of 'a' with line height in Consolas fontface

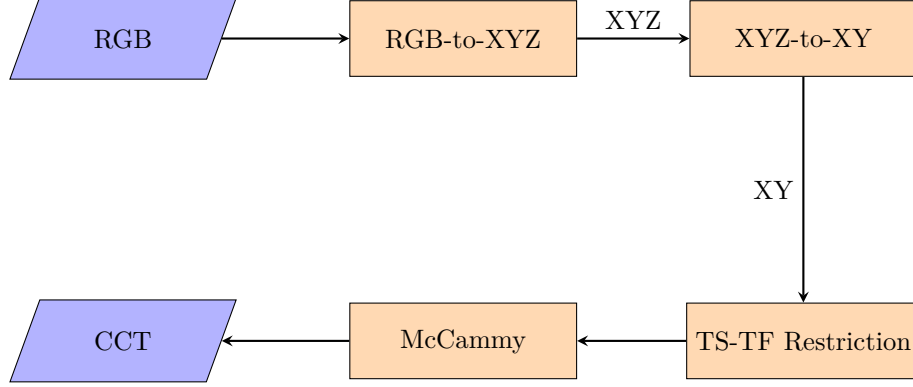
2.4 CCT Calculation

TODO D65 nedir? Ohno proposed a combination of triangular and parabolic calculations based on Robertson’s solution [5], which reduces the error to 1 K [9]. Recently, Ohno developed a combined solution integrating the LUT method (i.e., the triangular solution) with the fitting method (i.e., the parabolic curve fit), obtaining relatively high accuracy in a wide range of chromaticity. The combined method colligates the triangular and parabolic solution to cope with the dependence of the CCT calculation accuracy on the Duv value of a test light source. However, the LUT adopted in this method, including at least 303 rows of data, is considerably larger than that in Robertson’s method. Also, if higher accuracy is needed, the LUT would store up to 1200 rows of data, thus leading to relatively low search efficiency [61]. **TODO: bu cümleyi tekrardan yaz. Öncesini sadeleştir** In this study, Ohno’ CCT approximation was used since it is commonly found in a large number of studies and due to its simplicity of calculation.

In CCT calculations, as seen in the flow diagram shown in Figure 1, the production process is taken as inputs for colored code representation and font representation, which is explained in the previous sections. Within the scope of this study, the "Colour" library [62] written in Python was used in most of the color-related analysis, especially the CCT calculation. "Colour" is an open-source Python package providing a comprehensive number of algorithms and datasets for colour science.

To estimate the Correlated Color Temperature (CCT) value, a nonlinear optimization problem needs to be solved. Therefore, there is no analytical expression for calculating CCT, and scientists have long sought simple and practical methods to calculate CCT in industrial applications. In all previous methods available for calculating CCT, the aim is to only approximate the function and keep the estimates with limited accuracy. Researchers have proposed to calculate CCT using Newton’s method, which requires first and second derivatives of the objective function [63]. The proposed method, when initialized with Robertson’s method, produced fairly accurate estimates of less than 0.0012 K for light sources with CCTs ranging from 500 K to 106 K [5]. The method proposed by Qiu (1987) is based on established functional relationships between the CCT and the x, y, or u, v chromaticity coordinates of the light source. Qiu’s method is applicable for CCTs ranging from 2500 K to 10,000 K. [64] found a simpler formula for estimating the temperature from the x, y chromaticity coordinates for CCTs ranging from 2000 K to 12500 K. Hernández-Andrés et al. (1999) [8] developed another explicit formula that is valid for estimating a wider range of CCTs up to 106 K. The CCT value is accepted as the temperature of the black body radiation that gives the closest color to it under the same brightness and observation conditions. A low CCT (2,500 K) is called a warm color and a high CCT (6,500 K) is a cool color. The general structure of calculating the CCT from the digital image is shown in Figure 2.

