Canine Motion Control Using Bright Spotlight Devices Mounted on a Suit

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***Abstract*—Engineering to produce stimuli that trigger an organism's habits allows us to control it noninvasively. Because canines already have the habit to follow a light spot, light is a good stimulus for controlling their motion. We employed green laser beams to successfully control canine motion indoors. We developed a suit equipped with laser beam devices that face front, left, and right. The canine wore the suit and followed a light spot on the ground. Its trajectory was controlled remotely by switching the lights on the suit. However, this laser beam spot was too weak and small to be visible in grassy fields outdoors. Here, we propose a spotlight device that irradiates a bright and large spot (70 mm in diameter) for outdoor environments. The proposed spotlight device consists of a high brightness LED and a convex lens. To evaluate its performance, we conducted indoor and outdoor experiments using three canines. In the indoor experiments, the success rates of controlling the canine's motions were 100%, 83.3%, and 93.3% for each of the three canines, respectively. In outdoor experiments, these rates were 100%, 57.1%, and 62.5%, respectively. Hence, the proposed spotlight devices are effective for controlling a canine even in outdoor environments.**

***Index Terms*—Animals, biological control systems, navigation, optics.**

I. Introduction

OUR RESEARCH group studies canine control methods to expand the canine navigation capabilities with non-invasive method. Here, navigation means guiding a canine to the desired destination. By controlling canine motion, for example, it is possible to guide a search and rescue dog to a place where disaster victims are likely to be found, or to guide a service dog to when visiting a new place still unknown to the dog.

Animals can be controlled remotely using invasive and non-invasive stimuli. Here, invasive stimulations are stimulation methods in which a sensor or device is inserted under the skin or in the body of animals. And non-invasive stimulations are methods of stimulating animals with vibration, voice, gestures, sounds or light sources that are mounted onto the animal, not under the skin or in the body. Insects, fishes, reptiles, birds, and mammals have been controlled using invasive stimuli. Canines have been controlled using both invasive and non-invasive stimuli. As non-invasive stimuli, voices and gestures have been used to give instructions for search-and-rescue or military canines [1]. Recently, vibration and sounds [2], [3], [4], and lights [5], [6] have been used as non-invasive stimuli.

Light is a good non-invasive stimulus for controlling canine motion because canines already have the habit to chase a light spot. We studied canine motion control using lights. Green laser beams were selected to control canine motion because these laser beams have high brightness and clear contours. To control canine motion remotely using light, the light devices must move with the canines and irradiate lights in different directions. Therefore, we developed a canine suit equipped with several laser beams and evaluated its performance using both canines who were trained to chase a light spot and those with no training [5]. In this system, their trajectories were controlled remotely by switching among these lights on the suit.

However, these laser beams could not be used in grassy fields outdoors because the spot size of the laser beams is too small and their brightness is too low. The canines could not see the small and faint laser spot in a grassy field. This problem is more difficult than it first seems because bright and large lights usually consume more battery power and last only for a short time. It is necessary to solve this problem by developing energy-saving spotlight devices for bright and large light spots.

Here, we propose a new spotlight device that shines a bright and large diameter spot. Figure 1 shows the canine suit with the new spotlight devices. We developed a spotlight device that can irradiate a spot 26,000 lx in illuminance and 70 mm in diameter at 1 m away from a canine whose shoulder height is 0.6 m. The spotlight device consists of a high brightness LED

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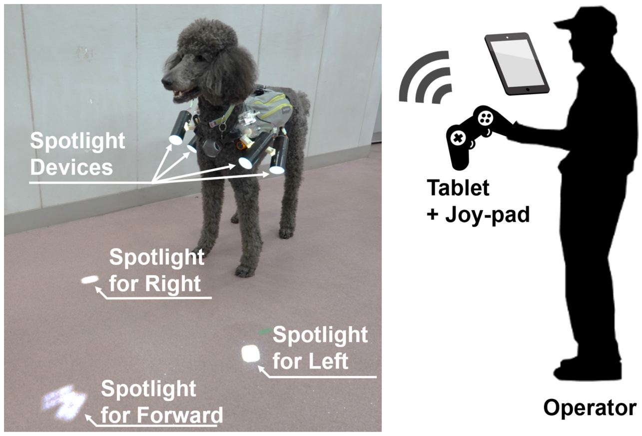


Fig. 1. Canine navigation using suit-mounted spotlight devices.

and convex lens configuration that saves energy. The spotlight devices are mounted on the front, left, and right sides of the canine suit. When the operator wishes to control the canine, the light direction can be switched using a game controller.

We evaluated the performance of the canine motion control using the new spotlight devices. The performance was evaluated in indoor and outdoor experiments using three canines. In this paper, we used canines that were trained to chase a light spot because in our past experiments we found that the reaction or urge to follow the laser spot suddenly weakened for canines that reached adulthood - after they had their first menstruation. After training, the canines would chase the light over long distances. The results show that the new spotlight can be used for controlling canine motion in indoor and outdoor environments. The performance was also evaluated using canine navigation on different paths indoors.

The contributions of this research are as follows:

1) We developed a new spotlight device that is visible in grassy fields outdoors. Canines are controlled by switching multiple fixed light devices mounted on a suit. The canine can be controlled remotely in the designated direction without the need for actuators to move the light devices.
2) We confirmed that the canine can be controlled in the forward, left, and right directions using our light devices in indoor and outdoor environments. We report the success rate of controlling canine motion in indoor and outdoor experiments.
3) We demonstrated that the canine can be navigated to different destinations on different routes using our light devices in an exploration environment. We present the canine's response to the light-based commands as time series data.

