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ANALYSIS OF THE POSSIBILITY OF USING MARKERS EMITTING PULSATING LIGHT IN THE TASK OF LOCALIZATION

Abstract

This work shows the possibility of using spectral analysis in order to detect characteristic points in recorded images. The specific point is a marker in the form of a diode that flashes at a certain frequency. Main assumptions of the processing algorithm are the recording of a sequence of images and treatment change of level of brightness for each pixel as a time signal. The amplitude spectrum is determined for each time signal. The result of data processing is an amplitude image whose pixels brightness corresponding to the intensity of source of pulsating light emitting specific frequency. This new data representation is used to detect position of markers. The algorithm was researched in order to select optimal marker colors and pulsation frequency. The results are described in a summary.

1. INTRODUCTION

Location systems perform a critical role in mobile robotics and in many fields of technology that support people in challenging tasks.

The localization focuses on the problem of determining the position of object in a given frame of reference. The localization solutions are widely used both in the ordinary car navigation and the advanced military location system. Location systems refer to a wide spectrum of techniques. The development of computers has contributed to the evolution of location systems that based on image processing and analysis. It is worth paying attention to the basic functional features of such systems and their properties, such as the scope of application (open area or indoors) or refresh frequency of measurements. Described features affect the decision to choose the best solution. In the area of authors interests was systems that allowed to obtain information about position in the range up to about 200 m. GNSS-based solutions were omitted due to their limited accuracy in buildings. The attention was paid on UWB radio systems and positioning systems based on camera and markers. Radio systems enable measurements on large distances but they also have many disadvantages which disposed the authors to supplement them with vision systems.

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Vision systems realize the location process based on markers which generally are distinctive object with known position. The vision system can recognize them and uses their coordinates to determine the position of another object or camera. Markers should stand out from their environment in order to the vision systems correctly recognizes them. It should be noted that vision solutions are very popular because of the relative low price and a small number of components which usually come down to camera, computer and markers. Vision systems are often supported by the machine learning algorithms which detect features like shape or color of the marker. Vision systems will able to recognize markers in the recorded images, if they achieve the appropriate learning cycle with known examples.

The use of machine learning elements is one of many ways to detect the marker in an image. However, the use of classic vision solutions seems unrealistic because of the expected measuring range and the limited ability to recognize markers at large distance. The solution of this problem might be identify of pattern powered by the frequency of the light emitted by the marker.

The aim of this article is to present an image processing algorithm that looks for pulsating light sources based on spectral analysis. The article presents the features of this methods, its properties, advantages and indicates potential application in location systems. The chapter 2 contains a literature analysis focusing on information about application markers and camera in various location systems. The chapter 3 describes the processing method, its main assumptions and shows the consecutive steps of algorithm operations. The chapter 4 presents the description of the test stand, whereas the last two chapters include the presentation of research results and conclusions.

2. LITERATURE ANALYSIS

The light source as a marker is often used in localization issues. Hassan, Naeem, Pasha, Jadoon and Yuen (2015), Maheepala, Kouzani and Joordens (2020), Wang C., Wang L., Chi, Liu, Shi and Deng (2015) all present the state of knowledge and techniques on the use of light markers in the process of determining the position. The reviews mainly focus on location methods that should be used for indoor localization. The use of light sources such as LEDs brings many benefits. Light signals are less susceptible to interference from radio waves. Moreover, they should ensure bigger accuracy of the location system operation compared to systems based on Wi-Fi or Bluetooth signals. The receiver of light signals can be a photo-receiver or a camera. The photo receiver responds to changes in illuminance whereas the camera records images. Maheepala, Kouzani and Joordens (2020) discuss the location methods with light markers and they give the common name of all methods as LIP (Light-based Indoor Positioning Systems). LIP systems use a light signal as the main way of transmitting information about markers location that is necessary to determinate the position of other object. Figure 1 shows the division of LIP systems into different categories.

