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Developing Thermal Endoscope for Endoscopic Photothermal Therapy for Peritoneal Dissemination

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***Abstract*— As a novel therapy for peritoneal dissemination, it is desired to actualize an endoscopic photothermal therapy, which is minimally invasive and is highly therapeutically effective. However, since the endoscopic tumor temperature control has not been actualized, conventional therapies could damage healthy tissues by overhearing. In this paper, we develop a thermal endoscope system that controls the tumor temperature so that the heated tumor gets necrotic. In fact, our thermal endoscope contains a thermal image sensor, a visible light endoscope and a laser fiber. Concerning the thermal image sensor, the conventional thermal endoscope has the problem that the diameter is too large, because the conventional endoscope loads a large thermal image sensor with high-resolution. Therefore, this paper uses a small thermal image sensor with low resolution, because the diameter of the thermal endoscope needs to be smaller than 15mm in order to be inserted into the trocar. However, this thermal image sensor is contaminated by much noise. Thus, we develop a tumor temperature control system using a feedback control and tumor temperature estimation based on Gaussian function, so that the noisy, small thermal image sensor can be used. As experimental results of the proposed endoscopic photothermal therapy for the hepatophyma carcinoma model of rats, it turns out that the tumor temperature by which the heated tumor gets necrotic can be kept stable. It can be said that our endoscopic photothermal therapy achieves a certain degree of therapy effect.**

I. Introduction

Despite the recent advancement of medical technologies, effective remedies for the peritoneal dissemination, which metastasizes digestive cancer cells and forms tumors in the peritoneum, have not yet been established. For surgical removal of the peritoneal dissemination, it is necessary to perform abdominal operation, which is heavy burden for the patient, and it is difficult to remove all the tumors scattered on the peritoneum. Another remedy for the peritoneal dissemination is chemotherapy such as anticancer drugs, but anticancer drugs tend not to reach the scattered tumors, which means that chemotherapy is not effective enough. According to Nakajima et al. [1], 5-year survival rate of peritoneal metastasis patients is as low as 12.4%. Therefore, it is highly required to establish a novel peritoneal dissemination therapy that is minimally invasive and effective.

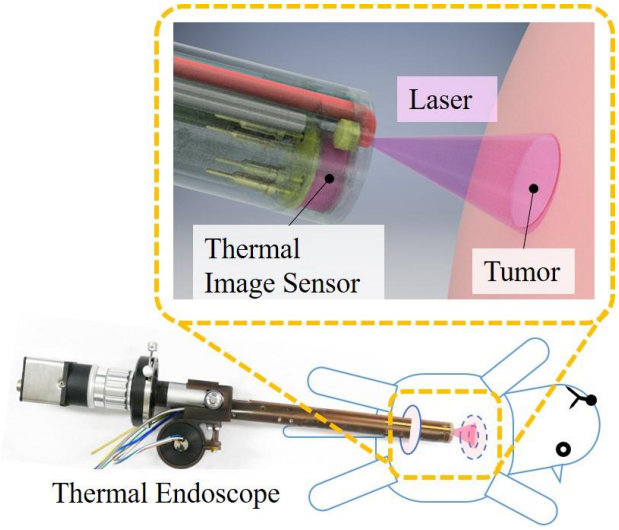

Figure 1 Overview of Endoscopic Photothermal Therapy using Thermal Endoscope

Research on photothermal therapy for the peritoneal dissemination has been started. To establish a diagnosis and effective therapy for the peritoneal dissemination caused by stomach cancer, Tsujimoto et al. developed photothermal therapy that uses indocyanine green loaded lactosomes (ICGm) for experimental peritoneal dissemination of mice [2]. Using a temperature control system that uses a thermography camera, Nomura et al. verified that photothermal therapy works well by keeping the tumors' temperature at 43 degrees [3],[4]; however, since the temperature needs to be measured by the thermography camera placed outside the body, this therapy requires an abdominal operation.

As shown in Fig. 1, if endoscopic photothermal therapy is achieved, the therapy could be the first effective therapy for

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the peritoneal dissemination. However, endoscopic photothermal therapy has not yet been achieved because of the following three reasons.

① Methods that control the tumor temperature using the thermocouples contacted to the tumor have been developed, but their methods can only measure the temperatures of the places the thermocouples contacted, which could result in a risk that the tumor and tissue areas not contacted by the thermocouples are overheated. Therefore, a method for controlling the temperature based on the measurement of the temperature distribution around the tumor is desired, but such a controlling method has not yet been developed.

② To measure the temperature distribution around the tumor, general thermography cameras [8], [9] and small thermography cameras with microbolometer sensor [10] cannot be used due to their too large size to be contained in the endoscope. On the other hand, the thermopile array sensor [11] can be contained in the endoscope, but due to its low resolution and high noise level, the accuracy for the temperature measurement is low.

