Control of Canine's Moving Direction by Using On-suit Laser Beams

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***Abstract*— Animal behavior can be controlled with non-invasive stimuli. Sounds, vibration, and lights are major non-invasive stimuli to lead animals such as canines, cats, and cows. Among them, a laser beam can be used to control motions of cats and canines without advance trainings. Previous studies reported that cats and canines responded motions of laser beam moved by human or electric devices. However, it has been still unknown whether a canine responds a laser beam from a device equipped on a canine suit (hereafter we call it on-suit laser beam). Here, we show that a canine's moving direction can be controlled with on-suit laser beams. We found that the high bright laser beam (1 mW) is suitable for the canine motion control at indoor environment. Brightness of laser beam was more important than color, and color difference (red, green, and blue) did not make a great difference in the canine's motion. We could control canine to move to left, right and forward direction using three laser beams that face to different direction. In our control system, a human operator can change the moving direction of the canine with a joy-pad. Our result demonstrates that the human operator guide the canine to the place where the canine can watch the target by using the on-suit laser beams. We consider that the on-suit laser beam based canine motion control is a starting point for expanding canine's working ability. Canines that wear the laser beam suit will explore the damaged building and capture photos of the damages instead of humans in search and rescue mission in the near future.**

I. INTRODUCTION

Animal behavior can be controlled with non-invasive stimuli such as sounds, vibration, and lights [1], [2], [3]. Generally, the control methods using these stimuli require advance trainings for the animals (e.g., canines, cats, and cows). However, a laser beam allows to control motions of cats and canines without advance trainings.

Non-invasive animal control without advance trainings has an advantage to lead animals without heavy loads. Therefore, we study non-invasive animal control without advance trainings for the canines. In previous study, motion of cats and canines could be controlled by a moving laser beam handled by an electric device [4]. However, this method or the method of a laser beam moved by humans would have the limit of the navigation area due to the range of laser beam from the operator.

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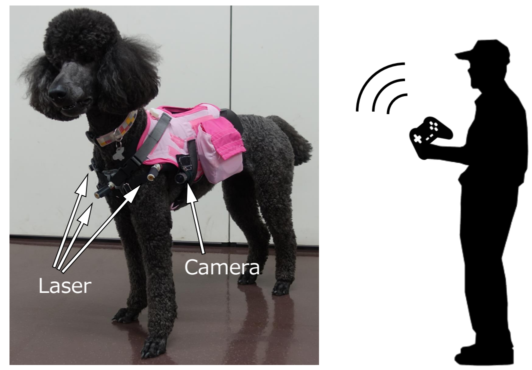


Fig. 1. Control of Canine's Moving Direction by Using On-suit Laser Beams

Here we propose the control method of canine's motion with a laser beam from devices equipped on the canine's suit (hereafter we call on-suit laser) (Fig. 1). The use of the on-suit lasers will allow to expand the navigation area because on-suit lasers follow to canines, not the operator. However, it has been still unknown that on-suit laser beams can control canines. Since on-suit lasers could not move its spot position to attract canine's attention, on-suit laser beams might not be enough stimuli to lead canines. Therefore, we examined whether the canine's moving direction is controlled with on-suit laser beams.

At first, we decided the specification of a laser beam (brightness, color, and shape) to control canines efficiently. Second, we designed laser beams' position and its angles. Then, we demonstrated that on-suit lasers could control canines, and a human operator could change the moving direction of the canine using a joy-pad. The human operator could guide the canine to the place where the canine can watch the target.

Section II describes the related works. Section III explains the selection of a laser that is suitable for canine motion control. We evaluate the laser power, color, and shape for the canine's motion control. Section IV describes laser beam lighting position. Suitable laser position and its angles are decided from the analysis of canine's reactions for the laser beam spot. Section V shows the design of canine suit for controlling the canine's motions. Three lasers are put on the canine's suit. The canine motions are controlled using these three on-suit lasers. Section VI shows a demonstration of canine motion control. We demonstrate navigation by using the laser-based canine's control method. Section VII concludes this paper.

