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Suggestions for Improvement of the Illumination System and The use of Colored Flashes in Endoscopic Capsule

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Improving specifications of wireless endoscopic capsules is a topical issue nowadays. This article is devoted to the illumination system of the wireless endoscopic capsule. The authors describe the advantages of using colored led flashes for illumination of the gastrointestinal tract when fixing images. It is also described how to achieve the uniform illumination of the digestive tract due to the change of the mutual arrangement of the optical axes of the light-emitting elements and the matrix. The described solution will improve the quality of the images captured by the capsule that will positively affect the process of automated recognition of pathologies of the digestive tract.

Key words: Endoscopic capsule, LEDs, illumination, optical axis of a matrix, colored flash, color filters.

Wireless capsule endoscopy is a modern method of non-invasive examinations of a human digestive tract by a miniature capsule with built-in camera. The camera captures images of the gastrointestinal tract (GIT) and sends them to the reader, which is then connected to a PC of a doctor for further processing of the received images[1-4]

A wireless endoscopic capsule can be outlined as shown in Figure 1[5].

The illumination system is a critical component of the endoscopic capsule, because the better the quality of recorded images, the more accurate abnormalities and morphological changes in the digestive tract can be detected[6]. To this end, the endoscopic capsule is equipped with a LED panel that provides illumination of the GIT for the image sensor to be able to capture images.

The issue of improving optical component of the endoscopic capsule to capture the images of the digestive tract was the subject of many scientific papers. For instance, Cerveri et al. study the feasibility of a novel miniaturized optical system for endoscopy[7]. Perspective shape from shading for wide-FOV near-lighting endoscopes is discussed in[8]. Lu et al. tell about a compact light-emitting diode lighting ring for video-assisted thoracic surgery[9].

Despite the successes achieved, the existing methods of image improvement have their drawbacks, for example, high-energy consumption, high cost of the system, etc.

This article will address the issues of improving the quality of an image of the digestive tract using colored led flashes and achieving the uniform illumination of the digestive tract.

Methodology

Let us consider some optical specifications of the endoscopic capsules PillCam SB 2, EndoCapsule and MiroCam[10-11] (Table 1).

The camera of the endoscopic capsule has a wide angle of view, which often varies, from 120 to 180 degrees[10].

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To obtain the video images of the mucosa of the GIT the endoscopic capsule comprises a photosensitive matrix (in our case it will be the CMOS (complementary metal-oxide-semiconductor) matrix OV7690[12]), on which a system of lens is "put on". As an example, let us consider an optical system of a wireless endoscopic capsule "Landish", which is shown in Figure 2.

The main technical characteristics of the photosensitive matrix used in the endoscopic capsule are shown in table 2[12].

Table 1. Endoscopic capsules' specifications

	PillCam SB 2, Given Imaging	Endo Capsule, Olympus	MiroCam, Intro Medic
Angle, degrees	156	145	170
Number of LEDs	6	6	6
Shooting speed, fps	24	2	3

Table 2. The main technical characteristics of the photosensitive matrix

Feature	Value
The size of 1 pixel	2.5×2.5mkm
Photosensitive area	1640×1220 mkm
Case size	6×6 mm
Sensitivity	1800 mV/Lx*sec
The matrix of pixels	640×480

Today different types of the illumination are widely used in the gastro- and colonoscopy studies[10, 13-16]. Typically, the white light is used for the illumination. However, for example, to detect bleeding and research vessels an endoscope equipped with a red filter which is governed by a gastroenterologist is used. The use of a filter allows to select visually the image area of the bleeding because blood reflects the red light, issued by the color filter[17].

Similarly, in the study of blood vessels of the GIT on the subject of varicose a blue filter is applied; in this case, the veins reflecting blue light are clearly and brightly visible in the image, while the rest area is darkened.

This technique is often used when conducting gastro- and colonoscopy by traditional

