Laser-Pointer Guidance System for Small Unmanned Ground Vehicle in Disaster Area

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Abstract. We are developing a small unmanned ground vehicle to support rescue missions by exploring sediment-related disaster areas. To simplify the vehicle operation, we employ a laser pointer as guidance system. In this paper, we describe a method to detect the laser-pointer spot under sunlight and a fuzzy learning method for guiding the vehicle towards the corresponding target position. To verify the spot detection, we performed experiments in laboratory emulating sunlight conditions, whereas to validate the guidance method, we developed a fuzzy control system whose input-variable ranges were determined from preliminary experiments and whose outputs include turning, backward, and forward motions of the vehicle. Likewise, experimental results confirm the effectiveness of the proposed guidance method.

1. Introduction
Currently, we are developing the small unmanned ground vehicle (UGV) shown in Figure 1 to explore sediment-related disaster areas and support rescue missions. However, unless used by a trained operator, it would be difficult to maneuver the vehicle in the event of a disaster. Therefore, to simplify the operation of the proposed UGV, we integrated a guidance system using a laser pointer. Although the idea of this laser pointer guidance system is implemented by Suzuki [1], it is difficult to use under the sunlight. Hence, the UGV can be guided towards the laser spot by relying on image processing to determine the spot position and corresponding motions to locate the UGV at the desired target. In this paper, we describe the method to detect the laser spot under sunlight and a fuzzy learning method for guiding the UGV towards the corresponding target.

Figure 1. Developed UGV.
2. Laser-pointer spot detection under sunlight

In general, it is difficult to determine the spot where a laser pointer hits in outdoor environments during the daytime. In fact, the high illuminance of sunlight almost vanishes the laser spot, thus compromising its detection with cameras or other means. Therefore, we have proposed to capture the moment when the laser-pointer spot is projected to a shaded area caused by the unevenness of the ground, aiming to resemble the way in which humans can distinguish objects under sunlight. Then, we employ a simple image processing method to detect the laser spot by calculating the difference among the luminance values surrounding the spot. Therefore, this method can be also used for detection at night.

2.1. Detection method

The detailed method for detecting the laser-pointer spot from a shaded area is described as follows. An image is acquired as shown in Figure 2.1(a). Then, we extract shaded areas larger than a predefined threshold by determining low luminance values in the image, as shown in Figure 2.1(b). Finally, consistently shaded regions among consecutive frames are defined as the shaded area, and the laser spot is extracted from this area, as shown in Figure 2.1(c).

To determine the shaded area, an enlarged image surrounding it is obtained. Still, as the enlarged image has low luminance, its luminance distribution is biased. Therefore, we perform a luminance flattening such that the contrast at the position of the laser spot becomes higher, thus facilitating its detection.

![Figure 2. Method for laser-pointer spot detection.](image)

2.2. Extraction Experiment

To emulate an outdoor environment under sunlight in laboratory settings, we limited the output power of the laser pointer to 1/100 of its capacity. Hence, we obtained an attenuation of the laser emission that can be considered similar to that under sunlight. Figure 3 shows different detection results.

![Figure 3. Experimental results of laser-pointer spot detection.](image)
3. UGV guidance using fuzzy logic

We propose a control method based on fuzzy logic to guide the UGV to the target indicated by the laser pointer. Let us define the line segment between target point $p_t = (u_t, v_t)$ and center $p_c = (u_c, v_c)$ in the image of the omnidirectional camera mounted on UGV (Figure 4). Slope $\alpha$ and length $\lambda$ of the line segment are respectively given by

$$\alpha = \frac{u_c - u_t}{v_c - v_t}, \quad \lambda = \sqrt{(u_c - u_t)^2 + (v_c - v_t)^2}$$

Figure 4. Omnidirectional image from UGV camera to determine target position.

When $\alpha = 0$ and $\lambda = 0$, the UGV has reached the target position. Therefore, we derived a control system that aims to set inputs $\alpha$ and $\lambda$ to zero by varying UGV speed $s$ and steering angle $\varphi$ using fuzzy logic. First, we perform the fuzzification of state variables to convert real values into fuzzy sets. The goodness of fit of each value is determined by membership functions. Based on the results of the preliminary experiments, we set the scope of the membership functions to have the following labels:

$$\tilde{\alpha} = \{NB, NS, ZO, PS, PB\}, \quad \tilde{\lambda} = \{ZO, PS, PB\}$$

and for outputs $s$ and $\varphi$, we defined the following fuzzy sets with three labels:

$$\tilde{s} = \{N, ZO, P\}, \quad \tilde{\varphi} = \{N, ZO, P\}$$

where NB, NS, ZO, PS, PB indicate high negative, low negative, zero, low positive, and high positive values, respectively, whereas P and N stand for positive and negative values, respectively.

Figure 5 shows the membership functions for the inputs and outputs, whereas Table 1 lists the control rules for the outputs, which are specified by antecedents (i.e., conditions) and consequents (i.e., actions). For instance, if $\tilde{\lambda}$ is ZO, then speed and tilting are set to ZO, as it indicates that the UGV has reached the target position regardless of the label of $\tilde{\alpha}$.

$$R_1 : \text{IF } \tilde{\alpha} = \text{NB, } \tilde{\lambda} = \text{ZO THEN } \tilde{s} = \text{ZO, } \tilde{\varphi} = \text{ZO}$$

$$R_2 : \text{IF } \tilde{\alpha} = \text{NB, } \tilde{\lambda} = \text{PS THEN } \tilde{s} = \text{N, } \tilde{\varphi} = \text{P}$$

$$\vdots$$

$$R_{15} : \text{IF } \tilde{\alpha} = \text{PB, } \tilde{\lambda} = \text{PB THEN } \tilde{s} = \text{N, } \tilde{\varphi} = \text{ZO}$$
Table 1. Fuzzy rules for the steering angle $\phi$

| Rule No. | Antecedent | Consequent | Antecedent | Consequent |
|----------|------------|------------|------------|------------|
|          | $\lambda$  | $\alpha$   | $\dot{\phi}$ | $\dot{s}$ |
| $R_1$    | ZO         | -          | ZO         | ZO         |
| $R_2$    | NB         | ZO         | N          |            |
| $R_3$    | NS         | P          | N          |            |
| $R_4$    | P          | ZO         | P          | P          |
| $R_5$    | PS         | N          | N          |            |
| $R_6$    | PB         | ZO         | N          |            |

Figure 5. Membership functions for inputs and outputs of the proposed fuzzy control system.

4. Conclusion

We propose a small UGV guidance system in disaster areas using a laser pointer. To realize the guidance system, we addressed the following problems:

(i) Detection of laser-pointer spot in an uneven surface on the ground under sunlight irradiation,
(ii) UGV guidance towards the detected spot.

Correspondingly, we developed the following methods:

(i) Detection of laser-pointer spot by determining a shaded area from consecutive images,
(ii) Fuzzy control system for UGV guidance including turning, backward, and forward motions.

The effectiveness of these methods was confirmed from experiments. Future developments will aim to integrate both methods to run on the UGV by using its onboard omnidirectional camera. In addition, we will develop an interface to displays the shaded area to the operator and a method to automatically determine the fuzzy variables.

- Development of interface that displays shade area to manipulator.
- Automatic determination of fuzzy variables without human intervention.

Acknowledgements

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References

[1] Suzuki T, et al 2005, Operation direction to a mobile robot by projection lights, IEEE Work shop on Advanced Robotics and its Social Impacts, 160–165