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PRELIMINARY STUDY ON POSSIBILITY TO USE AREA-BASED OPEN-SOURCE IMAGE ANALYSIS TOOLS IN ACCESSING SKIN TONE COLOR REPRODUCTION ACCURACY IN INK-JET PRINTING

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Abstract: *Colour is a complex and integral aspect of human visual experience, significantly impacting our daily lives by influencing emotions, behaviours, decisions, and even physical well-being. Colour perception is highly subjective, varying widely among individuals due to factors such as biological differences, psychological influences, and contextual conditions. To ensure accurate colour monitoring, objective colorimetric analysis is essential, particularly in the graphic industry where colour reproduction quality is paramount. This necessity becomes even more pronounced in the reproduction of skin tones, a critical area of research due to its association with memory colours and its influence on the perceived impression of people in images. Recent research has demonstrated that individuals with normal trichromatic vision can accurately differ subtle changes in skin colour, including slight shifts in chroma and hue towards more reddish tones compared to the actual skin shade. Objective colour reproduction analysis typically employs standard colorimetric measurement procedures, devices, and software solutions. However, commercially available devices are often expensive and robust, particularly in the objective quantification of colour reproduction on materials with specific surface properties and shapes. There is growing interest in quantitative colour measurements derived from low-cost, user-friendly software solutions paired with inexpensive imaging technologies, making objective colorimetric detection more accessible. In this paper, we investigate the potential of using two area-based open-source image analysis tools, ImageJ and Trigit, to assess skin tone colour reproduction accuracy. Targeted skin colour tones were ink-jet printed, scanned, and analyzed to extract colour coordinates using these tools, with manual measurements taken directly from the prints using a spectrophotometer as well. By calculating colour differences, we characterized the proposed colour measurement procedures. The research reviled certain advantages as well as limitations of usage of area-based open-source image analysis tools in characterizing skin colour reproduction.*

Key words: colour perception, skin tone reproduction, colorimetric analysis, image analysis tools, ink-jet printing

1. INTRODUCTION

Human colour vision can be explained through the integration of physics and biology, supported by the Young–Helmholtz theory and Newton's work in optics. According to Newton, the colour we perceive is the reflected light wavelength from an object's surface, while the remaining wavelengths are absorbed. In biology, colour vision relies on two types of photoreceptor cells in the retina: cone cells and rod cells. Cone cells, which number approximately 6 million per eye, dominate under bright conditions and are responsible for processing the three primary colours: red, green, and blue (Zeng, 2011; Woolf et al., 2021; Tjandra, Heywood & Chandrawati, 2023). These cells contain photopigments that are spectrally sensitive to specific wavelength ranges corresponding to these colours. In individuals with normal trichromatic vision, the brain processes and combines inputs from the three types of cone cells to reconstruct the observed colour. The human eye and brain then integrate this information to produce a unique signal that corresponds to a specific colour, with the number of distinguishable shades varying from person to person, ranging from 1 to 100 million colours (Zeng, 2011; Woolf et al., 2021; Tjandra, Heywood & Chandrawati, 2023).
The colour perception plays a significant role for humans, especially the colour perception of the skin. There are numerous studies highlighting the influence of facial skin tone perception not only on facial recognition but also on the interpretation of emotional expressions, health assessments, and evaluations of attractiveness (Shimakura & Sakata, 2022). Research has consistently shown that the perception of facial skin tone differs fundamentally from the perception of other colours. Individuals with normal trichromatic

vision are capable of detecting subtle variations in human skin colour with remarkable precision. The perception of skin colour serves as a key predictor of attractiveness and is closely linked to judgments regarding an individual's health based on facial appearance (Shimakura & Sakata, 2022).

The study of skin colour has been extensive over many years due to its importance in various industries, including photography, printing, medical fields, lighting, retail, and cosmetics where accurate reproduction is essential. Accurate reproduction of skin colour is crucial in most of these applications to ensure optimal results, whether it be for visual consistency, medical diagnostics, or product matching (Wang et al., 2017).