II. RELATED WORKS

Remote control of animals including insects (e.g., rats, cats, canines, cockroaches, and beetles) has been a hot research topic in a wide range of research fields. Animals' motion can be controlled by invasive or non-invasive methods. Electrode implant is one of typical invasive methods, and applied to rats, cockroaches[5], and beetles [6]. Vibration, sound, and light are non-invasive methods and applied to canines [1], [2], [3] and cats [4]. This paper presents non-invasive method for canines because invasive methods sometimes give dogs a certain load, and might have the risk of losing dogs' trust in humans. We would like to use this control method to expand the ability of the working dogs (eg. cyber-enhaced canine [8]), which have been brought up by a traditional canine training, and pet dogs.

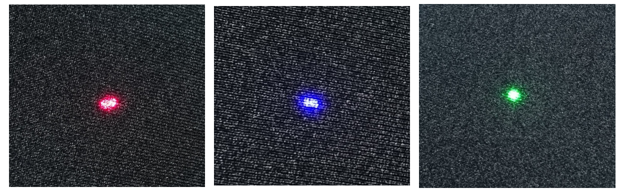
There are several works about canine motion control using non-invasive methods. Combination of vibration and sounds is studied in [1]. A dog is trained to conduct motions (forward, stop, left, and right) on the basis of different tone's sounds and vibrations generated by the left and right vibrators. Waypoint navigation was also conducted by using the sound and vibration based canine motion control [2]. For a method using light, flying UAV with light was used for the canine's motion control [3]. Canine was trained to follow the flying UAV with a light. The canine moved to the target point by seeing the flying UAV. There methods required advance trainings. On the other hand, there is a control method without advance trainings. It is well known that cats and canines chase a moving light. Laser is one solution without advance trainings. Obi is an electric device that moves a laser beam spot and controls the cat's motion [4]. It may be applied to canine motion control. We selected lasers as stimulus because it is a non-invasive solution and does not require advance trainings. This paper describes lasers equipped on our canine suit, which are not moved by actuators, can be used to control the canine motions.

A weird solution was developed in "Robohakcing a Dog" [7]. It may be non-invasive and without advance trainings. Canine's moving direction was specified by changing a food (sausage) position, which was hanged at front of the dog's face. Although we cannot check the efficiency without numerical evidences, it is an interesting approach to control pet dogs. However, since this solution always shows sausage to a dog, it cannot stop dog's motion. Therefore, the advantage of laser based motion control is to stop the canine's motion by turning off the laser, though we did not show the concrete evidence about stopping the canine's motion in this paper.

III. SELECTION OF LASER BEAM FOR CANINE'S MOTION CONTROL

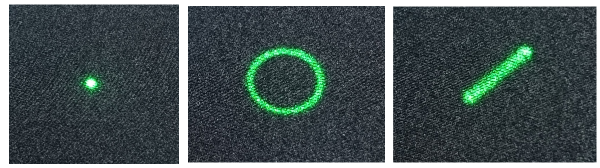
A. Outline

We control canine's motion using a laser beam spot without advance trainings. It is well known that canines and cats chase a moving laser beam spot. For efficient control of canine's motion, we should determine the specification of the laser beam that is suitable for controlling canines.



(a) (b) (c)

Fig. 2. Different color of laser beam spot (diameter 2mm at 1m): (a) red dot (wave length 650nm, power 1mW), (b) blue dot (wave length 450nm, power 1mW), and (c) green dot (532nm, power 1mW).



(a) (b) (c)

Fig. 3. Different shapes of the laser beam spot: (a) dot (2mm at 1m), (b) circle (30mm at 1m), and (c) line (30mm at 1m).

We investigated the effects of the brightness (power), color, and shape of the laser beam in experiments. We used three canines to evaluate laser beams in the experiments. We asked a suitable position of the laser beam spot to the operators in the experiments, and discussed about it with ethologists.

B. Materials and Methods

High power commercial handheld laser (1 mW) was used in the experiment. We compared three different color laser beams (red: wave length 650 nm, green: 532 nm, blue: wave length 450 nm) with the same power 1 mW (Fig. 2). The diameter of these laser beam spots is 2 mm at a distance 1 m. We also tested a green laser (1 mW) that can change the spot shape (dot, line, and circle). Figure 3 shows these spot shapes at 1 m: the dot diameter is 2 mm, the line length is 30 mm, and the circle diameter is 30 mm. Since the laser changes the spot shape using a prism, the brightness drastically decreased in the cases of line and circle.