The remainder of this paper is organized as follows. Section II describes related work. Section III explains the development of the high brightness spotlight devices. It also describes the development of the canine guiding suit with spotlight devices that can shine in the forward, left, and right directions. Section IV presents two evaluations of a canine guiding suit equipped with spotlight devices. One evaluation considers the control of a canine's motion forward, turning left, and turning right in indoor and outdoor environments. The other evaluation confirms that canines can be guided in an indoor environment to follow a path to a destination. Section V presents the results of the evaluations, Section VI discusses the results, and Section VII concludes this paper.

II. Related Work

Various invasive and non-invasive methods have been proposed to control animal motion remotely. Typical invasive method, electrodes are implanted into an animal body and the animal's motion is controlled by electrical stimulation. This method has been verified in dogs [7], rats [8], sharks [9], pigeons [10], cockroaches [11], and beetles [12]. Although invasive methods are effective to control animal motion, we selected non-invasive methods that are easy to install on animals and are controlled without distressing the animals. Apart from ethical issues of applying invasive methods to animals as mentioned in [13], [14], it would be hard to convince the owners of working dogs like search and rescue dogs, service canines, pets, etc to insert the device inside the canine body or under the skin.

There are several types of research on canine motion control using non-invasive methods. Canines can be guided by a small drone [15]. The canine is trained to follow the drone, which can navigate the canine to a destination. This method is effective in open places. However, animals such as search and rescue dogs must have the ability to be guided indoors at disaster sites or in a forest. In such places, it is difficult to fly guidance drones so that they do not collide with manned surveillance helicopters. The drone can be flown at a low altitude to avoid the helicopters, but it may not be possible to fly the guidance drone stably near obstacles, and the canine may not be able to see it. Therefore, we selected a canine guidance method that uses a device attached to a canine suit.

There are suits that are equipped with devices and the handler can monitor the dog's location or environment, interact with the dog or give instructions to the dog. Suits were presented that were equipped with GPS to measure the position of dogs [2], [3], [4], [16], [17], [18], suits that equipped with camera to know environment of dogs [4], [5], [17], [18], [19], suits that communicate with handlers by biting and tugging [16], [20], communicate with voice or sound [2], [3], [4], suits giving instruction with vibration [2], [3], [4], [21], [22], and suits guiding dog with an attached light source [5], [6]. Controlling canine's motion by sounds and vibration devices attached to a canine suit has been studied. The canine is trained to go forward, stop, and return according to different tones from a speaker on the suit [2], [3], [4]. In addition, the canine is trained to go left or right [2], [3], [4], [21] or touch a target [22] according to the vibrations of the devices mounted in different locations on the suit.

We selected a canine guidance method using light. Animals are known to change their behavior under the effect of light stimulation, as was shown for mice [23], rats [24], fish [25], [26] and shrimps [27], [28]. Also, it is known that dogs and cats follow a light, and it is possible to control animal

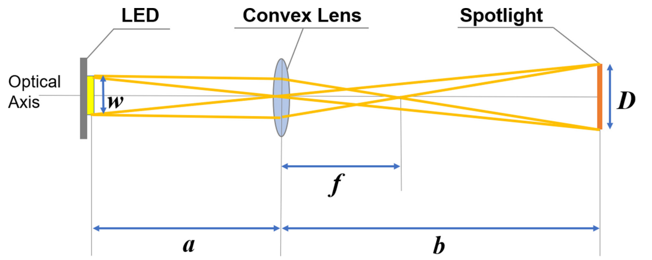


Fig. 2. Spotlight irradiation model. a: Distance between LED and lens, b: Irradiation distance, f: Focal length, w: Size of light emitting part of LED, D: Size of the spotlight.

motion using that habit. There is a toy for pets that controls the irradiation of a laser beam installed on a shelf or table so that pets can follow the laser beam and play [29]. The use of light is one method to spatially indicate a control direction. By irradiating the ground with light, it is possible to convey the direction in which the operator wants the canine to go. It was proposed a method of guiding a canine by mounting laser light devices on a canine suit [5], [6]. In this research, we developed a spotlight device that is small enough to be mounted on a suit and can be controlled remotely but is bright enough to be seen outdoors.

III. Development of the Spotlight Device and Canine Guiding Suit

A. Spotlight Devices With High Brightness

We developed a spotlight device with high brightness and large light spot that can be mounted on a canine suit. The spotlight devices were designed static to be safe for canines. It avoids the danger of catching a dog's hair or skin in the movable part. In addition, movable elements were not equipped because inertial momentum or sound of the movable object may distract canines.

In our preliminary experiments, several canines found and chased spotlights that had over 30 mm size and 20,000 lx brightness. Therefore, we selected these values as minimum constraints of the spotlight. In addition, it is necessary to make the light devices small for mounting on a canine suit. They must be within 50 mm in diameter and 150 mm in length.

In the spotlight devices, an optimum combination of high brightness LEDs and convex lenses were selected. Figure 2 shows the optical model of spotlight irradiation with a high brightness LED and convex lens.

Referring to Fig. 2, the model is expressed as two equations.

$$\frac{1}{a} + \frac{1}{b} = \frac{1}{f} \tag{1}$$

$$w : D = a : b \tag{2}$$

where a is the distance between the LED and lens and is related to the length of the spotlight device, b is distance between the device and the spotlight, f is the focal length, w is the size of the light emitting part of the LED, and D is the diameter of the spotlight. Equation (1) is known as the Gaussian form of the lens equation, and Eq. (2) describes the similar ratio of triangles. There is a trade-off between the irradiation distance, diameter of the spotlight, and length of the device.

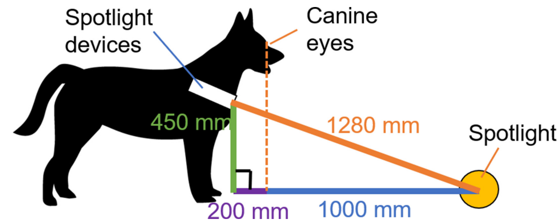


Fig. 3. Spotlight irradiation model with a canine.