③ In case of actual endoscopic therapy, it is highly possible that water droplet such as blood and hydroperitonia often attach to the end of the endoscope. If the water droplet attaches to the photodetector of the thermal image sensor, the sensor cannot acquire the thermal image, because water does not transmit LWIR (long-wave infrared) light. Therefore, in case of a general endoscope for visible light measurement, a flat optical glass needs to be mounted to the end of the endoscope, to prevent WDA (water droplet adhesions). However, since general optical glass (e.g. N-BK7) cannot transmit LWIR, thermal endoscope cannot be protected against WDA with general optical glass.

Therefore, in this paper, we develop a thermal endoscope hardware that contains a small thermopile array sensor and is protected against WDA with polypropylene film. Figure 2 overviews our proposed method. Also, we develop a tumor temperature control method based on the thermal image acquired by the small thermopile array sensor. By an experimental therapy for rats' hepatophyma carcinoma model, this paper shows that our proposed method is promising for endoscopic photothermal therapy.

II. Hardware Design

A. Technical requirements

As specifications of the thermal endoscope for photothermal therapy, the following two items are required. (i) The thermal endoscope needs to contain a thermal image sensor, visible light endoscope and laser projector. (ii) In endoscopic therapy, a trocar is inserted through a small incision of the patient, and the thermal endoscope is inserted through the trocar. Since the inner diameter of the largest general trocar for laparoscopic surgery is 15mm, the diameter of the thermal endoscope needs to be smaller than 15mm.

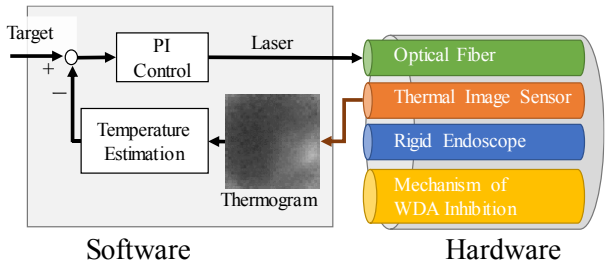


Figure 2 Overview of our Thermal Endoscope System

B. Design Concept

As conventional research on thermal endoscopes, Matsuura et al. [12] developed a flexible thermal endoscope whose diameter is 6mm, but their endoscope contains a bundle of 127 hollow optical fibers: i.e. the endoscope's spatial resolution is as large as 3mm; therefore, their endoscope cannot be used for tumors (of peritoneal dissemination) whose diameters are 1mm to 2mm. Wang et al. [13] developed a thermal infrared endoscope that is equipped with a bending driving system and contains a small thermography camera whose resolution is 160×120 pixels, but their endoscope cannot be inserted into the trocar, because the cross-sectional shape of its insertion part is a 14mm×14mm square. Also, their endoscope cannot be used for photothermal therapy, because it does not contain a visible light endoscope and a laser fiber.

As described below, the thermal endoscope in this paper contains a small-sized thermopile array sensor, a visible light endoscope, a laser fiber and a WDA prevention mechanism, and can be inserted into the trocar, because its diameter is smaller than 15mm.

TABLE I. Thermal Image Sensor

	Candidate 1	**Candidate 2**	**Candidate 3**	**Candidate 4**
Model Number	HTPA32x32d L2.1	HTPA80x64d L14.8	Lepton3.5	T530
Method	Thermopile Arrays	Thermopile Arrays	Micro Bolometer	Micro Bolometer
Size [mm]	ϕ9.14×4.45	ϕ20×14.6	9.5×13×20 (Including a circuit)	140×201×84
Resolution	32×32	80×64	160×120	320×240
Frame Rate [Hz]	8.3	9	8.7	30
NETD [mK]	140	230	50	40

C. Selection of thermal image sensor

It is important to select a small-sized thermal image sensor that can be contained in the thermal endoscope whose diameter is smaller than 15mm. Table I compares four thermal image sensors, where NETD stands for Noise Equivalent Temperature Difference. As shown in Table I, a microbolometer sensor has high resolution, but even Candidate 3 in Table I, which is the smallest, cannot be contained in the thermal endoscope.

Therefore, we focus on thermopile array sensors, which is small-sized, but has low resolution and is contaminated by noise. We select Candidate 1 "HTPA32x32d L2.1". Concerning the low resolution and noise contamination issues, we develop a software-based solution.