Figure 10: CCT computational flowchart



$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2126 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{bmatrix} \begin{bmatrix} sR \\ sG \\ sB \end{bmatrix} \quad (3)$$

The following equation was used to compute CIE xy chromaticity coordinates from CIE XYZ tristimulus values [65],

$$\begin{aligned} x &= \frac{X}{X+Y+Z} \\ y &= \frac{Y}{X+Y+Z} \end{aligned} \quad (4)$$

McCamy function [10] was used to calculate CCT with CIE xy chromaticity coordinates,

$$T_M = CCT(x, y) := p \left(\frac{x-0.3320}{y-0.1858} \right) \quad (5)$$

$$p(t) := -449 \times t^3 + 3525 \times t^2 - 6823.3 \times t + 5520.33$$

The correlated colour temperature (CCT) and Duv are then calculated from the chromaticity coordinates of the light source [9].

McCamy equation has $O(N^3)$ complexity and it is valid for CCT values between the ranges of 2.000 K to 12.500 K [64, 7]. The intermediate region indicated by isotherm line of $T_S = 2.000K$ and $T_F = 12.5000K$ was chosen as a safe region for computing CCT in the Planckian Locus. It was checked whether the xy chromaticity coordinates computed from the pixels in the image were within this region. The number of pixels outside this region were called as p_e , while the number of pixels inside this region were called as p_i . The rate of pixels being included in the computation is calculated in p_r percentage as follows,

$$p_r = \frac{p_i}{p_e + p_i} \times 100 \quad (6)$$

If the CCT value (T_M) computed with McCamy was outside the computation region, it was limited to the limit value,

$$T = \begin{cases} T_M < T_S & T_S \\ T_M > T_F & T_F \\ T_M & other \end{cases} \quad (7)$$

TODO Ortalama CCT hesabı nasıl yapılıyor? - Karakter bit yoğunluğunu da dikkate alarak eşitlik formunda yaz. - Belki bir flowchart da sunmak gerek

3 Results and Discussion

Bu çalışmada programlama editörü olarak seçilen VS Code ile uyumlu SH temalardan en popüler olanları üzerinde çalışılmıştır. Seçilen tüm temalar Tablo 1’de indirme sayıları, beğeni skorları ve yorum sayıları ile birlikte verilmiştir. Bazı temaların (ör. "Visual Studio C/C++") hem dark hem de light versiyonları aynı paket içinde bulunduğundan bu tür temaların grupları tabloda "dual" olarak belirtilmiş; salt dark veya light nitelikte olan temaların grupları ise sırasıyla dark ve light olarak belirtilmiştir.

Theme	Group	Installed	Like	Comment
One Dark Pro	dark	5051456	4.6	168
Visual Studio C/C++	dual	4695332	3.7	3
Github	dual	3504664	4.5	116
Dracula Official	dark	3364922	4.9	103
Atom One Dark	dark	2951962	4.8	98
Winter is Coming	dual	1558028	4.7	35
Monokai Pro	dual	1318719	3.7	188
Night Owl	dual	1298793	4.8	114
One Monokai	dark	1205736	4.9	81
Community Material	dual	1191276	4.7	6
Ayu	dual	1127068	4.7	92
Shades of Purple	dark	1122570	4.9	144
Material	dual	989586	5	13
Palenight	dark	832384	4.9	56
Atom One Light	light	639943	4.9	32
Nord	dark	541929	4.8	65
Andromeda	dark	387086	5	43
Tokyo Night	dual	375090	5	38
Gruvbox	dual	215607	5	30
Netbeans Light	light	87696	4.6	8
Plastic	dark	84556	5	34
Hop Light	light	76483	5	6
Snazzy Light	light	60368	5	4
Tiny Light	light	50676	4.8	6
Learn with Sumit	dual	26166	5	427

Table 1: Themes

Tablolar indirme sayılarına göre sıralı olarak sunulmuştur. Dark ve light temaların popülerlik karşılaştırılması yapılırken dual nitelikteki temalara ilişkin indirme sayılarının nihai durumda kullanılan tema grubunun kesin şekilde belirlenmesini olanaksızlaştırdığı dikkate alınmalıdır. Buna göre Tablo 1’de dual temalar göz ardı edilerek sadece tema grubunun kesin olarak bilindiği temalar dikkate alındığında salt dark temalar arasında en fazla indirme sayısına sahip olan temanın "One Dark Pro", salt Light temalarda ise "Atom One Light" olduğu görülmektedir. En fazla indirme sayısı bu çalışmanın yapıldığı tarih itibarıyla dark temalar için "One Dark Pro" ile 5 milyon civarı iken light temalar için "Atom One Light" ile 600 bin civarıdır. Salt dark ve light temaların toplam indirme sayılarına bakıldığında bu sayı dark için 15 milyon civarı iken, light için 1 milyon civarıdır.

