Opto-Electronics Review 29 (2021) 133-140

POLISH ACADEMY OF SCIENCES

Opto-Electronics Review

journal homepage: http://journals.pan.pl/opelre

Spectrum sensors for detecting type of airport lamps in a light photometry system

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Article info

Article history:
Received 10 Sep. 2021
Accepted 28 Sep. 2021
Available online 12 Nov. 2021

Keywords:
Optoelectronic sensors, colour detection, light photometry systems, airport lamps.

Abstract

The paper analyses the operation of different types of electronic colour sensors based on the light spectrum analysis. The application goal was to detect the type of the airport lamp based on differences in colour components of the light emitted by luminaires with specific spectral characteristics. Recognition of airport lamps is based on the analysis of the light spectrum. Proposed solution allows for an automatic software selection of appropriate conversion factors and comparison with specific standards necessary for this type of measurements. Various types of sensors were discussed and the AS7262 sensor was examined in detail. The colour sensor and the light intensity sensor were used in the mobile control device for examining elevated airport lamps and in the measurement platform for quality testing of embedded airport lamps. Two additional aspects were investigated: 1) influence of an additional acrylic glass cover; 2) distance between airport lamps and the spectrum sensor.

1. Introduction

The growing requirements of European and world aviation safety agencies have for several years been determining more and more accurate lighting control located at airport aprons, among others, on runways and taxiways [1]. The role of airport lamps is extremely important in supporting pilots in spatial orientation in various weather conditions at any time of the day and night. The way in which specific types of lamps are arranged in various configurations from the deck of the airplane may remind a layman of a multi-coloured Christmas tree-lights. In fact, it is the result of adhering to strictly defined standards of the aerodrome design instructions, which specify the correct arrangement of the airport lighting [2]. The airport lamps are equipped with halogen bulbs which have a limited lifetime [3]. Dirty prisms (e.g., by sticking powdered rubber from aircraft tires) determine decrease in the lamp light efficiency.

Lamps covers and their prisms can also be damaged by machines keeping the runways and taxiways clean, especially during winter snow removal. Metal brushes scratch the lamp fittings and chip their prisms, forcing the need to replace the damaged lamps.

Daily inspection of lighting operation is carried out by visual assessment. If airport control services notice a lamp malfunction, it is disassembled and replaced by another. Periodic assessments of the correct operation of the airport lamps can be carried out using special commercially available devices designed for individual airports. The two leading companies in this field are DeWiTec and DALMAS which offer the lighting control equipment.

However, our research team was motivated by the high cost aspect of the described commercial devices to develop a new, low-budget device with high utility values, adapted to the requirements of the Poznań-Ławica Airport, enabling quick, high precision [4], daily lighting control in the airport area.

As part of the project, the scope of the research was extended compared to the previous work [5], where the focus was only on lamps recessed into airport surfaces. In the present work, runway edge lamps and threshold lamps have been added. The general block diagram of the individual stages of the lamp measurement is presented in Fig. 1. In the first stage, the colour detection takes place, which allows for the identification of the type of the tested

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https://doi.org/10.24425/opelre.2021.139383
1896-3757/ Association of Polish Electrical Engineers (SEP) and Polish Academy of Sciences (PAS). Published by PAS

lamp. The matrix of light intensity sensors transmits a result, which, thanks to the specific type of the lamp recognized, is then converted in accordance with the laboratory-determined coefficients. This makes possible to read the correct lamp luminous intensity. The obtained results are compared with the relevant standards for an appropriate type of lighting to determine whether the lamp needs to be replaced or can still be used.

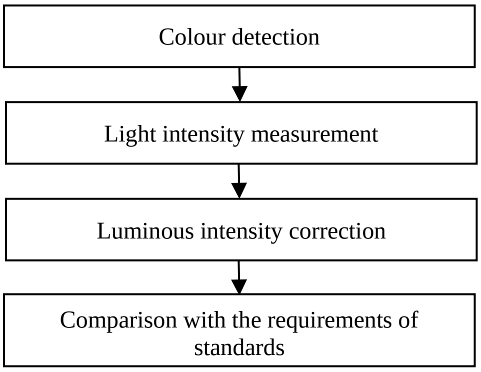


Fig. 1. Block diagram of the measurement process.