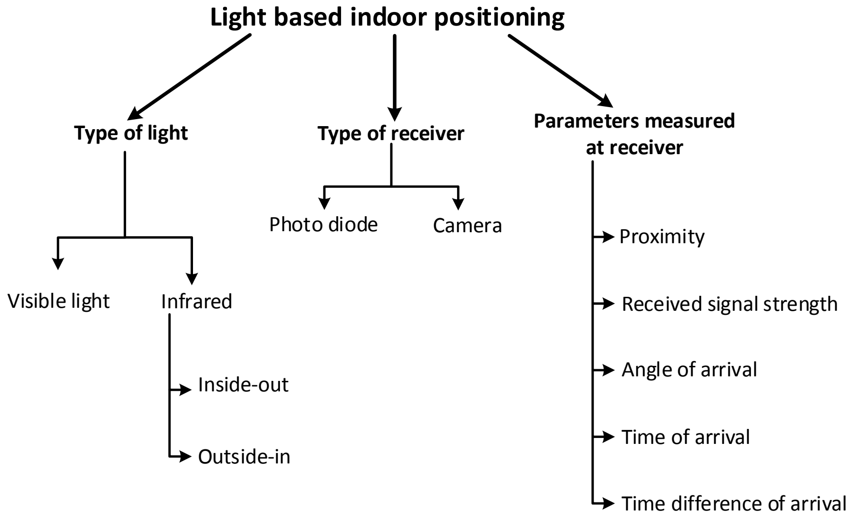

Fig. 1. Classification of LIP systems (Maheepala, Kouzani and Joordens, 2020)

The presenting algorithm of location of pulsating markers can be treated as a LIP system because it uses the signal of visible light that is received by the camera. The marker should be in the camera field of view in order to be recorded in images. The presenting algorithm needs just one pixel with capturing marker to determinate its position.

Some articles describe specific examples of location systems based on markers. Moon, Choi, Park and Kim (2015) use pulsating markers with a location system and a smartphone camera. Each marker has own unique pulsation frequency. The exposure time of each of the pixel columns changes during recording images. It looks like the matrix had a "moving shutter". Consequently, a band effect arises in the CMOS sensor while some columns register the LED on and others the LED off. If the recording image is conversed to grayscale, image areas with the figures of pulsated markers can be found by applying the OTSU binary filter (Moon, Choi, Park and Kim, 2015).

Raharijaona et al. (2015) use infrared diodes that send signals of different frequency. The receiving device is constructed in the form of a cube with three optical sensors (each in a different plane). It receives signals that are demodulated in order to identify the correct frequencies of LED pulsations. Then, the position of the object with infrared markers can be estimated by analyse of the power of the demodulated signal components. The solution from Raharijaona et al. (2015) shows a marker-based location method that does not use camera and image analyse.

The camera was not used in the solutions presented by Hossen, Park and Kim (2015), Jung, Hann and Park (2011), Moon, Choi, Park and Kim (2015) and Zhang, Chowdhury and Kavehrad (2014). The role of the signal receiver was played by an optical sensor. This sensor usually has a compact size, therefore it can be installed in small objects. The optical sensor records one-dimensional signals whose analyse can be faster than image processing and analysis (it depends on the hardware used to perform the calculations). This solution also allows to determine the position based on several parameters, like: received signal strength level (RSS), angle of arrival (AOA), or time of arrival (TOA). More information about the listed parameters can be found in Zhang, Chowdhury and Kavehrad (2014).

On the other hand some articles include examples of using a camera as a receiver. The camera makes it easier to obtain information about marker color compared to ordinary optical sensors. Kuo, Pannuto and Dutta (2014), Yeon Kim, Cho, Park and Kim (2012) all indicate that marker color can hide information about the coordinates of the marker in a given reference system. This solution has practical application in mobile robotics. The vehicle can correct its position based on the known information about the location of the markers that should be visible in the field of view of the robot camera. Guan, Wen, Zhang and Liu (2018), Hong et al. (2020) and Wu et al. (2020) all present solutions using machine learning algorithms that support the position estimation process. Thanks to this, the authors achieve a lower error in determining the position compared to the estimation results without machine learning elements.