We examined whether canines chased these laser beams' spots at an indoor environment without advance trainings. Floor is reddish brown color, and its surface material is linoleum. We used three standard poodles of the same age (Dog A, Dog B, and Dog C in Table I)(Fig. 4). We also did the experiment using Dog B with a green laser beam on a green artificial turf (Fig. 5). The blue markers in these experiments were set for helping the operator because it was hard for the operator to check whether the canine moved to an ideal direction without the reference point. We confirmed that there was no effect of blue markers on canines' motion. We also tested it for the two other breed of dog (data not shown) and for outdoor environment.

C. Results

We used different color laser beams shown in Fig. 2. It has been reported that the canine has low sensitivity for red color. Therefore, we had expected that green and blue were suitable

TABLE I
CANINE USED IN THE EXPERIMENT.

	DogA	DogB	DogC
Sex	♂	♀	♂
Date of birth	Jan. 1, 2015		
Breed of dog	Standard Poodle		

Fig. 4. Experiment in reddish brown floor. Canine chased a green laser beam spot (green dot), and we led the canine to the blue marker by the green laser.

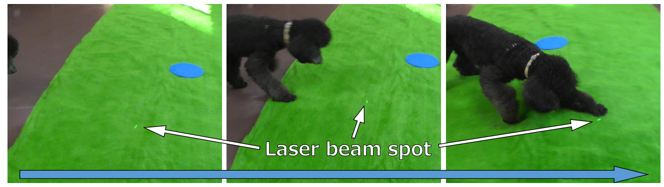


Fig. 5. Experiment in a green artificial turf that is the same color of the laser beam. Canine chased a green laser beam spot on the green artificial turf, and we led the canine to the blue maker by the green laser.

for controlling canines, and red was not suitable. However, we did not observe the effect of the color on canines' motion. In addition, the green laser could control canines at the same color background shown in Fig. 5. Dog A and Dog B chased the laser beam spot without advance trainings, but Dog C did not chase it. Dog C seemed to be indifferent to laser beams rather than the problem of visibility.

We used different spot shapes shown in Fig. 3. Dog A and Dog B chased the dot, but they did not chase the line and circles. Brightness of the line and circle was much lower than the dot because the laser changes the spot shape using a prism, which resulted in low brightness. Therefore, the canines could not be aware of the line and circle. In addition, we observed the canines did not chase the 1 mW laser beam when the laser batteries decreased. In such case, brightness of laser beam dot became low. From these results, we found that the brightness of laser beam is important. However, we will have to test whether the difference of the spot shape affects the canine's motion control using more bright line and circle.

As a trial, we also tested the dot laser beams (red, green, and blue) in outdoor environments. Dog A and Dog B did not chase them. It might be hard for the canines to find the small dot in the bright outdoor environments. We will continue to search a light source that can be used in outdoor environment.

D. Conclusion

We confirmed that Dog A and Dog B chased the laser beam spot without advance trainings. Brightness of laser beam was important for canines, and the dot shape that its brightness was the strongest was the best laser beam spot. Dog A and Dog B chased the green laser beam even when background color was the same. Therefore, we selected green dot laser as the light source in the following experiments.

IV. LASER BEAM LIGHTING POSITION

A. Knowledge about Laser Beam Lighting Position

We confirmed that the canines chased the laser beam spot in Sec. III. However, the canines did not always chase the laser beam. To know the tendency of canine's behavior, we interviewed the operators, and got the following comments from the operators.

The canine seemed to watch or chase the laser beam spot when

1) the laser beam spot was between a few decimeters and 1m from the canine at the canine's front area.
2) the laser beam spot was moved within the binocular view area of the canines.
3) the laser beam spot was synchronized with the canine's reactions or moved like small animals.

Item 1 and 2 were important to decide the laser beam lighting position. We decided the area on the basis of item 1 and 2 and evaluate the laser beam lighting position.

B. Investigation of Laser Beam Lighting Position

1) Experiment for Selection of Laser Beam Lighting Position: We investigated the suitable lighting position of the laser beam for canine's motion control. The canine's reactions were observed when the laser lights a point on the ground in the front area of the canines.

2) Materials and Methods: We developed a device that could point a laser beam spot on the ground precisely within the error of a few centimeters (Fig. 6). The device consists of one laser, 2 actuators, and one CPU board. The device can change the laser beam position by using 2 actuators, which change the yaw and pitch angles of the laser.