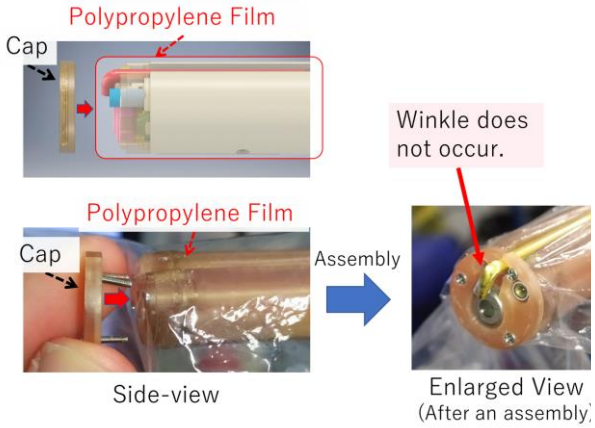


Figure 3 The design of Protection with Polypropylene Film

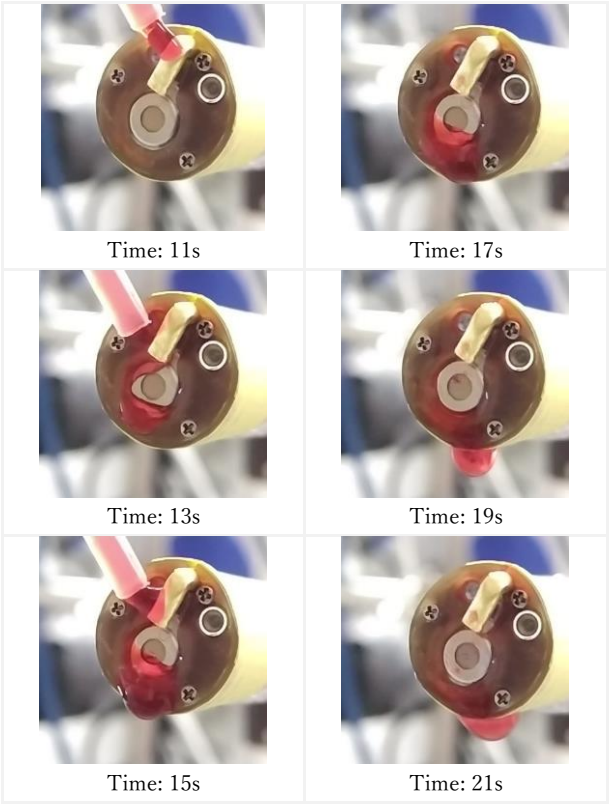


Figure 4 Experimental Results that water drop to our endoscope.

D. Laser Collimator Lens

Since a laser projector device is too large to be contained in the thermal endoscope, it is required to transmit laser beam through optical fibers from a laser projector device placed outside the thermal endoscope. Laser beam transmitted through the optical fibers has the property that the beam is not parallel and spread as conical. As the distance from the end of the optical fiber gets large, the density of the laser light per a unit area gets small, which causes that the temperature of the tumor is difficult to raise.

The design of this paper is that a convex lens collimates the conical laser beam irradiated from the optical fiber, so that the tumor temperature raises even if the distance between the tumor and the end of the optical fiber is large. As the laser collimator lens, we select a biconvex lens as shown in Table II.

TABLE II. SPECIFICATION OF BICONVEX LENS

Diameter [mm]	3.00
Radius of Curvature [mm]	3.50
Edge Thickness [mm]	1.64
Focal Length [mm]	3.00
Glass Material	N-SF5
Coating	Ravg ≤0.5% @ 600 - 1050nm

E. Protection from water droplet adhesions

In case of inserting the thermal endoscope to the patient's abdominal cavity, it is likely that hydroperitonia is attached to the end of the thermal endoscope. If water droplet attaches to the photoreceptor of the thermal image sensor, the sensor cannot acquire thermal images, because water does not transmit LWIR light. To solve this issue, we take the following measures E1~E3 as described below.

E 1. Protection with polypropylene film

One of the causes that water droplet attaches to the photoreceptor of the thermal image sensor is that water droplet is easy to remain on the lens part of the thermal image sensor by surface tension, because the lens part forms a concavity.

As shown in Fig. 3, the end of the thermal endoscope is covered with a polypropylene film, and the film is stretched to prevent wrinkles so that water droplet slides off on the surface of the film.

E 2. Air supply nozzle

We conducted an experiment to drop colorized water to the thermal endoscope that we actually built. The result of the experiment is shown in Fig. 4. It turns out that the dropped water slides off from the end of the thermal endoscope.

In the same way as general visible light endoscopes, the design of the thermal endoscope is that an air supplying nozzle is mounted so that air is sent to the end of the thermal endoscope through the nozzle and removes adhered water droplet.

