EVALUATION OF GROUND SLIPPERY CONDITION DURING WALK OF BIPEDAL ROBOT USING MEMS SLIP SENSOR

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ABSTRACT

This paper reports on a method to evaluate ground slippery condition using a MEMS slip sensor. The sensor discriminates between ground slippery and non-slippery conditions during walking motions of a bipedal robot, which enables the robot to prevent a slip. First, we evaluated the responses of the sensor pressed against an oiled or non-oiled surface. Then, we proposed a discriminating method between the oiled and non-oiled surfaces using the sensor. Finally, we demonstrated that a bipedal robot was able to evaluate the slippery condition of the ground where the foot of the robot landed during walk.

INTRODUCTION

Bipedal robots need to prevent a slip because it often causes a fall. Additionally, compared to other forms of locomotion such as multi-leg and multi-wheel, bipedal locomotion is unstable against a slip.

To prevent a slip during walk of a bipedal robot, some researchers have been trying to control the walking speed or the contact force between the foot and ground [1-3]. These studies show that the robot is able to walk without a slip by controlling the motions of the robot adequately. However, the robot needs to obtain the coefficient of static friction between the robot and ground in advance, which is generally unknown before a slip actually occurs.

On the other hand, several types of slip sensors which can acquire information about "slip" such as a sign of a slip or a frictional characteristic have been reported [4-6]. We also reported on a MEMS slip sensor which can measure coefficient of static friction using a local slip phenomenon [7]. The sensor provides coefficient of static friction before a slip occurs, which enables to evaluate ground slippery condition. Therefore, by applying the slip sensor to a bipedal robot, the robot can discriminate between slippery and non-slippery conditions of the ground where its foot lands so that prevent a slip during walk.

In this paper, we apply our slip sensor to a bipedal robot (Fig. 1). The sensor is attached to the sole of the foot of the robot. First, we design the sensor and fabricate it. Then, we evaluate the responses of the sensor by pressing it against slippery or non-slippery surfaces. Finally, we demonstrate that the sensor is able to discriminate between slippery and non-slippery condition of the ground.

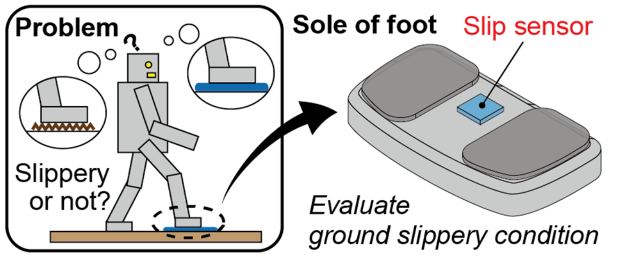

Figure 1: Concept sketch of the proposed evaluation method of ground slippery condition.

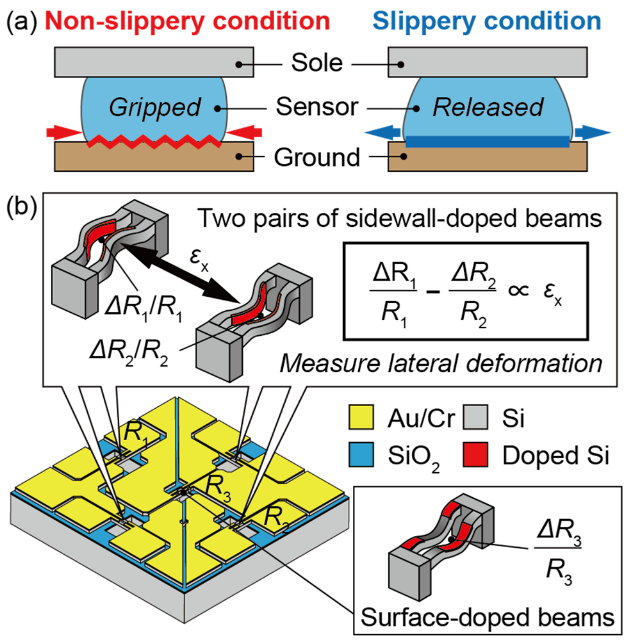

Figure 2: (a) Deformation of rubber pressed against non-slippery or slippery surface. (b) Structure of the sensor chip.

