8K Imaging Systems and Their Medical Applications
—World's First 8K Rigid Endoscope Camera—

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1. Introduction

8K also known as Super Hi-Vision is an ultimate broadcasting TV system with 33 million (M) pixels (7,680 × 4,320) conveying a strong sensation of reality. The research and development of 8K began in 2000 as the next-generation ultra-high-presence television at NHK Science & Technology Research Laboratories (NHK STRL).

Since then, 17 years have passed, and today, 8K TV is growing into NHK's featured technology. At the same time, our development efforts aim to achieve widespread use of 8K by 2020, the year of the Tokyo Summer Olympics, as an "All Japan" system. In this way, 8K TV is attracting attention both in Japan and abroad as a technology for which Japan can play a world-leading role. Studies are also beginning on the use of this technology in fields other than broadcasting such as medical care, disaster prevention, and art. In this paper, the author provides an overview of 8K technology and describes its application to endoscopic surgery, a field of growing interest.

2. 8K imaging toward ultra-high presence

8K features four times the number of pixels as 4K, but that does not mean to say that 8K specifications are decided based on a competition in pixel count. They are determined, rather, on human science research that aims to determine the conditions under which video can provide "high presence" that makes the viewer feel as if he or she is actually present in the scene shown. The layout of an experiment for investigating the relationship between viewing angle and psychological (induced) effects is shown in Figure 1. Additionally, on the basis of those experimental results, Figure 2 shows how the induced angle changes while varying viewing angle at the

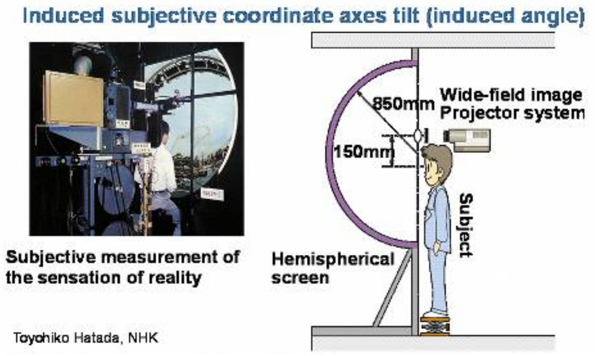

Figure1: Layout of experiment on viewing angle and induced effects.

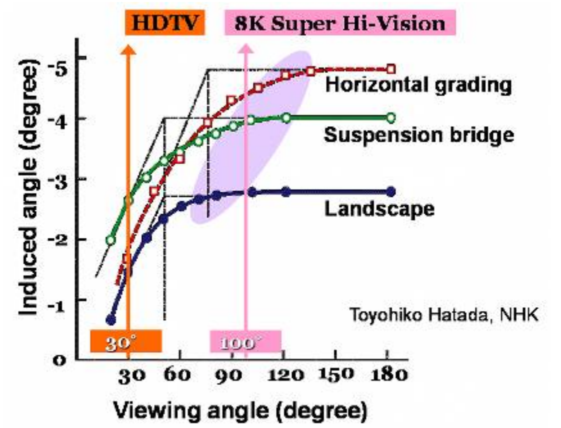

Figure2: Relation between viewing angle and induced effects.

time of viewing a still image tilted on the screen. The "induced angle" is obtained by measuring the observer's subjective body tilt. Increase in this angle intensifies the sense of presence in the observer. Although the results of this experiment differ somewhat according to the type of image presented, the induced angle gradually becomes larger as the viewing angle increases, eventually saturating around a viewing angle of 100 degrees. In other words, a viewing angle of at least 100 degrees is needed to obtain a high sense of presence. These results show that sense of presence is still in the process of increasing at the HD design angle of 30 degrees.