E 3. Prevention of condensation by heater

In case of inserting the thermal endoscope to the patient's abdominal cavity, it is likely that dew is condensed on the thermal endoscope, because of the temperature difference between the thermal endoscope end (about 25℃) and the

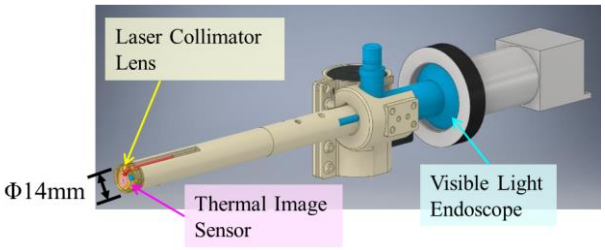


Figure 5 Isometric view of Thermal Endoscope Design

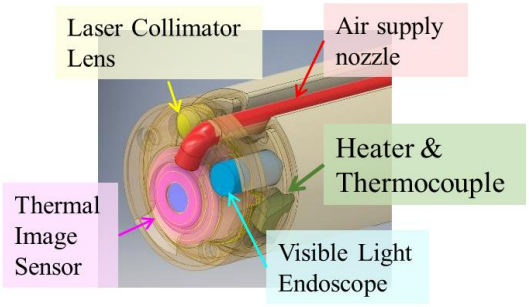


Figure 6 Enlarged view of Thermal Endoscope Design

Figure 7 Isometric view of Thermal Endoscope

patient's abdominal cavity (about 40°C). Therefore, our design is that a heater and a film thermocouple are attached to the end of the thermal endoscope to prevent condensation by preheating the end.

F. Final design and manufacture

Based on the design concept described in Chapter 2 A-E, we design the thermal endoscope hardware. The isometric view of the thermal endoscope design is shown in Fig. 5, and the enlarged view is shown in Fig. 6. The isometric view of the thermal endoscope manufactured is shown in Fig. 7. As a result, our thermal endoscope contains a thermal image sensor, a visible light endoscope and a laser fiber, and the diameter of the endoscope's insert part is designed as 14mm.

III. SOFTWARE DESIGN

In photothermal therapy, it is effective to heat the tumor above 43°C. However, if the tumor is overheated, it is likely that healthy tissues around the tumor is damaged: at the worst case, the tissues including the tumor is cauterized. Therefore, if the highest temperature of the tumor can be kept about 50°Cby irradiating the center of the tumor by laser beam, it is expected that the therapy is effective, and that damages by overheat can be avoided.

A. Temperature Control

As a control system for controlling the temperature constant, we use a PI feedback control system in which the tumor temperature is the controlled variable, and the laser intensity is the actuating variable. The control system in this paper is shown in Fig. 8. In Fig. 8, we let T be the actual tumor temperature, T^be the estimated tumor temperature, T_{ref} be the target temperature, K_p and K_i be the proportional gain and the integration gain of the PI feedback control system, K_L be the maximum intensity of the laser projector, W_0 be the command value of the normalized laser intensity, and W be the laser intensity output. The error of the tumor temperature e is obtained by Eq. (1).

$$e = T_{ref} - \hat{T} \tag{1}$$

The laser intensity output is obtained by Eq. (2), in which the values of K_p, K_i, and K_L are pre-set.

$$W = K_L \left\{ K_p e(t) + K_i \int_0^T e(t)dt \right\} \tag{2}$$

B. Tumor Temperature Estimation

In this paper, the temperature control system assumes that the maximum temperature in the laser irradiation area is the tumor temperature. The noise level of the thermal image sensor contained in the thermal endoscope is high. Thus, if we treat the peak value in the thermal image acquired by the thermal image sensor as the tumor temperature, the peak value is highly affected by the sensor noise.

Therefore, as shown in Fig. 9, we estimate the tumor temperature based on multiple pixel values so as to suppress influence of the sensor noise.

(i) We extract the 9x9 pixels around the peak temperature pixel from the thermal image. Let $q(x, y)$ be the pixel value at the position (x, y) of the extracted pixels. (ii) We extract high temperature pixels $\tilde{z}(x, y)$ from the extracted pixel $q(x, y)$ by Eqs. (3) and (4).

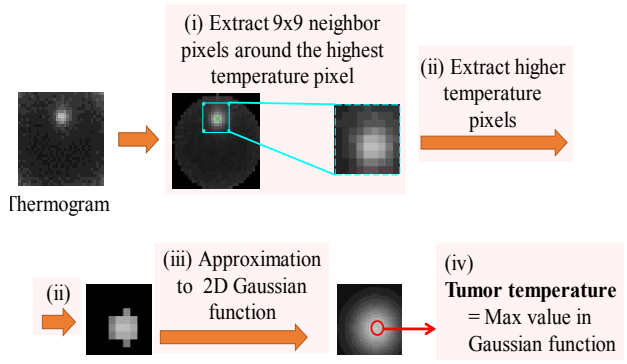


Figure 9 Overview of Tumor Temperature Estimation

$$\tilde{z}(x,y) = \begin{cases} q(x,y) & \textbf{if } \mathbf{q(x,y) > threshold}, \\ 0 & \textbf{else}. \end{cases} \quad (3)$$

$$\text{threshold} = \min(q(x,y)) + 0.6(\max(q(x,y)) - \min(q(x,y))) \quad (4)$$

(iii) The pixel group $\tilde{z}(x,y)$ is approximated by a 2D Gaussian function by Guo's algorithm [14]. The 2D Gaussian function z_g is indicated by Eq. (5), where Z_{max}, μ_x, μ_y, σ_x, and σ_y are a constant, means for x and y directions, standard deviations for x and y, respectively.