Bu noktada tema popülerliği için indirme sayılarının tek başına yeterli bir ölçüt teşkil etmeyeceğinin belirtilmesi gerekir. Bir çok temanın Github üzerinden erişilebilecek açık kaynak kod depoları incelendiğinde tema popülerliğini yansıtan bir başka ölçüt olarak ilgili deponun "star" sayısının dikkate alınabileceği görülmektedir. Örneğin indirme sayılarını baz alan popülerlik sıralamasında 4'ncü sırada olan "Dracula" temasının Github kaynak kod deposu 18.3 K "star" almıştır[66]. Bu değer listedeki diğer temaların Github kaynak kod depolarındaki "star" sayılarının çok üzerindedir. "Dracula" temasıyla karşılaştırıldığında indirme sayıları açısından birinci sırada olan "One Dark Pro" temasının "star" sayısı 1 K[67], ikinci sırada olan "Visual Studio C/C++" temasının star sayısı ise 4.6 K'dır[68].

Dark temaların oldukça yüksek bir indirme oranına sahip olduğu görülmektedir. Bu sonuçlar Sarath'ın yaptığı anket çalışması [47] ve Coyier'in CSS özelinde renk tema tercih anketi [69] başta olmak üzere farklı çalışmalarda geliştiricilerin dark tema kullanma eğilimiyle oldukça uyumlu bir sonuçtur. Gerek VS Code'un gerekse de Visual Studio'nun ilk kurulumda öntanımlı olarak yerleşik bir dark temayla kurulu gelmesi de dark temaların geliştiriciler arasında daha popüler olduğu gözlemine uygun bir tercih olarak yorumlanmalıdır.

Temaların indirme sayıları ile beğeni skorları ve yorum sayıları arasında anlamlı bir korelasyona rastlanmamıştır. İndirme sayısı yüksek olduğu halde beğeni skoru o derece yüksek değildir ve uyumlu olarak yüksek miktarda yorum da eklenmemiştir. "Visual Studio C/C++" light teması bu gözleme örnek olarak verilebilir.

TODO İnsanlar indiriyor, ancak neden beğenmiyor veya yorum eklemiyorlar? Bununla ilgili literatür desteği kesin vardır. İnceleyip ondan da destek alarak burayı zenginleştireceğiz.

Şekil 10'de verilen hesaplama akışı kullanılarak seçilen renk teması, font ve örnek kaynak kod için ortalama CCT değerleri hesaplanmıştır. Dark temalar için hesaplanan CCT değerleri Tablo 2'da ve light temalar için olanlar ise Tablo 3'da verilmiştir. Tablo sütunlarında:

- CCT_{avg} : Tema için hesaplanan ortalama CCT değerini (Kelvin cinsinde)
- CCT_{bg} : Temanın arka plan rengine ait CCT değerini (Kelvin cinsinde)
- D65 deviation: Ortalama CCT değerinin D65 (6500 K) seviyesi göreceli farkını (yüzde olarak)

göstermektedir.

Theme	CCT_{avg} (K)	CCT_{bg} (K)	D65 deviation (%)
Gruvbox	5686	6503	-13
Monokai Pro	6093	6792	-6
Default	6515	6503	0
Visual Studio C/C++	6802	6503	5
Community Material	7086	6503	9
Winter is Coming	7306	5591	12
Andromeda	8517	9800	31
One Monokai	8659	9566	33
Github	8920	8812	37
Plastic	9218	9219	42
Atom One Dark	9609	9566	48
One Dark Pro	9609	9566	48
Nord	9999	11306	54
Material	10205	10213	57
Dracula Official	10560	11329	62
Ayu	11986	13096	84
Tokyo Night	14447	13595	122
Palenight	16619	16766	156
Learn with Sumit	23913	27849	268
Shades of Purple	124575	147514	1817
Night Owl	124592	146772	1817