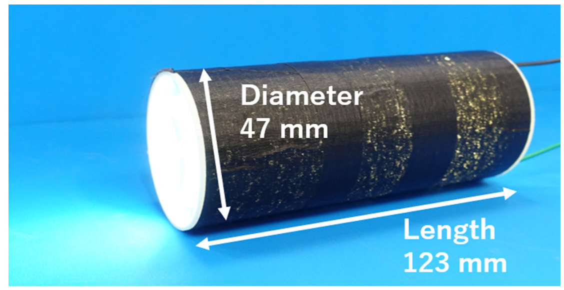


Fig. 4. Assembled spotlight devices.

TABLE I
SPECIFICATION COMPARISON OF THE DESIGNED AND ASSEMBLED MODELS

	Requirement	Assembled model
Size of Spotlight [mm]	more than 30	70
Illuminance [lx]	more than 20,000	26,000
Length of Light Device [mm]	less than 150	123

The device length a and diameter of the spotlight D are respectively

$$a = \frac{bf}{b-f} \tag{3}$$

$$D = \frac{b-f}{f} W \tag{4}$$

Equation (3) is a re-arrangement of Eq. (1), and Eq. (4) is obtained by substituting Eq. (1) into Eq. (2). Both Equations (3) and (4) depend on irradiation distance b.

Figure 3 shows the configuration of the canine-mounted spotlight irradiation for a medium-sized canine whose height is about 600 mm. Shoulder was selected as the spotlight device location. In this case, the horizontal distance from the canine's eyes and the spotlight is 1 m because canine can see the light more easily at this irradiation angle [5]. Therefore, irradiation length b was determined to be 1,280 mm, as shown in Fig. 3. A high brightness LED (CREE XLamp XHP70; w = 5 mm) and a convex lens (diameter = 45 mm; f = 100 mm) were then selected such that a is less than 150 mm and D is 30 to 70 mm.

Figure 4 shows one of the assembled spotlight devices, and Table I compares the design specifications with those of the assembled model. A heatsink was added to the spotlight device because a large quantity of heat is released from the high brightness LED. The illuminance of this spotlight device is

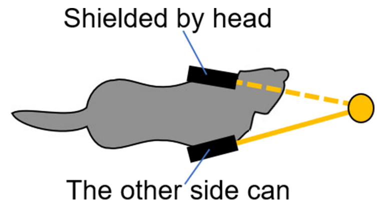


Fig. 5. Avoidance of occlusion by the canine's head. When the canine's head faces to the left, the left shoulder light is occluded. The light on the other side can shine the forward spotlight direction.

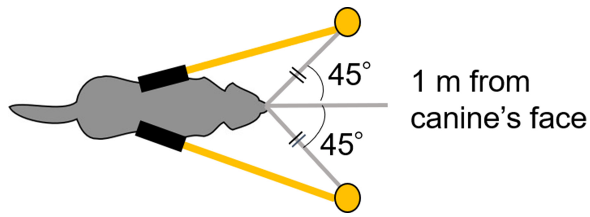


Fig. 6. Spotlight device on the side belly of the canine. It is possible to make the spotlights shine further to the left and right directions.

26,000 lx for 7.2 V voltage and 3.5 A of current when the irradiation distance is 1,280 mm.

B. Development of Canine Guiding Suit

The developed guiding suit holds the spotlight devices, which shine forward, left, and right. We located the spotlight devices on the suit so that they would not be shielded by the canine's head. The spotlight devices were also attached so that the direction of light could be adjusted with ease. The equipment on the suit can be controlled remotely.

First, we considered how to locate the spotlight devices on the shoulder of canine suit so that the light is never occluded by the canine's head location. However, the light could be shielded by the canine's head when it turns to the side, as illustrated in Fig. 5. Hence, we solved the problem by placing the spotlight devices on both sides of the shoulders, as Fig. 5 shows. In this way, if one spotlight device is shielded by the canine's head, the other side's spotlight can shine forward. The left- and right-pointing spotlight devices are mounted to the side of the belly position. Therefore, it is possible to shine the spotlight horizontally at an angle 15° to 45° to the left and right of the dog's front, as Fig. 6 shows. Moreover, the spotlight on the side of the belly cannot be blocked by the canine's head.

A ball joint was employed so that the spotlight direction can be adjusted and fixed with ease, as shown in Fig. 7. The joint is composed of a ball, bolt, bronze plate, and silicon rubber. If the bolt of the ball joint is loosened, the spotlight device can be moved with three degrees of freedom (roll, pitch, and yaw). The ball joint is fixed in place by tightening the bolt. Silicone rubber is inserted between the ball joint and bronze plate to secure the fixed position firmly. The range of adjustment of the joint is determined by the size of the opening and is 48°.

Figure 8 shows the structure of the guiding suit with the devices for controlling canine motion remotely. An operator can control the light direction remotely. The micro-controller board (Raspberry Pi 2 Model B) receives the light direction

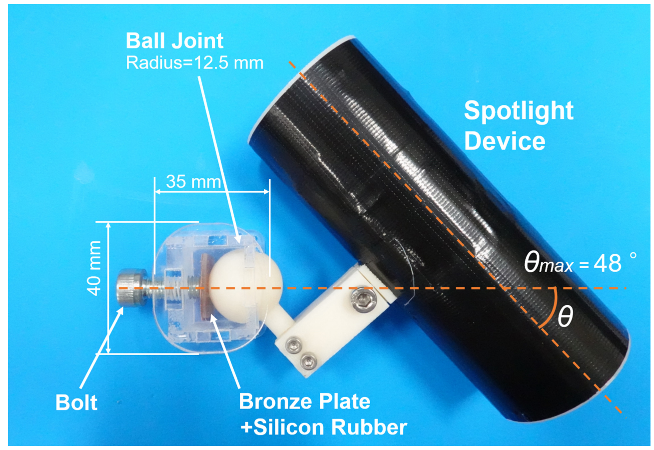


Fig. 7. Ball joint of the light devices. The roll, pitch, and yaw of the light direction can be adjusted easily by loosening or tightening the ball joint using the bolt.