The authors of article propose the interesting location algorithm contained to discussed solutions. Some of them are used in the task of indoor location whereas the presented algorithm can be used in an open space and outdoor location task. It can be replenishment of systems based on UWB technology. The algorithm refers to the general technique of analysing the change in pixel brightness levels over time. It is similar to the algorithm discussed by Kuo, Pannuto and Dutta (2014). The analysis of the operation of the presented method brings many interesting conclusions that will be discussed in the following chapters.

3. BASIC INFORMATION ABOUT THE ALGORITHM

The main purpose of the presented image processing method is to locate pulsating light sources on the recorded images. Light sources pulsate with a known frequency. If the brightness level of change of a single pixel is treated as a time-varying signal, such a signal can be subjected to spectral analysis in order to find the component in relation with the pulsation frequency markers. The recording images sequence can transform to amplitude image performing the above information on each pixel from a matrix. The amplitude image uses intensity of the signal with the searching frequency and shows the area with figures of pulsating markers. The amplitude image is also normalized in order to improvement the quality of image and cut out the noise.

3.1. Main assumptions

The basic assumption of the method is the use of light markers that emit pulsating light at a specific frequency.

Images should be recorded continuously in the basic variant. Then the selected number of frames should be subjected to spectral analysis. The frequency of recording images should be known and constant, because the marker pulsation frequency depends on it (the recording conditions must be maintained in accordance with the Nyquist statement).

Images should be recorded and saved in RGB format. Thanks to this, each layer can be analyzed separately. If the marker emits pulsating light in a specific color, only one layer of RGB format can be analysed. This assumption allows to curtail an operation time compared to analyse of all layer of images.

3.2. Scheme of operation

In order to locate pulsating markers, The presented algorithm needs the following input parameters:

- recording time and recording frequency of image by camera,
- resolution of recorded images,
- color and pulsation frequency of the light sources,
- processed layer of RGB format.

Figure 2 shows block diagram with successive processes that make up the presented method.

The camera records a sequence of images after entering the input parameters. Images is saved in RGB format. Then the algorithm selects one of the layers (red, blue or green) in order to read the brightness level change for each pixel.

The processing algorithm reads the brightness level for a pixel with the index [a, b] (where recorded image has size AxB and a = 1, ..., A, b = 1, ..., B) for each recorded image. The result of this operation is a signal of the brightness level changing of the pixel [a, b] over time. This signal is subjected to the Fast Fourier Transform in order to obtain amplitude spectrum. A harmonic for LED pulsation frequency should be located on the spectrum according to the diagram in Fig. 2.

Then the amplitude value of expected harmonic is read and stored on the new image at the position in accordance with coordinates of researching pixel (it will be position [a, b] for considered example).

The described procedure is repeated for each pixel from the set A*B pixels. The resulting image is the set of all amplitudes for the signal component related to the marker pulsation frequency. Then, the image is normalized. It consists in finding the amplitude with the maximum value in the resulting image and dividing all pixel by found value. Consequently, all pixels will be in the range <0, 1>. The location of pulsating marker is potentially represented by pixels whose value is closer to one. In the end, the image is binarized in order to better present the marker position.

