Design of illumination system in ring field capsule endoscope

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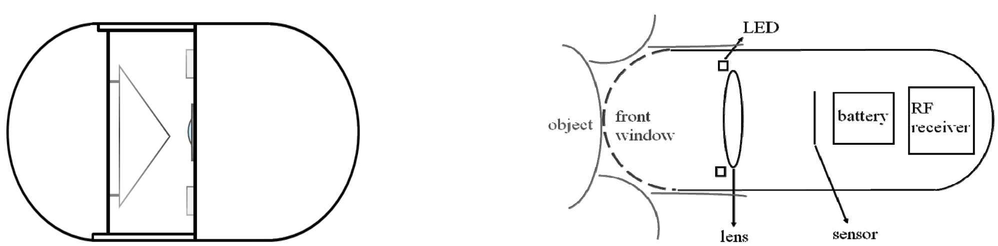
ABSTRACT

This paper is researching about the illumination system in ring field capsule endoscope. It is difficult to obtain the uniform illumination on the observed object because the light intensity of LED will be changed along its angular displacement and same as luminous intensity distribution curve. So we use the optical design software which is Advanced Systems Analysis Program (ASAP) to build a photometric model for the optimal design of LED illumination system in ring field capsule endoscope. In this paper, the optimal design of illumination uniformity in the ring field capsule endoscope is from origin 0.128 up to optimum 0.603 and it would advance the image quality of ring field capsule endoscope greatly.

1. INTRODUCTION

In the past, when pathological changes in the digestive tract, it use traditional endoscopy like gastroscopy to check the changes in general, and this method is an invasion type so that the patients will feel fear. The traditional endoscopy can just use in stomach; it cannot check the pathological changes in the intestines, because the intestines is wind and complex so that the endoscopy cannot arrive here to capture the images [1]. Due to this reason, this paper propose a new concept, which design a new generation capsule endoscope, it is called ring field capsule endoscope. The ring field capsule endoscope is different with typical capsule endoscope. For example, the ring field capsule endoscope can get ring shape images when it moves in the intestines, it is because the ring field capsule endoscope add a reflection mirror in front of the lens, the object on the capsule shell side will imaging by the reflection mirror. This is a big advantage because the imaging method can solve the dead pixel problem when typical capsule endoscope moves in the fold intestines, the capsule endoscopes are shown in Fig. 1.



(a)Ring field capsule endoscope (b)Typical capsule endoscope

Figure 1. Two kind of capsule endoscope

It is obvious that the ring field capsule endoscope can do something that the typical capsule endoscope cannot do, like the ring field capsule endoscope can get all the images in the intestines because it doesn't have dead pixel problem but will occur in typical capsule endoscope; the ring field capsule endoscope doesn't have long depth of field (DOF) because the object distance is almost equal to the half of capsule shell radious, but it need long DOF in typical capsule endoscope; the images capture by ring field capsule endoscope has overlap region, in other words, each image has high correlation coeficient in some region, so it can be use to reconstruct the 3D intestines images and the doctor can use this images to distinct the disease more effciency.

The illumination of ring field capsule endoscope is very different with typical capsule endoscope. Fig. 2 shows the illumination type between ring field capsule endoscope and typical capsule endoscope. It's clearly the typical capsule endoscope can use the optical elliptical dome to solve the stra light problem, the method is putting the LEDs on the focal

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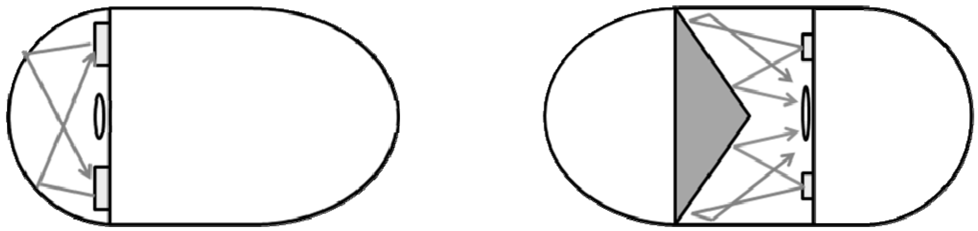
plane of the elliptical dome, the stray light will reflect to another LED, so the light uniformity of typical capsule endoscope is better than ring field capsule endoscope, because the ring field capsule endoscope cannot use this property to solve the stray light problem [2]. Due to this reason, this paper will use Advanced Systems Analysis Program (ASAP) program to simulate the illumination and find out the best solution of ring field capsul endoscope [3].