Table 2: Dark Themes Temperatures

Theme	CCT_{avg} (K)	CCT_{bg} (K)	D65 deviation (%)
Gruvbox	4678	5032	-28
Tiny Light	5260	5754	-19
Monokai Pro	5937	6503	-9
Ayu	6864	6578	6
Visual Studio C/C++	6872	6503	6
Netbeans Light	6903	6503	6
Snazzy Light	7086	6577	9
Hop Light	7206	6503	11
Github	7450	6503	15
Material	7518	6503	16
Community Material	7762	6503	19
Learn with Sumit	8165	6503	26
Default	8363	6503	29
Tokyo Night	8786	6783	35
Night Owl	10224	6503	57
Winter is Coming	10862	6503	67
Atom One Light	26553	6503	309

Table 3: Light Themes Temperatures

Ne dark ne de light temalar için indirme sayıları, beğeni skoru veya yorum sayısı ile ortalama CCT arasında anlamlı bir ilişki bulunamamıştır. Temaların descriptive istatistik sonuçları Tablo 4’de verilmiştir. Dark temaların ortalama CCT değerlerinin ortalaması yaklaşık olarak 20 K iken light temalar için 8 K hesaplanmıştır.

Theme	Mean (K)	Std (K)	Min (K)	Max (K)
dark	20996.0	34683.67	5686	124592
light	8617.0	4875.19	4678	26553

Table 4: Theme descriptive statistics

Dark tema olarak 21 tema analiz edilmiştir (Table 2. Ortalama CCT değerlerinin D65’den -13% ile 1.837% arasında bir sapmaya sahip olduğu görülmektedir. Sadece 3 tema D65 değerinde veya altında çıkmıştır.

Light tema olarak 17 tema analiz edilmiştir (Table 3. Ortalama CCT değerlerinin D65'den -28% ile 309% arasında sapmaya sahip olduğu görülmektedir. Sadece 3 tema D65 değerinde veya altında çıkmıştır.

Dark tema grubunda en düşük CCT ortalaması 5.686 K ile Gruvbox iken en yüksek CCT ortalaması 124.592 K ile "Night Owl" olmuştur. Bu sonuçlar, D65 referansı ile karşılaştırıldığında, Dark tema kullananların gün ışığının çok üzerinde bir mavi ışığa maruz kaldığını göstermektedir. En fazla indirmenin olduğu "One Dark Pro" için CCT ortalaması 9.609 K'dır. Sonraki en yüksek indirmenin olduğu "Visual Studio C/C++" temasının ortalama CCT değeri D65'de çıkmıştır.

Light tema grubunda en düşük CCT ortalaması 4.643 K ile "Gruvbox" iken en yüksek CCT ortalaması 26.553 K ile "Atom One Light" olmuştur. En fazla indirmenin olduğu "Visual Studio C/C++" için dark temada olduğu gibi CCT ortalaması D65'e yakın çıkmıştır (dark için 6.802 K iken light için 6.872 K). Sonraki en yüksek indirmenin olduğu "Github" teması için 7.450 K hesaplanmıştır.

VS Code'un öntanımlı temaları için hesaplanan ortalama CCT değerleri dark için 6.515 K ve light için 8.263 K olarak hesaplanmıştır. Elde edilen değerlere göre dark D65 değerinde, light ise dark'a göre daha yüksek bir CCT değerindedir. Öntanımlı light default temasını kullananların dark versiyona göre daha yüksek mavi ışığa maruz kaldığı görülmektedir. VS Code'un ilk kurulumunda default dark temayla ayarlı olarak geldiği dikkate alınırsa programlama editörünün gayet makul bir öntanımlı yapılandırma sunduğu belirtilmelidir.