2. Airport lamps visible light spectrum examination

Light as an electromagnetic wave reaching the human eye is focused on the retina. This is where the suppositories are located, which, when stimulated with light, send an impulse to the brain. Each of the three existing types of cones responds to a different range of electromagnetic wavelengths. The cones that are responsible for seeing short waves (S) give the strongest response to the wavelengths of approx. 420 nm (blue) and those that are responsible for medium waves (M), to ca. 530 nm (green). The third ones, those for seeing long waves (L) offer the strongest response to ca. 570 nm. This knowledge is used in the construction of instruments responsible for measuring colours [6].

In order to check the colour spectrum of the light emitted by the airport lamps, the taxiway centre line lamp, the touchdown zone lamp, and the runway centre line lamps (red and white) were tested [7]. For this purpose, a Gigahertz-Optik X4 Light Analyzer [8] spectrometer shown in Fig. 2 was used.

The test consists in measuring intensity of photometric illumination, intensity of radiometric irradiation, and intensity of spectral radiation in absolute light units. The main area of interest was to study the intensity distribution of spectral radiation. The graphs of the aforementioned quantity against the light wavelength in the visible range are presented in the article further section.

Fig. 2. Spectrometer Gigahertz-Optik X4 Light Analyzer [8].

As predicted, the taxiway lamps are characterized by the spectrum with the highest composition of green and, also, blue light, i.e., the colours best recognized by the human eye, therefore, also by sensors available on the market that represented them. On the other hand, the other components had an imperceptible effect on the spectrum, and the waves corresponding to the colours considered warm hues were basically not emitted by these lamps (Fig. 3).

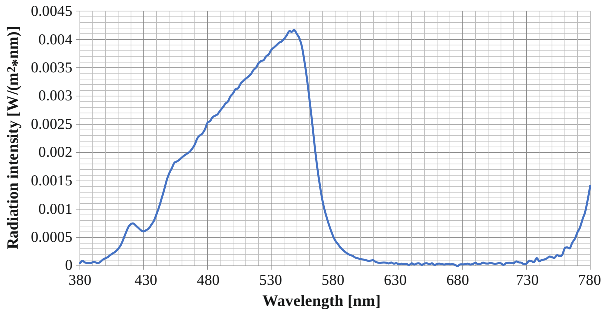


Fig. 3. Spectral radiation intensity of the taxiway centre line lamp IDM5582.

The lamps of the touchdown zone shine in white (warm) colour, therefore, their spectrum was made up of various wavelengths from the entire visible light range. The highest intensity was emitted by colours with longer wavelengths (Fig. 4), which could have happened, due to the fact that this value was the product of the light source power per specific area multiplied by the wavelength.

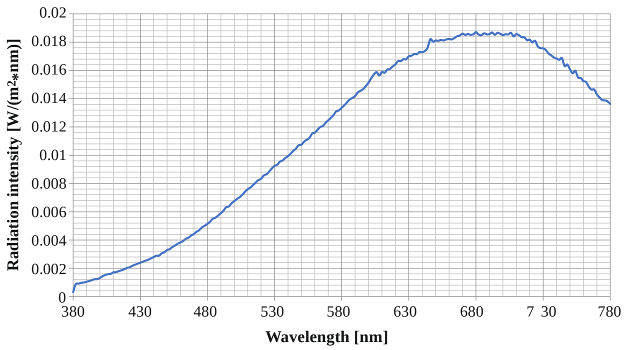


Fig. 4. Spectral radiation intensity of the touchdown zone lamp IDM4671.

The light spectrum characteristics of the red runway centre line lamps were based, in particular, on longer wavelengths in the visible light range. The wavelength of 680 nm, corresponding to the orange-red colour, naturally has the highest intensity. These lamps almost do not emit wavelengths corresponding to the colours considered cold, which coincides with the eye observations (Fig. 5).

The spectral characteristics of the white-coloured centre line lamp (Fig. 6) follow a very similar course to that of the touchdown zone lamp. However, they differ in terms of values, because the luminaires mounted on a central line have a higher radiation intensity.

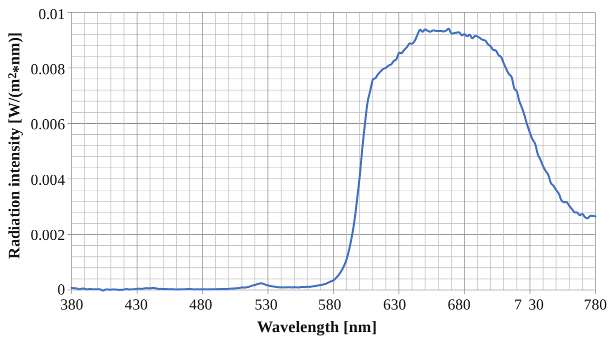


Fig. 5. Spectral radiation intensity of the runway centre line lamp IDM4582 (red).