(a)Illumination of typical capsule (b) Illumination of ring field capsule endoscope

Figure 2. Illumination methods of capsule endoscope

2. MODELING

This paper mainly uses Advanced System Analysis Program, ASAP ™ (ASAP) software to build the optical model. ASAP is flexible and very high efficient tool, it uses the Monte Carlo ray tracing method to simulate the optical structure, and it is a standard optical design software in the industry and had been verified for a long time. In this paper, it mainly discuss the illumination problem of ring field capsule endoscope, the research kernel is using different light source parameter to reach the optimum design of illumination. The first work is building the original model, which includes define the system elements, geometric structure and optical properties, when the optical model is built, it can focus on raise the complex of the model to reach the optimum case; second, build up the light source, it should build a realize light source of the optimize design, so that it can simulate the optical property of light source which likes coherence and energy. Third, ray tracing of the optical model, it should use the rays to do right things on the model, so that it can get the simulation results correctly. Finally, after the three steps as describe before, it should be analysis of the optical system, which includes calculating the energy, luminance, light intensity, and then estimate the performance reach the specification or not.

It can separate into two parts of the ring field capsule endoscope model, the first part is optical imaging system, like lens and cone mirror; the second part is optical illumination system, like LED and PCB. When the two parts are built, the ring field capsule endoscope model can be built by combining the two parts model, the ring field capsule endoscope model is shown in Fig. 3.