Yapılan çözümlemelerin gösterdiği bir diğer sonuç temada yapılan arka plan renk seçiminin temanın ortalama CCT değerini önemli ölçüde etkilemesidir. Arka plan rengiyle ortalama CCT değeri arasındaki güçlü ilişki özellikle dark tema sonuçlarında belirgin şekilde ortaya çıkmaktadır. Tablo 2 incelendiğinde Dark temalarda arka plan rengine ait CCT değerlerinin ortalama CCT değerlerine çok yakın olduğu görülmektedir.

Dark temalarda arka plan renk seçiminin sonuçları nasıl etkilediğini daha çarpıcı şekilde görmek amacıyla tüm temalarda arka plan renginin CCT değeri 6500 K değerinde sabit tutularak bir çözümleme yapılmış ve dark/light gruplarıdaki temaların ortalama CCT değerlerinin ortalamaları hesaplanmıştır. Sonuçlar Tablo 5'de sunulmuştur.

Theme	Mean (K)	Std (K)	Min (K)	Max (K)
dark	3319.05	795.55	2158	5013
light	5176.82	4799.63	2356	23025

Table 5: Theme descriptive statistics taking the background CCT as 6500 K

Tablo 5’deki sonuçlara göre temaların arka plan renkleri D65 seviyesinde bir renkle değiştirildiğinde ortalamada dark temaların light temalara göre daha düşük CCT değerinde olacağı görülmektedir. Tema geliştiricileri açısından önemli olan bu sonuç, light temalara göre daha popüler olan dark temalarda arka plan rengi olarak D65 seviyesine yakın bir rengin seçilmesinin tema kullanıcılarının maruz kalacağı mavi ışık miktarını azaltacağını göstermektedir. Tema geliştiricilerinin bu sonucu dikkate alarak görsel uyumu bozmadan yine dark nitelikte fakat daha düşük CCT değerinde bir arka plan rengi kullanmaları yerinde bir seçim olacaktır.

Temaların ortalama CCT değerini arka plan rengi dışında etkileyen bir diğer faktörün kaynak kodda baskın olan söz dizimi grupları için yapılan renk seçimleri olduğu görülmüştür. Örneğin "Atom One Light" temasında kullanılan renkler sıklık sırasıyla Tablo 6’de sunulmuştur.

Color	CCT (K)	Frequency
#383a42	8377	4467
#a626a4	142967	2313
#fafafa	8377	1101
#e45649	1561	1070
#4078f2	2380426	421
#986801	2644	301
#a0a1a7	6943	223
#50a14f	6129	174
#0184bc	145246	39

Table 6: Atom One Light theme colors

Bu tabloya göre, birinci sıradaki düşük CCT değerli renk bir yana bırakılacak olursa ikinci sırada görülen **#a626a4** hex kodlu rengin programlama dilinin rezerve kelimelerini içeren sözdizimi grubunu renklendirmekte kullanıldığı belirlenmiştir. Bu rengin hesaplanan CCT değeri 142967’dir. Kaynak kodda rezerve kelime sıklığı büyük olduğundan temanın bu gruba ilişkin yaptığı renklendirme nihai CCT değerinde baskın olarak etki göstermektedir. "Atom One Light" temasının 26553 gibi çok yüksek bir ortalama CCT değerine sahip olmasının ana nedeni budur.

Sonuç olarak temaların ortalama CCT değerlerini sunan tüm tablolarda görülen yüksek CCT değerlerinin arkasında bu iki faktörün, yani arka plan rengi ve yüksek sıklıklı söz dizimi grubuna ait rengin baskın rol oynadığı söylenmelidir.

Dual temalar için hesaplanan ortalama CCT değerleri Figure 11’de verilmiştir. Temaların light versiyonlarının belirgin bir şekilde dark versiyonlarına oranla daha düşük CCT ürettiği ancak yine de D65’in üzerinde olduğu görülmektedir. Tablo 2 ve 3’deki CCT_{bg} sütunları karşılaştırılacak olursa Dark temaların yüksek CCT değeri göstermesinin temel nedeni bu temalarda yüksek CCT değerli mavi yoğun renklerin kullanılmış olmasıdır.