The lighting positions were decided base on the view angle in the canine's field of view. The area becomes fanwise on the ground. Horizontal angle was $\pm$ 30 degrees based on the standard poodle's binocular view. Vertical angle was 79.8 degrees based on the canine's leg length. Figure 7 shows the vertical angle of the area. The area was divided into 3 areas: short, middle, and long. Short area was defined on the basis of the canine's leg length (0.35 m). The vertical angle of the short area was 26.6 degrees. Middle and long areas were defined based on the view angle of the short area.

Each area was divided into 5 vertical lines and 5 horizontal lines. 25 points were allocated at the cross points of these lines. 10 points that located near the canine in the short area were close to each other. Since it was hard to point them by using the laser, 65 points (13×5) were marked on the ground.

To reduce the canine's load, 5 points were randomly selected in each area (i.e., 15 points were randomly selected from 65 points). The laser beam spot pointed each point for over 5 sec. We observed the reaction of the canine while the

Fig. 6. Device for putting laser beam spot and the experimental setup: 65 points are marked at the front of the canine (black standard poodle).

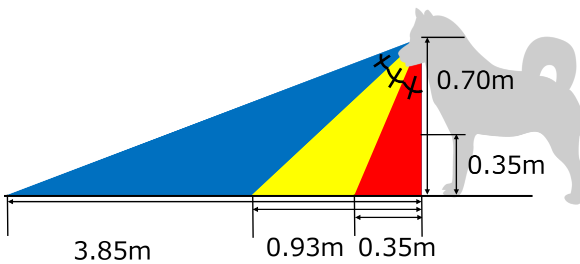


Fig. 7. Definition of canine's field view: Short range is decided based on its leg length. Middle and long range areas are decided based on the view angle of the short range.

laser beam spot pointed. When the laser beam spot seemed to get into canine's eyes during the experiment, we turned off a laser light source. We used Dog A and Dog B in the experiment because they responded to the laser beam in Section III.

3) Results: The canines showed more reactions (look or chase) at middle and long ranges than at short range (Table II). To visualize the area where these canines showed reactions, we applied the polygon to each Dog A and Dog B data. Figure 8 shows the polygon where the Dog A and Dog B showed reactions for the laser beam spot. The center of the Dog A polygon was horizontal 6.0 degrees and vertical 57.2 degrees. The center of the Dog B polygon was horizontal 6.0 degrees and vertical 53.1 degrees. The average was about 55.0 degrees. If the laser inclined to 55.0 degrees at vertical direction, the laser beam spot existed at 1 m on the ground. This result well corresponded to the interview shown in Sec. IV-A. We decided that the laser was inclined 55.0 degrees at vertical direction or it lighted 1 m distance from the canine on the ground.

4) The effect of Canine's Character: We had an interview with the keepers about the character of these canines. Dog A, Dog B, and Dog C are slightly curious, curious, and patient, respectively. We considered that Dog C had the ability of controlling itself, and did not chase the laser beam spot. Therefore, the laser based control method can be used for the canines that have the curious character. We used Dog B that had the most curious character at the following experiments.

TABLE II

THE NUMBER OF CANINE'S REACTIONS TO THE LASER BEAM SPOT: A LASER LIGHTS UP 5 TIMES AT EACH AREA.

Range	The number of Reaction: Looking (Moving)	
	Dog A	Dog B
Short	0(0)	1(1)
Middle	1(0)	4(1)
Long	3(2)	4(3)

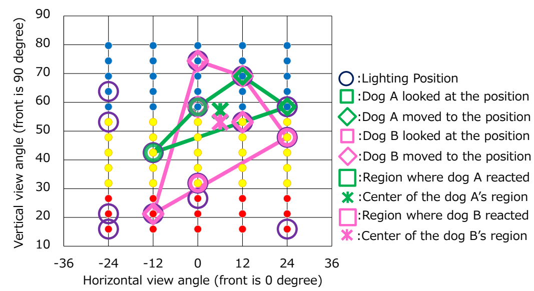


Fig. 8. Viewpoint area where the canines had reactions (facing or moving): Green area shows the viewpoint area where the Dog A had the reactions. Pink area shows the viewpoint area where the Dog B had the reactions.

is to control the canine's moving directions using the spots generated by the three lasers equipped on the canine's suit instead of a moving laser handled by electronic device or humans.