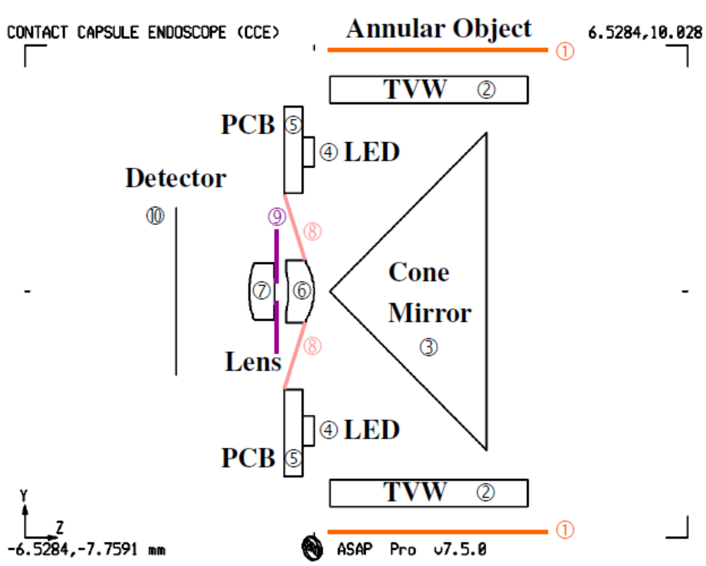


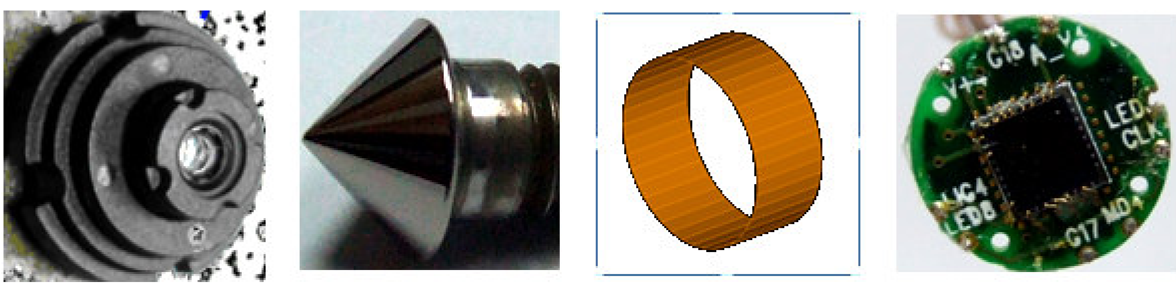
Figure 3. Illumination model of ring field capsule endoscope

The marks ⑥~⑨ are elements of doublet lenses, can the doublet lenses had been fabricated before, the Table 1 shows the doublet lenses specification [4]. By the way, the mark ⑧ is optical mask; it can resist the rays which do not pass through the doublet lenses, propagate into the image sensor directly, this behavior can reduce the stray light and increase the light uniformity of the ring field capsule endoscope model.

Table 1. The specification of doublet lenses

Surface	Type	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD	Infinity	6.819421		11.6504	0
1	EVENASPH	1.257744	0.6901632	APEL	1.709404	−1.237028
2	EVENASPH	2.248327	0.3120441		1.172508	5.483633
STO	STANDARD	Infinity	0.05		0.5416241	0
4	EVENASPH	3.432116	0.6875531	APEL	0.85343	−61.36225
5	EVENASPH	−2.37155	1.96		1.450896	3.522382
IMA	STANDARD	Infinity			2.230158	0

The most important element in the ring field capsule endoscope is cone mirror, which is the mark ③, due to the ring imaging method, the ring field capsule endoscope put a cone mirror in front of the doublet lenses, so that the intestines object can imaging by the cone mirror and doublet lenses, and form a ring image type on the image plane. The cone mirror specification are cone angle equals 45°, high equals 4.21 mm, and set reflection type on the cone mirror. The mark ① is object plane; it uses a tube shape element to be the intestines object in the simulation, the radius equals 6.4 mm, object width equals 5.8252 mm, and set the surface as absorb property to analysis the light intensity and uniformity. The mark ⑩ is image plane, the CMOS sensor resolution is 512 × 512, and pixel size is 5.6 μm, so the image plane equals a square which size is 2.867 mm. The all elements are shown in Fig. 4.



(a) (b) (c) (d)

Figure 4. The elements of ring field capsule endoscope. (a) Doublet lenses, (b) cone mirror, (c) tube object and (d) CMOS sensor.

The mark ⑤ is PCB, the purpose of it is to fix the LED and connect to the circuit, which can supply the power to keep the LED lighting on the object. The inner radius is 5.2 mm, outer radius is 9.8 mm, the circuit board thickness is 0.5 mm, and here uses six LEDs arrange uniformly on the circle, as show in Fig. 5. The mark ④ is LED; the LED type is part No. NESWC04T, it was produce by Nichia. The LED specifications are long equals 1.1 mm, width equals 0.8 mm, and high equals 0.3 mm as show in Fig. 6. In this paper uses one million rays per LED to simulate the optical model, and define the total energy is 100.The mark ② is transparent view window, the material is PU DOW plastic, the type is ISOPLAST*2530, and the index is about 1.59 [5-6]. After build up all the elements, the ring field capsule endoscope model is shown in Fig. 7.