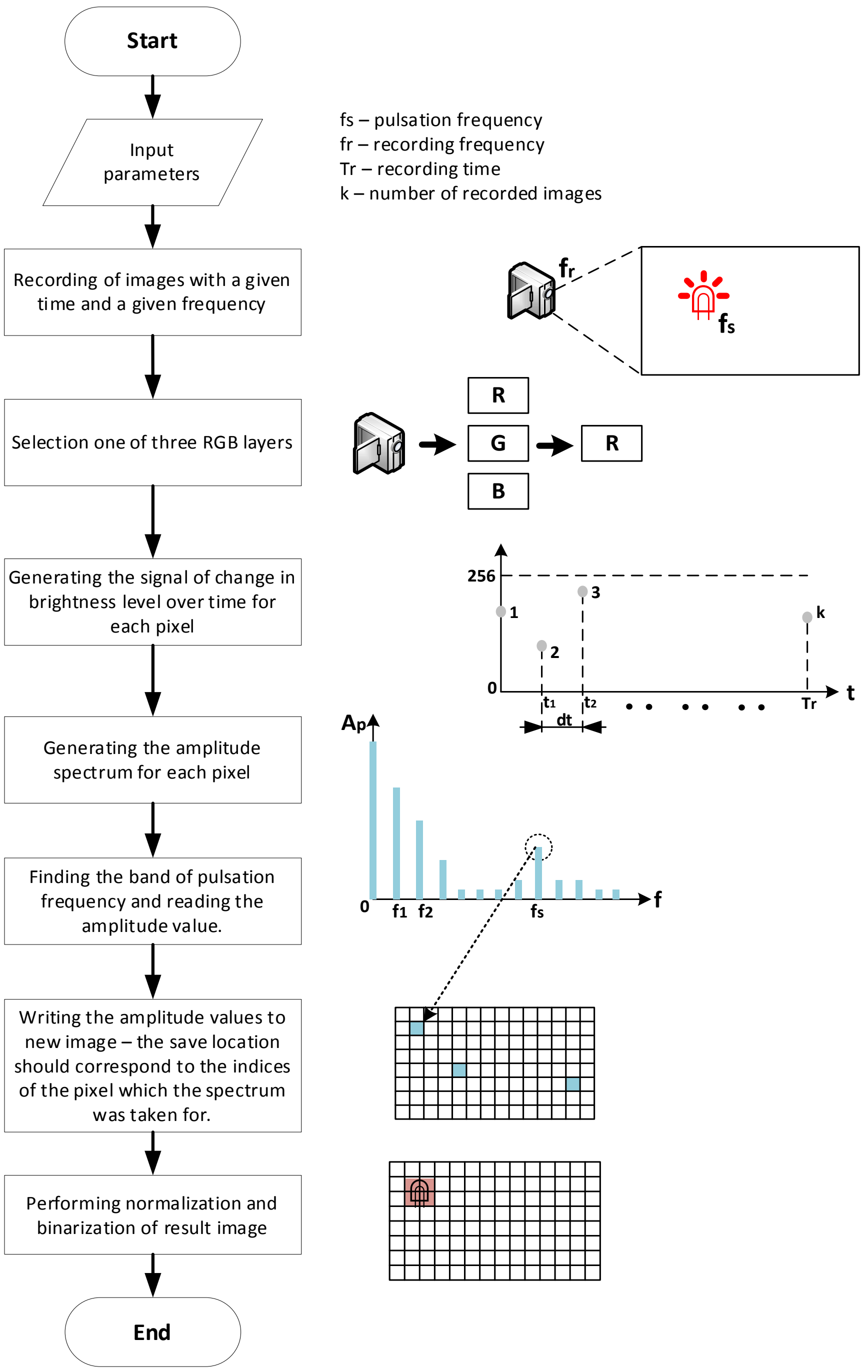

Fig. 2. Block diagram showing the steps of examined method of image processing

4. PURPOSE OF THE RESEARCH AND STAND TEST

The MATLAB program was used to present the results of the image processing method because the MATLAB has extensive possibilities in the field of image processing and analysis. The operation scheme in Fig. 2 has been implemented as a computer program. The captured images were processed and the algorithm generated a binary image with a figure representing the found marker as a result.

The aim of the research was to verify the operation of the method and selection the optimal parameters in terms of the quality of the obtained images. The tested parameters were the color and frequency of the marker pulsation.

4.1. Equipment used for tests and input parameters

The following components were used for the tests:

- markers: four LEDs, each of them has a different color,
- the recording device: a PlayStation Eye camera,
- the STM32 F411 board, which generated a PWM signal with a given frequency, which powered the LEDs,
- computer equipped with MATLAB.

The connected measuring equipment is shown in Figure 3.

The input parameters for the tested method were as follows:

- image sequence recording time: 2s,
- resolution of recorded images: 640 x 480 pixels
- recording frequency: 75 Hz,
- diode color: red, green, blue, yellow,
- LED pulsation frequency: 5, 10, 15, 20, 25, 30 and 35 Hz.

