Hyperspectroscopic imager for baby fibers

T. Nagaoka - *IEEE Member*, A. Nakamura, T. Yamazaki, Y. Nakata, K. Endo, T. Sakaguchi, N. Kawata and T. Sota - *Non-Member*

***Abstract*—Hyperspectral imaging system for diagnosing digestive diseases was newly developed in order to obtain information on pathology beyond morphology of lesions. In order to guide light reflected from a lesion, a baby fiber, which can be inserted in a forceps channel of the electronic endoscope, was also developed. The performance of the system was evaluated by animal experiment. Obtained hyperspectral data were found to have sufficient quality endurable to practical use. Harmful phenomena to a living body were not observed within the experiment. It was considered from the animal experiment that the present system could be practically used for humans.**

I. Introduction

An endoscope is a fundamental tool for examination and treatment of digestive diseases. Although a lot of computer-assisted detection systems for digestive diseases were proposed [1-5], they just mimicked observation technique by endoscope physicians.

Clinically, color information of a membrane is considered to be very important in endoscopic diagnosis. Narrow band imaging is also widely used for examination of superficial cancer. [6] These observed images give physicians information on morphology of lesions. Generally speaking, changes in morphology of a lesion is considered to depend on variation of concentration and distribution of included pigmented molecular. Information on molecular morphology of a lesion at pigmented molecular level is expected to secure the objectivity of differential diagnosis. Such information can be obtained from spectra reflected from mucous membrane of digestive organs. Furthermore, spectral information and high quality color image of a lesion should be complementary to each other.

Hyperspectral imaging technique [7, 8] makes it possible to acquire spectra varying from site to site in the field of view within a relatively short period. This technique is considered a promising one to obtain molecular morphology of a lesion at pigmented molecular level. However, this technique cannot be directly integrate into any recent electronic endoscopic systems because they do not have any optical fiber except for illumination use, Thus, it is also necessary to develop a baby fiber, which can be inserted in a forceps channel of the electronic endoscopes and guide light reflected from a lesion to an external hyperspectral imager (HSI). In this paper, we present a baby fiber and a HSI dedicated to the baby fiber and report their performance. It has been suggested that the system is useful for observing lesions at pigmented molecular level.

II. Method

Baby fibers, which can be inserted into a forceps hole of an electronic endoscope, were developed. The fiber made from silica glass which can guide light in the visible wavelength region. Major specifications of the baby fiber were as follows: diameter, 2.0 mm; length, 2.5 m; focal distance, 10 mm; viewing angle, 80 degree; depth of field, from 5 mm to 30 mm; outer covering tube for the baby fiber, reactor made thermoplastic elastomer (WELNEX; Japan Polypropylene Corporation, Japan). Figure 1 (a) shows a photograph of one of baby fibers developed in the present study.

A HSI dedicated to the baby fiber was also developed. Figure 1 (b) shows its photograph. For principles of hyperspectral imaging technique, see references 9 and 10. The developed HSI consisted of optical systems integrated on a high precision one-axis automated stage and a imaging spectrograph (ImSpector V8E; Specim, Oulu, Finland) attached to a high sensitive electron multiplying charge-coupled device (EMCCD) camera (Zyla; Andor Technology PLC, Belfast, UK). Special attention was paid to the former component as follows. A connector with the baby fiber ensured high reproducibility of the joint position. The focal plane of image of a subject, on which the entrance slit of the imaging spectrograph was arranged, was in error within 1 μm during scanning the image itself except for chromatic aberration. The principal specifications of the HSI were as follows: field of view, ϕ40 mm; number of CCD pixels, 360 x 1000 pixels; minimum spatial resolution, 2.6 μm; ideal wavelength region, 410-890 nm; minimum spectral resolution, 0.96 nm; data accumulation time, approximately 10 s; polarization condition, unpolarized condition. The accumulated hyperspectral data (HSD) represents a data cube measuring 360 (spatial pixels) x 1000 (spatial pixels) x 500 (spectral pixels) .

This research was supported by program to support development of medical equipment and devices to solve unmet medical needs, Ministry of Economy, Trade and Industry and KAKENHI (23700584) of the Japan Society for the Promotion of Science.

T. Nagaoka and A. Nakamura are with the Waseda Research Institute for Science and Engineering, Waseda University, Shinjuku, Tokyo, 1698555 JAPAN (corresponding author to provide phone: +81-3-5286-3378; e-mail: nagaoka@aoni.waseda.jp).

T. Yamazaki and Y. Nakata are with the Mitaka Kohki. Co., Ltd., Mitaka, Tokyo 1810014 JAPAN. (e-mail:yamazaki@mitakakohki.co.jp).

K. Endo and T. Sakaguchi are with the OHBAKIKO CO.,LTD., Fujinomiya, Shizuoka, 4180037 JAPAN (e-mail: k-endoh@ohbakiko.co.jp).