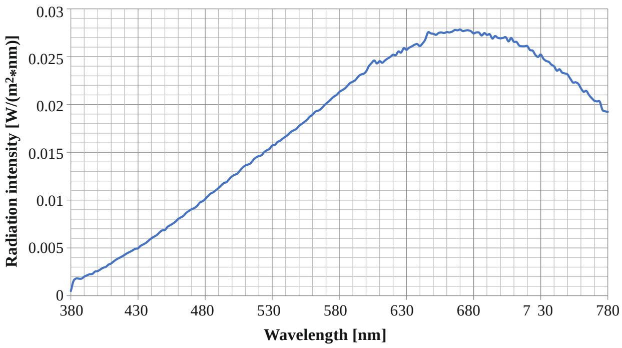


Fig. 6. Spectral radiation intensity of the runway centre line lamp IDM4582 (white).

3. Comparison of the available colour and spectrum sensors

On the market, there are many different sensors for determining colour. Some of them are aimed at detecting the colour of the environment without additional support, and others use the optional LED backlight. The most basic modules, such as TCS34725, APDS9960, or ISL29125, allow only for the measurement of the three basic RGB components. Technical documentation of the mentioned sensors leaves no doubt that the sensitivity of each of the channels is low.

The module with the TCS34725 sensor, when normalizing the readings for the wavelength of 755 nm, tends to lower the individual RGB components (Fig. 7). In cases where measurement precision is not essential, the sensor can enable a correct colour recognition. The advantage is the built-in IR filter that allows to cut out the unwanted component of the infrared light [9].

The colour sensor equipped with APDS9960 allows to measure RGB component values, as well as detect gestures: up/down, left/right. As in the case of TCS34725, individual components have an underestimated value in relation to the standard [10]. Blue is much worse, where the difference is particularly visible. The mapping of other two components: green and red, remains at a similar level (Fig. 8).

The best representation of the green component is shown by a module equipped with the ISL29125 sensor. It is much worse at rendering the correct value in the range of a blue light wavelength. In this case, the readings are greatly underestimated. A similar situation also takes place for the third component. The value read by this module for the red-light wavelengths is lower than the reference value (Fig. 9).

Despite the attractive price of described modules, the use of such sensors is not an option for the precise task of determining the airport lamp type based on the colour of the emitted light. This operation requires colour measurement with a greater accuracy because each type of the airport lamp has its own standards allowing its use. Correct identification of a specific model will allow the selection of appropriate conversion factors for the matrix of light intensity sensors, which will measure the luminous intensity of the main beam.

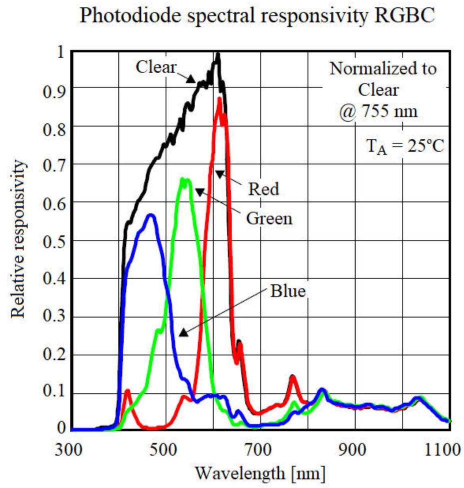


Fig. 7. TCS34725 spectral response [9].

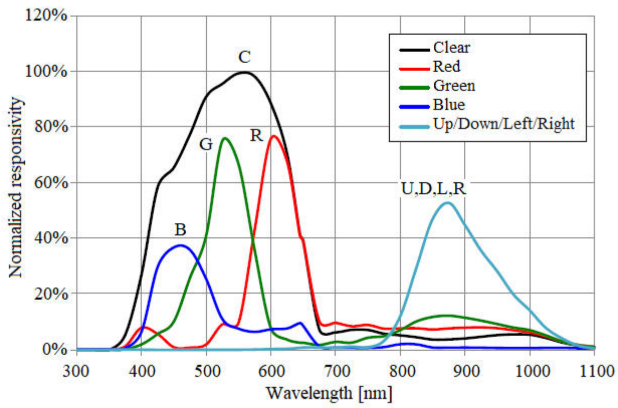


Fig. 8. APDS9960 spectral response [10].