Each of the RGB layers of the recorded images was processed. The frequencies were selected so as to they were less than half the recording frequency of the camera. The marker was stationary and it was located on the contact plate. The STM board powered the diode with a signal of a given frequency. The LED flashed with pulsating light as a result.

Fig. 3. The test stand to research method of pulsating markers location

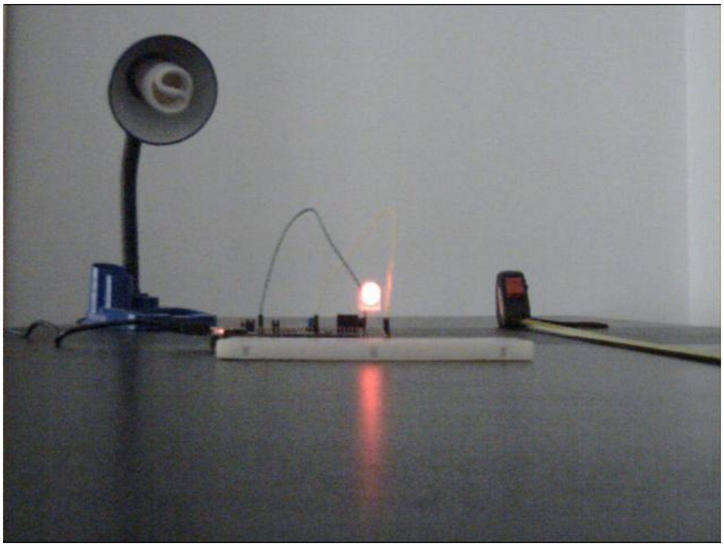

Fig. 4. The image from the perspective of the PlayStation Eye camera lens

5. RESEARCH RESULTS

This chapter presents the most important observations and conclusions from the stage of research on the processing algorithm. The following sections present examples of amplitude spectrum of changes in pixel brightness levels and the amplitude images obtained as a result of the algorithm. The results of the research on the selection of the appropriate color and frequency of the marker pulsations were also presented.

5.1. Frequency analysis of images

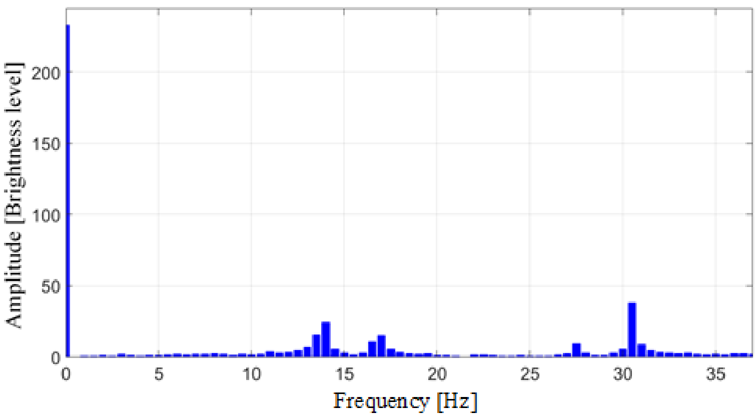

Fig. 5. Amplitude spectrum of the signal of brightness level change for an pixel which the marker was registered on – marker parameters: red color of light, R layer (red) of image, pulsation frequency 30 Hz

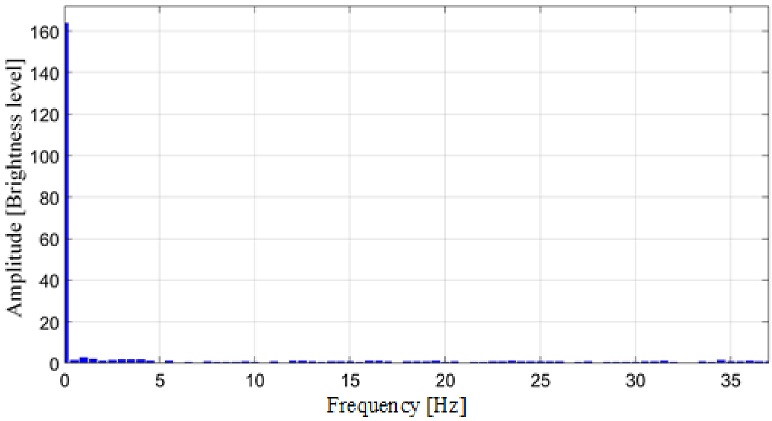

Fig. 6. Amplitude spectrum of the signal of brightness level change for an pixel which the marker was not registered on – marker parameters: red color of light, R layer (red) of image , pulsation frequency 30 Hz