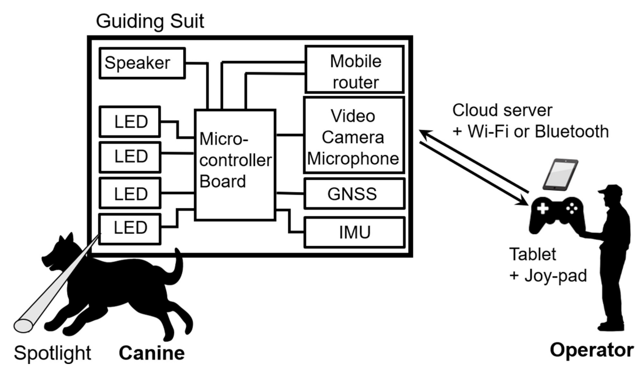


Fig. 8. Structure of a guiding suit. An operator can switch the spotlight direction with a wireless game controller. In addition, the sounds from the speaker can be controlled. Video camera images and microphone sound are uploaded to a cloud server and broadcasted to a PC or tablet. The IMU can record the data of the canine's motion.

TABLE II
CANINE USED IN THE EXPERIMENTS

	Dog A	Dog B	Dog C
Sex	♂	♂	♀
Date of birth	Jan. 1, 2015		
Breed of dog	Standard Poodle		

command from a game controller wirelessly and powers the spotlights accordingly. The operator can also remotely play sounds from the speaker on the canine suit. The forward view of the canine can be seen using a camera mounted on the suit. In addition, the canine motion can be recorded by a GNSS (Global Navigation Satellite System) and IMU (Inertial Measurement Unit) modules (Advanced Navigation, Spatial) equipped on the canine suit.

IV. EVALUATION

A. Canine Motion Control Indoors and Outdoors

We evaluated the ability of the proposed system to control a canine's motion forward, left, and right. This evaluation used three canines, as shown in Table II. In order to avoid the influence of the difference in the character depending on the dog

TABLE III
ILLUMINANCE OF THE TEST FIELDS

	Indoor Illuminance [lx]		Outdoor Illuminance [lx]		
	First Test	Second Test	First Test	Second Test	Third Test
Dog A	550		10,000	36,000	6,900
Dog B			40,000	57,000	16,000
Dog C			24,000	33,000	29,000

(a) (b)

Fig. 9. Test environments: (a) Indoor environment. The floor is flat, and the illuminance is 550 lx on average. (b) Outdoor environment. The ground is grass and soil. The illuminance of the environment in the image was 24,000 lx.

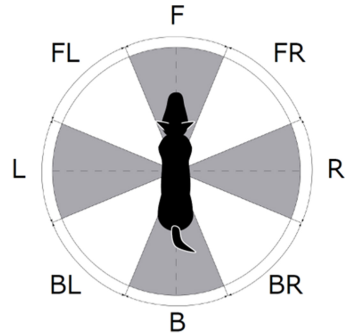


Fig. 10. Definition of the eight moving directions. Directions FL, F, and FR are defined as a dog's forward direction. Directions FL, L, and BR are defined as a left turn, and directions FR, R, are BR are defined as a right turn.

breed, we asked handler for canines that can participate in the experiment with multiple dogs of the same dog breed. Three standard poodles, born on the same birthday from the same mother dog, were selected to participate in experiments. They were trained to follow the light. The merit of using spotlights is that they can be used both indoors and outdoors to guide canines.

Therefore, we evaluated indoor and outdoor environments at different illuminances, as shown in Table III. Figure 9 (a) shows the indoor environment with a flat floor. The indoor evaluations were performed twice, and the average illuminance was 550 lx. Figure 9 (b) shows the outdoor environment with a ground of grass and soil. The outdoor environment is the same place where a laser beam could not be used to control canine motion. The outdoor evaluations were performed three times at different times of day to obtain different outdoor illuminances because of the position of the sun. Table III shows the average of illuminances at the start and end of each evaluation, which lasted about 20 minutes.

The three canines were trained to follow a handheld spotlight. In addition, the canines were trained to find spotlights when the operator said, "Look." When the canines followed the spotlight, they were praised with a clicker sound. For the experiment, the canines were trained to follow the spotlights using the guiding suit. Recorded verbal "Look" commands and clicker sounds can be played from the speaker on the guiding suit. When the operator wishes to control the canine's movement, he or she shines the spotlight and plays the recorded "Look" command to instruct the canine to find the spotlight. Then, the operator switches the direction of the light to the direction in which the operator wants the canine to move. After the canine follows the spotlight, the operator plays the recorded clicker sound from the speaker on the suit.

The tests were occasionally restarted. It did not occur in Dog A's trials. Although, for the trials of Dog B and C, the canines were occasionally distracted by people moving around the field and ran up to them in about 20% of the trials. In that case, the handler made the canine be calm for several seconds, then the evaluation was restarted after the distracting animals and people had left the field.

To evaluate the control of canine movements forward, left, and right with the game controller, their trajectory was observed using videos of their motion captured from behind them using a handheld camera.