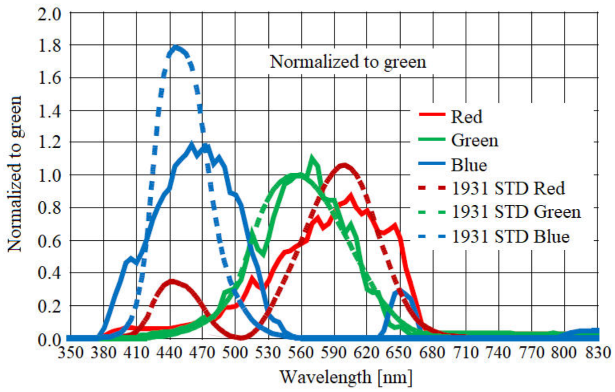


Fig. 9. ISL29125 spectral response. [11].

The second group of modules in the category of colour sensors are devices used to analyse the light spectrum. It is worth mentioning that among them there are also devices enabling the analysis of not only the visible light, but the measuring range covers the area from infrared to the beginning of the UV range. Such functionality is offered by the AS7265x module, however, from the point of view of the airport lamps testing, it is not necessary, and it would significantly increase the device cost. This module consists of three interconnected sensors AS72651, AS72652, and AS72653. They allow the examination of light with wavelengths from 410 nm (UV) to 940 nm (IR). Readings are made on 18 channels operating with a precision of ±12% [12].

Technical data provided by the manufacturer is reflected in the mapping charts of the wavelength reading for each channel (Fig. 10). Based on them, it can be concluded that the sensor is very advanced and shows very good precision. However, its potential use in the airport lamp recognition device is low. This is mainly due to the high price of the module which cannot be fully used. Simpler modules offering only the examination of the visible light range are sufficient.

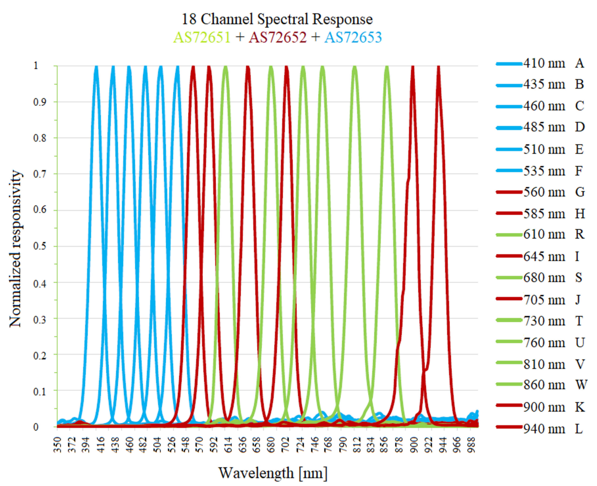


Fig. 10. AS7265x spectral response [12].

Sensors like AS7341 and AS7262 can be distinguished focusing only on modules of this type. The main difference between them is in the number of visible channels. The first one has 11, while the second one has only 6 [13,14]. Their representation of the reading values for individual wavelengths is very good.

The module is equipped with the AS7341 sensor, in addition to the components for visible light, it also allows for the identification of the NIR (near infrared) range [13]. In relation to the reference waveform, all channels show very good sensitivity and precision (Fig. 11). Comparing the technical documentation and the results of research carried out with a professional spectrometer, it was concluded that the use of a module with a smaller number of channels, i.e., AS7262, would be sufficient for the planned task.

Therefore, the device module responsible for detecting a specific type of the tested lamp was finally built based on the AS7262 visible light spectrum sensor (Fig. 12) [14]. Performed tests of the stationary and moving sensor showed differences in the values of the individual colour

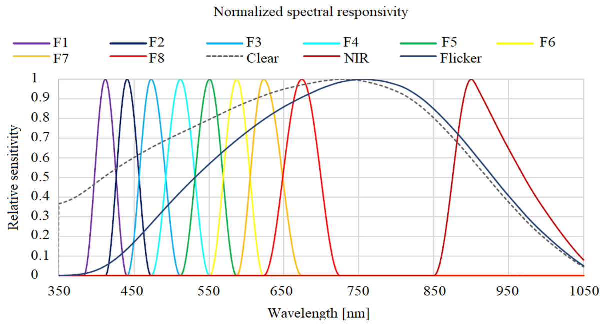


Fig. 11. AS7341 spectral response [13].