$$z_g(x,y) = Z_{max} \exp\left\{-\left(\frac{(x-\mu_x)^2}{2\sigma_x^2} + \frac{(y-\mu_y)^2}{2\sigma_y^2}\right)\right\} \quad (5)$$

Let the matrix of the measured values be M_{XYZ} in Eq. (6), where the parameters A-E are given by Eq. (7),

$$M_{XYZ} = \begin{pmatrix} \Sigma\tilde{z}^2 & \Sigma x\tilde{z}^2 & \Sigma x^2\tilde{z}^2 & \Sigma y\tilde{z}^2 & \Sigma y^2\tilde{z}^2 \\ \Sigma x\tilde{z}^2 & \Sigma x^2\tilde{z}^2 & \Sigma x^3\tilde{z}^2 & \Sigma xy\tilde{z}^2 & \Sigma y^2\tilde{z}^2 \\ \Sigma x^2\tilde{z}^2 & \Sigma x^3\tilde{z}^2 & \Sigma x^4\tilde{z}^2 & \Sigma x^2y\tilde{z}^2 & \Sigma x^2y^2\tilde{z}^2 \\ \Sigma y\tilde{z}^2 & \Sigma xy\tilde{z}^2 & \Sigma x^2y\tilde{z}^2 & \Sigma y^2\tilde{z}^2 & \Sigma y^3\tilde{z}^2 \\ \Sigma y^2\tilde{z}^2 & \Sigma xy^2\tilde{z}^2 & \Sigma x^2y^2\tilde{z}^2 & \Sigma y^3\tilde{z}^2 & \Sigma y^4\tilde{z}^2 \end{pmatrix} \quad (6)$$

$$\begin{pmatrix} A \\ B \\ C \\ D \\ E \end{pmatrix} = {M_{XYZ}}^{-1} \begin{pmatrix} \Sigma\tilde{z}^2\log(\tilde{z}) \\ \Sigma x\tilde{z}^2\log(\tilde{z}) \\ \Sigma x^2\tilde{z}^2\log(\tilde{z}) \\ \Sigma y\tilde{z}^2\log(\tilde{z}) \\ \Sigma y^2\tilde{z}^2\log(\tilde{z}) \end{pmatrix} \quad (7)$$

The parameters of the Gaussian function are obtained by Eqs. (8-12) by the Guo's algorithm [14].

$$\sigma_x = \sqrt{-\frac{1}{2C}} \quad (8)$$

$$\sigma_y = \sqrt{-\frac{1}{2E}} \quad (9)$$

$$\mu_x = B\sigma_x^2 \quad (10)$$

$$\mu_y = D\sigma_y^2 \quad (11)$$

$$Z_{max} = A + \frac{1}{2}\frac{\mu_x^2}{\sigma_x^2} + \frac{1}{2}\frac{\mu_y^2}{\sigma_y^2} \quad (12)$$

(iv) Since in the thermal image the temperature range 20～80℃ linearly maps to the pixel value range of 0~255 of the pixel values in this paper, the tumor temperature is obtained by Eq. (13) using the peak value Z_{max} in the 2D Gaussian function.

$$\hat{T} = \frac{Z_{max}}{255}(80-20) + 20 \quad (13)$$

IV. Experiment

To confirm the validity of the proposed method, we conducted the temperature control experiment and the endoscopic photothermal therapy experiment.

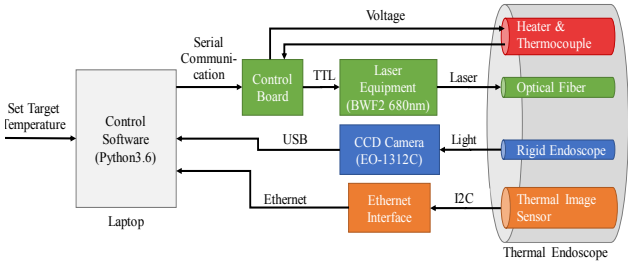


Figure 10 Thermal Endoscope Setup to execute our experiments.

A. Experimental Setup

The configuration of the thermal endoscope system used in the temperature control experiment and the endoscopic photothermal therapy experiment is shown in Fig. 10. Each component of Fig. 10 is listed below.