When talking about sense of presence, number of pixels must also be considered separate from viewing angle. Given a situation in which the number of pixels is small and the pixel structure of the screen is unavoidably visible, a sense of presence will naturally be lost. Incidentally, a person with a visual acuity of 1.0 can distinguish up to 60 pixels filling a viewing angle of 1 degree. Consequently, to prevent a person with such eyesight from making out individual pixels when viewing a TV screen with a viewing angle of 100 degrees, more than 60 × 100 = 6,000 pixels in the horizontal direction would be needed. At the same time, there is already a well-established 2K HD standard, and considering the need for convenience in system conversion, 8K has been designed to have 7,680 pixels or four times that of 2K, which means a number of pixels in the horizontal direction exceeding this number of 6,000. Of course, the number of pixels in the vertical direction in 8K is also four times that of 2K or 4,320 pixels.

3. Development of a compact 8K camera for medical use

In 2012, the author teamed up with Dr. Toshio Chiba and camera manufacturer to establish the Medical Imaging Consortium (MIC; chairman: Toshio Chiba). At MIC, we completed development of a compact 8K camera in February 2013 for use in endoscopic surgery. This camera used a single 2.5-inch CMOS image sensor making for a compact configuration. It was 170 mm high, 140 mm wide, and 200 mm deep and weighed 2.5 Kg.

4. Animal experiment with 8K endoscope camera

At MIC, we performed an open experimental laparoscopic surgery by the 8K rigid endoscope camera using an animal (pig) on December 7, 2013. [1)]

The advantages of using endoscopes applying 8K technology are summarized below centered on the comments and opinions voiced by doctors who participated in the above experiment.

(1) Creation of more space for endoscopic surgery

An existing endoscope using, for example, a 2K camera must be brought close to the surgical target to obtain a detailed view as shown by the illustration in

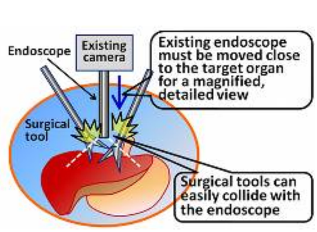

Figure 3: Existing endoscopic surgery.

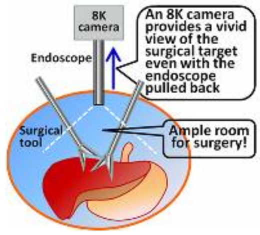

Figure 4: 8K endoscopic surgery.

Figure 3. As a result, interference between the endoscope itself and surgical tools becomes an additional problem in an already tiny surgical space. Many doctors consequently feel that such an endoscope is more of a nuisance than a benefit as it can hinder efficient and safe surgery. In contrast, when using an 8K endoscope system to capture an entire surgical field with the endoscope pulled back from the surgical target, the approximately 33M pixels offered by 8K, which is 16 times that of 2K, enables detailed viewing of the desired area without a loss of sharpness. That is, the application of 8K technology eliminates the problem of surgical space taken up by the endoscope resulting in ample space for surgery compared with that of existing endoscopes as shown in Figure 4. In short, 8K imaging enables a surgeon to safely manipulate surgical tools in the surgical space.

(2) Identification of very fine blood vessels and nerves and boundaries between organs

An 8K endoscope makes it easy to make out very fine blood vessels and nerves and to perform anastomosis between them. It also facilitates anastomosis between tubular structures such as the intestinal (digestive) tract and pancreas duct (the duct connecting the pancreas with the common bile duct extending from the gallbladder), anastomosis with the bile duct (the duct through which bile synthesized by the liver flows into the duodenum), and anastomosis with the ureter (the duct carrying urine synthesized by the kidney to the bladder). Furthermore, in addition to anastomosis, an 8K endoscope makes it easy to identify the boundaries between the pancreas and surrounding tissues (blood vessels and nerves, lymph nodes, etc.) that are often of similar shapes and colors making it difficult to distinguish between them. An 8K endoscope can also help to distinguish between cancer tissues and healthy tissue, which should make it easier to avoid damage to critical sites in a wide range of procedures such as exfoliation, excision, and removal.

