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Automation of optical quality control in the example of the furniture industry

Streszczenie. *Przedstawiony został prototyp systemu kontroli jakości opartego na algorytmach detekcji optycznej. W swojej funkcjonalności zawiera przykładową aplikację webową, za pomocą której klient może złożyć zamówienie – w tym przypadku szafę, na podstawie której pracownik będzie mógł kontrolować jakość zamówienia, a dokładniej – sprawdzać, czy poszczególne elementy danego zamówienia, jak np. lakier, nie zostały poddane procesowi starzenia się. (**Automatyzacja optycznej kontroli jakości na przykładzie branży meblarskiej).***

***Abstract**. A prototype of a quality control system based on optical detection algorithms will be presented here. In its functionality, it will include an exemplary web application used by the customer to place an order - in this case, a wardrobe, based on which an employee will be able to control the quality of the order and, more precisely - to check whether the components of a given order in the warehouse have not undergone the ageing process, e.g. paintwork.*

Słowa kluczowe: BPMN, mikroserwisy, fotografia obliczeniowa, różnica kolorów, kontrola jakości.
Keywords: BPMN, microservice, computational photography, color difference, quality control.

Introduction

In industries such as furniture or automotive, the coloring of product elements is of great importance [1]. The color differences between the panels that make up the final product determine its approval for sale or use. They are also very often the subject of complaints filed by customers. Defects in the product's color may arise at the production stage and may result from aging or poor storage of ready-made elements. The verification of such processes is one of the stages of the quality control system. In technological processes, many solutions are used for optimization [2-10]. However, the human eye is prone to many disorders resulting from color perception, lighting, and even fatigue. The use of expensive color validation systems is out of the question for small businesses. Therefore, the project aimed to create an inexpensive, noise-resistant, and automated system that would allow for color verification of painted product elements. Automating the process of comparing the colors of individual product elements - assessing their compliance or identifying differences - can significantly affect the efficiency of order fulfilment, their quality, and, as a result, customer satisfaction. The article describes the design of a system supporting the quality control process. In addition to the database, the system includes a web client application for placing orders and a mobile application module for evaluating the tested element. Testing consists of comparing the tested element with the pattern, which is performed by the created microservice. Orders placed by customers are carried out based on the processes described by BPMN and are controlled by this flow.

A Simplified quality control process

The implementation of the process solution was based on modelling using BPMN. Business process models known as BPMN are primarily used to present these processes. On the other hand, the use of BPMN is much broader because the notation is used to identify, verify, refine and implement business processes [11].

The Camunda tool was chosen as the engine of the process presented in the article. It is a Java-based BPMN platform supporting the automation of work and processes [12]. Camunda BPM provides a REST API interface that allows one to build applications that connect to a remote process engine. Fig. 1 shows the implementation, management, and, monitoring of processes using the Camunda platform tools.

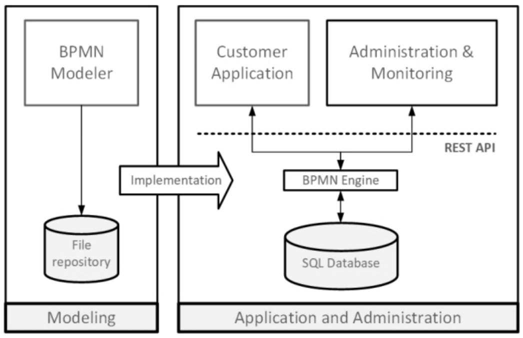

Fig.1. Implementation, process management with Camunda.

Fig. 2 shows a schematic of the entire system. As shown in the figure, three main components of the system connect to the MSSQL database, the operation of which is managed and monitored by the Camunda framework.

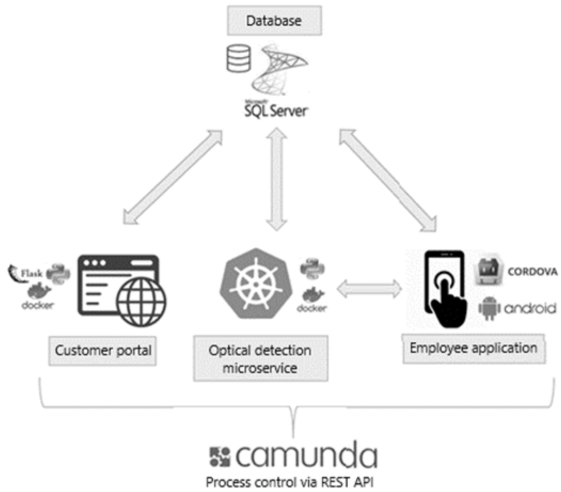

Fig.2. Implementation, process management with Camunda.