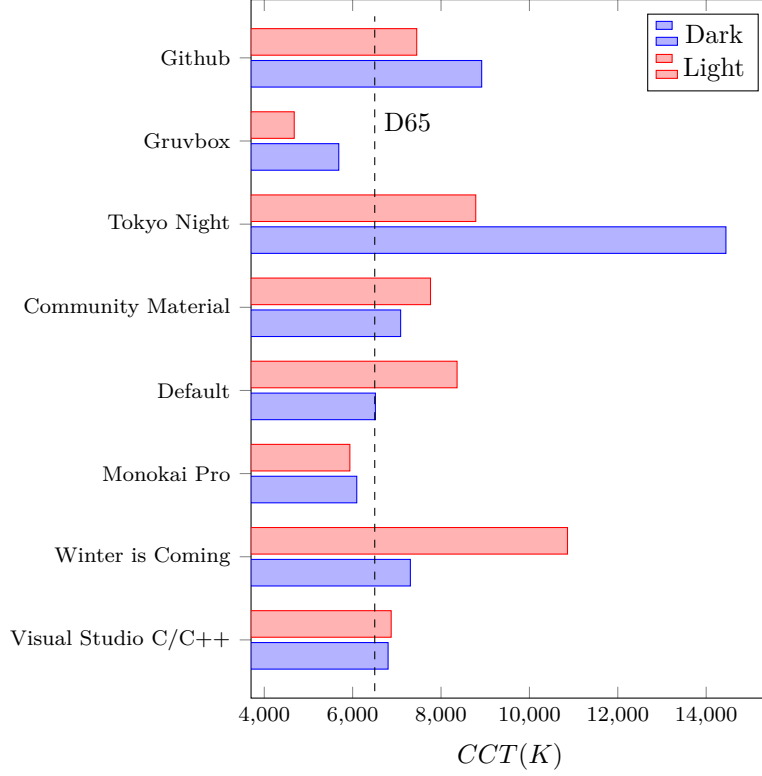


Figure 11: Dark-Light CCT value comparison of themes in pairs

Figure 12’de dark temaların ortalama CCT değerleri verilmiştir. ”Default” tema haricindeki temaların ortalama CCT değerleri D65’in üzerindedir. ”Night Owl” ve ”Shades of Purple” ise hesaplanmış en yüksek CCT değerlerine sahip, dolayısıyla en fazla mavi ışık barındıran temalardır.