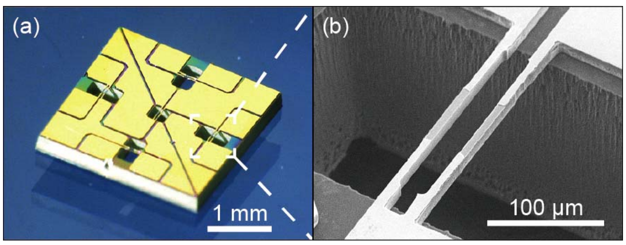

Figure 3: (a) Photograph of the fabricated sensor chip. (b) SEM image of the beams.

METHODS

Design of a MEMS slip sensor

We propose an evaluation method of ground slippery condition using a MEMS slip sensor (Fig. 2a). The sensor is composed of a sensor chip and rubber covering it. Under non-slippery condition (large coefficient of static friction), the contact area between the ground and the rubber is gripped by frictional force. On the other hand, under slippery condition (small coefficient of static friction), the contact area is released and the rubber deforms laterally. Therefore, the ground slippery condition can be evaluated as the amount of the lateral deformation of the rubber.

The sensor chip is designed and embedded in the rubber in order to measure its deformation (Fig.2b). The deformation of the rubber is measured as the fractional resistance changes using the piezoresistors. A pair of sidewall-doped beams measures the lateral deformation. That is, the beams measures the lateral deformation in one direction. Therefore, by forming two pairs of sidewall-doped beams in parallel, the lateral deformation caused by the spread of the rubber can be measured as $\Delta R_1/R_1-\Delta R_2/R_2$. A pair of surface-doped beams arranged at the center of the chip measures pressure applied on the sensor as $\Delta R_3/R_3$. Fig. 3 shows the fabricated sensor chip. The detailed information of fabrication processes was described in the previous work [7].

A discriminating method between ground slippery and non-slippery conditions

We introduce a discriminating method using the MEMS slip sensor. In this paper, we try to discriminate between two different surfaces in coefficient of static friction such as surfaces coated with/without oil. When the sensor is pressed, the sensor outputs shows the linear relationship between $\Delta R_1/R_1-\Delta R_2/R_2$ and $\Delta R_3/R_3$ [7]. Additionally, the slope of the linearity varies with whether the surface condition is slippery or non-slippery. In order to discriminate between the two surface conditions, we define a scholar value S, as

$$S = \arctan\left(\frac{\frac{\Delta R_1}{R_1}-\frac{\Delta R_2}{R_2}}{\frac{\Delta R_3}{R_3}}\right). \tag{1}$$

θ_a and θ_b are angles shown in the slope of the linear relationship under the slippery and non-slippery conditions, respectively. Under this definition, S means the angle of the linear relationship between $\Delta R_1/R_1-\Delta R_2/R_2$ and $\Delta R_3/R_3$. S is close to θ_a if the ground is estimated as slippery; on the other hand, S is close to θ_b if the ground is estimated as non-slippery. Therefore, the judgement whether the ground is slippery or non-slippery is possible by monitoring S.

EXPERIMENTS AND RESULTS

Responses of the fabricated sensor pressed against an oiled or non-oiled surface

We evaluated the responses when the fabricated sensor was pressed against the oiled or non-oiled surface. Fig. 4a shows the experimental setup. The sensor was fixed on an XYZ manual stage. An acrylic plate was fixed above the sensor. By moving the stage vertically, the sensor was able to be pressed against the acrylic plate coated with/without silicone oil (oiled or non-oiled surface).

Fig. 4b shows the relationship between $\Delta R_1/R_1-\Delta R_2/R_2$ and $\Delta R_3/R_3$ when the pressure increased to 80 kPa. $\Delta R_1/R_1-\Delta R_2/R_2$ of the oiled condition was larger than that of the non-oiled condition when the values of $\Delta R_3/R_3$ were the same. This result indicates that the lateral deformation becomes larger under slippery condition than non-slippery condition, which matches the principle of the sensor shown in Fig. 2a. By fitting a line to the data with least squares method, we determined that θ_a and θ_b were 0.32 and 0.54 rad, respectively.