From the recorded video, the canine's changes in direction were evaluated using the eight directions shown in Fig. 10. The direction of movement of the dog was determined when the dog moved several steps after irradiation. It was judged as successful when it moved in the same direction as the irradiation direction while looking at the light and following it. During the training of the canines, we observed that the canines occasionally followed the spotlight with slightly bend trajectories. To take this behavior into account we also considered a movement toward FL and FR direction (see Fig. 10) as a success if a movement in F direction was commanded. The same criteria were employed for a commanded movement to the left (L, FL, and BL were considered a success) and to the right (R, FR, and BR were considered as a success). Other cases were defined as failures. From these results, the success rates were calculated.

B. Navigation of a Canine in an Indoor Environment

Control of the canine's route to a destination by switching the light direction is called navigation, and was also evaluated in this study. In this verification, we performed in the indoor environment, since we wanted to conduct the experiment with the canine under the same conditions during navigation of a trajectory of about10-15m. In the outdoor environment, illuminance changed over time. In the indoor environment, it can be excluded success or failure due to a change in illuminance of environment light. Therefore, in the indoor test, success or failure can be judged by stimulation with the spotlight. The verification was performed once in each direction without repeating. This is in order to eliminate the effect of the canine remembering the route by repeated verification. We used Dog A, which had the highest success rates in all three directions. In this navigation evaluation, the operator was able to see the dog motion, so he or she directed the canine to pass through a route to the goal by switching the direction of

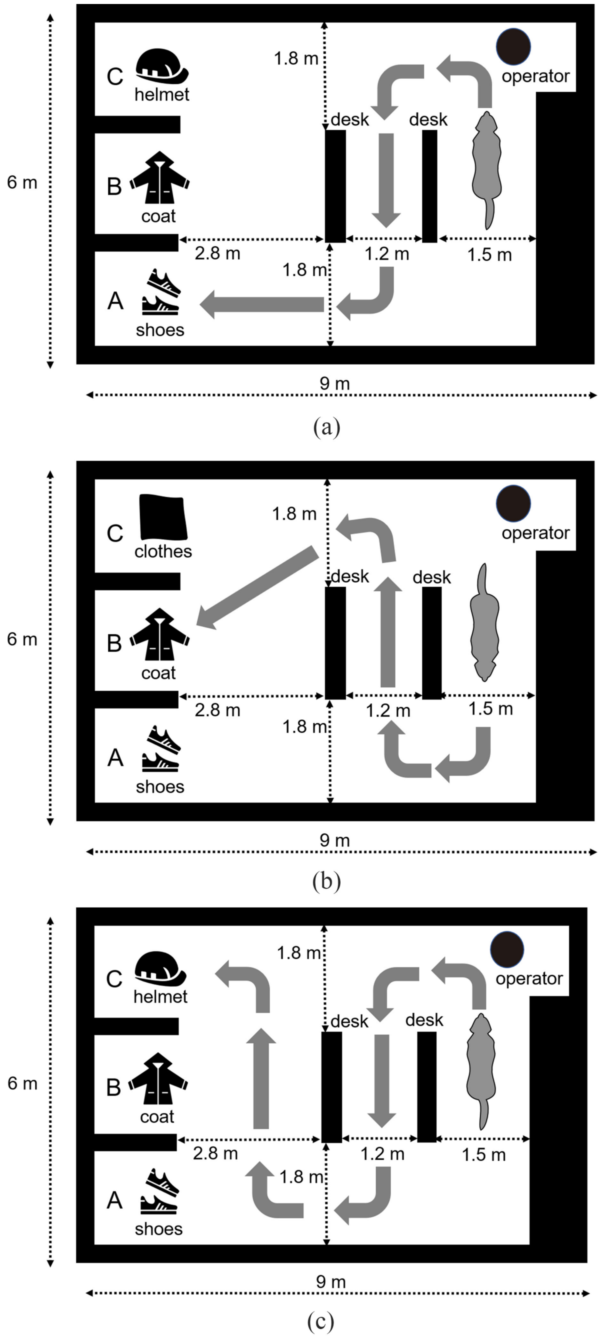


Fig. 11. Navigation routes in the room. (a) Route to destination A. (b) Route to destination B starting in the opposite direction to that of A. (c) Route to destination C.

the spotlight. At the start, a recorded "look" command was played from the speaker on the suit as the spotlights were lit. The operator played the clicker sound from the speaker when the canine reached the destination. Camera images and IMU data were recorded using devices on the guiding suit.

Figure 11 shows the environment and the route to the destination in the navigation evaluation. Three destinations (A, B, and C) were arranged indoors and different objects were put at each destination. Two desks were set as obstacles between the start and destination points. We verified that we could navigate the canine to each destination along different routes.

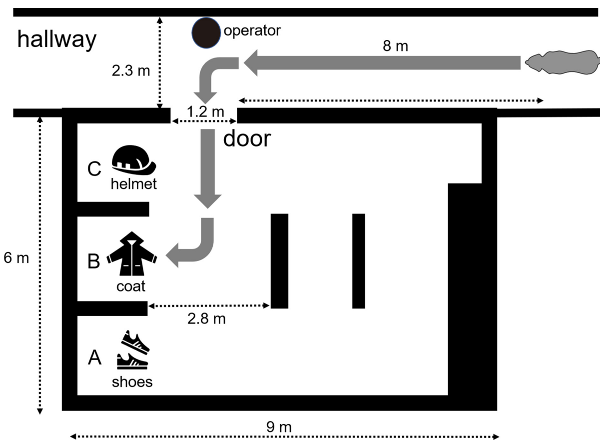


Fig. 12. Navigation Route from Hallway to the Room and B.

In addition, we recognized the object at the destination with the camera on the suit.

Figure 11(a) shows the route to destination A. After starting, the canine turns left, passes through a narrow corridor defined by two desks, and then turns to the right to reach destination A. The starting direction of destination B, shown in Fig. 11(b), differs from that of destination A. First, the canine turns to the right, passes through the obstacles, and then turns to the left to reach destination B. Figure 11(c) shows the route to destination C, which is the same as the first part of the route to destination A. However, in the last part, the canine turns right to arrive at destination C.