5. Human gallbladder-removal surgery by 8K endoscope

Based on the experimental results described above, we at MIC and the Faculty of Medicine, Kyorin University have been working together on preparing for clinical applications of 8K technology, and on November 10, 2014, we successfully performed the world's first human gallbladder-removal surgery using an 8K endoscope camera. In this clinical application, we used a newly developed 8K camera having a compact configuration. This camera is shown with the existing camera in Figure 5. The newly developed camera features a volume 63% that of the existing camera and enhanced operability. The operating room scene during the surgery is shown in Figure 6 and the difference in the appearance of the large-intestine's surface between the existing 2K system and the 8K surgical system from images recorded at that time is shown in Figure 7. It can be seen that the 8K image enables fine blood vessels to be distinguished with vivid images that represent a major improvement in performance compared with 2K. Professor Toshiyuki Mori of Kyorin University, the operating surgeon, had this to say about the 8K endoscope: "I was impressed with 8K high-definition imaging that enables very fine structures to be observed. A surgeon that can clearly identify nerves, lymph nodes, and blood vessels can perform safer and more detailed surgeries."

6. Technical issues surrounding the 8K endoscope system

Surgery using an 8K endoscope camera has a variety of advantages as described above, and operating surgeons have also commented that it helps to prevent eye strain. However, our series of trials and experiments to date have revealed a number of technical issues that must be addressed before an 8K endoscopic surgery system can be made practical for widespread use. These include (1) achieving a high-sensitivity camera, (2) making the camera significantly smaller and lighter and (3) improving the resolution characteristics and uniformity of the endoscope optical system. Each of these is a critical issue, but here we take up the problem of insufficient camera sensitivity.

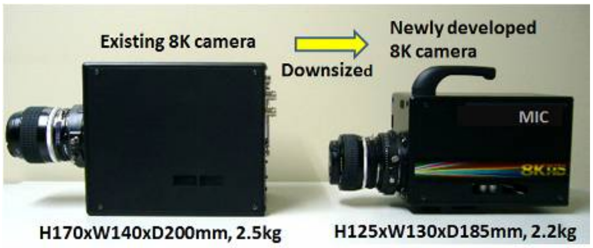

Figure 5: Newly developed 8K compact camera for surgical use (right side).

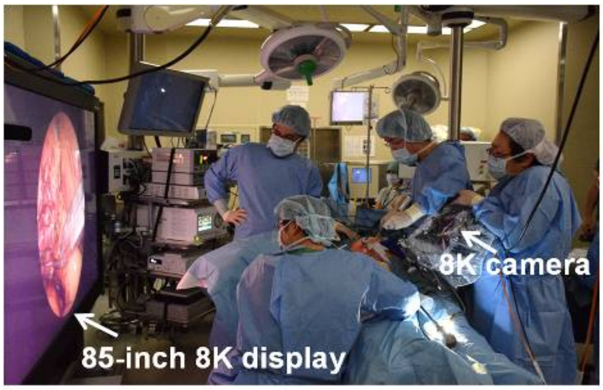

Figure 6: World's first human 8K endoscopic surgery (Kyorin University Hospital).

2K endoscope image. 8K endoscope image.

Figure 7: Difference in appearance between 2K and 8K images in endoscopic surgery (both images equally magnified for comparison).

The sensitivity of a camera is determined by the sensitivity of its image sensor. The 8K endoscope camera developed by MIC uses a 2.5-inch CMOS image sensor as described above. This camera has a sensitivity of 2000 lux, F4.8. However, the sensitivity of a standard HD camera for broadcasting using a 2/3-inch image sensor is 2000 lux, F10. Here, the area of the image sensor must be considered on comparing the sensitivities of these cameras. In other words, the diagonal length (34 mm) of the receiving section of a 2.5-inch sensor is approximately three times that of a 2/3-inch sensor (11 mm), so the sensitivity of the above 8K camera when converted to the equivalent sensitivity of a camera using a 2/3-inch sensor is 2000 lux, F1.6. The sensitivity of the 8K camera is therefore only about 1/40 that of the standard HD camera for broadcasting. In the endoscopic surgeries describes above, this required that lighting be increased more than usual and that the camera's amplifier gain be increased higher than its standard state to avoid extremely dark images caused by insufficient sensitivity, even though such measures would degrade the signal-to-noise ratio (S/N) somewhat.