The proposed solution includes encapsulated in a Docker container customer portal for placing orders, an optical detection microservice that performs analysis for quality control, and a mobile application, which the employee uses to perform the inspection [13]. The theoretical foundations based on which the microservice was built are presented in the *Algorithm assumptions* chapter.

The process (see Fig. 3 below) begins when the customer places an order using the web application. Inside this application, there are connections with database tables to properly illustrate the user with information about products, their details, or their orders. At this point, a new task also appears for the employee in his application. He sees the list of orders to be checked and can proceed to the examination of the individual items. After examining the element, a query is made as to whether all elements have already been considered. If so, the process ends, if not - the next element is checked by the employee, and the photo sent by him is sent to the microservice for optical color analysis. Based on the image sent by the employee and the reference image downloaded from the database, the algorithm determines whether a given element is compliant with the order placed or whether it is significantly different.

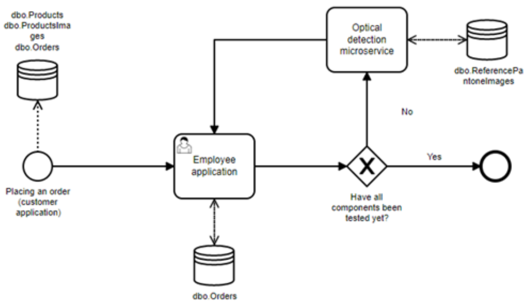

Fig.3. BPMN model of the quality control process.

The entire process is monitored by Camunda via REST API. A diagram of such a process after checking one element of a given order is presented below (Fig. 4). Thus, the employee checked one of the line items at the time presented, and since it was not the last - the process requires him to check the next items.

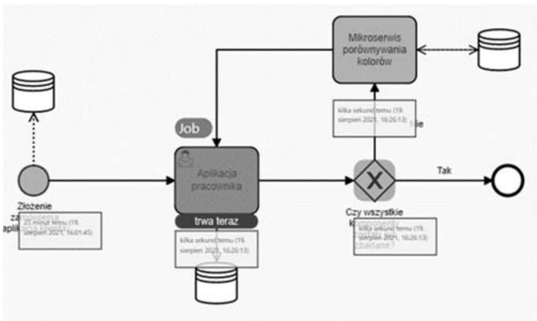

Fig.4. A simplified diagram of the quality testing process.

Description of the methodology and tools used

Two methods can be used to solve problems related to comparing colors and detecting differences between them. The first is the histogram [14], [15] and the second is the ΔE method [16], [17].

By using histogram matching, you analyze the color distribution of one image and fit it to the next. In real-world color-matching applications, to perform basic color correction, start with determining color consistency [18]. The purpose of this procedure is to be able to perceive the colors of objects regardless of differences in lighting. This consistency can be provided by color correction cards.

So assuming that some safe ambient lighting conditions can be achieved, it will be possible to dispense with costly deep learning algorithms that sometimes help to get the desired results under imperfect conditions. Instead, basic image processing methods can be used that allow setting parameters to be determined in computer vision techniques [19]. To standardize the lighting conditions, a special stand was created (Fig. 5) in which a color card was installed, a lamp ensured the same lighting, and a smartphone holder allowed the employee to use the application during the inspection.

Fig.5. The kit used in the process of quality testing.

Histogram equalization is an image processing method that adjusts the contrast with the histogram of the image. This method tends to increase the global contrast of many images, especially when useful image data is represented by close contrast values. With this adjustment, the intensity can be better distributed in the histogram. This allows areas with lower local contrast to obtain higher contrast. The smoothing of the histogram achieves this by efficiently decomposing the most common intensity values. In real-world color-matching applications, to perform basic color correction, start by specifying color consistency. The purpose of color stability is to correctly perceive the colors of objects regardless of differences in light sources, lighting, shadows, etc.

In contrast, determining the appropriate color spaces helps in assessing color differences. Experimental psychology focuses its attention on senses, sensations, and perceptions. From the research conducted within this discipline, a phenomenon appeared related to the threshold of the difference in the selected stimuli. It is a phenomenon known as just-noticeable difference. This is the number of stimuli that need to be changed for the difference to be noticeable and detectable at least half the time (absolute threshold). In neuroscience and psychophysics, the absolute threshold was originally defined as the lowest level of stimulus that the body could detect (e.g., the amount of light, sound, touch, etc.). Using the signal detection theory, the absolute threshold is defined as the level at which a stimulus is detected for a certain percentage of the time (assumed to be 50%). The absolute threshold can be influenced by several different factors, such as the subject's motivations and expectations, cognitive processes, and the subject's adaptation to the stimulus.