- Control Software (Python3.6)
- Laptop (GPD MicroPC, GPD)
- Control Board (Arduino Uno R3)
- Heater (2W 100Ω Chip Resistor)
- Thermocouple (MF-O-K, Toa Electric)
- Laser Equipment (BWF2 680nm, BWTEK)
- Optical Fiber
- CCD Camera (EO-1312C, IDS)
- Rigid Endoscope (No.120147, Shinko Optical)
- Trocar (Versaseal Plus 10-15mm, Medtronic)
- Ethernet Interface (included in Application Set, Heimann Sensor)
- Thermal Image Sensor (HTPA 32x32d L2.1, Heimann Sensor)

In the two experiments, we get thermal images from the thermal image sensor contained in the thermal endoscope and estimate the tumor temperature by Eqs. (3)-(13). We get the laser intensity output from the estimated tumor temperature by Eqs. (1) and (2). In Eq. (2), the control parameters are preset as $K_p = 2/255$, and $K_i = 2/255$ so as to avoid overshoot; the maximum intensity of the laser projector was preset as $K_L = 0.4$[W].

B. Temperature Control Experiment

To confirm that it is possible to perform the temperature control using the proposed method despite changes in the laser irradiation distance, we conducted the temperature control experiment. The experimental procedure is described below.

① A wooden block painted as black is fixed to a desk.
② The thermal endoscope is fixed, where the central axis of the thermal endoscope is perpendicular to the block, and the laser irradiation distance is set as the

pre-specified value.

③ By setting the target temperature as 50℃, the temperature control of the proposed method is performed. The temporal change in the temperature is recorded.

④ For comparison, the temperature change is recorded without the temperature control.

Figure 11 shows the obtained thermal images from 15 sec. to 30 sec. after starting the laser beam projection with the temperature control, where the laser irradiation distance is 20mm. In Fig. 11, (a) shows visible light images acquired by the visible light endoscope; (b) shows thermal images acquired by the thermal image sensor; (c) shows images in which the peak temperature pixel in the image (b) is indicated by red and the area of the extracted 9x9 pixels is indicated by light blue; (d) shows the 9x9 pixels extracted from the image (c); (e) shows the image in which the Gaussian function is reconstructed from the image (d) using our proposed method.

Figure 11 (b) and (c) show that the 9x9 pixels are properly extracted as the area heated by the laser irradiation. Figure 11 (d) and (e) show that the Gaussian distribution which is close to the measured distribution is estimated from the extracted 9x9 pixels.

From these results, we can verify the effectiveness of controlling the temperature based on detecting the peak of the highest temperature. First, in case of not controlling the temperature using our method, Figure 12 shows the temporal tumor temperature change, changing the laser irradiation distance between 10mm and 60mm.

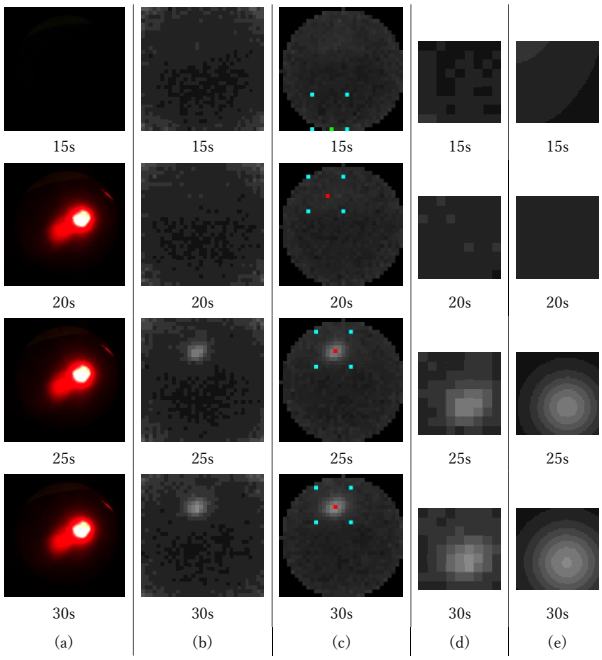


Figure 11 Image of Detecting the peak temperature from Our Thermal Endoscope using our algorithms.

Next, in case of controlling the temperature, Figure 13 shows the temporal tumor temperature change, changing the laser irradiation distance between 10mm and 60mm.In addition, Fig. 13 shows that the tumor temperature is kept stable at the target temperature 50℃ if the laser irradiation distance is between 10mm and 60mm. From these results, it can be said that the proposed system for controlling the temperature can effectively keep the target temperature.

C. Endoscopic Photothermal Therapy of Hepatic Tumor

To confirm that it is possible to control the tumor temperature in vivo and that the endoscopic photothermal therapy is effective, we conducted an endoscopic photothermal therapy experiment for hepatophyma carcinoma model of rats.

The experimental procedure is described below.