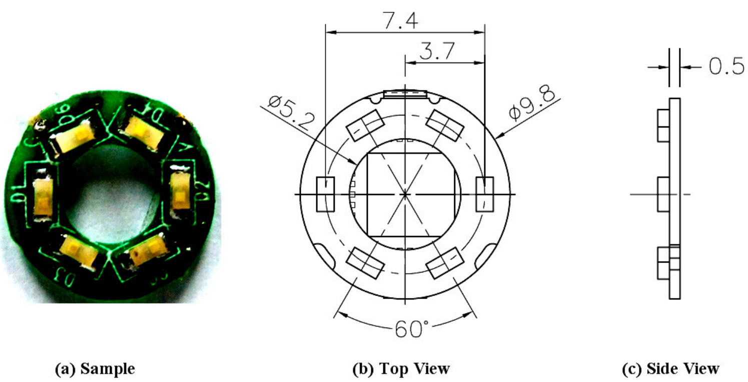


Figure 5. PCB associate with LED element

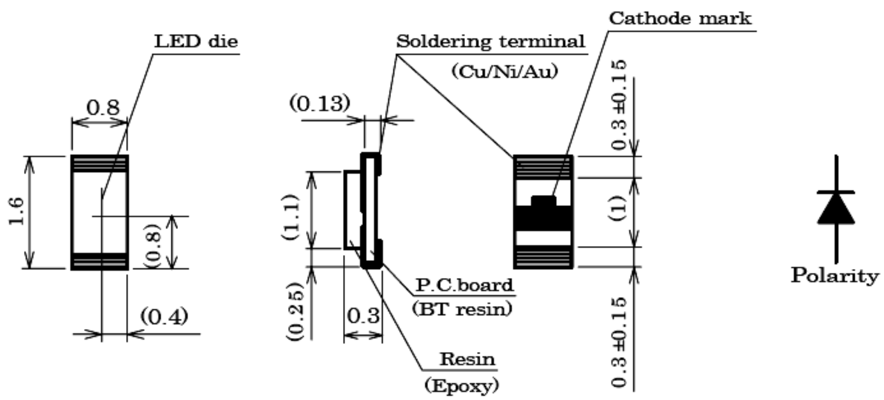


Figure 6. Part No. NESWC04T specification

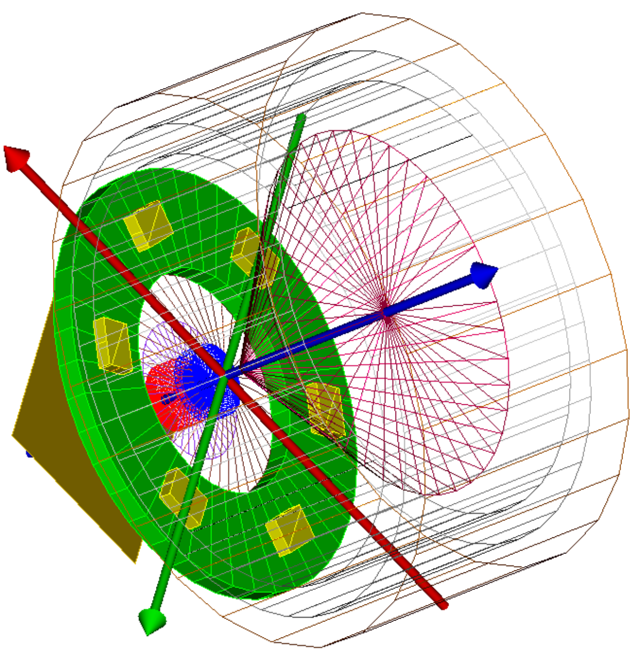
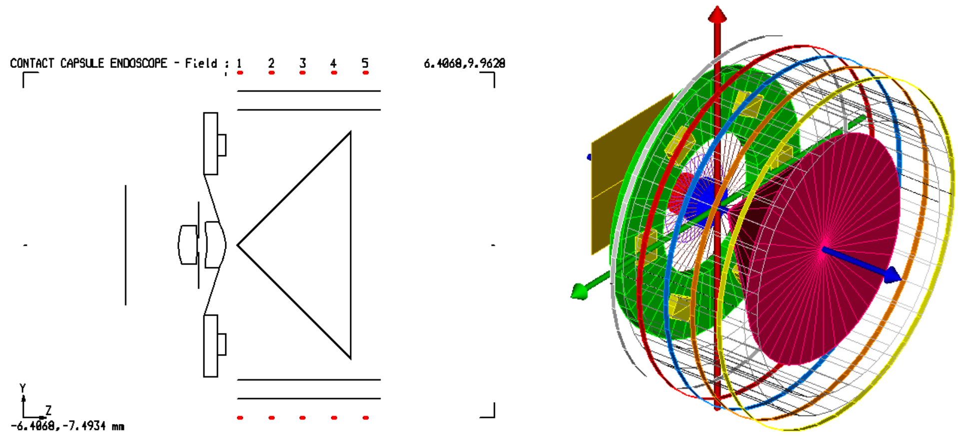