Skin colour is considered a memory colour, playing a crucial role in how people are perceived in images. With the widespread use of mobile devices such as smartphones and tablets, and the growing popularity of image capture and sharing applications, user demands have evolved beyond traditional accurate colour reproduction toward achieving preferred colour reproduction (Peng et al., 2023).

Accurately reproducing skin tones in a visually appealing manner is a crucial aspect of colour reproduction. Given that individuals often rely on their memory of object colours to assess the quality of colour reproduction, it is essential to understand the preferred colour reproduction range of skin tones and the methodology of colour measuring, for optimal preference-based colour reproduction (Zeng & Luo, 2010).

Skin colour must be accurately printed and calibrated to ensure proper colour reproduction. Utilizing a human vision detection method is inherently subjective and influenced by individual variability, potentially leading to inconsistent or inaccurate results (Tjandra, Heywood & Chandrawati, 2023).

In terms of quantifying colour, objective quantification of colours through empirical models of the colour space is required. Several methods and equations are available, with the most commonly used being the CIE L*a*b* colour space and colour difference equations (Sharma, 2018). It is hypothesized that skin tones have a lower tolerance for deviations, making them particularly important in colour management. Skin tones present a greater challenge in printing because changes or errors in colour are more readily perceptible compared to other hues.

Recently, there has been increasing interest in the quantitative colour measurement based on images captured using low-cost commercial technologies such as smartphones, scanners, and digital cameras for scientific applications. Image processing technology, a technology within the field of computer science and a important component of Industry 4.0, can be defined as a type of signal processing in which the input is an image, and the output can either be a modified image or a set of characteristics and parameters extracted from the image (Babič, 2018; Milošević et al., 2022). The advancement of affordable imaging technologies has enhanced the feasibility of objective colorimetric detection during the image acquisition process. Commonly used colour analysis software by researchers for those purposes includes ImageJ, MATLAB, Pantone Studio, Digital Colorimeter by Apple, Trigit, and various developer-customized tools (Tjandra, Heywood & Chandrawati, 2023). With this in mind, the present study explores the feasibility of utilizing two area-based open-source image analysis tools- ImageJ and Trigit- for assessing the accuracy of skin tone colour reproduction. Specifically, selected skin colour tones were printed using an inkjet printing machines, scanned, and analyzed to extract colour coordinates using the aforementioned tools. Additionally, manual measurements were conducted directly on the printed samples using a spectrophotometer. By calculating colour difference values, the proposed colour measurement procedures were evaluated and characterized. The research led to conclusions regarding the applicability of area-based open-source image analysis tools for the characterization of skin tone colour reproduction.

2. METHODS

For the purpose of this study, a test chart comprising twenty selected skin colour patches was developed (Figure 1). The chart was created using Adobe Illustrator CC, with 20 patches chosen from Adobe's original skin colour palette to represent the most commonly used skin tones in graphic design. The PDF file was prepared for printing in accordance with the colour specifications embedded in the Coated Fogra 39 profile. Printing was conducted on two different fully calibrated ink-jet printing machines: a solvent-based SOLJET Pro 3 Print and Cut XC-540, and a UV-based UV Print and Cut LEC-540, using two distinct output resolutions- 360x720 dpi and 720x1440 dpi-representing the lower and upper resolution limits, respectively. All other settings were consistent across both machines: the dither option was selected for rasterization, the nearest neighbour method was used for interpolation, and the bi-directional option was selected for print head movement. The printing substrate used was commercially available Display PP paper.