N. Kawata is with the Endoscopy Division, Shizuoka Cancer Center, Nagaizumi, Shizuoka, 4118777 JAPAN (e-mail: n.kawata@scchr.jp)

T. Sota is with the Department of Electrical Engineering and Bioscience, Waseda University, Shinjuku, Tokyo, 1698555 JAPAN (e-mail: tkyksota@waseda.jp)

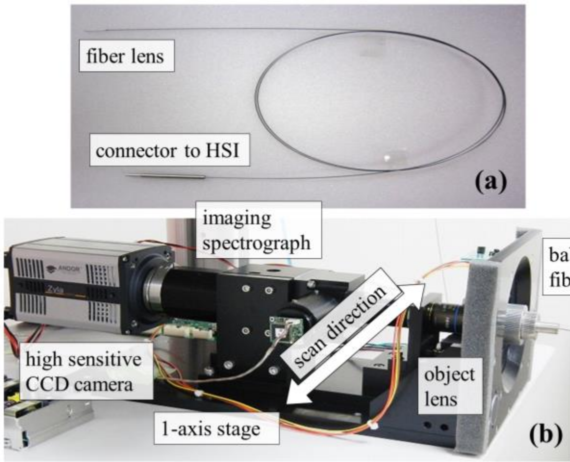

Figure 1. Photographs of baby fiber (a) and hyperspectral imager dedicated to the baby fiber (b).

An all optical endoscope system of an old style (GIF-P30; Olympus, Japan) was used as a main scope. Neither antifoamer nor air feed, liquid feed suction device was used in the present experiment. This endoscope was also used for monitoring a subject. Experimental systems are shown as Fig.2.

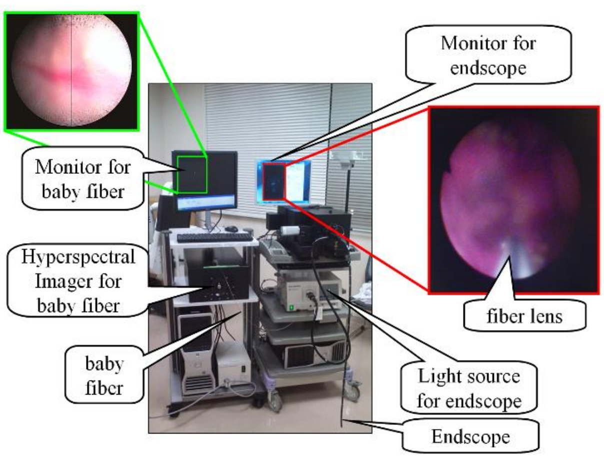

Figure 2. Experimental systems. Hyperspectral imager for baby fiber (left) and endoscopy for upper digestive tract (right)

The HSI system was evaluated by an animal experiment with the help of a veterinarian. A small and sound pig was anesthetized and connected to the respirator. The main scope was inserted into the esophagus or the stomach. HSDs from membrane of these organs were measured manually expanding them by air using a large syringe attached to gas/water supply channel. Throughout the experiment, yields of baby fiber and fundamental performance of the HSI such as an optimum exposure time per line were also examined. Furthermore, we evaluated safety of the baby fiber against both the digestive organs and the main scope. A snap shot of animal experiment is shown in Fig.3.

This study was approved by animal experiment ethical review board of Waseda University.

Figure 3. A snap shot of animal experiment

III. Results

Figure 4 shows spectral features of two areas of the esophagus membrane. Absorption due to hemoglobin and that due to water were clearly seen in both spectra. This is probably attributed to a lack of melanin in the digestive organ membrane.

It was found from Fig. 5 that excess exposure time per line obscured fingerprints of absorption due to hemoglobin, while the shorter exposure time led to the lower signal to noise ratio. The optimum exposure time was estimated to be around 25 ms per line.

Major factors disturbing HSD measurements, which were encountered in the animal experiment, are summarized in Fig. 6. They included influences of (a) respiratory body motion, (b) defocusing, and (c) backward flow of gastric juices on measurements.

Five baby fibers prepared for the experiment were confirmed to have almost the same optical and mechanical performance.

Safety of the baby fiber against the digestive organs was considerably high: hemorrhage of the stomach membrane was not seen even when the baby fiber was pressed against the stomach membrane for about 5 minutes and any baby fiber did not break during the animal experiment.

With respect to safety of the baby fiber against the main scope, the expert physician (NK) pointed out that the back side of the lens cover should be round chamfering not to cause damage to a forceps channel of the main scope, although no such problem occurred during the present experiment

IV. Discussion

HSDs shown in Fig. 4 revealed that spectra reflected from digestive membrane are dominated by absorptions due to hemoglobin and water. The former characteristic bands appear in the wavelength region between 500 and 600 nm and at 760 nm. The latter band appears at near 740 nm. [11] As is well known, features of absorption bands due to hemoglobin change depending on the oxygen saturation. Angiogenesis increases amount of blood and, consequently, will increase absorption due to hemoglobin and water in membrane spectra. Therefore, it is suggested that digestive membrane spectra can monitor changes in membrane at molecular level such as hemoglobin and water.