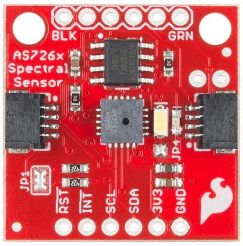


Fig. 12. Visible light spectrum sensor module SparkFun AS7262.

components. On this basis, the lamps to be inspected were properly classified, and the software for selecting coefficients for the results obtained from the light intensity sensors was developed.

The constructed device for testing airport lamps is equipped with a module for examining the visible light spectrum. Detected wavelengths are shown in Fig. 13. Beams with wavelengths of 450, 500, 550, 570, 600, and 650 nm are captured with a corridor of 40 nm with a width of half the maximum detection. This method allows to easily distinguish the tested lamp colours indicated in the design assumptions. The sensor communicates with the microprocessor via the I2C or UART interface. In our case, the first interface is used. The device manufacturer selects this way as default. Data is transferred digitally using 16 bits. The voltage of all module signals that must be supplied to the device is of 3.3 V [14].

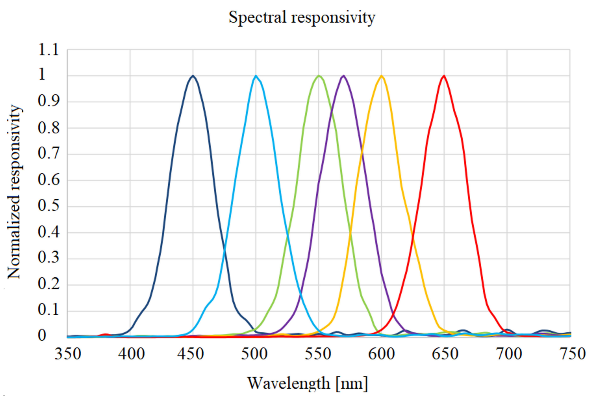


Fig. 13. AS7262 spectral response [14].

4. Results of embedded airport lamps spectrum measurements with the use of AS7262 module

As part of the research on the selected visible light spectrum sensor AS7262, the number of experiments and measurements was carried out using original airport lamps. Luminaires embedded in the surface of the runway and taxiways, apart from direct measurement, were also tested with a measuring matrix built-in with acrylic glass. This cover is a necessary equipment due to the measuring method. The matrix is mounted on a special frame under the chassis, close to the surface. The risk of damaging the matrix, including the sensors, is high, so additional protection had to be applied. These types of lamps were tested in the laboratory conditions at a constant distance of approx. 1 m between the light source and the sensor.

Three different types of brand-new lamps were used to test the lighting from: runway centre line white (RCW), runway centre line red (RCR), and taxiway centre line (TC). Each of them was tested in several series of measurements, and the average results are presented in Table 1.

Table 1.
Spectrum results of the embedded airport lamps examination [in count/(μW·cm^2)].

	Channel	RCW	RCR	TC
Without cover	V	61259.47	16596.37	42350.37
	B	65474.53	11769.84	63098.99
	G	57115.52	5666.82	52538.19
	Y	48994.17	28503.14	34594.12
	O	51246.94	51246.94	4319.873
	R	45703.38	45703.38	2086.367
With cover	V	61259.47	15113.16	38246.94
	B	65474.53	11228.07	60962.59
	G	57115.52	5701.4	49748.65
	Y	48994.17	27103.2	31231.9
	O	51246.94	51246.94	3978.233
	R	45703.38	45703.38	1896.83

Based on the collected data (Fig. 14), the obtained graphs of the individual VBGYOR components (Table 1) are approximately similar to the graphs of spectral radiation intensity. The shape of the characteristics for the respective lamp types has been retained and allows for the identification of a given luminaire based on the measurement of the emitted light beam spectrum. The white-coloured lamp of the centre line of the runway has the dominant colours of blue and purple and the red one is characterized by the dominance of orange, red and yellow components. Violet, blue, and green channels had much lower readings in the second case of a runway centre line luminaire. The light emitted by taxiway centre line lamp is characterized by dominant blue and green components. Violet and yellow channels recorded moderate results with very low readings for orange and red.

It was also decided to check the influence of using an acrylic glass cover put on the AS7262 module on the visible light spectrum graphs for each type of the tested lamps. The results are presented in Fig. 15.