Moreover, navigation from a hallway to a destination in the room was evaluated. As shown in Fig. 12, the canine starts from the hallway, enters the room through the door, then goes to destination B.

V. Results

A. Canine Motion Control Indoors and Outdoors

Table IV shows the results of controlling the canine's motion in each direction indoors and outdoors for all three dogs. We divided the outdoor experiments into three groups for different ranges of illumination. Totally, in the indoor floor experiments, the success rates of controlling the moving directions of the canine were 100%, 83.3%, and 93.3% for Dog A, Dog B, and Dog C, respectively. In the outdoor grass experiments, the success rates were 100%, 57.1%, and 62.5%, respectively. These results show that the canines can be guided indoors and outdoors by the proposed suit. Especially, Dog A could be controlled with a 100% success rate indoors and outdoors in each direction.

B. Navigation of a Canine in an Indoor Environment

The navigation of Dog A was successful for the routes to all destinations. Fig. 13 shows images of the canine being navigated to destination C. The canine passed through the route to destination C as shown in Fig. 11(c). Other images of the routes to destinations A and B are shown in Fig. A1 in the Appendix.

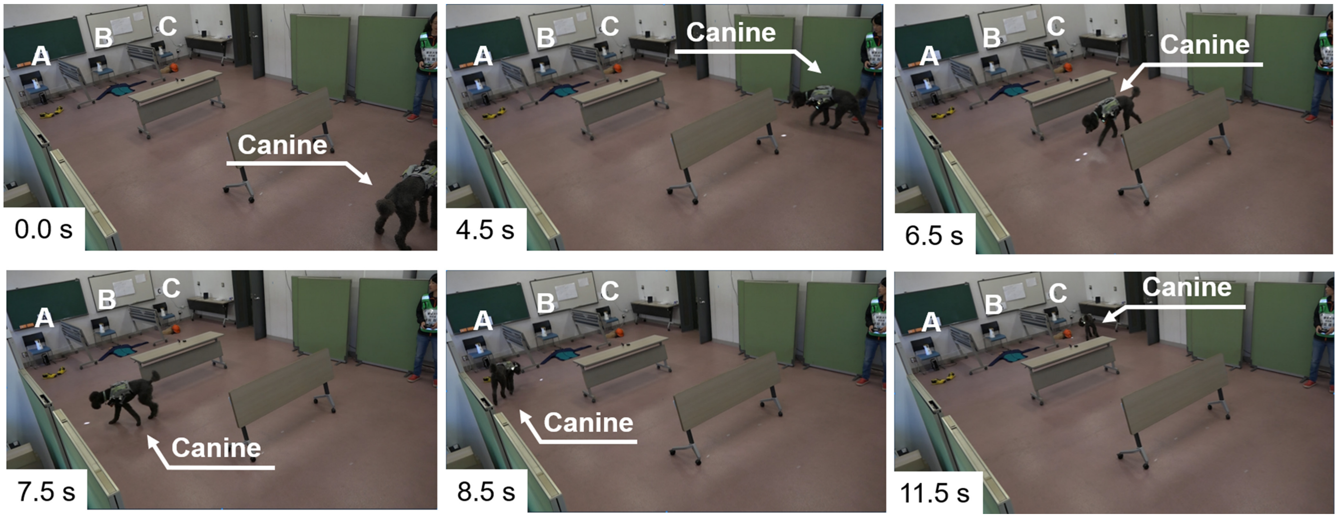


Fig. 13. Navigation of a canine using three light directions. Operator guided the canine's moving direction by switching the spotlight directions. The canine passed through between two desks and navigated to destination C.

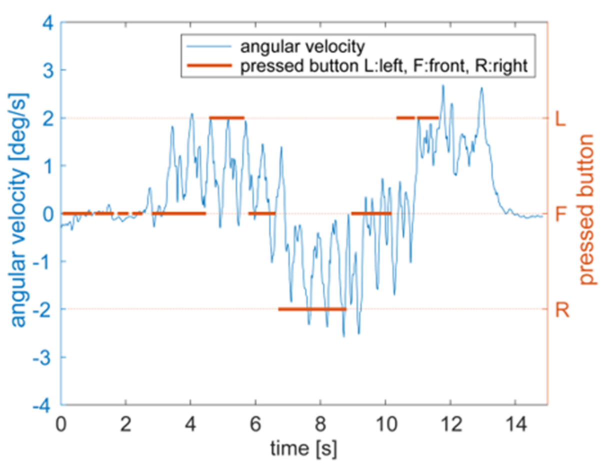
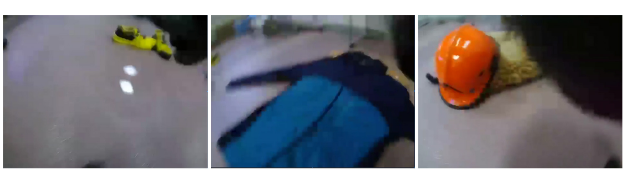


Fig. 14. Data of yaw axis angular velocity and pressed buttons for guiding the canine to destination C. The horizontal axis is the elapsed time from the start of navigation, the vertical axis on the left is the angular velocity of yaw axis rotation, and the vertical axis on the right indicates the pressed buttons on the game controller. When the left button was pressed, the angular velocity increased, indicating that the canine turned to the left by following the spotlight. In contrast, when the right button was pressed, the angular velocity decreased, indicating that the dog turned to the right by following the spotlight.



(a) (b) (c)

Fig. 15. Camera images at destinations A, B, and C. These pictures were taken by the camera on the suit at each destination to which we navigated the canine. (a) The yellow shoes at destination A. The two white circles in the middle are spotlights and the canine's head is in the upper right. (b) The blue coat at destination B. (c) The orange helmet at destination C.