Based on information stating that the sensitivity of CMOS image sensors for 8K use will be nearly four times that of existing levels in newly developed products, we can assume that the sensitivity of future 8K endoscope cameras will be improved by that amount. However, considering the role of future 8K image sensors not limited to medical use, achieving an ultra-high-sensitivity sensor that can secure a sufficient depth of field necessary to make the most of that ultra-high-definition feature and support a future high frame rate of 240 fps (decreasing the sensor's charge storage time) is a major issue. Consequently, to achieve a significant improvement in sensitivity, we are looking to new research on the solid-state High-gain Avalanche Rushing amorphous Photoconductor (HARP), which features a CMOS layer overlaid with a HARP film [2] to obtain high sensitivity while suppressing noise through electron avalanche multiplication. Researchers in the research laboratories of the School of Medicine of Stony Brook University, New York have been researching solid-state HARP for X-ray medical diagnosis with the aim of early cancer discovery, and in 2016, they successfully developed a large-area solid-state HARP imager that uses a thin-film-transistor (TFT) array in the signal read-out circuit. [3] Researchers at the same laboratories are also developing a solid-state HARP device with a new structure as shown in Figure 8. In this structure, grids are designed within amorphous selenium (a-Se) photoconductive film using nanotechnology so that avalanche multiplication occurs only within a limited area within that film. [4] In this new solid-state HARP, the electric field intensity at the bonding interface with the read-out circuit is significantly weaker than the conventional value of about 10^8 V/m, which means that dark current can be suppressed at that location resulting in a high-sensitivity image sensor with stable operation. In short, achieving ultra-high sensitivity in an 8K image sensor requires challenging research and development efforts as in 8K solid-state HARP that deposits a-Se film on the CMOS read-out circuit using the technology described above.

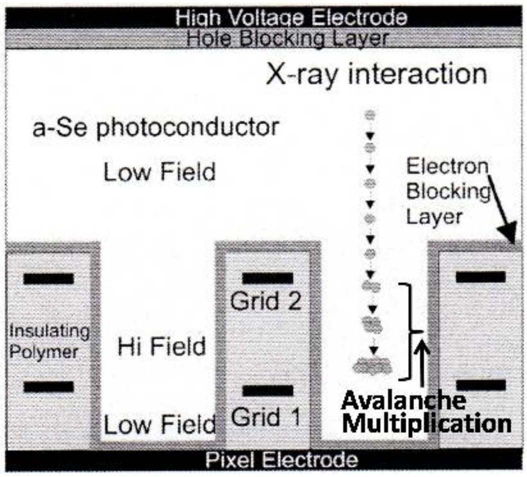

Figure 8: Solid-state HARP with new structure.

7. Conclusion

This paper provided an overview of 8K imaging technology developed for next-generation ultra-high-presence television and described the application of this technology to endoscopic surgery.

We are currently developing the world's smallest and lightest practical 8K endoscope camera. Its weight will be about 450 g. The sensitivity of the 8K camera is also expected to be significantly improved compared to the conventional 8K cameras for medical use.

Finally, I would like to extend my deep appreciation to all concerned for their participation and cooperation in this research on the application of 8K imaging technology to medical treatment.

References

1) H. Yamashita, *et al.*, "Ultra-high definition (8K UHD) endoscope: our first clinical success," SpringerPlus 5:1445, 2016.

2) K. Tanioka, *et al.*, "An avalanche-mode amorphous selenium photoconductive layer for use as a camera tube target," IEEE Electron Device Letters, Vol. EDL- 8, No. 9, pp. 392-394, 1987.

3) J. R. Scheuermann, *et al.*, "Solid-state flat panel imager with avalanche amorphous selenium," Proc. of SPIE, Vol. 9783, pp. 978317-1-9, 2016.

4) Goldan, A. H., and Zhao, W., "A field-shaping multi-well avalanche detector for direct conversion amorphous selenium," Med Phys, 40(1), 010702 (2013).