The intention to use the ΔE (dE) method is to describe the distance between two colors [20]. For reasons related to psychophysics, it is assumed that the limit of distinguishing colors for humans is the value of ΔE = 2.3. Therefore, if for two colors ΔE < 2.3, then the difference between them is imperceptible, and ΔE > 2.3 allows the human eye to distinguish these colors (in the range from 0 up to 100, where between 50 to 100 colors are opposite). For many sensory modalities, over a wide range of stimulus magnitudes far enough from the upper and lower limits of perception, the just-noticeable-difference (JND) is a constant proportion of the reference sensory level. So the ratio of JND to reference is approximately constant - that is, JND is a constant ratio/percentage of the reference level. It is given by the formula:

$$\frac{\Delta I}{I} = k, \tag{1}$$

where I is the original intensity am a given stimulation, ΔI is the addition required for the perception of change (JND), and k is a constant.

Table 1. Ranges of color perception.

Delta E	Color perception
[0, 1.0]	Not felt by human eyes
(1, 2.3]	Subtle differences over an extended observation
(2.3, 10]	Perceptible at first glance
(10, 50]	The colors are more similar than the opposite
(50, 100]	The colors are exactly the opposite

Algorithm assumptions

An example of using a correction card is to compare colors and determine the differences between them by calculating histograms. Then they are compared - usually using five methods. In the presented solution, the correlation expressed by the formula was used:

$$d(H_1,H_2)=\frac{\sum_I(H_1(I)-\overline{H_1})(H_2(I)-\overline{H_2})}{\sqrt{\sum_I(H_1(I)-\overline{H_1})^2\sum_I(H_2(I)-\overline{H_2})^2}}, \quad (2)$$

wherein:

$$\overline{H_k}=\frac{1}{n}\sum_J H_k(J), \quad (3)$$

where n is the number of bins in the H histogram of the I image [5].

Due to the use of colors, the appropriate color space should be selected. The color space is their specific organization. Combined with color profiling supported by various physical devices, it supports reproducible color representations - whether that representation involves an analog or digital representation.

The color space can be arbitrary, for example, with physically realized colors assigned to a set of physical samples with corresponding assigned color names, or can be mathematically structured (as in the case of RGB). As an abstract mathematical model, it describes how colors can be represented as tuples of numbers.

Determining the appropriate color spaces requires changes in the perception of these spaces and their trichromatic X, Y, and Z components stimulating human visual receptors, which were made by the Inter-National Commission on Lighting (CIE, Commission Internationale de l'Eclairage) by calculating the reference stimulus, that is: L *, u *, v * or L *, a *, b *. The idea was to create a linear color space where the distance between the points that define each color would be proportional to the perceptual difference between them (perceptual color spaces) and to represent the colors using coordinates describing one of their key attributes: brightness, saturation, and hue [7], [8].

Many different factors affect color perception. Such factors may include the physical properties of the observed object, in particular, its absorption properties. Additionally, the spectral composition of the light source and the characteristics of the environment through which it passes may have an influence. It is also worth considering the observer's feelings and the state of his nervous centers. An important aspect is also the distance of the object from the observer and other objects. It can therefore be concluded that the observed difference in color (perceptual difference) is a psychophysical difference perceivable by the observer, determined by the actual observation of the two samples. So the calculated color difference depends on the color model. Since a color stimulus can be represented as a point in space, the color difference ΔE between two stimuli is calculated as the distance between the points representing these stimuli [20].

An example of a color model is device independent Lab model. It is a transformation of the XYZ color space. The main purpose of the Lab color space is to assume that colors that are the same distance apart will be perceived to be equally different. So it is assumed that the color cannot be purple and blue and yellow or green at the same time. Hence, the following components were selected for the description: L - brightness (luminance), a - color from green to magnet, and b - color from blue to yellow. The a and b axis scales are between -150 and +100 and -100 and +150. Because color perception was taken into account when creating the space, the color spectrum is not a square but an irregular solid.