During examination of white-coloured lamps of the centre line in the runway, lack of influence of the acrylic glass cover on the readings for individual channels can be seen (Fig. 15). In the case of the second type of the tested centre line runway embedded lamps with red light beam, the authors observed slight differences in the luminous intensity values for the channels responsible for violet and

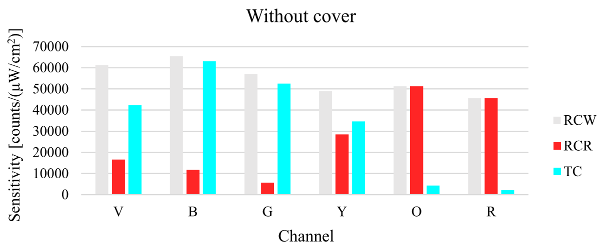


Fig. 14. Average visible light spectrum of embedded airport lamps without the acrylic glass cover on the AS7262 module.

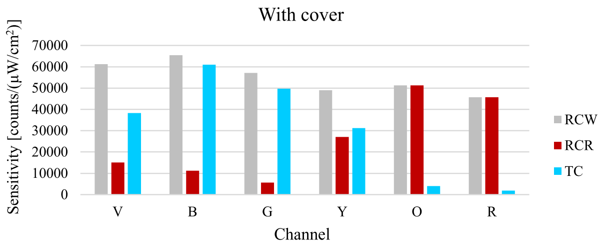


Fig. 15. Average visible light spectrum of embedded airport lamps with the acrylic glass cover on the AS7262 module.

yellow components. The obtained results were lower than in the test without cover. With luminaire of the taxiway centre line, the acrylic glass cover effect is visible for each channel. It causes a slight decrease in the reading value for each channel.

$$d(\mathrm{LT}_1, \mathrm{LT}_2) = \sqrt{\sum_{channel=V}^{channel=R} \left(\mathrm{LT}_{1\,channel} - \mathrm{LT}_{2\,channel}\right)^2} \qquad (1)$$

$$d(\mathrm{LT}_1, \mathrm{LT}_2) = \sqrt{\sum_{channel=R}^{channel=B} \left(\mathrm{LT}_{1\,channel} - \mathrm{LT}_{2\,channel}\right)^2}. \qquad (2)$$

To visualize differences between different types of the tested airport lamps, Euclidean distances were calculated following Eq. (1) for 6-channel sensors and Eq. (2) for RGB sensors, where d variable is the Euclidean distance and LT is the lamp type. The obtained results are summarized in Table 2.

Table 2.
Results of calculated Euclidean distance of different types of the embedded airport lamps [in count/(μW/cm^2)].

Euclidean distance between airport lamps spectrum			
6-channels (VBGYOR)			
	RCW	**RCR**	**TC**
RCW	0	89139.43	68528.13
RCR	89139.43	0	98166.03
TC	68528.13	98166.03	0
3-channels (RGB)			
	RCW	**RCR**	**TC**
RCW	0	74371.79	43920.83
RCR	74371.79	0	82061.26
TC	43920.83	82061.26	0

The analysis of the collected results shows that a programmable differentiation of individual types of the airport lamps is possible, based on the analysis of readings from the AS7262 spectrum sensor. Euclidean distance values for a larger number of channels are higher which shows that the use of more advanced sensors than RGB colour detection modules increases decision-making confidence. Location for each type of the tested lamps in RGB colour space for the 3-channel sensor is shown in Fig. 16.

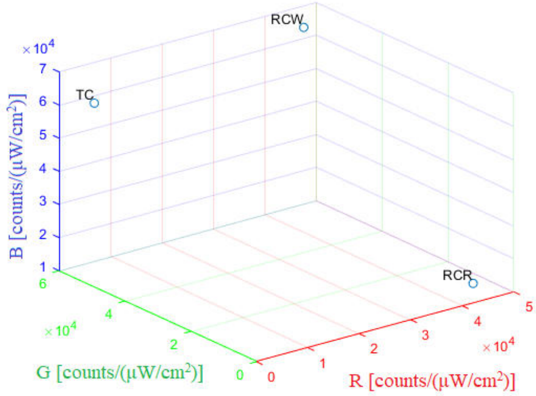


Fig. 16. RCW, RCR, and TC airport lamps in RGB colour space.

It can be seen in which planes there are similarities and differences in the visible light spectrum emitted by individual luminaires. A similar characteristic cannot be visualized for 6-channel sensors due to the number of dimensions it should be placed in.

5. Results of examination of airport elevated lighting using the AS7262 module

During the elevated edge lamps examination, the luminaire at the end of the runway marked ADB Safegate 1-045-RED-STOPBAR – TEFT was focused on Fig. 17(a). According to the documentation, it is a high intensity unidirectional luminaire for the approach, threshold, or runway end system. It emits red light from a 45-W halogen bulb. It is powered by a 6.6-A current source [15].