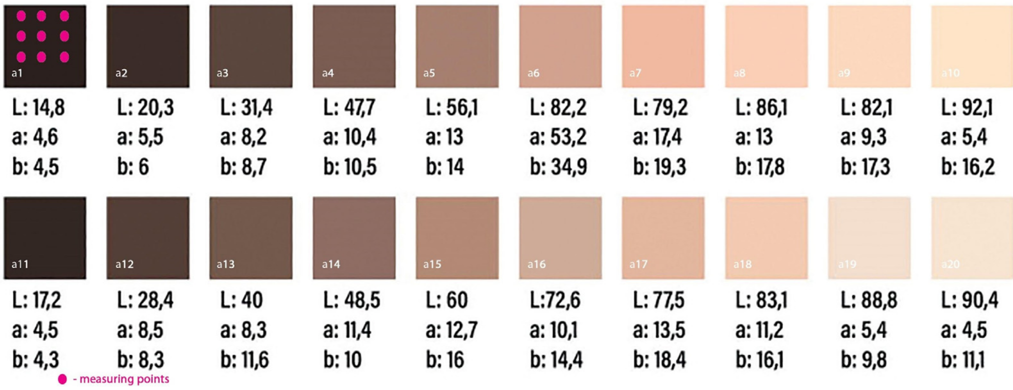

*Figure 1: The test chart and L*a*b* values of chosen samples with marked measuring points*

Colorimetric measurements of the L*a*b* values were conducted using a Techkon SpectroDens spectrophotometer (measurement geometry 0/45, illuminant D50, and 2° standard observer). Each patch was measured six times (Figure 1), and the average values were used for subsequent data analysis. The digitalization of the printed samples was performed using a CANON CanoScan 5600F scanner at native resolutions of 300 dpi, 600 dpi, 800 dpi, and 1200 dpi, with all image enhancement options disabled during scanning. The extraction of RGB and L*a*b* values from the digitized samples was carried out using two area-based, open-source image analysis tools: the latest versions of ImageJ (Figure 2a) (ImageJ, 2024) and Trigit (Figure 2b) (Trigit, 2024). In both software programs, the square selection tool was employed to define the area of interest (one colour patch). In Trigit, L*a*b* values were directly calculated, while in ImageJ, RGB values were initially extracted (Plugins > Analyze > RGB Measure) and then converted to L*a*b* values using reference XYZ values of 94.811, 100.00, and 107.304 (EasyRGB, 2024). The colour difference values, ΔE00 (EasyRGB, 2024), were calculated using the L*a*b* values obtained from both the spectrophotometer and the image analysis software. These colour difference calculations were used to characterize the proposed colour measurement procedures.

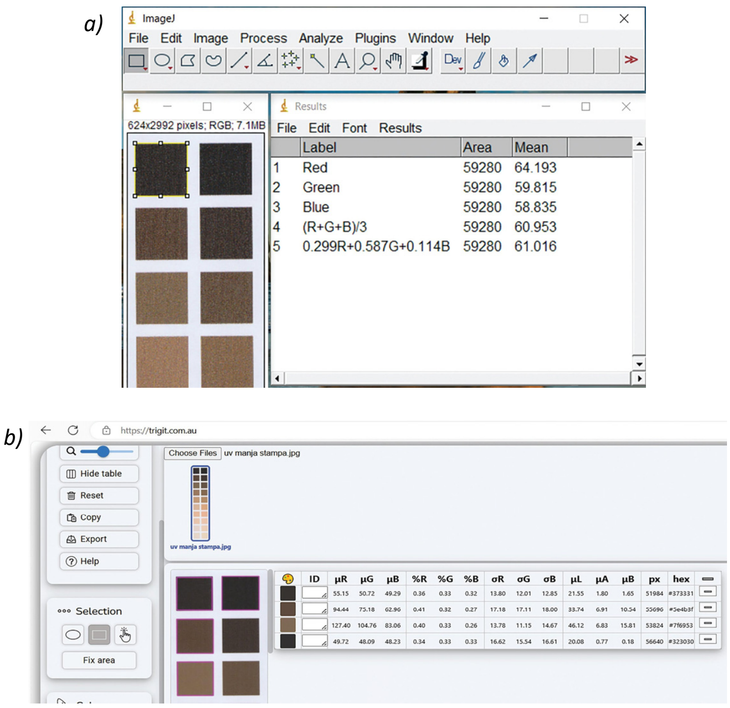

Figure 2: a) ImageJ, b) Trigit

3. RESULTS AND DISCUSSION

Figures 3–6 present the calculated colour differences (ΔE00) between the L*a*b* values of each colour patch, as measured by the spectrophotometer and those extracted from the scanned images using the open-source image analysis software, Trigit and ImageJ.