① Seven six-week-old female experimental rats are transplant-ed hepatic tumor cell lines N1-S1(7×105

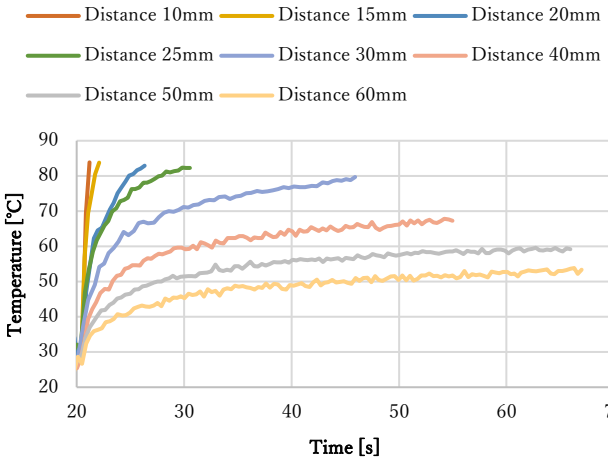


Figure 12 Temperature Transition (Temperature Control: OFF)

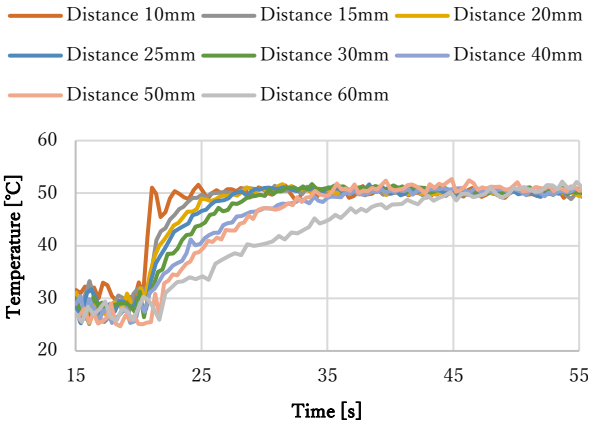


Figure 13 Temperature Transition (Temperature Control: ON)

pieces) into liver parenchyma through a small abdominal incision. They are left for two weeks after transplanting.

② The thermal endoscope is inserted through a small abdominal incision in the lower abdomen of each rat.

③ After visual inspection of the tumor by the visible light endoscope, the position of the thermal endoscope is adjusted so that the laser beam hits the tumor.

④ The tumor temperature is kept 50℃ for about five minutes by performing the tumor temperature control.

⑤ The procedures ②～④ are executed for the seven rats.

⑥ In two days after the therapy experiment, rats are taken as a beneficial death, and their tumors are extracted as a specimen.

⑦ The ratio of the necrotic tissues in the cross section of the tumor is histopathologically calculated by a photomicrograph of the cross section of the tumor.

Our experimental situation is shown in Fig. 14. Table III lists the result overview of the temperature control and the ratio of the necrotic tissues of the seven rats.

In detail, Fig. 15 shows an example of the images acquired by the thermal endoscope in the therapy for Rat No.7, where Rat No. x is the rat number in Table III. Concerning Rat No.7, Fig. 16 shows the temporal tumor temperature change, and

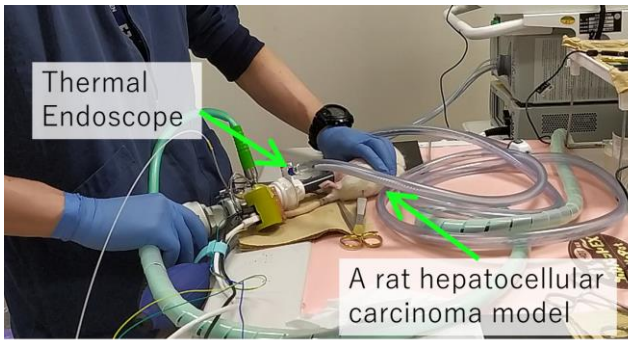


Figure 14 Experimental situation of Photothermal Therapy

Fig. 17 shows the photomicrograph of the cross section of the tumor after the therapy.

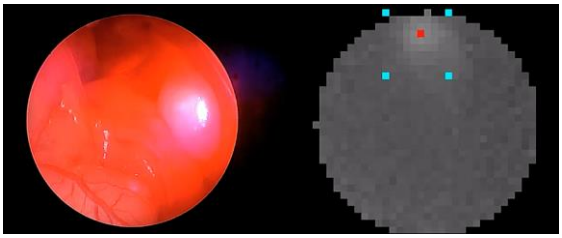
TABLE III. RESULT OF THE PHOTOTHERMAL THERAPY IN EACH RAT

Rat Number	*Temperature result overview*	*Ratio of necrotic tissue [%]*
1	kept about 45℃ for 3 minutes, about 50℃ for 2 minutes	**12.9**
2	heated up at most 45℃	**21.3**
3	kept about 45℃ for 2 minutes, about 50℃ for 3 minutes	**22.0**
4	kept about 50℃ for 5 minutes	**17.6**
5	kept about 50℃ for 5 minutes	**17.7**
6	kept about 50℃ for 5 minutes	**23.3**
7	kept about 50℃ for 5 minutes	**16.7**

V. DISCUSSION

In case of the photothermal therapy, since an irradiation target moves due to the cardiac beat of the patient, it is difficult to keep the laser irradiation distance stable. Therefore, if the temperature control is not performed, the tumor could be overheated as shown in Fig. 12, which causes severe damage to healthy tissues. On the other hand, as shown in Fig. 13, with the proposed temperature control, the overheat risk can be reduced, because it is possible to keep the tumor temperature stable despite the change in the laser intensity.