Figure 7. The 3D structure of ring field capsule endoscope

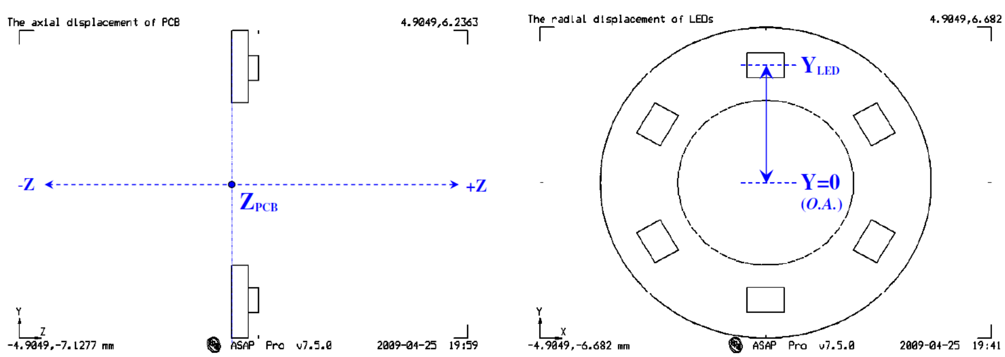
3. SIMULATIONS

Before the simulation, the object plane are define with five fields, which are 0%, 20%, 40%, 60% and 80% of object width, as show in Fig. 8. The simulation uses four methods to solve the stray light problem, which are move the PCB and LEDs, rotate the LEDs and coding on the transparent view window, as show in Fig. 9.

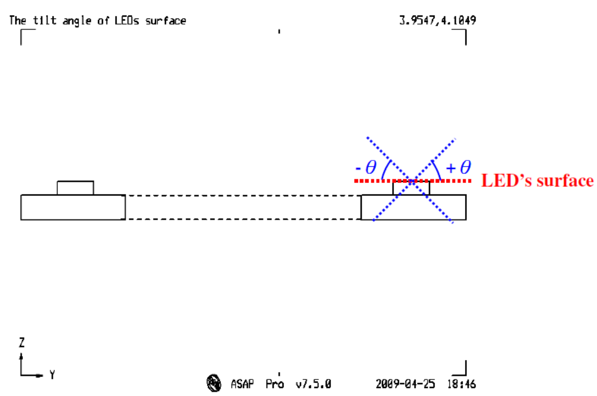


(a) 2D structure (b) 3D structure

Figure 8. Five fields of the object plane



(a) Move the PCB (b) Move the LEDs



(c) Rotate the LEDs

Figure 9. The methods of solving light uniformity

Firstly, we simulate different position of z axis which is move the PCB from - 1.0 mm to - 0.7 mm, and the quantity is 0.1 mm, the results are shown in Fig. 10 and Fig. 11. it is obvious that the uniformity and total flux increase when the LEDs move to +z direction (except the z= - 0.9 mm), the uniformity and total flux have the maximum value when z equals - 0.7 mm, they are 41.25% and 0.025 respectly.