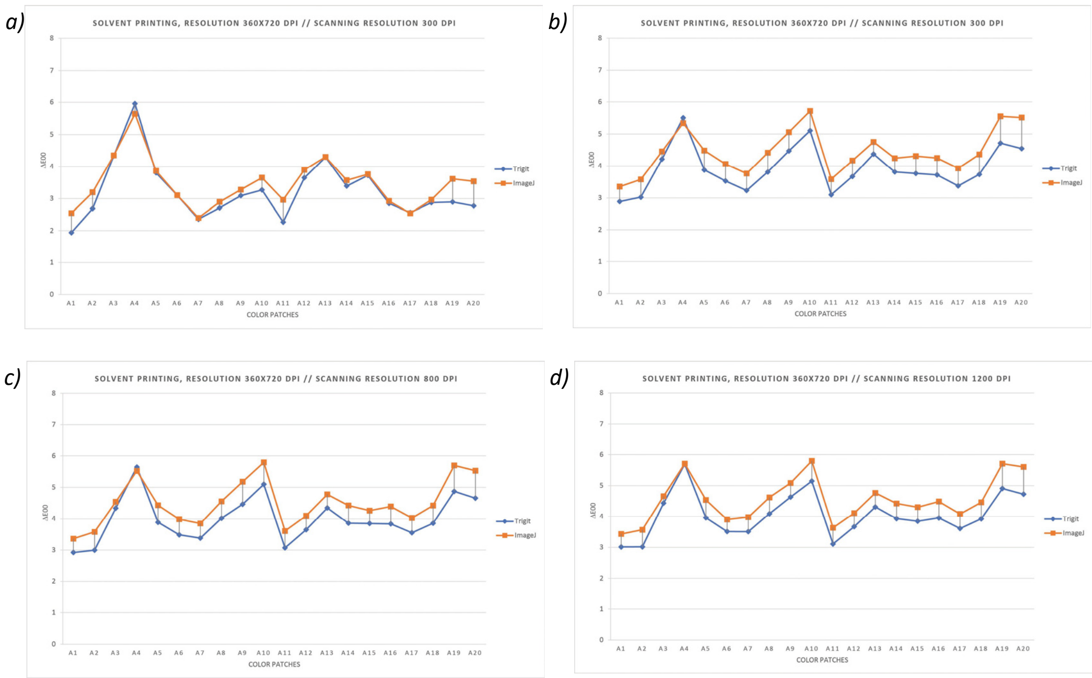

Figure 3: Colour difference values (ΔE00); solvent ink -jet printing, output printing resolution of 360x720 dpi and scanning resolution of a) 300 dpi, b) 600 dpi, c) 800 dpi and d) 1200 dpi

Figure 3 presents the calculated colour differences (ΔE00) for samples printed using a solvent-based inkjet digital printing machine at a lower printing resolution. As observed from the graphs, the calculated colour differences range from 1.5 ΔE00 to 6 ΔE00, with higher values for the lighter colour patches compared to the darker ones. The results clearly indicate that the colour differences between the measured L*a*b* values and those extracted in the Trigit software are lower than those obtained using ImageJ. This discrepancy may be attributed to the RGB to L*a*b* colour conversion methods employed. Furthermore, depending on the scanning resolution, these differences do not exceed 1.0 and are more pronounced at higher scanning resolutions. At lower scanning resolutions, the colour differences between the measured and extracted L*a*b* coordinates are reduced, with the lowest scanning resolution yielding the smallest colour differences.

Figure 4 presents the calculated colour differences (ΔE00) for samples printed using the same solvent-based inkjet digital printing machine but at a higher printing resolution. The colour differences range from 2 ΔE00 to 6 ΔE00, again showing higher values for the lighter colour patches than for the darker ones. A similar trend is observed, where lower colour differences are calculated between the measured L*a*b* values and those extracted in Trigit compared to ImageJ. As with the low-resolution samples, the differences are more pronounced at higher scanning resolutions but remain under 1.0. Additionally, the lower the scanning resolution, the smaller the colour differences between the measured and extracted L*a*b* values, with the lowest scanning resolution again producing the least deviation.