The endoscope physician (NK), who participated in the present experiment, judged that the present system is worth being tested in a clinical trial. Clinically used electronic endoscope system is always fully equipped with the air feed, liquid feed suction device. Then, the backward flow of gastric juices can be controlled and is considered to cause no problem in measuring HSDs. In order to make the present system much safer and practical, we should improve the back side shape of lens cover of the baby fiber and examine a method reducing an effect of respiratory body motion on measuring HSD. In future clinical trial, we, first of all, have to confirm an ability of the present or improved system to recognize cancers and to specify an area of them.

V. Conclusion

We have developed baby fibers and a HSI dedicated to them. It has been demonstrated that the system can collect spectral information on digestive membrane at molecular level such as hemoglobin and water. Therefore the present system can provide data based on function of digestive membrane via spectra, which is complimentary to morphological data obtained from color images. The present system is considered to open a door to a machine diagnosis based on such a new concept as spectral diagnosis.

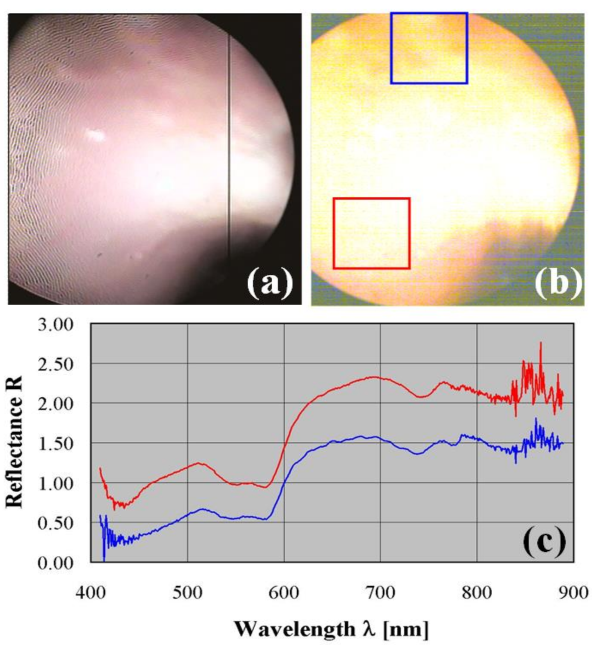

Figure 4. Spectral features of an area of the esophagus membrane. (a) Color image of the area under observation. (b) The corresponding false color image reconstructed from the accumulated HSD. (c) Spectra averaged over the square region in the panel (b)

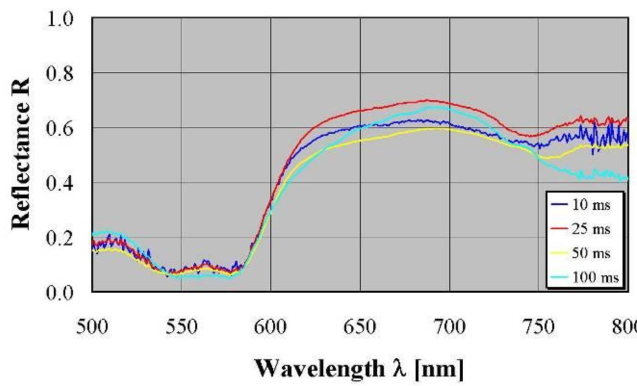

Figure 5. Dependence of averaged spectra on EMCCD exposure time.

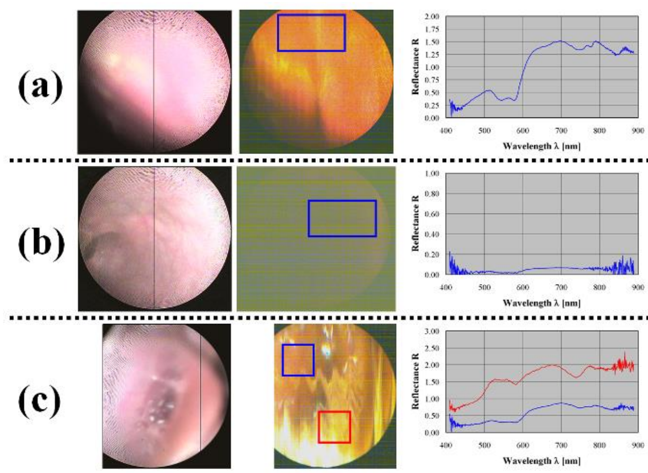

Figure 6. Major factors disturbing hyperspectral measurements. Influences of (a) respiratory body motion, (b) defocusing, and (c) backward flow of gastic juices on measurements.

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