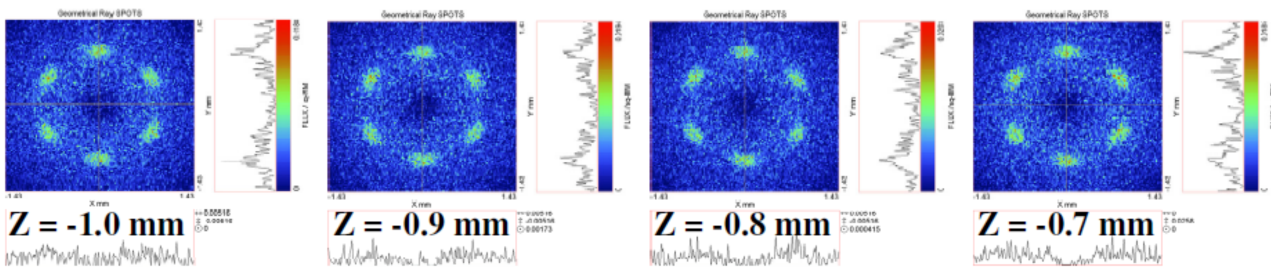


Figure 10. Energy distribution on the image plane (change PCB position)

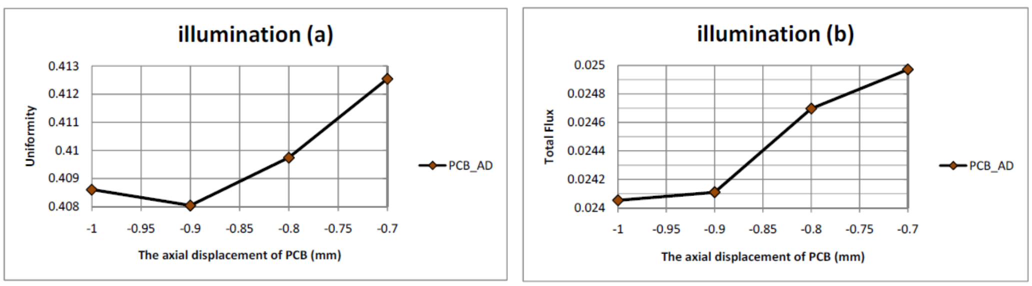


Figure 11. Uniformity and total flux (change PCB position)

And then fixed the PCB at the position of z equals - 0.7 mm to change the LEDs position from y equals 3.0 mm to y equals 4.4 mm, the change quantity is 0.2 mm, the results are shown in Fig. 12 and 13. It can be found the uniformity and total flux decrease when the LEDs move to the outer position, they are 42.85% and 0.0254 respectly.

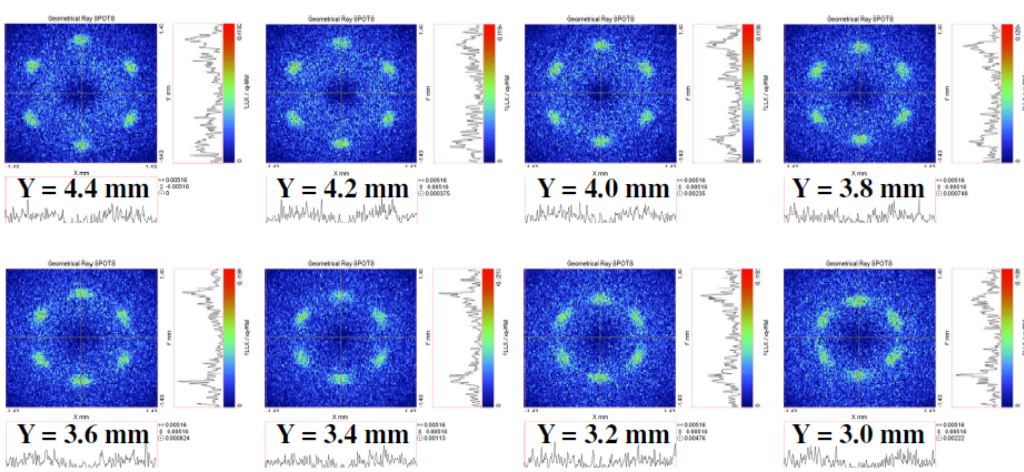


Figure 12. Energy distribution on the image plane (change LEDs position)