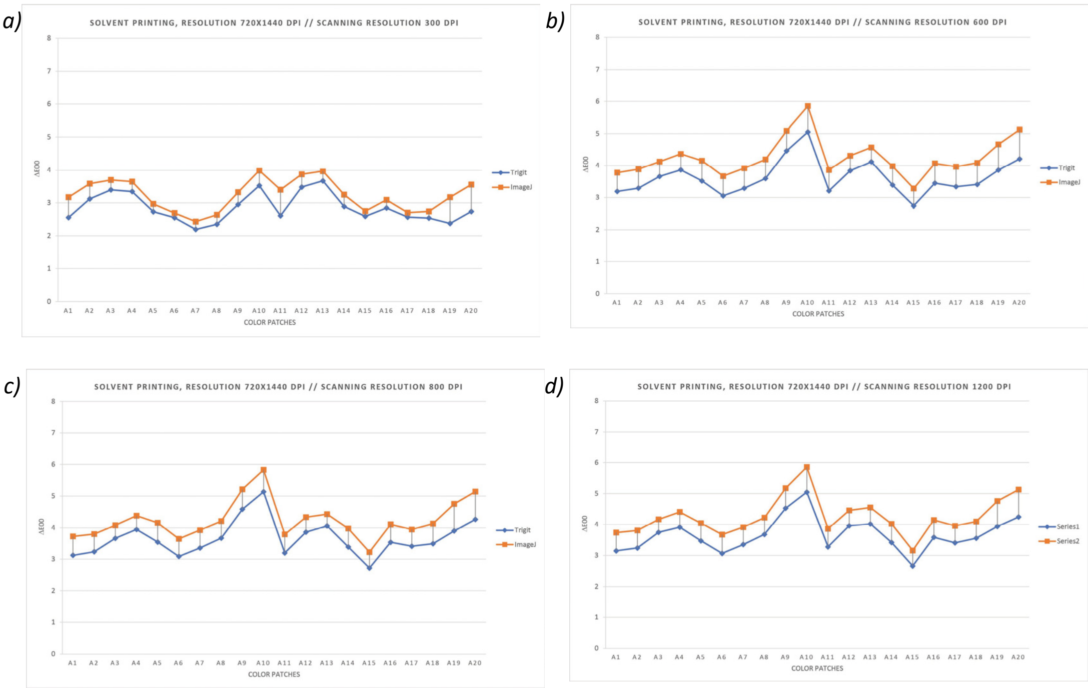

Figure 4: Colour difference values (ΔE00); solvent ink – jet printing, output printing resolution of 720x1440 dpi and scanning resolution of a) 300 dpi, b) 600 dpi, c) 800 dpi and d) 1200 dpi