According to Table III, concerning Rat No.1~3, the tumor temperature did not keep 50℃ because of lack of the laser irradiation intensity. According to Table III and Fig. 16,



(a)Visible Endoscope Image (b)Thermogram

Figure 15 Thermal Endoscope Image

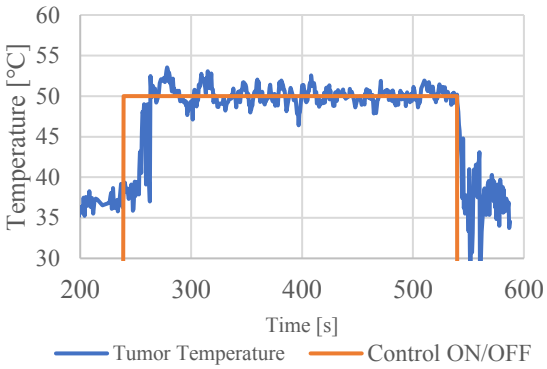


Figure 16 Temperature Transition (Photothermal Therapy, Rat No. 7)

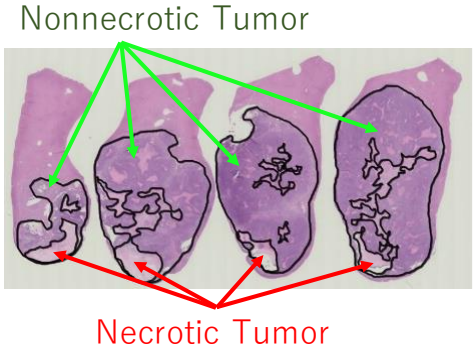


Figure 17 Photomicrograph of Rat No. 7 Tumor

concerning Rat No,4~7, the tumor temperature kept 50℃, because we narrowed the laser irradiation area.

From these experimental results, by using laser irradiation that has enough intensity to heat the tumor, it can be said that the endoscopic photothermal therapy is possible by the proposed control system. Therefore, it can be said that using the proposed temperature control system, high intensity laser projector and the photosensitizer, the temperature control is possible even if the laser irradiation area is not narrowed.

From Table III, it is confirmed that the tumor of every rat got necrotic. Thus, the experimental result indicates that the endoscopic photothermal therapy achieved a certain degree of therapy effect. Figure 17 shows that the necrotic tissue is close to the tumor surface, and the ratio of necrotic tissue of the Rat No.7 is as low as 16.7% in case of keeping 50℃ for the tumor temperature. The cause of this low necrotic ratio could be that the tumor far away from the laser irradiation spot was not heated up enough, because the laser was irradiated from the side of the lower abdomen in this experiment. In case of the peritoneal dissemination, whose tumors are less thin than the rats' tumors in this paper, our proposed method could work well. However, if the tumor is large, the tumor should be heated from multiple directions.

VI. CONCLUSION

Towards the actualization of photothermal therapy for human peritoneal dissemination, this paper has developed a thermal endoscope that can control the tumor temperature so that the heated tumor gets necrotic.

Concerning the hardware of our proposed method, we developed a thermal endoscope that contains a thermal image sensor, a visible light endoscope and a laser fiber; the diameter of the thermal endoscope is smaller than 15mm in order to be inserted into the trocar. In addition, the thermal endoscope is mounted a laser collimator lens and is protected against water droplet adhesions. Concerning the software, we developed a tumor temperature control system with feedback control and a tumor temperature estimation method using Gaussian function.

From the results of the temperature control experiment, it is possible to perform the temperature control using our proposed method despite the change in the laser irradiation distance. According to the experimental results of the endoscopic photothermal therapy for the hepatophyma carcinoma model of rats, the tumor temperature is kept stable at 50℃ in four rats among the seven rats using the proposed method. Concerning the other three rats that could not be kept the tumor temperature 50℃, it can be considered that the therapy is possible if a high power laser projector and a photosensitizer are used. In the therapy experiment, the average ratio of necrotic tissue of the seven rats was 18.8%; it can be said that the endoscopic photothermal therapy has a certain degree of therapy effect.

The future work includes the development of endoscopic photothermal therapy for large tumors by laser irradiation from multiple directions.

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