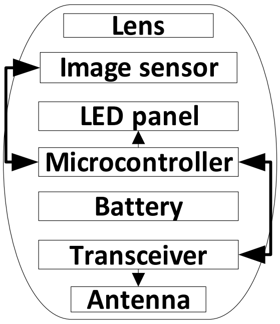

Fig. 1. Wireless endoscopic capsule scheme

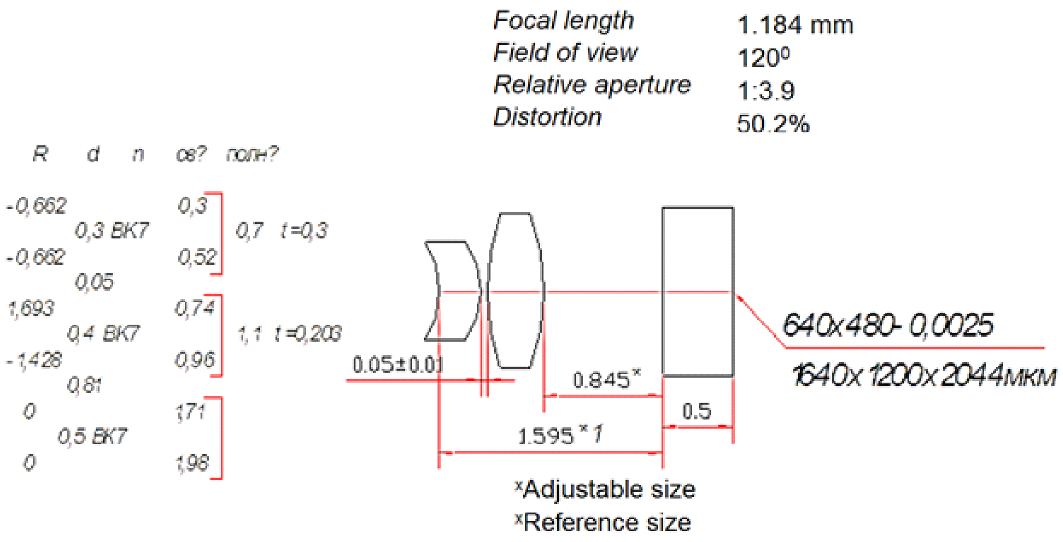

Fig. 2. Scheme of the optical system of the endoscopic capsule

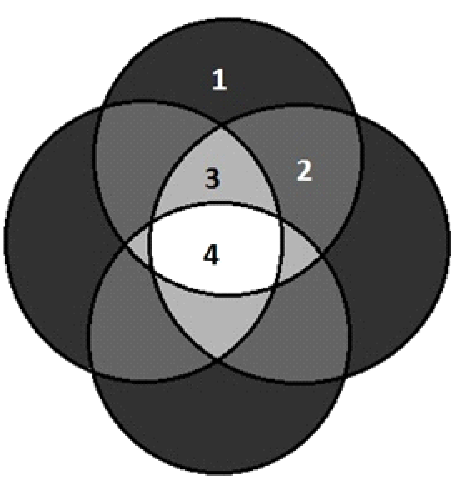

Fig. 3. Scheme of illumination of the GIT when using four LEDs with optical axes parallel to the optical axis of the matrix

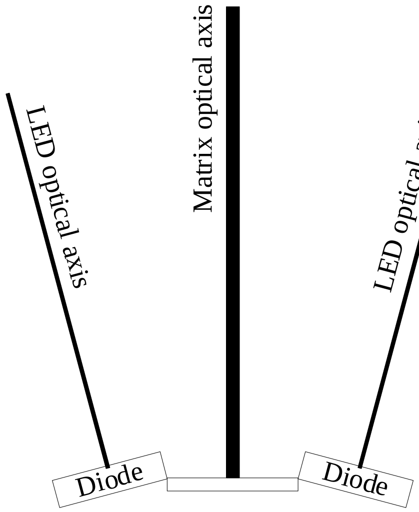

Fig. 4. The optical axises of the LEDs form an angle to the optical axis of the matrix

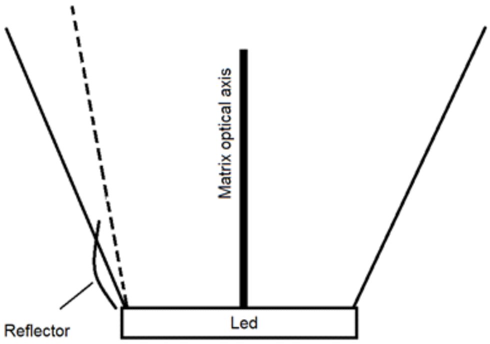

Fig. 5. Use of a reflector in the system LED lighting

methods, however, is difficult to implement for the capsule endoscopy due to the design features of the capsules: the use of mechanically exchangeable filters is problematic because of the small size of the capsules and hard limits on energy supply.

However, the endoscopic capsule can be compatible with the advantages of observation in different light ranges. It is suggested to use the colored LEDs to obtain the desired light wavelengths. Since the capsule is an autonomous device, a human-controlled change of light does not seem rational. Instead, it is proposed to use the pattern of flashes, for example – white-red-yellow-blue[18].

To make the images contain as detailed information for diagnosis as possible, the endoscopic capsule is proposed to use light-emitting diodes with 16-bit color encoding, which are activated when the camera captures an image[5].

The change of the colors in the capsule occurs in cycles that gives better results after automatic processing of the images in comparison to the conventional lighting. This keeps a reasonable number of images shot in standard white flash, and though provides specific information with flashes of red, yellow and blue colors.

The LEDs of the same color are arranged in pairs, which provides a uniform light distribution in the digestive tract. The camera captures images of the GIT cyclically in white, red, yellow and blue light. It should be noted that a greater number of diodes can be used (for example, 12). The Multi-color diodes can also be used[18].

For a uniform distribution of the light special mirror-reflectors may be used in combination with the diodes. Note that the colored LEDs can significantly reduce the expenditure of the capsule battery.

A similar function (getting an image of the GIT in a certain color) can be implemented by the software, for example, highlighting only the blue channel pixels. However, because of the mutual illumination of neighboring pixels the software processing of the image will not give accurate results. In addition, if a single color is selected by software, the brightness of the image goes down three times, which negatively affects the process of the automatic recognition of abnormalities and morphological changes in the GIT.