The elevated approach system luminaires are located off the roads where the aircrafts are moving. The tested system luminaires were ADB Safegate UEL 1-150 – CLEAR [Fig. 17(b)] and ADB Safegate UEL 1-150 – RED [Fig. 17(c)]. According to their documentation, these are unidirectional high-intensity over-ground lamps that emit white or red light with a source in the form of a 150-W halogen bulb. The life of the light source according to the catalogue note is of 1000 h. Lamps are powered by a 6.6-A current source [15]. Luminaries intended for testing were new (they have never been used).

Method of testing efficiency of an operation of the second type of lamps in elevated luminaires differs significantly. The test device is not mounted on a vehicle but is an independent tool in the form of a tube terminated with a measuring module. During the inspection, the operator manually mounts it to the original lamp holders, and it is also a structure preventing direct access to the sensors without prior disassembly. All this means that there is no need for additional protection of the measurement modules, so the results of the spectrum study for these

(a) (b) (c)

Fig. 17. Elevated runway end lamp (a) and approach system lamps (b), (c).

lamps were limited to readings obtained when the beam was shining directly onto the sensor. Due to the design of the device for testing lamps of this type, laboratory tests took into account the variation in a distance between the light source and the visible light spectrum of the sensor module.

The brand-new lamp of the white-coloured approach system was tested on the emitted light beam spectrum. Several measurement series were carried out, the averaged measurement results are presented in Table 3.

Table 3.
Spectrum results of the approach system lamp (white) examination [in count/(μW/cm²)].

Approach system lamp (white)					
Channel	Distance from lamp [m]				
	0.5	0.75	1	1.25	1.5
V	30285.84	30285.72	30285.88	30285.91	20518.76
B	34167.91	34166.84	34165.87	34169.84	25872.91
G	27988.54	26220.12	24041.31	22989.64	6324.16
Y	24041.03	24039.81	24041.18	20357.57	15134.46
O	24898.79	24898.74	24899.81	22988.64	24853.31
R	23949.38	23948.46	23950.31	23947.47	23948.16

The collected results showed that with the distance increase of the sensor from the light source, the reading value decreases for the distance above 1.25 m. Measurements in the range from 0 to 100 cm are repeatable, while for 125 cm and 150 cm the obtained data introduce the measurement fall. The analysis of the visible light spectrum for the approach system lamps with the emitted white beam shows that the dominant colours are blue and purple (Fig. 18). Due to the fact that the white light is a mixture of all components, all channels recorded a clear signal.

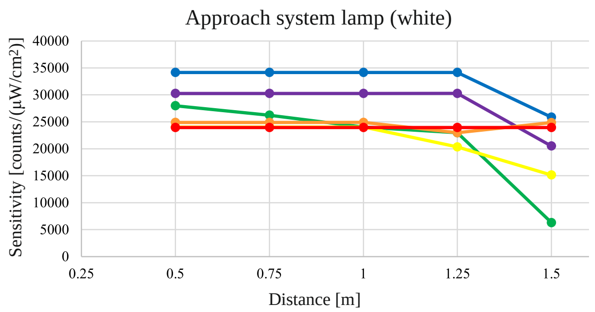


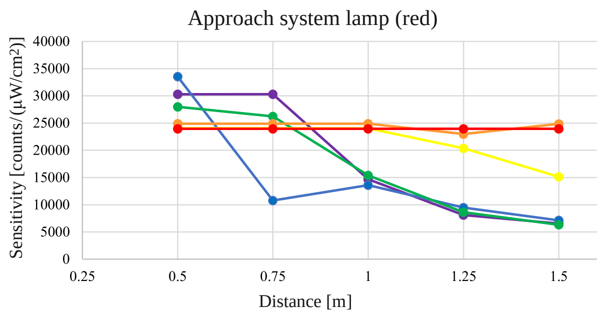
Fig. 18. Visible light spectrum of the approach system lamps (white).

As in the previous case, the brand-new example of the red approach lamp was tested on the emitted light beam spectrum. Several series of measurements were carried out, the averaged measurement results of which are presented in Table 4.

Table 4
Spectrum results of the approach system lamp (red) examination [in count/(μW/cm^2)].