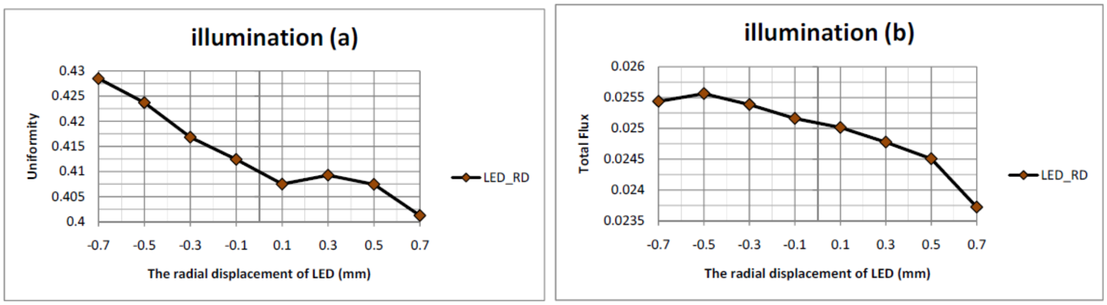


Figure 13. Uniformity and total flux (change LEDs position)

Fixing the PCB at the position of z equals - 0.7 mm and LEDs at the y equals 3.0 mm, then rotate the LEDs angle from θ equals - 45° to θ equals 25°, the change quantity is 10°. The result is shown in Fig. 14 and 15, it can be found the uniformity and total flux have the maximum value at θ equals - 5°; they are 44.65% and 0.0255 respectly.

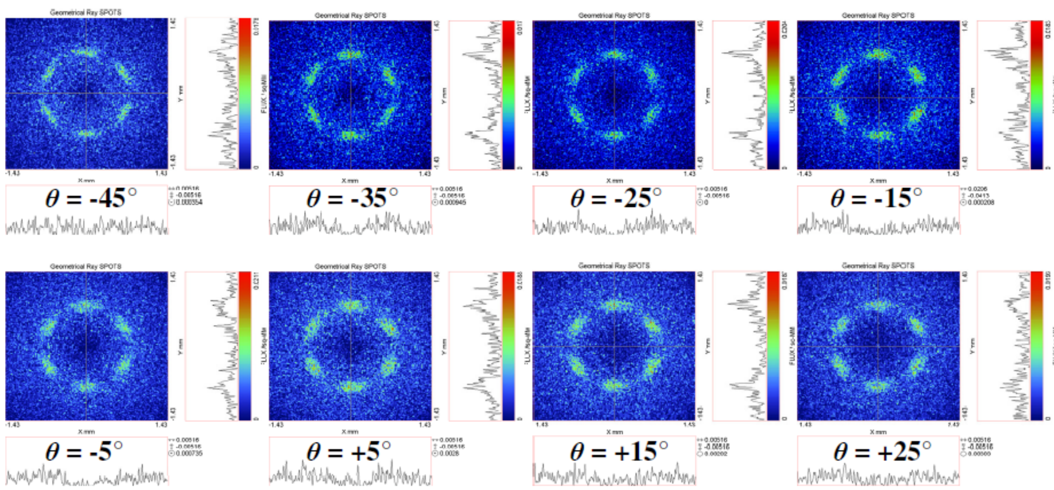


Figure 14. Energy distribution on the image plane (rotate LEDs angle)