Figure 9 shows the suit equipped with three lasers. Forward direction laser is set on the fore-chest. Left and right direction lasers are set on the left and right shoulders, respectively. We decided these positions by analyzing the position error of the laser beam spot. Figure 10 shows the definition of the position error of the laser beam Δd. Candidate positions of lasers are head, shoulder, fore-chest, and chest. D, H, and θ were measured at each position of Dog B, and its error Δd was calculated for the analysis. Figure 11 shows the position error at each position. This graph shows that the head position is the best, the shoulder and fore-chest are the second best, and the chest is the third.

However, the position of the laser beam spot from head changes easily by swinging the canine's head. The laser beam from the canine's head might require an actuator for controlling its direction. It becomes a complex and heavy system. Therefore, we selected the shoulder and the fore-chest to fix the lasers.

We made a short length laser whose length is 50 mm. The lasers contain two joints to change the pitch and yaw angles. After the canine wears the suit, the pitch angle of these lasers is adjusted to light at 1 m from the canine. Yaw angle of the left and right laser devices was adjusted to be 15 degrees because the standard poodle's binocular vision area is ± 30 degrees, and laser beam spot is lighted in the binocular vision area.

V. DESIGN OF CANINE SUIT FOR CONTROLLING CANINE'S MOTIONS

A. Outline

We developed a suit for leading the canine to forward, left, and right direction. We set three lasers that face the forward, left, and right direction on the canine suit. Our challenge

B. Evaluation of Canine's Motion Control based on Laser Beams

We examined whether the canine was controlled using the on-suit lasers. Figure 1 shows a canine control system. An operator specified one direction (forward, left, or right)

Fig. 9. Canine suit equipped with three lasers: (left) Front view of the suit, (Right) Laser device that consists of a laser and a 2 axes laser holder.

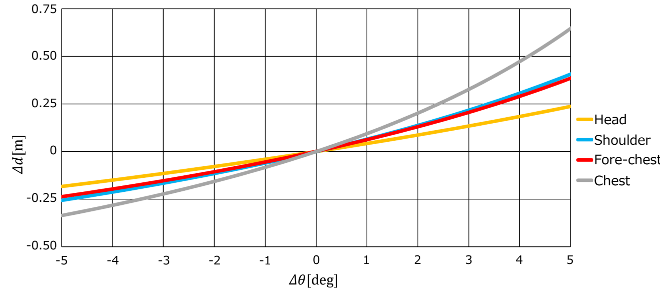


Fig. 11. Position error of the laser beam spot at each position (head, shoulder, fore-chest, and chest)

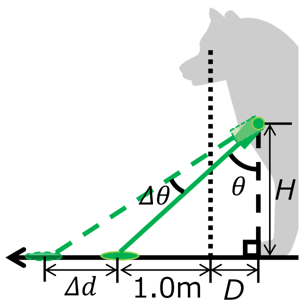


Fig. 10. Definition of position error of the laser beam spot Δd

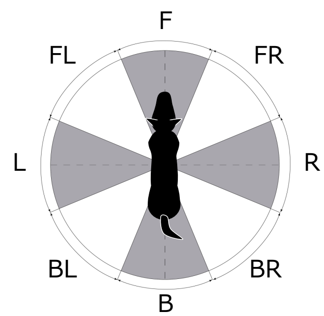


Fig. 12. Definition of moving direction: We divide the angle into 8 areas.

with a joy-pad. To observe the moving direction, we took a movie of the canine's motion from the back of the canines using a handheld camera. 6 persons judged the 8 moving direction (Fig. 12) or no-movement of the canine from the movies. Areas of FL, F, and FR were defined as the canine's forward direction. Areas of FL, L, and BL were defined as the canine's left direction. Areas of FR, R, and BR were defined as the canine's right direction.