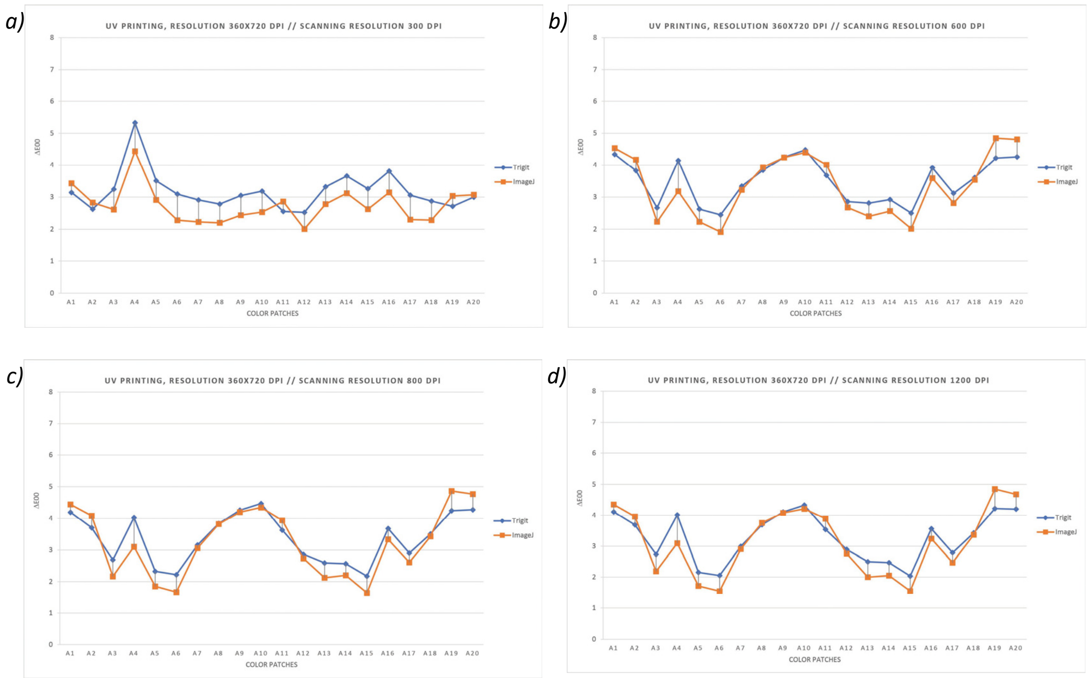

Figure 5: Colour difference values (ΔE00); UV ink - jet printing, output printing resolution of 360x720 dpi and scanning resolution of a) 300 dpi, b) 600 dpi, c) 800 dpi and d) 1200 dpi

Figure 5 presents the calculated colour differences (ΔE00) for samples printed using a UV inkjet digital printing machine at a lower printing resolution. The colour differences range from 1.5 ΔE00 to 5 ΔE00, with higher values observed for the lighter colour patches compared to the darker ones. Overall, the calculated colour differences are lower than those for samples printed with the solvent-based inkjet printing machine, which may be attributed to the higher image sharpness achieved with UV inkjet printing, even at lower output resolutions.

Except for the lowest scanning resolution, the lower colour differences were generally calculated between the measured L*a*b* values and those extracted in Trigit compared to ImageJ. However, it is important to note that for most colour patches, the calculated colour difference values are quite close between the two software tools, and the differences do not appear to be significantly influenced by scanning resolution. This may again be related to the higher image sharpness associated with UV inkjet printing, where higher scanning resolutions do not significantly enhance sharpness during image analysis, as might be the case with solvent-based prints.