In addition, the IMU data indicate that the control of the canine's trajectory was successful. Fig. 14 shows the angular velocity of the yaw axis and the pressed illumination buttons on the game controller, to the route for destination C as shown in Fig. 11(c). "L", "F", and "R" indicate buttons of the left direction light, the forward direction light, and the right direction light, respectively. The canine found a light after about 3 s and started to move, as indicated by the oscillation of the blue line. When an instruction to the left was given (the solid orange line for "L"), the angular velocity was positive because the canine was turning to the left. When an instruction to the right is given (the solid orange line for "R"), the angular velocity was negative because the canine was turning to the right. Thus, the timing of the light switching and IMU data confirm the canine was navigated by the guiding suit.

In addition, we confirmed the object placed at the shows an image from each destination: yellow shoes at A, a blue coat at B, and an orange helmet at C. This demonstrates that it is possible to gather information at the destination from the camera on the suit.

The canine was also successfully navigated from the hallway to the destination in the room. Images showing the canine being navigated from the hallway to destination B are presented in Fig. 16. This result shows that our proposed guiding suit can navigate the canine not only within a room but also from other places to the destination. Likewise, for this route, the IMU data indicate that the canine was successfully navigated from the hallway to a destination. Similar to Fig. 14, Fig. 17 shows the angular velocity of the yaw axis and pressed lighting buttons on the game controller to destination B. When the light indicating the left direction was lit, the blue lines become positive because the dog turned to the left. Corresponding results were obtained for the right. The canine moving speed was 1.4 to 2.1 m/s, as shown in Table V, which also shows the approximate distance of the route from the start to the destination and the evaluation.

VI. Discussion

In this study, a canine was successfully controlled using a suit with spotlight devices mounted on it. By shining

TABLE IV
RESULTS OF CONTROLLING CANINE MOTION

Dog A

Test	Illuminance (lx)	Direction	Trials	Successes				Success rate(%)
Indoor Test	550	Left	10	10	L	FL	BL	100
					10	0	0	
		Front	10	10	F	FL	FR	100
					9	1	0	
		Right	10	10	R	FR	BR	100
					8	2	0	
	Total		30	30				100
Outdoor Test	6900, 10000(DogA), 16000(DogB)	Left	15	15	L	FL	BL	100
					14	1	0	
		Front	13	13	F	FL	FR	100
					10	2	1	
		Right	11	11	R	FR	BR	100
					11	0	0	
	24000(DogC), 29000(DogC), 33000(DogC), 36000(DogA), 40000(DogB)	Left	5	5	L	FL	BL	100
					5	0	0	
		Front	5	5	F	FL	FR	100
					5	0	0	
		Right	5	5	R	FR	BR	100
					4	1	0	
	57000(Dog B)	Left	-	-	-			-
		Front	-	-	-			-
		Right	-	-	-			-
	Total		54	54				100

Dog B

Test	Illuminance (lx)	Direction	Trials	Successes				Success rate(%)
Indoor Test	550	Left	10	9	L	FL	BL	90.0
					4	5	0	
		Front	10	10	F	FL	FR	100
					8	0	2	
		Right	10	6	R	FR	BR	60.0
					4	2	0	
	Total		30	25				83.3
Outdoor Test	6900, 10000(DogA), 16000(DogB)	Left	7	6	L	FL	BL	85.7
					4	2	0	
		Front	5	4	F	FL	FR	80.0
					3	1	0	
		Right	3	2	R	FR	BR	66.7
					0	2	0	
	24000(DogC), 29000(DogC), 33000(DogC), 36000(DogA), 40000(DogB)	Left	5	4	L	FL	BL	80.0
					4	0	0	
		Front	5	2	F	FL	FR	40.0
					0	2	0	
		Right	5	1	R	FR	BR	20.0
					1	0	0	
	57000(Dog B)	Left	3	2	L	FL	BL	66.7
					1	1	0	
		Front	3	1	F	FL	FR	33.3
					1	0	0	
		Right	6	2	R	FR	BR	33.3
					0	2	0	
	Total		42	24				57.1

Dog C

Test	Illuminance (lx)	Direction	Trials	Successes				Success rate(%)
Indoor Test	550	Left	10	8	L	FL	BL	80.0
					4	4	0	
		Front	10	10	F	FL	FR	100
					7	1	2	
		Right	10	10	R	FR	BR	100
					3	7	0	
	Total	30	30	28				93.3
Outdoor Test	6900, 10000(DogA), 16000(DogB)	Left	-	-	-			-
		Front	-	-	-			-
		Right	-	-	-			-
	24000(DogC), 29000(DogC), 33000(DogC), 36000(DogA), 40000(DogB)	Left	15	8	L	FL	BL	53.3
					3	5	0	
		Front	15	10	F	FL	FR	66.7
					8	0	2	
		Right	10	7	R	FR	BR	70.0
					4	3	0	
	57000(Dog B)	Left	-	-	-			-
		Front	-	-	-			-
		Right	-	-	-			-
	Total		40	25				62.5