Table III shows the success rate of the motion control (forward, left, and right direction). For front in Table III, the operator specified the forward direction with the joy-pad at 11 times. From the 11 movies, 6 persons judged the moving direction of the canine. Among total 66 judgements, the number of the forward direction answered by 6 persons was 50. Therefore, the operator succeeded that canine moved to the forward direction (FL, F, and FR) at 75.8%. The success rate of left direction (FL, L, and BL) was 97.6%. The success rate of right direction (FR, R, and BR) was 100.0%. These results show that Dog B was controlled using the on-suit lasers. Dog B moved to the direction where the operator specified with a joy-pad.

We analyzed the details of the moving direction for each input command. Table IV shows the details of 6 person's judgments. Interestingly, there were two peaks at "FR" and "FL" for the forward command. For the left command, there was a peak at "BL". For the right command, there was a peak at "R".

We considered the reason why the distribution of the canine's motion has such bias. For the forward direction, we expected that the canine chased the laser beam spot when the canine inclined the head. When the canine inclined the head at the left side, the canine found the laser spot at the right side. In opposite case, the canine found it at the left side. As the result, the canine might move the left or right side at the forward command. For the left and right directions, we expected that the canine chased the laser beam spot when the canine took lower pose. When the canine took low pose, the laser beam spot was closer to the canine. As the results, the canine turned left or right rapidly and excessively. We will clear the cause and find the solution in the near future.

We confirmed that the canine can be controlled using lasers, and the use of three lasers that face to forward, left, and right direction allowed us to move the canine to the forward, left, and right directions.

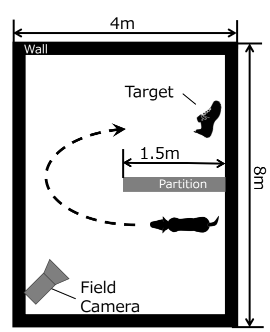


Fig. 13. Field setup of canine's motion control experiment: Canine cannot directly watch the target. Human operator controls the canine's motion and moves it beyond the partition panel for taking a photo of the target.

Fig. 14. Navigation of a canine by using 3 laser beams: Upper figures show the canine's motion. Lower figures show the on-suit camera images. Operator controlled the canine's moving direction by a joy-pad. Canine moved beyond partition panel and took images of target object.

TABLE III

SUCCESS RATE OF CANINE'S MOTION CONTROL.

Direction	Total number (Trials × Annotators)	Answer	Success rate (%)
Left	42	41	97.6
Forward	66	50	75.8
Right	48	48	100

TABLE IV

THE DETAILS OF CANINES MOVING DIRECTION FOR EACH COMMAND.

	Annotated direction								
	BL	L	FL	F	FR	R	BR	B	Other
Left	32	9	0	0	0	0	0	1	0
Forward	0	8	21	8	21	6	0	0	2
Right	0	0	0	0	3	38	7	0	0

VI. DEMONSTRATION OF CANINE MOTION CONTROL

We demonstrated the navigation of a canine using the canine's control method based on laser beam spots. The task is to take a photo of the target object (shoe) by a camera equipped on the canine. Figure 13 shows field setup of the experiment. The difficulty of this task is to go around the barrier in the field. We set the barrier (partition panel) to prevent the canine from watching the target object directly. Therefore, a human operator must guide the canine beyond the partition panel and make the canine face the target object.

Figure 14 shows the images of the canine from a field camera and the canine's front view images from a camera equipped on the canine. We conducted the same examination at several times, and confirmed that the human operator could lead the canine from the start to the goal, and take the photo of the target object.

This demonstration shows the possibility of canine's navigation using the laser beams. It would expand the working dogs' ability.

However, Dog C did not chase the laser. We consider that Dog C also has the ability to chase the laser. There is a possibility to appear the ability using a few traning. The training might be more easy than the advance training for sounds, vibrations, and lights stimuli. One of our future works is to control the canines that does not chase the laser.

VII. CONCLUSIONS

We proposed a control method of canine's motion with a laser beam from devices equipped on the canine's suit (on-suit laser beams). We confirmed that the canine's moving direction was controlled using on-suit laser beams. At first, we decided the specification of laser beam: power 1 mW, green color, and dot shape. Brightness was more important than color for the canine motion control. Second, we designed laser beams' position and its angles. Vertical angle of laser was adjusted to point at 1 m. Horizontal angle of left and right lasers was adjusted at 15 degrees. Then, we demonstrated that a human operator could change the moving direction of the canine using a joy-pad. The human operator guided the canine to the place where the canine could watch the target.

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