As noted above, the main purpose of the

LED illuminator in an endoscopic capsule is to ensure the uniform illumination of the GIT area, where the image is taken. The matrix for image capturing of a wireless capsule has its optical axis, as well as light emitting elements, and sight radius. The optical axis of the matrix goes through the center of the field of observation, which is also the center of the endoscopic capsule.

If the capsule has a small number of LEDs (for example, four), the central axis of which are parallel to the optical axis of the matrix, the situation occurs (Figure 3), when the illumination of various parts of the GIT are uneven.

In Figure 3: 4 – the maximum, four-fold illumination of the digestive tract (this area gets light from the four diodes); 3 – three-fold illumination; 2 – double illumination; 1 – single illumination.

Thus, there are four zones, the illumination of which differs n times from each other. Therefore, if the power of lighting of the LEDs is the increased to obtain the desired brightness in the area other than the central, the central area becomes brighter than necessary. In addition, it leads to increase of power consumption of the endoscopic capsule.

Due to the different illumination of the areas, there are difficulties with the automated image analysis: some areas are overexposed, while the others are dark; it has a significant impact on the effective functioning of the software for recognition of abnormalities and morphological changes of the digestive tract[10].

In the patent[19] several constructive ways of dealing with the problem of non-uniform illumination of the gastrointestinal tract are described.

The following solutions were considered.

Increasing the number of LEDs

In order to smooth the luminance of the image, the number of the LEDs in the endoscopic capsule can be increased, for example, twice. This will make transitions from one lighting zone to another smoother, but will not solve the problem of over lightening the central zone of the image.

Here is the calculation of the optimal number of the LEDs based on the light sensitivity of the matrix in question (OV7690). The matrix sensitivity is 1800 mV*Lx/sec. Light intensity of the white SMD LED, which consumes a current of 20 mA, is about 300 MCD. Thus, based on the ratio between the intensity of light in Lux, and the light intensity in candelas, the following is found:

$$E = I / (d^2), \quad ...(1)$$

where E is the luminance of a surface,
I is the light intensity,
d is the distance to the light source.

It is necessary to take into consideration that the matrix gets reflected light from the LEDs, which fades upon reflection from the mucosa. The reflection coefficient from the mucosa K is in the range of 10-55%[20]. Thus, the illumination created by the intersection of the light fluxes of n LEDs and recorded by the camera, is described by the formula

$$E = n*I * K / (4*d^2), \quad ...(2)$$

because the distance from diodes to the mucosal surface and from the mucosal surface to the sensor matrix is almost the same and is 2*d (d in this case is the distance from the surface of the matrix to the surface of the mucosa).

Let us assess the multiplier of the illumination in an extreme case of the maximum distance (approximately 180 mm – the distance from the bottom of his stomach to the lower pole of it) and the weakest reflectivity of the surface (10%).

$$I * K / (4*d^2) \quad ...(3)$$

The multiplier in this case takes the value of 0.92 Lux. Now let us estimate the potential created by a given luminance on the photosensitive cell of the matrix:

$$V = 1.8 * n * 0.92 * 1/fps, \quad ...(4)$$

where fps is the number of images per second.

Considering fps = 30 (standard mode of the matrix, used even in the case of only 2 images per second transfer due to the Rolling Shutter effect[21]), we get:

$$V = n * 0.055 \quad ...(5)$$

The resulting potential is measured in volts. Thus, the potential is 0.01 from the number of the LEDs covering the most remote area.

Since the reference voltage of an analog-to-digital converter of the sensor matrix is 3.0 V, not less than 0.3 V is required to ensure the picture brightness making 0.1 from the maximum.

The minimum number of the LEDs that provide this condition, is equal to 6 (n is also equal to the total number of the LEDs, since at a distance of 180 mm a mixture of light of all wide directional

LEDs takes place).

The optical axis of the LED slightly deviates from the optical axis of the matrix (Figure 4).

Every radiating element is tilted outward from the central axis of the endoscopic capsule so that the central axis of each light emitting diode is positioned at an angle to the central axis of the matrix. Thus, the light intensity in the central zone, which is normally illuminated by several LEDs, and the periphery, which receives light from only one diode will be about the same.

Reflectors are installed (Fig. 3).

The uniformity of illumination of the digestive tract can be controlled via reflective elements that allow to “move” some of the light from the central part and to send it to the periphery.

It should be noted that the uneven brightness of the image can be adjusted programmatically. However, any software modification of the image leads to defects and cannot entirely compensate for the phenomenon of light pollution and restore the brightness balance of the image.

CONCLUSION

Thus, the existing drawbacks in the illumination system and imaging of the wireless endoscopic capsule can be adjusted by the hardware or the software methods. The solutions described in this article will allow to improve the illumination system of the wireless capsule, increasing the quality of the recorded the images, which greatly affects the efficiency of the algorithms for the automated detection of the gastrointestinal diseases.

In future, we plan to continue the work on the improving of the illumination system of the wireless capsule to ensure the uniform and stable lighting of the digestive tract.

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