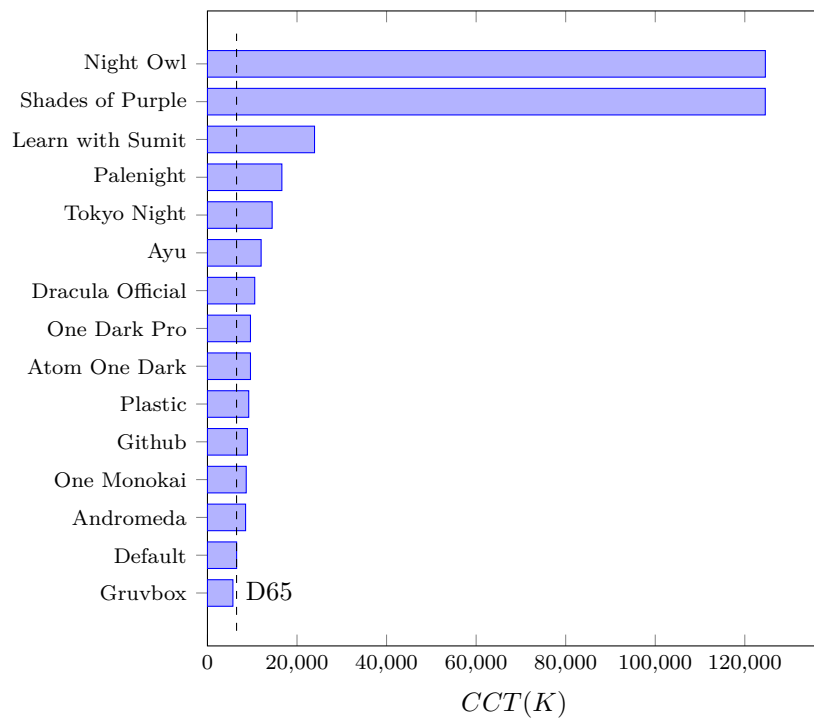


Figure 12: CCT value comparison of dark themes

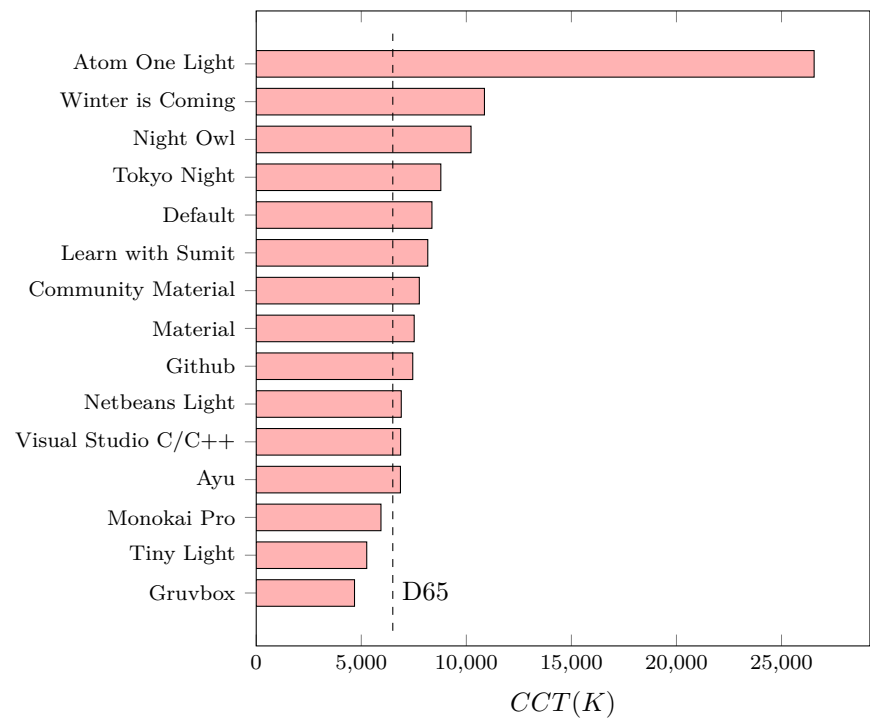


Figure 13: CCT value comparison of light themes

Sarath'ın yaptığı anket çalışması [47] ve Coyier'in CSS özelinde renk tema tercih anketi [69] başta olmak üzere farklı çalışmalarda geliştiricilerin dark tema kullanma eğiliminde olduğu görülmüştür. Bu tercihin altında "Soothing to Eye", "More Concentration" ve "Save Energy" önplana çıkmaktadır. Diğer taraftan bu çalışmanın da ortaya çıkardığı CCT'nin yüksek olması ve mavi ışık tehlikesinin yüksek olduğu gerçeği, dark temaların özellikle arkaplan renklerinin tekrardan gözden geçirilmesini gerektirmektedir.

İncelenen temaların dark versiyonları, light olanlarına oranla daha yüksek CCT değerine sahiptir. Özellikle mavi ışığın zararlı etkisinin sonucu olarak light temaların daha uyarıcı (**TODO** referans gerekebilir) olmasına karşın uzun süreli kullanımda insan sağlığı açısından olumsuz etkilerinin renk tema tercihinin light yerine dark olmasını açıklamaktadır. Bauer vd.lerinin [70] yaptıkları çalışmada ortaya konan dark temanın okuma üzerine olumlu katkısının da bu tercih önemli bir katkısı olduğu değerlendirilmektedir. Ancak mavi ışığın uzun süreli olumsuz etkilerinden korunmak adına CCT'nin ortalamasını yükselten özellikle arkaplan renginin tekrardan gözden geçirilmesi gerekmektedir.

3.1 Kısıtlamalar

Bu çalışmanın aşağıda listelenen çeşitli kısıtlamaları mevcuttur.