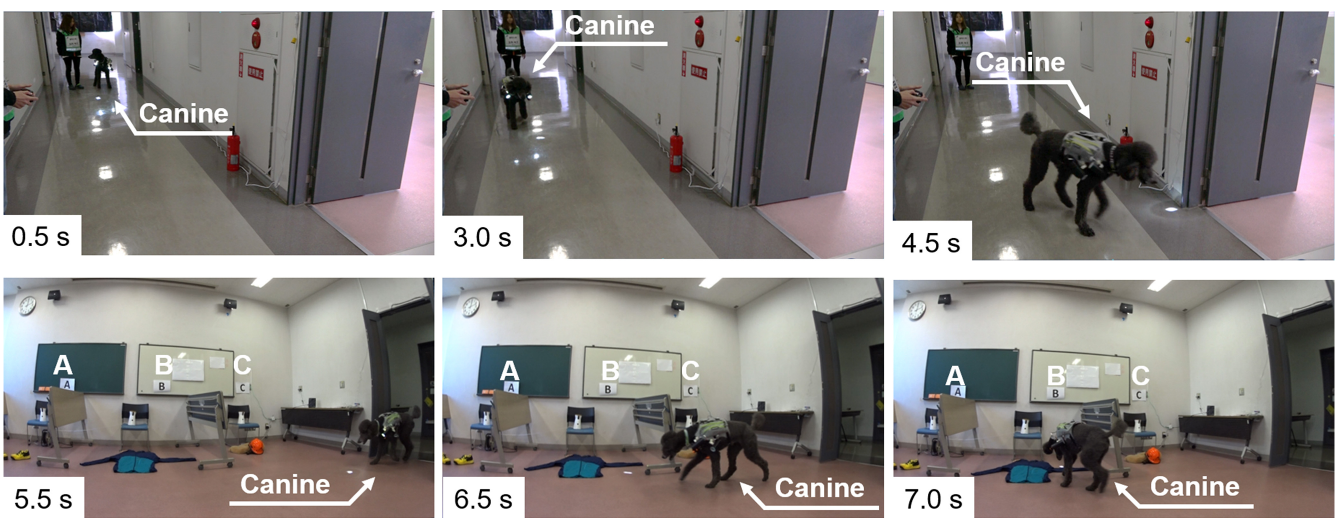


Fig. 16. Navigation of canine from the hallway to destination B in the room. The operator guided the canine's trajectory by switching the spotlight directions on the game controller. The canine was navigated from the hallway, entered the room, then was guided to destination B.

a large spotlight, it was possible to control the canine's trajectory on grassy field ground outdoors where a laser beam could not be used to control canine motion. Moreover, we succeeded in navigating canine to several destinations by passing along a predefined the route. These results indicate that our proposed canine control method can be used for navigation. As an application, an operator could control a search and rescue dog to the disaster site from a remote place to gather information with a camera on the suit.

Sometimes the canines didn't follow the light. The main cause is that the spotlight was difficult to find under high illuminance environments. Results of Dog B in Table IV indicate a tendency for the success rate to decrease as the environment illuminance increases. In the 57,000 lx environment light experiment, which had the highest environment illuminance of

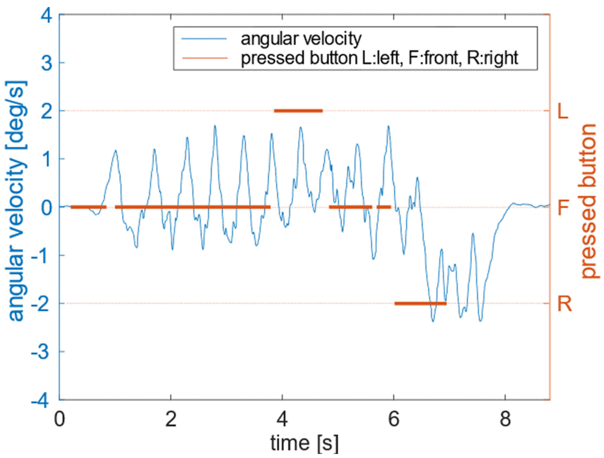


Fig. 17. Data of yaw axis angular velocity and pressed buttons when guiding the canine from the hallway to destination B.

TABLE V
EACH ROUTE LENGTH, TIME AND CANINE'S AVERAGE SPEED

Navigation Route	Length [m]	Time [s]	Average Speed [m/s]
A	11	7.6	1.4
B	12	8.0	1.5
C	13	6.1	2.1
From hallway to B	15	9.5	1.6

Fig. A1. Navigation of a canine using three light directions. (a) and (b) The canine guided to destinations A and B, respectively. The operator guided the canine's trajectory by switching the spotlights. The canine passed through the route, as shown in Fig. 11.

this experiment, Dog B did not follow the spotlight in 7 out of 12 trials. In these seven trials, the canine moved without looking at the spotlight. We presume that it was difficult for Dog B to find the As a measure against this problem, improvement to the spotlight device to irradiate higher illuminance can be mentioned.

Furthermore, according to Table IV, for Dog B, the success rate in the right direction was lower than the other irradiation directions both indoors and outdoors. We heard from Dog B's handler that the canine is not good at following the spotlight to the right direction. This could be due to individual differences. Also, from Table IV, Dog A chase the spotlight with 100% success rate in all experiments. While Dog B and C sometimes failed to follow the spotlight. Even with the same breed and the same birthday, there were such differences in success rates. For applying the proposed control method, we want to reduce the variance of control success rate. For this purpose, we need to propose a more efficient training method that can reduce the variance of the control success rate.

VII. Conclusion

We proposed a method to control a canine's motion with spotlight devices equipped on a canine suit. We succeeded in remotely controlling and navigating a canine to a destination. A small light device that can be mounted on the canine suit was first developed. The light spot is bright and large in diameter so that the canines can find and follow the spotlight on grassy field ground outdoors. Next, a suit for canine guidance was designed. A ball joint was developed that could easily adjust the direction of the spotlight devices. When the canine lowers its head, this can occlude the light devices and the spotlights cannot be seen. This problem was solved by locating the spotlight devices on both sides of the shoulder on the canine suit. Moreover, sound instruction is used with the spotlights to help the canine look for the spotlights. As a result, we succeeded in controlling the canine's motion in the forward, left, and right directions both indoors and outdoors. Further, we succeeded in navigating the canine through a route to a destination using an operator who controls the switching of the spotlight directions with a game controller.

Appendix

See Fig. A1.

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