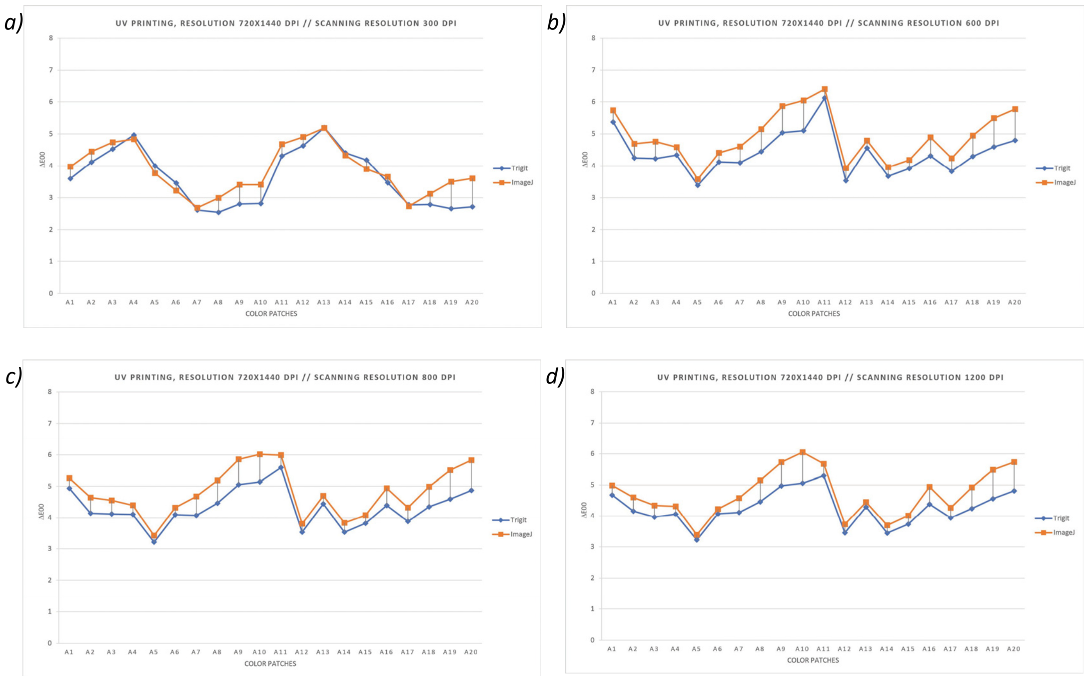

Figure 6: Colour difference values (ΔE00); UV ink - jet printing, output printing resolution of 720x1440 dpi and scanning resolution of a) 300 dpi, b) 600 dpi, c) 800 dpi and d) 1200 dpi

Figure 6 presents the calculated colour differences (ΔE00) for samples printed using a UV inkjet digital printing machine at a higher printing resolution. The colour differences range from 2.5 ΔE00 to 6.5 ΔE00, with higher values observed for the lighter colour patches compared to the darker ones. Overall, the calculated colour differences are slightly higher than those for samples printed at a lower resolution. As with the previous cases, lower colour differences were calculated between the measured L*a*b* values and those extracted using Trigit compared to ImageJ. However, these differences remain below 1.0 and appear to be largely unaffected by the scanning resolution. This may again be attributed to the higher sharpness achieved with UV inkjet printing, where increased scanning resolution does not significantly improve sharpness during image analysis, as might occur with solvent-based prints. As the scanning resolution increases, the colour differences tend to slightly increase, suggesting that lower scanning resolutions may result in marginally lower colour differences.

5. CONCLUSIONS

In this paper, we investigated the feasibility of using two area-based, open-source image analysis tools-ImageJ and Trigit-for assessing the accuracy of skin tone colour reproduction. The conducted research and data analysis led to the following conclusions:

- Quantitative colour measurements obtained from cost-free, tailor-made, user-friendly software solutions such as Trigit and ImageJ, combined with inexpensive image digitization technologies (e.g., scanning), can be characterized as straightforward and easy to perform.

- Both software tools require the manual definition of the region of interest (ROI). Trigit offers more convenient colour calculations, as it directly computes L*a*b* values, whereas ImageJ requires post-processing of extracted RGB data to derive L*a*b* values. The method of calculation (i.e., the definition of the illuminant and the standard observer via XYZ reference values) can impact the final results in both cases.
- The calculated colour differences between instrumentally measured L*a*b* values and those derived from scanned images of selected skin colour patches ranged from 1.5 ΔE00 to 6.5 ΔE00, reflecting low to highly distinguishable differences.
- Colour differences tend to be higher for lighter colour patches compared to darker ones. Trigit consistently produced lower colour differences between measured and extracted L*a*b* values than ImageJ, potentially due to differences in the methods used for calculating L*a*b* colour coordinates.
- The analysis revealed the impact of both scanning resolution and image sharpness (linked to the output resolution and printing method—solvent or UV-based) on the results. However, scanning resolution appears to have a lesser effect on colour differences compared to image sharpness.
- Generally, lower scanning resolutions resulted in lower colour differences.
- The potential for using open-source image analysis tools to assess colour reproduction accuracy is considerable. However, further investigation is needed to evaluate the influence of various printing substrates and conditions, digitalization methods and their potential, as well as colour coordinates and colour differences calculation methods in order to express with more certainty that this methodology could substitute devise-based colour measurements. This is especially important to be further investigated in the domain of accessing colour reproduction accuracy of skin colours, since even slightest changes in the reproduction could be detected by the human eye, thus methods used for monitoring and delivering accurate colour reproduction must be repeatable, stable and if possible standardized.

6. ACKNOWLEDGMENTS

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