Evaluations of ground slippery condition during walk of a bipedal robot

We demonstrated that a bipedal robot was able to evaluate the slippery condition of the ground where the foot of the robot landed. We used a bipedal robot KHR-3HV (Kondo Kagaku). The weight of the robot was 1.5 kg. The robot walked on an acrylic plate with/without silicone oil

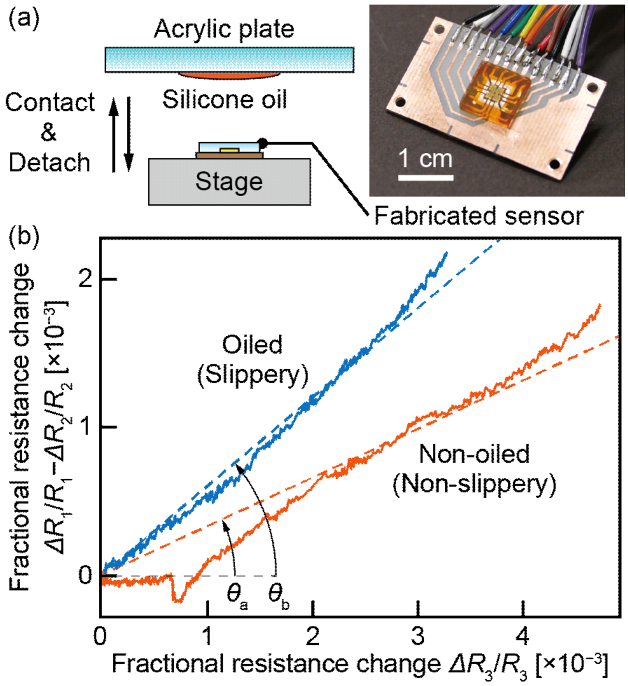

Figure 4: (a) Experimental setup. (b) Relationship between $\Delta R_1/R_1-\Delta R_2/R_2$ and $\Delta R_3/R_3$.

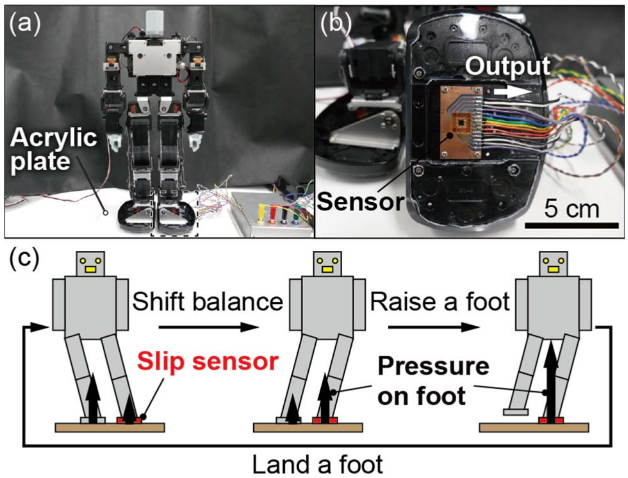

Figure 5: Photographs of (a) the bipedal robot and (b) its sole of foot. (b) Walking motions of the robot.

(Fig. 5a). The fabricated sensor was attached on the sole of the left foot (Fig. 5b). As shown in Fig. 5c, the walk of the bipedal robot was composed of three motions; the robot shifted its balance, raised a foot of the opposite side of the supporting leg and landed the foot. To prevent a slip, the ground condition must be evaluated while changing the supporting legs. Thus, in this paper, we validated the proposed evaluation method when the robot shifted its balance. First, the right foot supported the weight of the robot. Then, the robot started shifting its balance to the left foot. Finally, the robot ended the motion before lifted up the right foot. The motion of the robot was created by a software (HeartToHeart4, supplied by Kondo Kagaku).