Figures 5 and 6 show the signal spectrum of the brightness level change for the pixel where the marker was captured and for the background. There is a harmonic for the frequency close to the marker pulsation frequency in the spectrum in Fig. 5. No additional bands were observed for the normal pixel from the background without the band for the mean value. Additional fringes around 15 Hz are related to the aliasing phenomenon. The amplitude image is presented in Figure 7 in order to better understand the formation of the resulting image. It is the amplitude values composite for the frequency of 30 Hz for all pixels of the matrix.

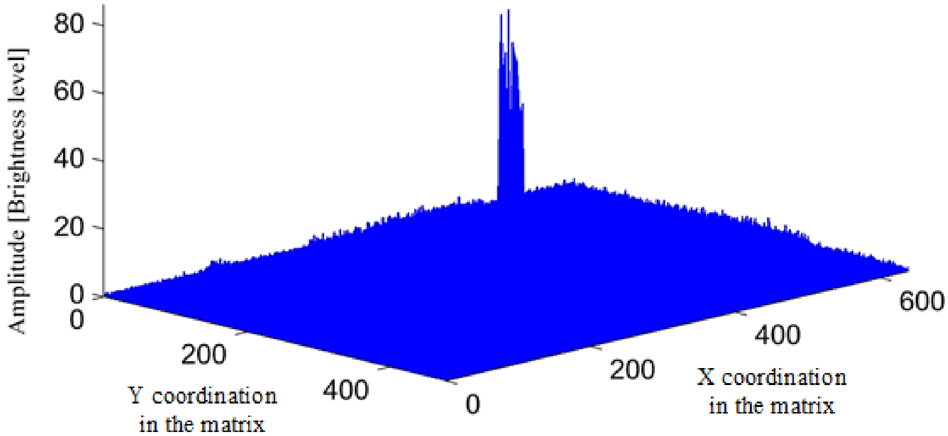

Fig. 7. The amplitudes of the pulsation frequency of 30 Hz for each pixel in form of a three-dimensional graph

The high amplitude values are the area where the marker was recorded. The results were normalized and the exemplary results are presented in the next section.

5.2. Result images

The following figures from number 8 to number 11 show the images that are result of applying the processing using spectral analysis. The images are shown in normalized and binary form. The result was obtained for each tested color and frequency. The figures below show only some of the considered cases.

Fig. 8. Normalized result image for a blue LED pulsating with a frequency of 15 Hz

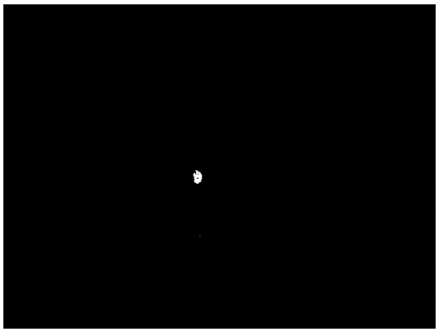

Fig. 9. Binary result image for the blue LED pulsating with a frequency of 15 Hz, binarization threshold 0.6

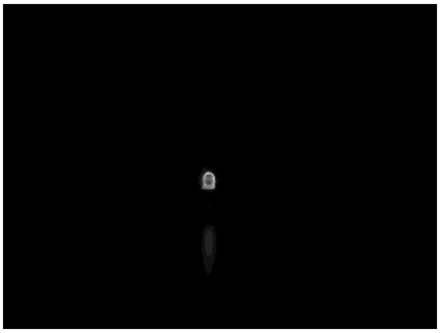

Fig. 10. Normalized result image for a red LED pulsating with a frequency of 30 Hz