However, when the ΔE method was used, in 2013, both ISO and IDEAlliance adopted ΔE as the new industry standard for calculating color differences. This is described in the basic form by the formula:

$$\Delta E=\sqrt{(L_2-L_1)^2+(a_2-a_1)^2+(b_2-b_1)^2} \quad (4)$$

where: L_1 value of CIE L* reference color, a_1 – value CIE a* reference color, b_1 – value CIE b * reference color, L_2 – value CIE L* color of a sample, a_2 – value CIE a* color of a sample, b_2 – value CIE b* color of a sample ΔE(a,b) provides useful information about the linear distance between two colors. Many studies are showing that ΔE is better than other color-differentiation patterns.

Experimental application

As already mentioned, by using the histogram adjustment, you can take the color distribution of one image and match it to another. In real-world color-matching applications, to perform basic color correction, start with determining color consistency. The purpose of color consistency is to correctly perceive the colors of objects regardless of differences in light sources, lighting, shadows, etc. Color correction cards can provide this consistency.

By using the color correction card, you can:

- Detect the card in the input image.
- Calculate the card histogram, which includes graduated colors of different colors, shades, and degrees of black, white, and gray.
- Adjust a histogram obtained with a color chart to another image to ensure color consistency.

The most important benefit of using this type of solution is lighting control. If one can control the image capture environment as much as possible, it will be easier to write code to parse and process these images captured from the controlled environment. So, assuming that some safe ambient lighting conditions can be assumed, it will be possible to dispense with costly deep learning algorithms that sometimes help to obtain the desired results in imperfect conditions. Instead, basic image processing procedures could be used to define parameters in computer vision techniques.

a) b)

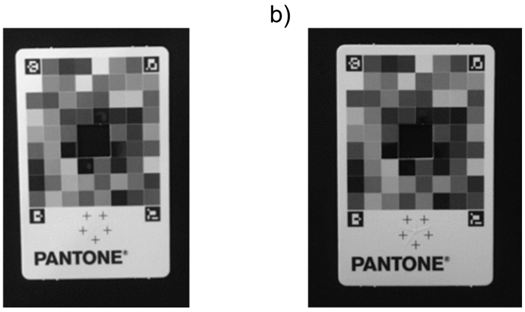

Fig 6. Pictures (a, b) taken under different lighting conditions.

One can influence the control of your surroundings, even if the lighting conditions change slightly, is to apply color correction. One example is automatic color correction, where from two photos taken, you need to transfer the histogram from one to the other (see Fig. 7).

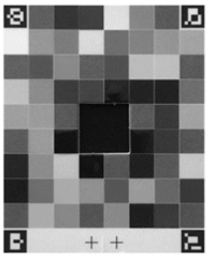

Fig 7. The histogram equalization results.

Automatic color correction, where two photos were taken (see Fig. 6 a,b) is needed to transfer the histogram from one to the other. Thanks to this, it is possible to compare the colors and determine the differences between them by calculating the histograms. Additionally, to get a better result, switch from the RGB color space to L * a * b**.**

a) b)

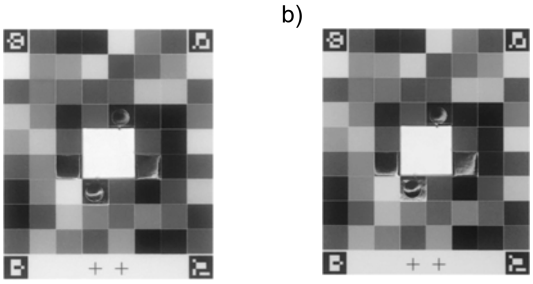

Fig 8. L-channel comparison – pictures (a, b).

Discussion of the results and summary

Fig 8 shows an example of detecting differences between two histograms. The measures are expressed by the color difference in the L*a*b space for which the values are [0.6635, 0.9015, 0.1741]. The most important benefit of using this type of solution is lighting control. If one can control the image capture environment as much as possible, it will be easier to write code to parse and process these images captured from the controlled environment. The presented methods and the device were used to automate the quality control process of varnished furniture fronts. It turns out that the analysis of color similarity is a key element of the order picking process and has a direct impact on customer satisfaction

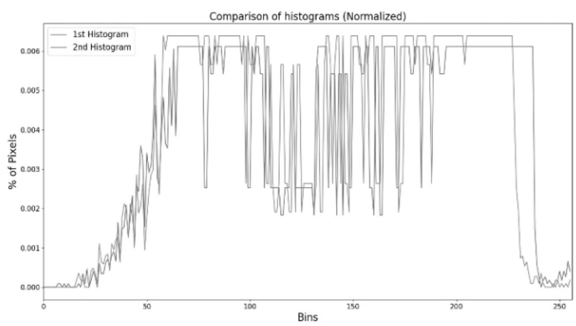

Fig 9. Percentage of pixels in each bin.

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