Fig. 6a, b and c shows the temporal changes of $\Delta R_1/R_1-\Delta R_2/R_2$, $\Delta R_3/R_3$ and S, respectively. The robot started the motion at T = 0 s and ended it at T = 1.8 s. As shown in Fig. 6a and b, $\Delta R_1/R_1-\Delta R_2/R_2$ and $\Delta R_3/R_3$ increased over time, which means the pressure was applied

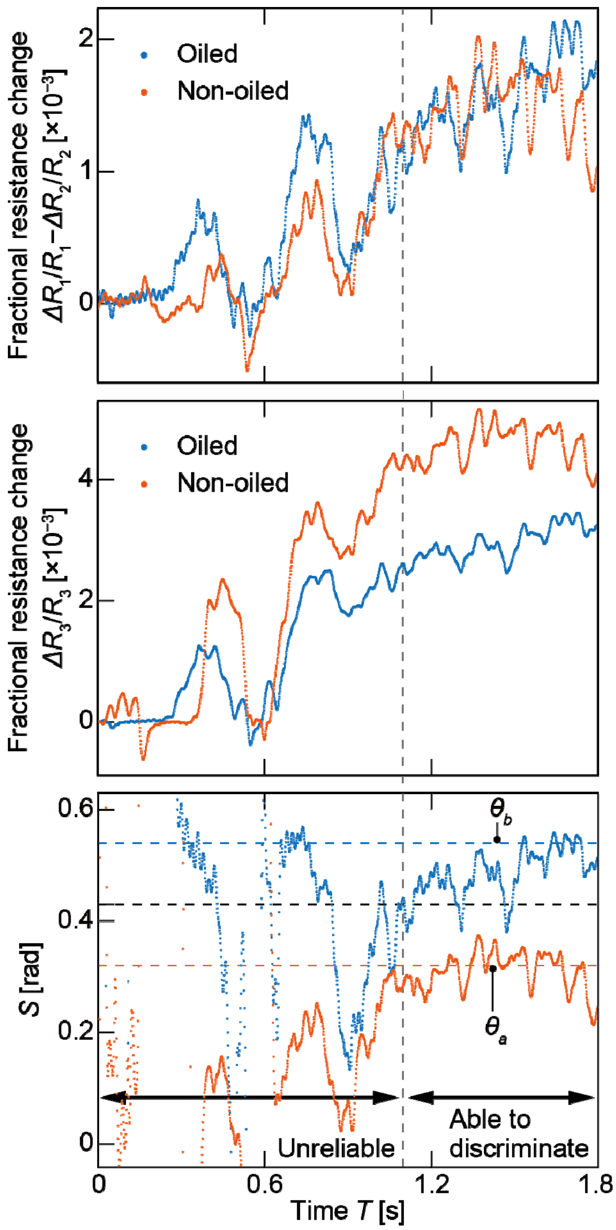

Figure 6: Temporal changes of (a) $\Delta R_1/R_1-\Delta R_2/R_2$, (b) $\Delta R_3/R_3$ and (c) S while the robot shifted its balance.

to the sensor while the robot shifted its balance from the right foot to the left foot. As shown in Fig. 6c, S was unreliable until T = 1.1 s. One of the reasons of this unreliable output was a shake of the body of the robot during the motion. When the pressure was not applied on the sole enough, the sensor was sometimes detached from the ground by a shake, which led to unreliable outputs. For the same reason, it seemed that $\Delta R_1/R_1-\Delta R_2/R_2$ and $\Delta R_3/R_3$ were 0 around T = 0.5 s. After T = 1.1 s, the pressure seemed to be applied enough. Then, S became closer to θ_b (= 0.32) under oiled condition; on the other hand, S became closer to θ_a (= 0.54) under non-oiled condition. This result matches the expected sensor responses shown in Fig. 4b, which indicates the robot was able to discriminate between the slippery and non-slippery conditions by using the slip sensor.

CONCLUSION

We proposed an evaluation method of ground slippery condition using a MEMS slip sensor. We demonstrated that a bipedal robot was able to discriminate between ground slippery and non-slippery condition during the motion of shifting balance by using the slip sensor.

ACKNOWLEDGEMENTS

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