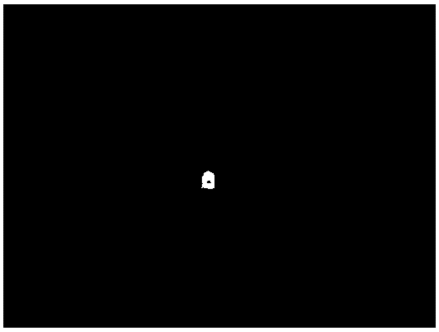

Fig. 11. Binary result image for a red LED pulsating with a frequencyof 30 Hz, binarization threshold 0.3

The amplitude images were realized for each marker color. However, the visibility of the LED in the image depends on its parameters. The binarization threshold was different for each marker color.

5.3. Selection of the marker pulsation frequency

The authors proposed a comparative measure of the obtained images in order to select the appropriate pulsation frequency. This measure is called the normalized average value of the background brightness level. The proposed measure is the average value of the brightness levels of the background pixels after the normalization process. The smaller the value, the final binary image should contain less noise. The following figures show graphs with the calculated index of the normalized average value of the background brightness level for different cases of the diode color and pulsation frequency.

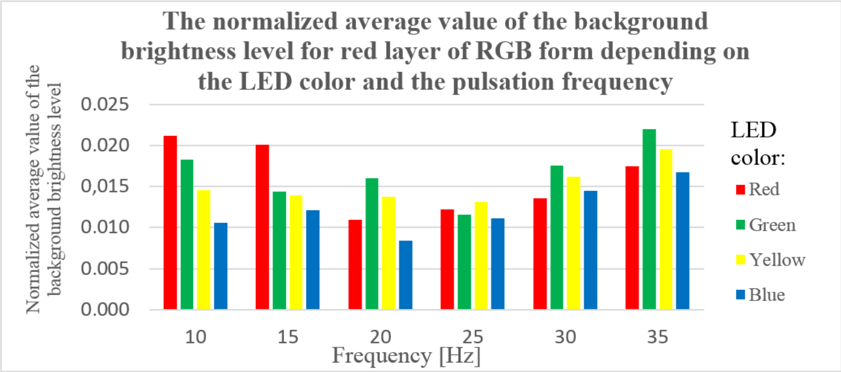

Fig. 12. Graph showing the normalized average value of the background brightness level for red layer of RGB form and for different cases of the LED color and pulsation frequency

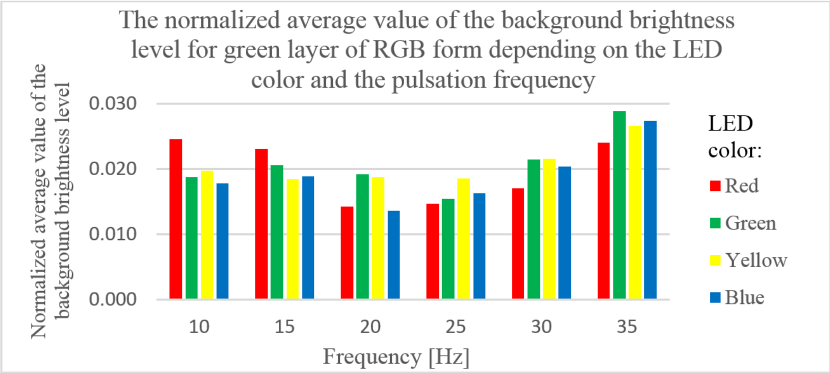

Fig. 13. Graph showing the normalized average value of the background brightness level for green layer of RGB form and for different cases of the LED color and pulsation frequency