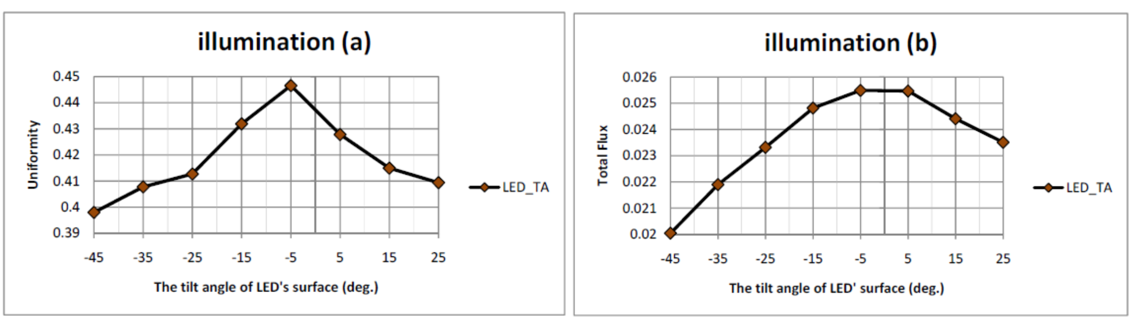
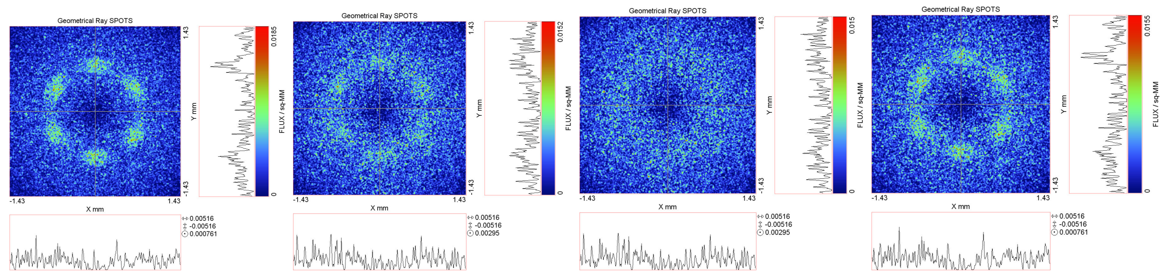


Figure 15. Uniformity and total flux (rotate LEDs angle)

Finally, we maintain all the situations as simulation before, then using the coding method on the view window to improve the uniformity, the Fig. 15 shows different ways of coding like only inner layer coding, only outer layer coding, two layers coding and multi-layers coding, and the results are shown in table 2.



(a) No coding (b) Single layer coding (c) Multi-layers coding (d) Single layer coding (only inner)

Table 2.The results of coding

Optical property \ Coding type (inner/outer)		Non/Non	Single layer/Non	Multi-layer/Non	Single layer/ Single layer	Multi-layer/ Multi-layer
Reflectance	**Inner**	0.053	0.0075	About 0	0.0075	About 0
	Outer	0.053	0.053	0.053	0.0075	About 0
Uniformity		45.17%	55.47%	56.34%	58.75%	60.36%

4. RESULTS

In this paper, it design a ring field capsule endoscope model to simulate the illumination, and using four methods to improve the uniformity and total flux, they are changing the PCB and LEDs position, rotating the LEDs angle and coding on the view window, the table 3 shows the results of different method.

Table 3. The simulation results of different methods

The performance of optimum design		
Methods	**Value**	**Uniformity**
Moving PCB	z= - 0.7 mm	0.4125
Moving LEDs	y=3.0 mm	0.4285
Changing LEDs angle	θ= - 5°	0.4465
Coding	multiple layer, inner & outer	0.6036

5. CONCLESIONS AND DISCUSSION

This paper mainly focuses on illumination design. Firstly, we build up ring field image capsule endoscope model, which are including the doublet lenses, cone mirror, transparent view window, tube shape object, lighting source and image plane. Second, set the specification to the all elements to build up realize model and then simulating the model to get the results. Third, the results depend on different methods, which are changing the PCB and LEDs position, rotating the LEDs angle and coding on the view window. Finally, the simulation reach a optimum value, the uniformity and total flux are 60.3% and 0.0255 respectly.

Although we have improve the original uniformity 12.8% to 60.3%, but there are some methods to increase the uniformity. For example, the LED surface can add a diffuser to improve the light uniformity directly; or using illumination optical fiber to be a light source.

6. ACKNOWLEDGEMENT

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