- İndirme sayılarına bakılarak sadece en popüler temalar araştırmaya dahil edilmiştir. Tema seçimi 2.1.2 bölümünde açıklanmıştır.
- Çözümleme için örnek dil olarak C dili tercih edilmiştir. Bu tercihin gerekçeleri 2.1.3 bölümünde açıklanmıştır.
- Çözümleme sadece bir font için gerçekleştirilmiştir. Font seçimi 2.1.4 bölümünde açıklanmıştır.
- CCT hesabında, seçilen hesap yaklaşımının kısıtından ötürü T_S ve T_F aralığı dışında kalan renkler göz ardı edilmek zorunda kalmıştır.
- Ekran veya ekran kartının renk bozucu etkisi göz ardı edilmiştir.
- Ortamın aydınlatması göz ardı edilmiştir.
- Geliştiricinin renk algısı tek tip olarak kabul edilmiştir.

TODO Aşağıya copy-paste yaptıklarımı da değerlendireceğiz.

Although CCT has been widely used to evaluate light sources, it suffers from the loss of information caused by reducing often complex spectral power distribution shapes and twodimensional chromaticity coordinates into a single number. Since chromaticity diagrams are twodimensional spaces, two coordinates are required to specify each unique point. As a result, two visually distinct light sources can have the same CCT. In addition, CCT calculations are based on colour matching functions devised to estimate colour precept matches made by standard observers under confined environmental conditions. The background and surroundings affect colour perception (e.g. simultaneous contrast). For example, a 4000 K light source may look warm next to a 6500 K light source, but it may appear cooler next to a 2700 K light source [71].

Research also shows that visual differences can be perceived among similar CCT sources. For example, observers can perceive a variation in light sources along isometric CCT lines (identical CCTs with different chromaticity coordinates), especially for high CCT light sources ($T_{cp} > 4500$ K).^{21,22} Since CCT inaccuracy increases with distance from the Planckian locus, measuring the chromaticity distance to the Planckian locus was suggested. ²¹[71]

4 Conclusion

Bu çalışmada kullanılan temaların indirme sayıları incelendiğinde dark temaların light olanlara oranla çok daha fazla indirildiği görülmüştür. Bu durum farklı anketlerde ortaya konan dark tema kullanım sonuçları uyumludur.

Hem dark hem de light tema grubu için hesaplanan ortalama CCT değerleri D65'in çok üzerinde çıkmıştır. Dark tema ortalamaları light'a göre daha düşüktür. Bu durum farklı anketlerde ortaya konan dark tema kullanım eğilimiyle uyumludur.

Hem dark hem de light tema grubunu kullananların gün ışığının üzerinde bir mavi ışığa maruz kaldığını göstermektedir. Bu durum hem editör ile öntanımlı gelen temalar hem de indirme sayısı yüksek olan temalar için de geçerlidir. Göz sağlığı başta olmak üzere genel insan sağlığı için light yerine dark tema tercih edilmelidir. Dark temalar arasında ise D65'in altında yer alan temalardan seçim yapılmalıdır.

Çift olarak sunulan temaların hem dark hem de light versiyonlarının CCT değerleri de D65'in üzerinde çıkmıştır. Tema çiftlerinden illa birisi tercih edilecekse dark tercih edilmelidir.

In order to minimize these effects, it is possible for screen producers to know how the products they make will influence melatonin levels and to use model estimations to adjust spectral power distribution of self-lighting devices to adjust them to circadian rhythm or individuals to resort to different methods (using filters, using special lens, using special glasses, using screen specific night/reading mode and software to adjust color temperature) to minimize the harmful effects during the use of these devices. However, considering that it was not possible to reduce BLH' effect to a great extent due to screen technology although blue filtering level was increased and that artificial color temperature changes in theme create visual discomfort, the most common solution will be creating theme with lower mean CCT without sacrificing coding cognitive level in the source where they are created and this will be an acceptable solution in terms of human health. Tema tasarımı yapılırken mavi ışık tehlikesi göz önüne alınarak renk paleti oluşturmayla ilgili ileri çalışmalara ihtiyaç duyulmaktadır. Var olan temaların mavi ışık etkisini azaltmak için gün ışığına bağlı olarak CCT ayarlayan yazılımların SH temalarında context de dikkate alınarak gerçekleştirilmesi daha yerinde olacaktır.

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Conflicts of interest

The author declares no conflicts of interest.

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