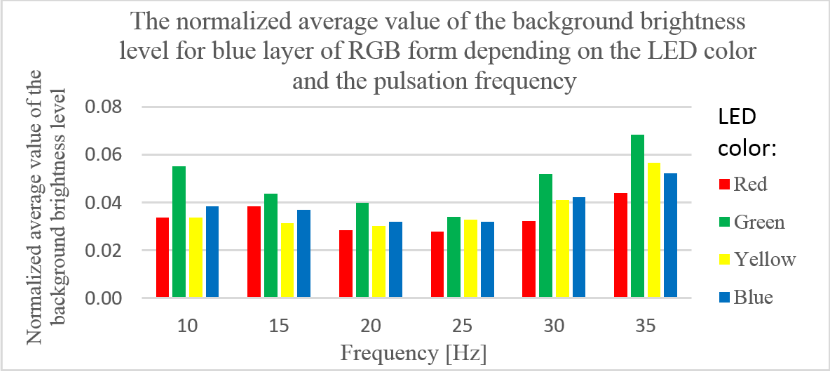

Fig. 14. Graph showing the normalized average value of the background brightness level for green layer of RGB form and for different cases of the LED color and pulsation frequency

The above charts show higher index values for the blue layer compared to the other layers. The blue layer has twice the normalized mean value of the background brightness level. Higher values could potentially indicate a greater susceptibility to noise in the resulting images. Therefore the R and G layers will be chosen to the processing image.

Moreover the graphs was analyzed in order to search frequencies which the indicator value was the lowest for. Both for the red and green layers, the searching values were 20 and 25 Hz. Measurements showed that these are the leading markers pulsation frequencies whose the average value of the background level is as low as possible.

5.4. Color selection of markers

The best colors for marker light were chosen red and green based on the following observations:

- the images obtained for the yellow marker had lower quality than the images for the other markers – the yellow color did not correspond to any of the RGB recording layer colors,
- the images obtained for the blue marker showed the LED with too bright contours – the blue LED emitted too high light intensities and the matrix was too saturated,
- the best quality of the detected markers is for the green LED on the normalized amplitude images – the markers shape in this case has been best preserved,
- the images obtained for the red marker had the lowest indicators of the normalized average value of the background brightness level.

6. SUMMARY

The presented processing algorithm treats images as a series of two-dimensional data recorded in time. It allows to obtain binary images representing the registered marker, which was demonstrated during the presentation of the research. The presented method can potentially be used to build a location system that looks for objects equipped with pulsate markers. What is more, the algorithm can locate markers both indoors and outdoors, over long distances. It should only be remembered that the spectral analysis of high-resolution images might require a lot of computing power in order to achieve an acceptable level of the algorithm working time. It is worth emphasizing that the amplitude image presents initially and effectively filtered data that may constitute a starting point for further analyzes and a more sophisticated marker search. Nevertheless, this approach solves the problem of modern methods of tag detection by searching for a shape or color.

6.1. Conclusions

The assumptions of the presented processing algorithm are correct. The authors managed to obtain binary images with the detected pulsating marker as a white figure in the black background. The resulting images were obtained in each case, however, they differed in the quality of the figures. The most scattered figure and the most background noise were observed in the case of the blue diode. The images generated for the yellow LED had the lowest quality compared to the other marker colors. The most compact diode image was obtained for the green color, whereas the lowest value of the background brightness was obtained for the red diode.

The using of spectral analysis allowed to obtain clear binary images without using of advance image processing methods. The analysis of changes in pixel brightness level over time requires looking at several images simultaneously. This is a different approach to processing than performing operations on a single image. The best results were observed for the pulsation frequencies of 20 and 25 Hz. However, it should be emphasized that these are the values selected for the camera used in the research. It is possible that the best pulsation frequencies will be different for an other class of equipment. The method based on pulsed markers has potentially many advantages. Not only the amplitude of the signal can be analyzed, but also its phase. Potentially, the orientation data of the tags can be encoded in the phase and color information.

6.2. Further research directions

The presented processing algorithm is a method with great potential, which makes us look at images as a set of signals of brightness level changing over time. In further research, an attempt will be made to use more sophisticated algorithms for time-frequency analyzes in order to detect temporary amplitude values. The Fourier analysis has averaging properties, which can be a problem in the case of changing marker positions. The possibility of modifying the marker color or the phase shift of the generated light signal by various markers is another interesting area of development of the proposed method.

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