Approach system lamp (red)					
Channel	**Distance from lamp [m]**				
	0.5	**0.75**	**1**	**1.25**	**1.5**
V	30285.84	30285.72	14668.18	8113.64	6547.41
B	33532.45	10767.21	13588.13	9492.25	7122.26
G	27996.43	26221.31	15389.41	8597.91	6322.05
Y	24038.98	24038.98	24039.11	20359.15	15134.99
O	24899.78	24899.77	24898.94	22984.92	24851.86
R	23951.41	23951.43	23950.94	23950.94	23950.41

As the distance increased, also in this case a clear decrease in the readings for some individual channels was observed above the distance of about 75 cm. The analysis of the visible light spectrum for the approach system lamp with the emitted red beam shows that blue has the lowest part in the components (Fig. 19).



Fig, 19. Visible light spectrum of the approach system lamps (red).

The sample of a brand-new runway end lamp was tested on the emitted light beam spectrum. Several series of measurements were carried out, the averaged measurement results are presented in Table 5.

Table 5.
Spectrum results of the runway end lamp examination [in count/(μW/cm^2)].

Runway end lamp					
Channel	**Distance from lamp [m]**				
	0.5	**0.75**	**1**	**1.25**	**1.5**
V	2262.99	1907.87	1347.51	774.71	606.81
B	392.13	1024.31	325.84	673.14	387.62
G	4827.02	1682.15	1062.01	699.79	498.02
Y	5395.98	3504.98	1949.52	1636.88	1101.84
O	24203.85	10956.67	7504.14	4126.21	3292.67
R	26148.37	13943.97	5178.99	5932.31	5080.03

The results of the study of the distance effect between the spectrum sensor and the light source in the case of this lamp showed that the readings decreased with increasing distance. No limit distance can be distinguished, up to which the measurements would have almost constant values, as in the case of other luminaires. The characteristic curve has a shape similar to a hyperbola. The analysis of the visible light beam spectrum emitted by the runway end lamp consists mainly of orange and red wavelengths. The remaining components constitute a very small part of the entire light beam (Fig. 20).

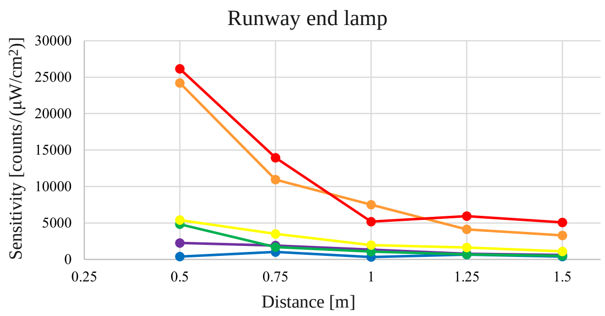


Fig. 20. Visible light spectrum of the runway end lamp.

6. Construction of a prototype measuring matrix with a spectrum sensor

Sensors forming the rear matrix of the measurement platform are primarily two centrally located BH1750 modules measuring the light intensity. The system implements their simultaneous operation on the I2C bus, thanks to the use of different addresses by entering a low or high state on the ADDR pin. An additional sensor supporting the work of that previously mentioned is the VEML7700 module. It was used due to the different characteristics of the transducer, as it may enable greater precision of the measurement. Additionally, to implement the automatic mode of distinguishing between lamp types, the AS7262 visible light spectrum sensor has been installed. Its operation makes it possible to recognize the colour of the light beam, using the values of its individual components. Figure 21 shows the finished rear matrix before mounting to the chassis of the measurement platform [7].

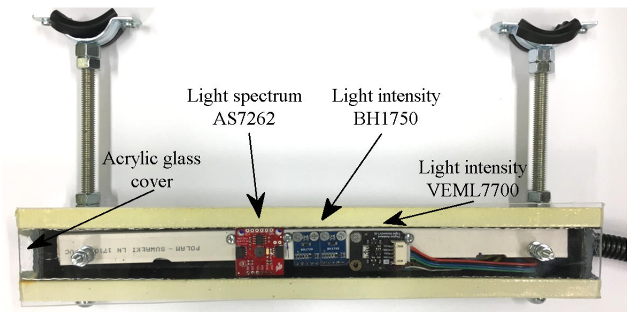


Fig. 21. Prototype of the measuring matrix for testing lamps embedded in airport surfaces.

7. Conclusions

The aim of the paper was to test the operation of the colour sensor in detecting the light colour of airport lamps. The AS7262 sensor was examined in detail. In the case of the embedded airport lamps, the repeatability of the measurements can be noticed even with the use of an acrylic glass cover, while for the elevated lamps, the variability for the components is visible due to changes of distance between sensor and light source.

Research carried out shows that there is a dependence on distance. Along with its increase components mainly red and orange require corrections. This task can be implemented programmatically, but it is worth remembering that the proper calibration is necessary.

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